US Army Corps of Engineers
Hydrologic Engineering Center

HEC-5
Simulation of Flood Control and Conservation Systems

User's Manual
Version 8.0

October 1998

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CPD-5

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Foreword

The HEC-5 computer program was developed at the Hydrologic Engineering Center (HEC). The original software was written by Bill S. Eichert, with the support of HEC staff. Since his retirement in 1989, the HEC-5 package of programs have been developed and maintained by Mr. Richard Hayes and Ms. Marilyn Hurst, with support and direction from Vern Bonner, Chief, Training Division. This manual was written by Messrs. Bonner and Hayes and Ms. Hurst. Mr. Darryl Davis, as HEC Director since Mr. Eichert's retirement, has actively supported the continued development and application of the HEC-5 package.

Chapter 1

Introduction

1.1 Origin of Program

The HEC-5 computer program was developed at the Hydrologic Engineering Center by Bill S. Eichert. The initial version was written for flood control operation of a single flood event and was released as HEC-5, "Reservoir System Operation for Flood Control," in May 1973. The program was then expanded to include operation for conservation purposes and for period-of-record routings. This revised program was referred to as HEC-5C up to the February 1978 version. Mr. Eichert retired from HEC in 1989 and he continues to develop his version of the program. HEC continues to develop and maintain HEC-5 and has released several versions since 1989. The HEC-5, Version 8, October 1998, is the current edition and the basis for this user's manual.

1.2 Purpose of Program

This program was developed to assist in planning studies for evaluating proposed reservoirs in a system and to assist in sizing the flood control and conservation storage requirements for each project recommended for the system. The program can be used in studies made immediately after the occurrence of a flood to evaluate pre-project conditions and to show the effects of existing and/or proposed reservoirs on flows and damages in the system. The program should also be useful in selecting the proper reservoir releases throughout the system during flood emergencies in order to minimize flooding, while maintaining a balance of flood control storage among the reservoirs. After flooding recedes, the program will empty the flood volume in storage as quickly as possible.

The purposes noted above are accomplished by simulating the sequential operation of a system of reservoirs for short-interval historical or synthetic floods, for long duration non-flood periods, or for combinations of the two. Specifically the program may be used to determine:

- Flood control and conservation storage requirements for each reservoir in the system.
- The influence of a system of reservoirs on the spatial and temporal distribution of runoff in a basin.
- The evaluation of operational criteria for both flood control and conservation purposes (including hydropower) for a system of reservoirs.

- The energy generation for specified energy demands and capability for a single project, or system of hydropower projects operating for a system demand.

- The system of existing and proposed reservoirs or other alternatives including nonstructural alternatives that results in the maximum net flood control benefits for the system by making simulation runs for selected alternative systems.

1.3 Dimension Limits

Dimension limits for the distribution version are as follows:

80	KMXCPT	=	Number of control points
40	KMXRES	=	Number of reservoirs
18	KCHSTG	=	Number of values of channel storage and discharge
40	KDIV	=	Number of diversions
40	KLEV	=	Number of reservoir target levels
60	KNCAPT	=	Number of values of reservoir storage, discharge, etc.
35	KPWR	=	Number of power plants

These dimension limits are shown at the beginning of the output file that is created during program execution.

1.4 Hardware and Software Requirements

The HEC-5 program,[1] written in FORTRAN V, was originally developed on a CDC CYBER 865 computer. PC and Unix versions have been developed. The PC version of HEC-5 runs in a MS-DOS window under Win95 or NT and operates with extended memory. Eight (8) Mb or more of RAM are recommended.

[1]The program is actually two separate programs (HEC-5A and HEC-5B) that are linked by temporary scratch files and executed in sequential order as one job by job control records. The first program reads input and simulates reservoir operation. The second program reads the scratch files and creates the output tables and performs the economic analysis. Certain applications require only the first program (conservation optimization (J7 Record) and output to DSS). If output to HEC-DSS (ZW Record) is requested, output displays, economic analyses and duration and frequency analysis can be performed by other HEC programs.

1.5 User's Manual Organization

This manual provides HEC-5 program description at two levels. The chapters present general descriptive information on program capabilities, while the appendices present more detailed information and input/output examples.

Chapter 2 presents basic capabilities

Chapter 3 presents flood reduction capabilities.

Chapter 4 provides low-flow capabilities.

Chapter 5 provides hydropower capabilities.

Chapter 6 presents system operation.

Chapter 7 gives an overview of input and output.

Appendix A presents the HEC-5 routing options.

Appendix B describes HEC-5 use of the data storage system (HEC-DSS).

Appendix C presents detailed information and examples on flood operations.

Appendix D presents detailed information and examples on water supply features.

Appendix E presents detailed information and examples on hydropower options.

Appendix F is the output description

Appendix G is the input description.

Chapter 2

Basic Capabilities and Requirements

Computer program HEC-5 is designed to perform sequential reservoir operation based on specified project demands and constraints. Demands can be minimum channel flows, diversion requirements, and energy requirements. Demands can be specified at the reservoir and at downstream locations (called Control Points). Physical reservoir constraints define the available storage for flood control and conservation purposes and maximum outlet capability. Operational constraints can include maximum non-damaging flows and reservoir release rate-of-change. The simulation is performed with specified flow data in the time interval for simulation. The simulation process determines the reservoir release at each time step and the resulting downstream flows. Detailed output is available to evaluate the reservoir performance and resulting regulated flow.

2.1 Reservoir System Configuration

Any dendritic reservoir system configuration may be used as long as dimension limits are not exceeded for number of reservoirs, number of control points, number of diversions, etc. (see Chapter 1 for dimension limits). Figure 2.1 is an example system diagram, showing basic model components of reservoirs and downstream control points. Model data are defined starting at the upstream boundaries of the system, and data for each location are entered sequentially downstream. All upstream locations must be defined before entering the data for the downstream location.

The most upstream location on each tributary must be a reservoir. If no reservoir exists, a dummy reservoir with no storage can be used.

Non-reservoir locations are called control points, where flow constraints and demands can be specified. The last (most downstream) location in the system must be a non-reservoir control point.

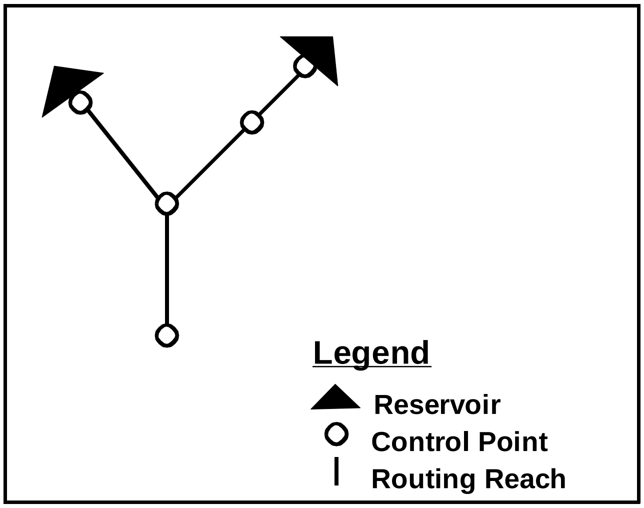

Figure 2.1 Reservoir System Diagram

All locations, including reservoirs, require control point data, which includes routing criteria to the next downstream location. The system configuration is defined by routing reaches and specified downstream locations. All locations upstream from a control point must be defined before that control point's data are defined.

The entire reservoir system, based on reservoir and control point data, is defined in an ASCII (text) data file. Then, following the model data, the flow data for simulation are provided. Together, these data constitute the input data file. The following sections provide additional information on reservoirs, control points, routing methods and flow data. The data record identifiers, associated with the different model components, are provided with the descriptions. Detailed input data description is provided in Appendix G of the User's Manual.

2.2 Reservoir Index Levels

An index level is associated with the primary reservoir storage zones: Inactive, Buffer, Conservation, and Flood Control. Figure 2.2 illustrates the levels associated with reservoir storage zones. Within a system model, all reservoirs must have the same number of levels and the Index Level for the primary storage zones must be the same. These data are defined on the first Job Record (**J1**) for all reservoirs in the model. The actual storage allocated to each level is defined with the reservoir data, on the **RL** Record.

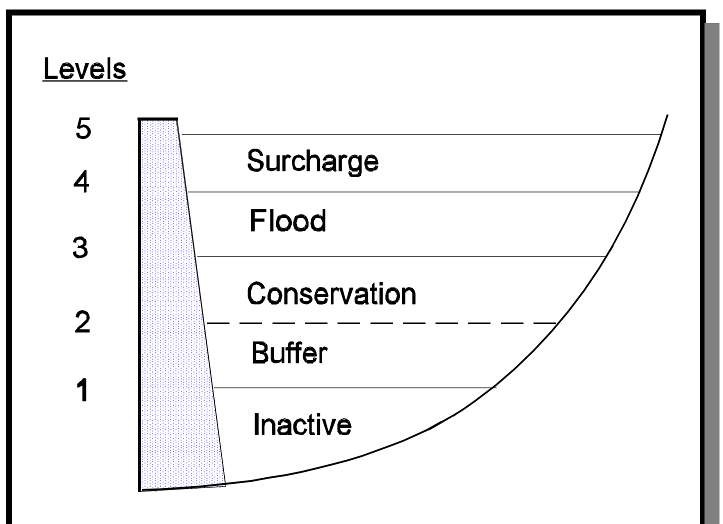

Figure 2.2 Reservoir Storage Zones and Index Levels.

Level 1 is top of the Inactive pool. No reservoir releases are made below this level. The storage at this level may be zero, or some minimum pool.

Level 2 is usually associated with the top of Buffer pool, a special subdivision of the Conservation pool. When the pool level drops into a Buffer Zone, a drought condition is indicated. Then, only essential demands will be met (Required Flow). Above the Buffer Level, all conservation demands are met (Desired Flow). If the concept of Buffer Storage is not used, the Buffer Level would also be Level 1, the top of Inactive pool.

Level 3 is usually associated with the top of Conservation pool. The conservation pool can be subdivided into multiple levels (see Chapter 6 for a description of system levels.)

The fourth essential level is the top of Flood Control pool. Typically, the zone between top of conservation and flood control is the active flood storage zone. Water is stored in this zone when it cannot be safely passed through the downstream channel system. If a reservoir in the system does not have flood control storage, the cumulative storage at the top of flood control would equal the storage at the top of conservation. If none of the reservoirs have flood storage, the Index Level for Flood Control (**J1** Record) would be the same as Conservation.

Usually, the top of Flood Control Level is not the maximum level. Typically, a reservoir has surcharge storage to accommodate water above the emergency spillway. In the surcharge zone, the outflow is determined by the spillway capacity; the reservoir no longer makes release decisions. However, this Surcharge Index Level is not explicitly defined on the **J1** Record. An Index Level, greater than the top of Flood Control would indicate the surcharge zone.

The **J1** Record allows three additional Index Levels associated with hydropower. They are left blank for non-hydropower applications. Their significance is described in Chapter 5, Hydropower Capabilities.

2.3 Reservoir Description

For a reservoir, the primary physical data are the cumulative storage for each operational zone and the maximum outflow capability, given as a function of storage. The minimum reservoir data are described below. The control point data, also required for each reservoir, are described in the following sections. Beyond the required data, optional data can be added to utilize other program features.

Storage. Each reservoir must have a starting storage and the cumulative storage at each Index Level. *(The concept of Reservoir Index Levels is described in the previous section.)* The reservoir storage for each Index Level can vary seasonally, monthly or remain constant. (**RL** Records)

Operation Locations. Each reservoir operates for itself and specified downstream control points (**RO** Record). The reservoir always considers it's own requirements. In addition to itself, only those downstream locations specified on the **RO** Record are considered before making a reservoir release.

Reservoirs which have flood control storage may be operated to minimize flooding at any number of downstream control points.

Reservoirs without flood storage will be operated for their own requirements (power or low flow) and can be operated to provide low flow requirements for any number of downstream control points (same locations as for flood control).

Upstream tandem reservoirs may not be operated directly for control points below a downstream tandem reservoir; however, the downstream tandem reservoir considers the upstream system storage when making its release.

Reservoirs in the system that operate for a common control point are kept in balance (in terms of reservoir level) for both flood and conservation operation. See Chapter 6 for information on system levels and operations.

Outlet Capacity. Each reservoir must have a table of maximum outlet capacities as a function of reservoir storages (**RS** and **RQ** Records). The table defines the maximum outflow capability for any reservoir storage, using linear interpolation on the input data. Therefore, the entire operation range of reservoir storage should be defined.

Control Point Data. Each reservoir is also considered a control point and requires control point data (**CP**, **ID**, **RT** Records). See Control Point Description below.

Identification Number. Reservoir and control point identification number (on **RL** and **CP** Records) may be any integer number up to six digits. The program uses a series of internally generated numbers for storage of variable arrays.

Additional Data. Reservoir areas, elevations, diversions, and costs can be given as a function of reservoir storages (**RA**, **RE**, **RD**, **R$**, **RS** Records, respectfully). Area data are required to compute reservoir evaporation and elevation data are required for hydropower computations; otherwise, they are informational only.

Delete Reservoirs. Reservoirs may be deleted by specifying the applicable identification number on the **J5** Record (becomes a reservoir with no storage) or by removing the appropriate records **RL - PE** (becomes only a control point).

2.4 Control Point Description

Every location in the reservoir system model must have control point data. Minimum data requirement includes an identification number, channel capacity, a location name, and the connection to the next downstream location (routing information). The required data are described in the following paragraphs. As with reservoir data, additional data can be added to use program options.

Identification Number. Each control point must have an identification number (**CP** Record). Only integer values can be used.

Channel Capacity. An operating (maximum) channel capacity must be provided. The channel capacity can be constant (**CP** Record), or vary by month, by season, or vary with channel flows at any location, or reservoir levels at any reservoir (**CP** and **CC** Records). .

Minimum Flow Requirement. Each control point can have low flow requirements (minimum desired and/or minimum required) which are constant (**CP** Record), or vary monthly, or by season, or vary period by period. (**CP** and **QM** Records)

Location Name. Each control point has an identifying alphanumeric name with up to 14 characters. (**ID** Record)

Downstream Link. Each control point is linked to the next downstream point by specifying the channel routing reach (*route from and route to data on* **RT** Record). Stream routing options are described below. The last control point in the system must have a **RT** Record; however, the route to location and routing criteria are not specified.

Additional Data. Each control point can have a discharge-stage rating curve for determining regulated and natural stage hydrographs (**QS** and **EL** Records). Also, discharge vs. channel storage data can also be given for the channel (**QS** and **SQ** Records)

2.5 Channel Routing Methods

Stream routing procedures incorporated in the program are hydrologic routing methods, typically used in the Corps. These methods are described in Engineering Manual (EM) 1110-2-1417, "Flood-Runoff Analysis," U.S. Army Corps of Engineers, August 1994, and are briefly summarized in Appendix A. For short time-interval simulation (daily or less), the routing criteria are used to model the translation of flow through the channel system. Hydrologic routing options provided are:

- Straddle-Stagger,
- Tatum,
- Muskingum,
- Modified Puls,
- Modified Puls as a function of inflow,
- Working R&D,
- SSARR Time-of-storage, and
- direct input of routing coefficients.

The program will use the channel routing data if the time interval for simulation is equal to, or less than the value of the NOROUT variable (default value is 24 hours). For longer time intervals, the routing criteria are ignored. The NOROUT value can be changed with the **J3** Record, field 7.

The routing reach and method are defined on the **RT** Record. Each routing reach may be subdivided into several steps (field 3). For Modified-Puls, the storage is divided by the number of steps and the routing is processed sequentially through each subset for storage-outflow data.

Routing criteria for natural flow conditions can also be specified (**RT** Record, field 8).

For each routing reach, two sets of flood routing criteria (at least one linear) can be specified along with the applicable routing interval (i.e., 3-hr and 12-hr).

When reservoir releases are routed by nonlinear methods (Modified Puls or Working R&D), linear approximations are used to determine the reservoir's releases. The actual releases are then routed by the nonlinear method.

Steady state is assumed for flows prior to the first period of routing.

2.6 Flow Data

Model Structure. The format for model data attempts to separate the reservoir system data from the time dependent data, like flow. The time interval for simulation, starting date, and number of simulation periods are all defined with the flow data. The initial reservoir storage, at the start of simulation, can also be defined here using the **SS** Record (instead of using the initial storage on the **RL** Record).

Incremental Local Flow. The program uses incremental local flows (flows between adjacent control points) in the system routings. The flow data set must be in the same uniform time interval as used in the simulation. The time interval can be in minutes, or hours up to one month (720 hours).

Incremental local flows can be computed from observed discharges and reservoir releases. (**J3** Record, field 6) Incremental local flows can also be calculated from natural flows.

Computed incremental local flows can be output into a DSS file for subsequent system operations. (**JZ**, **ZW** Records)

Period Average Values. Flow data are average values. If end of period flow data are given, the program will first average the flow data. (**J3** Record, field 8)

Ratio of Flow. Flow data at some of the control points can be a ratio of the flow at another system point. The flows can also be shifted several whole computation time intervals. (**C1** Record)

Cumulative Local Flow. Cumulative local flows are computed for each downstream location. They are computed by routing and combining the incremental local flows downstream from a reservoir. The cumulative flow would represent the flow without any reservoir release. Uncontrolled cumulative local flows do not include flows above a reservoir that has more than ten acre-feet of active storage. Otherwise, uncontrolled local flows will include flows from the upstream reservoir drainage areas.

Natural Flow. The accumulation of all incremental flow, without any reservoir holdouts, represents the flow in the system without reservoirs (unregulated flow). If requested on **J3** Record, field 4, natural flows are calculated for printout purposes.

Flow Processing. Data on flow records can be for more time periods than the internal program's dimension limit and the program will automatically generate an equivalent series of events so that the entire event is operated.

Flow data are normally read in a 10 field record-image format (defined by the **BF** Record, field 1).

Flow data or any other time series data can be read from a separate data file (HEC-DSS) by entering **ZR** Records.

Flow data can be shifted in time and/or converted to any other time interval (from one hour to one month) by use of a separate program HEC-DSSMATH.

2.7 Input Data

Details on input data are provided in Appendix G. The following provides basic information on the minimum required data for reservoir system modeling. The input data for a basic HEC-5 model 1 is shown Table 2.1. Examples are also provided in the Appendices for various program applications.

All data records use the first two columns for identification.

Most data records are optional and can be omitted unless options are desired.

Input is coded into ten 8-column fields for all input except for the **ID**, **ZR** and **ZW** Records.

A blank field is taken as a zero input.

Table 2.1 HEC-5 Data Input Example

```
T1      Single Flood Control Reservoir Operating One Downstream Location
T2      Basic Flood Control Options, Metric Units
T3      Rocky River Basin, Aaron Dam Site to Zachary
J1      1       1       5       3       4       2
J2     24     1.2       0       0       0
J3      5                      -1               1
JZ333.09  333.10  333.12  333.13  222.04  222.17  222.18  222.02  333.22  333.11
C
C  ============= Aaron Dam =============
RL    333  188000  131400  146500  188000  562200  630100
RO      1     222
RS     12       0  124100  146500  188000  253600  362000  417700  465200  546300
RS562200  589300  630100
RQ     12       0     660     680     727     800     870     910    2320    5660
RQ  6460    7650    9630
RE     12   209.7   249.6   251.5   255.6   262.1   270.5   274.3   277.4   282.2
RE 283.2   284.7   286.8
CP    333     425      80       3
IDAARON DAM
RT    333     222     1.2     0.3     3.0       0
C
C  ============== Zachary ==============
CP    222     450
IDZACHARY
RT    222
ED
C     ------------------- Flood of 20-28 Dec 1964 -------------------------------
BF      2      72       0       64121924       0       3                    1900
C     ------------------ Inflow at Aaron Dam Site ----------------------
IN    333
IN    193     193     198     217     242     272     286     290     297     297
IN    297     418     559     715     909     973    1005    1104    1260    1522
IN   1933    2478    2896    3087    3016    2705    2400    2174    2096    2060
IN   1947    1791    1749    1827    1912    1890    1763    1593    1437    1345
IN   1296    1267    1218    1161    1104    1048     984     935     899     857
IN    826     797     767     746     722     701     687     667     647     632
IN    609     581     552     523     487     453     425     396     375     354
IN    326     297
C     ----------- Local Incremental Flow at Zachary ------------------------
IN    222
IN     49      49      54      63      89     102      94      94      95     102
IN    122     192     248     367     531     539     473     460     509     608
IN    756     934    1036     982     815     629     474     426     517     606
IN    577     480     454     517     627     670     587     459     377     346
IN    335     325     335     378     400     350     286     288     300     288
IN    276     282     309     321     332     345     323     285     256     239
IN    223     209     200     189     174     129     151     190     167     173
IN    177     173
ZW    A=ROCKY RIVER     F=METRIC TEST
EJ
ER
```

All records used must be in correct order (as shown in the sequence of input records summary on the inside back cover of Appendix G); and, control points must be in sequential order of treatment in routing and combining flows.

Either SI (Metric) or English units can be used.

Input data (T1 through BF only) can be checked for possible errors by the use of separate program CKHEC5.

2.8 Basic Reservoir Model Data

The example input shown in Table 2.1 illustrates the format and basic input for a flood control reservoir model, with one reservoir operating for one downstream control point.

2.9 Reservoir Routing

Reservoir routing is performed sequentially, in the order the reservoir data are given. All locations are processed for each time interval of flow data. The primary decision variable is the reservoir release for each time interval. Once the release is determined, the reservoir end-of-period storage is computed using the Accounting Method. However, when the proposed release exceeds the outlet capability of the reservoir, Surcharge Routing is used. And, when the flood control storage is going to fill to capacity, Emergency Release determination can be invoked.

Accounting Method. When the reservoir release is determined based on specified operation goals, reservoir end-of-period storage is equal to the previous period's storage, plus the average inflow, minus the outflow and reservoir evaporation (if specified).

Surcharge Routing. When the desired release is greater than the physical outlet capacity, an iterative method is used to find the outflow. This method provides the same results as the Modified-Puls method.

Emergency Releases. When the desired release for the current period plus channel capacity releases for future periods (up to the limit of foresight specified) would cause a reservoir to exceed maximum flood storage in the current or future periods, a release can be made for the current period so that the reservoir does not exceed the top of flood pool in the near future.

2.10 Reservoir Operation

Reservoir operation simulation primarily depends on the state of the reservoir at each time interval. The general goal is to keep the reservoir at the top of the conservation pool. As the pool level moves into flood control, conservation, and inactive storage zones, the operation goals change.

Flood Control Zone. If there is flood control storage and the pool level is in that zone, the reservoir will operate for flood control goals and try to evacuate the flood water as quickly as possible.

Conservation Zone. If the pool level is in the conservation storage zone, the program will only release water when it is necessary to meet specified conservation demands (e.g., minimum flow, diversions, or energy requirements).

Inactive Zone. No reservoir releases can be made when the pool level drops below the top-of-inactive storage.

2.10.1 Flood Operations

Flood control operation will attempt to keep channel flow, at specified downstream control points, at or below control point channel capacity. Excess water is stored in the reservoir pool to avoid control point flooding within a specified future time window (foresight). When downstream flows decrease, excess water is evacuated from the flood control pool as rapidly as possible. A more detailed discussion of flood reduction capabilities is described in Chapter 3.

Space. The concept of SPACE is used to define how much additional flow can be added to the downstream control point without exceeding its channel capacity. SPACE is computed by taking the difference between the control point local flow and the defined channel capacity. Then, considering routing criteria, the reservoir release to fill the available SPACE can be computed.

Release estimate. The determination of a reservoir release required to bring the flow at a downstream control point to channel capacity is based on solving the following linear-routing equation:

$$O_n = C_1 R_n + C_2 R_{n-1} + C_3 R_{n-2} + \dots \qquad (2\text{-}1)$$

where:

O_n = Routed release at a downstream location at time n.

R_n, R_{n-1}, etc. = Reservoir releases at times n, n-1, etc.

C_1, C_2, etc. = Routing coefficients, as coefficients of inflow

The routing coefficients in equation (2-1) are determined from routing criteria input to the program. Theoretically, there can be an infinite number of coefficients; however, the sum of the coefficients will equal 1.

Contingency Factor. A contingency factor (**J2**, Record, field 2) can be used to temporarily increase the downstream local channel flow to allow for uncertainty in flow forecast. By using the contingency factor, the computed SPACE and the reservoir release will be smaller. This is to recognize the effects of forecast errors (that the actual flows may be larger than input values).

Foresight. Reservoir operations do not have unlimited knowledge of future flows. The limited future information can be evaluated by specifying the number of hours of foresight on inflows (**J2** Record, field 1). The program will be limited to that foresight when making release determinations.

Rate-of-change on Releases. A rate-of-change variable can limit how rapidly the reservoir release can be increased, or decreased. The default value is equal to the channel capacity at the reservoir over a 24 hour period (**J2** Record, field 3; or **R2** Record).

2.10.2 Conservation Operations

In addition to flood control operation, conservation operation may be specified to provide minimum flows at one or more downstream locations, meet diversion schedules and generate hydropower. Water supply capabilities are described in more detail in Chapter 4 and hydropower is described in Chapter 5.

Minimum Flow. Minimum flow requirements can be defined at any location (control point). Based on reservoir storage level, two levels of flow target can be defined: desired and required. Desired flows are met when there is sufficient water supply above the buffer level (**J1** Record, field 6). Required flows are met when water in storage drops into the buffer pool.

Hydropower. A power reservoir can operate to meet at-site firm energy requirements or allocated system firm energy in kilowatt-hours (kWh). A power reservoir can also operate based on a rule curve relating plant factors to percent of conservation storage.

Specified Releases. Outflows can be specified for any number of reservoirs for any or all time periods (**QA** Records). Provided there is sufficient water and outlet capacity, the release will made. If not, the program will adjust the reservoir releases as necessary.

Limited Simulations. System operation can be made for a fewer number of time periods than are input on the flow records (**BF** Record, field 6). Also, part of the system can be operated without removing the remaining system records by stopping the operation at a mainstream control point (**J2** Record, field 7).

2.11 Reservoir Releases

In addition to making the reservoir release decision for each time interval, the program provides output for a CASE variable to indicate the basis for the reservoir release. In some instances, there may be more than one reason; however, only one value can be given. It is often helpful to review the reason for the release determination along with the actual release and resulting downstream flows. Table 2.2 shows the primary CASE options.

2.12 Output

Input data record images and a rearranged labeled input summary are provided in the output file. A description of the available output from the program is provided in Chapter 7. Appendix F provides a detailed description and examples of the available output options. The following output can be requested (**J3.1** and **J8** or **JZ** Records):

- Flow data.
- Computation of incremental local flows.
- Results of system operation arranged in downstream sequence for reservoirs and control points (all defined output data are shown).
- Reservoir data by period (Inflow, Outflow, EOP Storage, Case, Level, and Equivalent Level for all reservoirs).
- Rreleases and control point regulated flow by period.
- Summary of flooding in system for each flood.
- Summary of maximum and minimum values for all floods.
- Economic output, including summaries of expected annual damages for system, and of reservoir and control point costs and system net benefits for flood control.
- Frequency curve printer plot.
- Hydrologic efficiencies based on multi-flood events.
- Summaries of hydropower energy and benefits.
- Annual summaries of sum, maximum, minimum or average for selected variables at selected control points.
- Specified variables at selected control points can be printed for all time periods (user determined output using **J8** and **JZ** Records).
- Selected output (**JZ** Record) from the program can be stored in a data file (HEC-DSS) for later processing by other standard HEC programs by using a **ZW** Record.
- Trace features can be used for printing out intermediate answers for specified control points (**TC** Record), time periods (**TP** Record) and subroutines (**TS** Record).
- Output error check.

Table 2.2 CASE Options

Basis for reservoir release	Case[1]
• Based on **channel capacity** at dam	.01
• Based on **rate-of-change** of release	.02
• Based on not exceeding the **top of conservation pool**	.03
• Based on **emergency releases** (see also cases 20-24):	
Outflow based on holding storage at **top of flood control pool**	.04
Surcharge routing (**maximum outlet** capacity)	.06
Pre-release based on not exceeding flood control pool during foresight period	.29
• Based on keeping **tandem** reservoirs in balance	.05
• Based on **maximum outlet** capacity	.06
• Based on not drawing reservoir **empty** (level 1)	.07
• Based on **minimum required** low flow at the dam	.08
• Based on releases to draw to **top of buffer** pool	.09
• Based on **primary energy** demand for hydropower	.10
• Based on minimum release if all higher priority reservoirs in parallel with this project are not releasing	.11
• Based on **system energy** requirement allocation	.12
• Based on **power** release (**leakage**)	.13
• Based on **power** release (**penstock limit**)	.14
• Based on **power** release (**generator capacity**)	.15
• Based on emergency **gate regulation** curve operation	
(a) Gate regulation curve release - rising pool	.20
(b) Emergency release - partial gate opening	.21
(c) Emergency release - transition	.22
(d) Emergency release - outflow = inflow	.23
(e) Emergency release - gates fully opened	.24
• Based on release given on **QA** Record	- *release*
• Based on **minimum desired** low flow at the dam	.00
• Can be based on filling the downstream channel at location X at Y time periods in the future for either flood control or conservation operation	X.Y

[1] Shown in HEC-5 Output

Chapter 3

Flood Reduction Capabilities

The basic program capabilities were described in Chapter 2, which presented the primary considerations for simulating reservoir operation. In HEC-5, flood operations are a priority in release determination. This chapter provides more detailed information on the concepts and procedures used in the program to support the flood reduction goal. In Appendix C, three example problems are provided to illustrate some of the program considerations during release determination for flood reduction.

3.1 Basic Flood Operation Data

Three important items of input in an HEC-5 flood control simulation are:

① the number of hours of **foresight** on inflows and local flows used in system operation,

② the coefficient by which flows are multiplied as a **contingency** allowance in the determination of flood control releases, and

③ the maximum **rate-of-change** of reservoir releases during a specified time period.

Special attention should be given to determine appropriate values for these key parameters because reservoir operation during a flood is particularly sensitive to these three variables. Default values are used in the program simulation if input is left blank. The simulation time intervals for flood operations should be 24 hours or less to obtain accurate simulations. Also, some of the flood control options are not used for intervals longer than 24 hours because channel routing is not normally applicable to weekly or monthly intervals.

Foresight. The number of hours of foresight for all reservoirs in a system is given on the **J2** Record in field 1. In addition, foresight may be specified for individual reservoirs on the **R2** Record in field 5. This number should be approximately equal to a reasonable meteorological forecasting period in the basin. A longer forecast period will produce a better operation but may not be realistic. Typically, 24 hours is used in flood studies. However, if there is a long travel time for releases to get to downstream locations, a larger foresight may be required to "see" the impact of current releases on those distant locations. In the summary tables for input data (see "*Routing / Operation Summary"), HEC-5 provides the cross products of routing coefficients from reservoirs to operational control points. These routing coefficients are the ratios of flow and indicate how many periods it will take for a current release to reach each location. For real-time water control applications the time of foresight should typically as long as the travel time of the longest set of coefficients shown in the listing of routing coefficients. The default value for foresight is 24 hours.

Contingency. A contingency allowance is a coefficient by which local flows are temporarily adjusted when used in the determination of upstream flood control releases. The inflows are multiplied by this factor, for the forecast period, before the available SPACE is computed. A value of 1.2 is typically used for flood studies, which indicates a 20% uncertainty in the local flow data. For real-time water control applications, a contingency value of 1.0 may be used if the flow data embodies the uncertainty of rainfall forecasts. If, however, forecasted flows do not reflect the uncertainty, a contingency value greater than 1.0 may be appropriate. The contingency allowance is input for all locations in a system on the **J2** Record in field 2. In addition, the contingency allowance may be specified for individual control points on the **CP** Record in field 6. The default value for contingency allowance is 1.0.

Global Maximum Rate-of-Change of Reservoir Releases. The maximum rate-of-change at the reservoir may be based on the downstream channel's ability to accept decreasing amounts of water without bank sloughing, or other considerations. However, it is also a simulation tool to prevent the reservoir releases from changing too much between time steps. The rate-of-change is entered on the **J2** Record in field 3 as a ratio of the channel capacity during a one hour time period. The default rate-of-change is .043 times the channel capacity at the reservoir per hour. For a 3-hour simulation interval, the rate-of-change is 12.9% (.043 x 3) of channel capacity.

Maximum Rate-of-Change For Individual Reservoir. The rate-of-change given on the **J2** Record applies to all reservoirs in the system, unless a different rate is given on an **R2** Record for a specific reservoir. The rate-of-change on the **R2** Record can be defined either as a ratio, or as a fixed value in m^3/s (ft^3/s) per hour, and can be different for increasing or decreasing releases (fields 1 and 2, respectively).

Flooding Priority. When flood control releases conflict with conservation releases in a multi-purpose reservoir system, a priority of operation must be defined. In general, the default (normal) priorities in HEC-5 are to operate for flood control first, and conservation second. The priorities can be changed by entering the appropriate priority code in field 4 of the **J2** Record (see Appendix G, Input Description, for listing of codes).

3.2 Special Flood Operation Data

The basic options provide the "default" HEC-5 operation for flood reduction. Generally, the program will store excess water until it is safe to release it. The channel capacity at specified locations is the primary concern. This style of operation will generally provide the maximum downstream protection, if there is sufficient reservoir storage.

The basic HEC-5 reservoir operation is classified in Corps of Engineer practice as "Method A" regulation. The classification of regulation types in to Methods A, B and C is documented in Section 3-3, Development of Regulation Schedules and Water Control Diagrams, *Management of Water Control Systems*, EM 1110-2-3600 (USACE, 1987). A summary of these regulation types follows:

Method A - Regulation is based on maximum beneficial use of available storage during each flood event. Reservoir releases may be reduced to zero when flooding is occurring at downstream locations.

Method B - Regulation is based on control of the reservoir design flood. Reservoirs using this type of regulation may be characterized as having limited flood control storage and a primary operation goal of minimizing losses during a specified design flood. During minor floods, regulation is based on providing continual releases that increase as flood storage is filled. Reservoir release rates are determined such that all the flood storage capacity is utilized during the regulation of the design flood.

Method C - Regulation is based on a combination of Methods A and B. With this type of regulation, minor floods are regulated with a Method A style which switches to a Method B style when a specified portion of the flood storage is filled. Method C regulation could also be achieved by regulating with a Method B regulation during winter months when the probability of large floods is greatest and Method A during the remainder of the year.

Many reservoirs have insufficient flood storage capacity and should not be operated with a Method A style of regulation. To change from the default HEC-5 operation to a Method B or C style requires application of one of the following special options:

Storage-Release Schedules. The simplest implementation of Method B regulation may be specified by the addition of pre-defined storage-based releases on **RD** Records (**RD** Record, field 1 = -1), which are paired with **RS** Record storage values, and the selection of the storage-based diversion option (**DR** Record, field 7 = -2). With these data, excess flood waters are handled as diversions to a specified location below the dam.

Pre-Release Options. The pre-release options are sometimes useful in managing large floods. With this option, the program will change its operation once it determines that the remaining flood space will be filled within "foresight" time. There are two pre-release options defined by a code specified on the **J2** Record, field 5.

① Option 1 will make releases equal to the channel capacity at the reservoir as soon as it can be determined that the reservoir will exceed the flood control storage within the allowable foresight period (**J2** Record, field 1). For pre-release option 1, a value of 1 is entered on the **J2** Record, field 5.

② Option 2 allows releases to be made which are larger or smaller than channel capacity so that the top of the flood control pool will just be reached within the foresight period. For pre-release option 2, a value of 2 is entered on the **J2** Record, field 5.

Gate Regulation Curves. HEC-5 also includes an option to simulate the operation of gated spillways during large floods. This option is based on the development of "gate regulation curves" which determine reservoir releases as a function of the elevation and rate-of-rise of the reservoir. Required data for this option (which includes definition of a induced surcharge storage pool, physical description of the gated spillway, a hydrograph recession parameter and operational criteria) are input on the **RG** Record. The basis for this procedure is documented in Section 4-5 Induced Surcharge Storage, *Management of Water Control Systems*, EM 1110-2-3600 (USACE, 1987).

Information required to develop the gate regulation curves includes an "induced surcharge envelope curve" (ISEC). The program allows the user to enter a specified ISEC or optionally it will determine a default ISEC.

① The user-specified ISEC is entered on **RD** records. Discharge data on the **RD** Records correspond to storages, discharges and elevations on **RS**, **RQ** and **RE** records. Typically, additional data must be added to the **RS-RE** records to provide sufficient detail at the top of the flood pool (and above) to adequately define the shape of the ISEC.

② The program-developed ISEC is defined by the specification of three parameters on the **RG** Record: the top and bottom of the induced surcharge pool (**RG** Record fields 1 and 2 respectively); and, the discharge of the ISEC (**RG** field 3) at the top of the flood pool (bottom of the induced surcharge pool).

Clock Times for Reservoir Release Decisions. The HEC-5 program makes a release determination every time step. However, in practice, reservoir release decisions may be made less frequently. To provide a more realistic operation, an option to specify clock times when reservoir release decisions are made can be entered using **JR** Records. With this option release changes will only be made on the day of the week and time specified on the **JR** Records, during all other time periods the release determined in the last **JR** decision period will be repeated until the next **JR** decision period. The **JR** Records are inserted after the **J8/JZ** Records. If **JR** Records are omitted, release decisions are made for all time periods.

Release Scheduling. The HEC-5 default procedure for determining reservoir releases (to fill space during flood operation) is based on the assumption that in future periods, releases will be reduced to zero at a rate governed by the rate of change. This assumption enhances the program's ability to maximize releases and fill downstream space, however, it often results in releases with large fluctuations. Even with "rate-of-change" controlling how quickly releases can be increased or decreased, there are situations when there may be large fluctuations in reservoir releases. The scheduling option will calculate reservoir releases assuming future releases are the same as the current period's release. As a result, releases determined with the scheduling option tend to be more realistic. The release scheduling option is requested with a 10 in field 6 of the **J2** Record.

Reservoir Guide Curves. In regions with distinct seasonal variability in precipitation, reservoir storage allocated to flood control is typically greatest during the wet season and is reduced during the dry seasons. Correspondingly, storage allocated to conservation purposes is at a minimum during the wettest season and must be greatest during the dry season. In HEC-5 flood control and conservation storage zones are defined by reservoir index levels (**RL** Records). In practice index levels are referred to as Guide Curves or Rule Curves. Three options are available in HEC-5 to define reservoir guide curves. The reservoir levels can remain constant during the year, can vary monthly, or can vary seasonally. For seasonal input, HEC-5 requires a definition of the seasons in number of days from December 31 (**CS** Record), and the corresponding reservoir storage values for each season are specified on the **RL** Records. Up to 36 seasons are allowed and any or all reservoir index levels may vary. Twelve seasons are not allowed on the **CS** Record to avoid confusion with monthly storage variations.

3.3 Reservoir Operation Criteria

The simplified operation goals for flood control, in priority are:

① Do not endanger the dam
② Do not contribute to downstream flooding
③ Do not unnecessarily store water in the flood control pool
④ Evacuate flood control storage as quickly as possible

Reservoirs are operated to satisfy constraints at individual reservoirs, and to maintain specified flows at downstream control points. Constraints at individual reservoirs with gated outlets are as follows:

① When the level of a reservoir is between the top of conservation pool and the top of flood pool, releases are made in an attempt to draw the reservoir to the top of conservation pool without exceeding the designated channel capacity at the reservoir or at operational downstream control points. Operational control points are those specified on the **RO** Record.

② Releases are made equal to or less than the designated channel capacity at the reservoir until the top of flood pool is exceeded, and then all excess flood water is dumped if sufficient outlet capacity is available. If insufficient capacity exists, a surcharge routing is made. Input options permit channel capacity releases (or greater) to be made prior to the time that the reservoir level reaches to top of the flood pool if forecasted inflows are excessive (Pre-release option).

③ Rate-of-change criteria specifies that the reservoir release cannot deviate from the previous period release by more than a specified percentage of the channel capacity at the dam, unless the reservoir is in surcharge operation.

④ Releases are made equal to, or greater than, the minimum desired flow when the reservoir storage is greater than the top of buffer storage, and equal to the minimum required flow if between level one and the top of buffer pool. No releases are made when the reservoir is below level one (top of inactive pool). Releases calculated for hydropower requirements will override minimum flows if they are greater than the controlling desired or required flows.

Operation criteria for gated reservoirs for specified downstream control points are as follows:

① Releases are not made, as long as flood storage remains, which would contribute to flooding at one or more specified downstream locations within the foresight allowed. The limitation is the smaller of foresight or number of routing coefficients.

② Releases are made, where possible, to exactly maintain downstream flows at channel capacity (for flood operation), or for minimum desired or required flows (for conservation operation). In making a release determination, local intervening area flows are adjusted by the contingency factor (greater than 1 for flood control and less than 1 for conservation) to account for uncertainty in forecasting flow.

3.4 Channel Routing

For short-interval simulations, channel routing must be incorporated in reservoir release determination. Generally, HEC-5 simulation considers short-interval as a computational time interval of 24 hours, or less. The **NOROUT** Variable (**J3** Record, field 7) tells the program to not use routing when the time interval for simulation is greater than its value. The default value is 24 hours.

HEC-5 routing methods are described in Appendix A. For reservoir release determination, the basic linear-routing equation 3-1 is applied. When non-linear routing methods are used, a linear estimate is made for release determination. However, the release is routed with the input routing option and data as described in the following sections on SPACE and release determination.

$$O_n = C_1 R_n + C_2 R_{n-1} + C_3 R_{n-2} + \dots \qquad (3\text{-}1)$$

where:

O_n = Routed release at downstream location at time n

R_n, R_{n-1}, etc. = Reservoir releases at times n, n-1, etc.

C_1, C_2, etc. = routing coefficients, as coefficients of inflow

3.5 Channel SPACE

SPACE is defined as the difference between the local flow, plus routed previous reservoir releases, and the channel capacity. It is the measure of the residual capacity in the channel for release of flood water from the reservoir. As previously stated, the determination uses a local flow adjusted by the contingency factor to account for uncertainty in flow forecasts.

The computed SPACE is transferred up to the reservoir by “reverse routing.” That is, the downstream SPACE is divided by the routing coefficients to obtain the upstream releases that would just fill the remaining SPACE. Because routing distributes the release over time, the previous period releases will continue to reduce future SPACE in the channel. Therefore, SPACE must be computed for each time period.

3.6 Reservoir Release Determination

For the coefficient routing methods, the reservoir releases will be determined with the coefficients. However, for non-linear storage methods, there is no single set of coefficients. The program will make a linear approximation of the storage-outflow relation and use the coefficients from that to make the release estimate to fill SPACE. The actual release is routed with the given routing criteria. The program will check to determine if the estimated value was within five percent of the actual value.

The release determination for the current time step must recognize the rate-of-change criteria. That is, a current period release may also set future minimum releases based on the rate-of-change for decreasing releases. For example, a channel capacity release at the current time step will require four 6-hour periods to reduce the flow to zero if the rate of change is .043 per hour (the program default).

During flood operations, the program will make the maximum release possible based on the considerations described. If the constraint was at the reservoir, the CASE variable will be a decimal code indicating the controlling rule. If a downstream location defined the maximum possible release, the location number and the number of future time periods that the constraint occurred is displayed in the CASE variable. For example: a value of 100.02 for the CASE variable would indicate that location 100, two time periods in the future, defined the maximum release that could be made at the current time. Often, in flood operations for downstream locations, the first occurrence will be at the limit of the foresight time.

Chapter 4

Water Supply Capabilities

The basic model data, described in Chapter 2, are required for most HEC-5 reservoir models. In addition, model data can be added to utilize other program features. This chapter summarizes options typically associated with low flow augmentation and water supply purposes. However, the options also can be applied to flood operations. Appendix D provides examples with more detailed descriptions of options available for Water Supply simulation.

4.1 General Capabilities

Reservoir operation to provide water supplies to meet downstream flow requirements such as municipal, industrial, irrigation, navigation, fishery maintenance, recreation or water quality needs may be simulated with HEC-5. The water supply demands are either defined as specified minimum flow targets at control points or diversion schedules from reservoirs or control points. As with flood control operations, the reservoirs are told which locations they operate for (**RO** Records) to meet the specified demands. The reservoir simulation will attempt to meet the specified flow and diversion demands by releasing supplemental water whenever the local flow is not sufficient to supply the demands.

4.2 Seasonally Varying Conservation Storage

The basic allocation of reservoir storage is accomplished with **RL** Records. Generally, these storage values remain constant throughout the year. For many regions there is a reliable seasonal variation in flow, which allows for changes in the space required for flood storage and conservation storage through the year. In HEC-5, the reservoir storage allocation to some levels can remain constant while others vary. The storage allocation can be varied monthly or seasonally.

Monthly Storage Allocation. To vary the storage monthly, additional **RL** Records are required, a set for each level. The first field indicates the level number, and the sets are input in increasing order of level starting with level one. The third field indicates how the storage varies: constant, monthly, or seasonally. For monthly values, the third field is zero and the fields 5 - 10 provide the first six monthly values and a second **RL** provides the remaining six values (fields 5 - 10).

Seasonal Storage Allocation. The seasonal storage input is similar to the monthly, in that additional **RL** Records are input for each level. For seasonal, the third field indicates the number of seasonal values. The seasons are defined by cumulative days, from December 31, on the **CS** Record.

4.3 Evaporation

While evaporation can be simulated in any reservoir model, it is usually ignored for flood studies. That is why reservoir evaporation is typically considered as a water supply or hydropower option. The evaporation data are defined in units of depth and the program computes the evaporation volume based on the average pool area for the time interval. Therefore, reservoir area data (**RA** Records) are required to compute evaporation.

The input evaporation depths are considered **net evaporation**. This reflects the reservoir gains from precipitation directly on the surface area, as well as the evaporation loss. If the reservoir were not there, the precipitation would fall on the ground and only a portion would runoff to the stream. With the reservoir in place, all of the precipitation on the pool surface area is available. Therefore, when precipitation exceeds the evaporation there is a net gain to the reservoir. For time-periods where there is a gain, the net evaporation is negative.

Evaporation data can be defined on a monthly schedule or on a period-by-period basis:

(1) Monthly evaporation data can be read for the entire basin (**J6** Records). Every reservoir in the system would be subject to the same evaporation rates.

(2) Evaporation data are input for individual reservoirs by monthly periods (**R3** Records). Different rates can be defined for each reservoir.

(3) Period-by-period evaporation data can be provided for any reservoir in the system (**EV** Records). This data would be input with the time-series data (after the **BF** Record).

4.4 Minimum Channel Flow

Instream flow demands may be specified at control points within the system being simulated. They may represent a variety of low-flow requirements: minimum flows for fishery or wildlife, navigation, stream recreation, minimum water quality flows, and various other water supply purposes. Two types of low-flow may be specified: **minimum desired** and **minimum required**.

Minimum desired flows are the targets when reservoir storage is above the top of the buffer level. This would be the normal (typical) operation goal.

Minimum required flows would be the essential flow target during drought conditions. When streamflow is low and reservoir storage is low (below the top of the buffer) the minimum required flow allows the user to cut-back and reduce requirements allowing minimum needs to be met until supplies are replenished.

Four options exist for specifying desired or required flow: constant, monthly, seasonally or period-by-period.

(1) **Constant desired and required flow.** A constant desired and/or required flow target can be defined at any location on the **CP** Records, fields 3 and 4 respectively.

(2) **Monthly desired flow.** A monthly desired flow target varies from month to month, but not year to year. The **QM** Records are used to define the monthly values. The first monthly value is for the starting month, usually January (**J1** Record, field 2).

Monthly required flow. Since there is no separate input record for monthly required flow, the **QM** Record is used. By setting the constant required value to minus one (**CP** Record, field 4 = -1), the data input on the **QM** Record will define the minimum required monthly schedule. Because only one set of **QM** Records can be input at a control point, it is necessary to add an extra control point to define both desired and required flows on a monthly schedule. The desired flow schedule would be input at one location and the required flow schedule at the other.

(3) **Seasonally varying desired and required.** In addition to desired or required flows varying monthly, the user can also specify a seasonal rule curve to vary desired or required flows. The **CS** Record defines the seasons for the year (up to 36 seasons in number of cumulative days from December 31). A companion **CG** Record can be used to specify the reservoir elevations corresponding to the defined seasons. Minimum desired or required flows on **QM** Records can vary throughout the year and the target release is based on the reservoir level for the specified season. Each minimum flow given on the **QM** Records corresponds to one seasonal guide curve on the **CG** Record. To vary required flows instead of desired flows, use a -1 in field 4 of the **CP** Record, as previously described for monthly varying flows.

(4) **Period varying desired and required flow.** Each period may be assigned a minimum flow value with **MR** Records. The period-by-period data are input after the **BF** Record with other time series data. This record is used to define minimum desired flow. As in the monthly varying options, a -1 in field 4 of the **CP** Record will indicate that the period varying flows are required, not desired. Also, when both desired and required flows vary by period, an extra control point must be added, one defining desired and the other required.

4.5 Diversions

Diversions may be specified from any control point or reservoir. However, there can only be one diversion from that location. Diversion records (**DR**) are input at the locations where the flow is diverted from and are not used at the locations where the flow returns to the system. The maximum number of diversions is 40.

Diversions can be returned to any downstream control point or reservoir, or they can also leave the system. A special option also allows a diversion to an upstream location. If diversions return to the system, they may be routed using any linear method allowed and multiplied by a constant representing the ratio of return flow.

Eight types of diversions may be specified:

(1) Diversions can be constant (**DR** Record, field 8).

(divert a constant 150 from location 55 to location 77)

DR 55	77	0	0	0	0	0	150		

(2) Diversions can vary monthly **(DR** and **QD** Records).

(divert 90-150 from location 55 to location 77)

DR 55	77					1			
QD 90	90	100	100	110	120	150	150	150	130
QD 95	90								

(3) Diversions can be a function of inflows (**DR**, **QS** and **QD** Records).

(divert variable 0-100 from location 55 to location 77)

DR 55	77					-1			
QS 5	0	100	110	500	600	10000			
QD 5	0	0	10	10	100	100			

(4) Diversions can be a function of reservoir storage (**RS**, **RD**, and **DR** Records).

(divert variable 0-600 from location 55 to location 77)

RS 7	100	2500	10000	33000	50000	150000	250000		
RD 0	0	0	100	100	500	600	600		
...									
DR 55	77	0	0	0	0	-2	0		

- OR -

(divert excess flood water from location 55 to location 77)

RS 7	100	2500	10000	33000	50000	150000	250000		
RD -1	0	0	100	100	500	600	600		
...									
DR 55	77	0	0	0	0	-2	0		

(5) Diversions can be a function of energy for pumped storage hydropower analysis (**RL-RT** and **DR** Records).

(divert based on energy schedule at reservoir 55 and available storage at reservoir 77)

RL - RT for reservoir 55									
DR 55	77	0	0	0	0	-3	0		

(6) Diversions can be pumped to upstream location 55 from downstream location 77 (**DR** and **QD** Records).

(pump 90-150 from location 77 to location 55)

DR 55	77					-4			
QD -90	-90	-100	-100	-110	-120	-150	-150	-150	-130
QD -95	-90								

(7) Diversions can vary by period (**DR** Record plus **QD** Records in time series data).

(diversions which vary by period (20 periods) from location 55 to location 77)

DR 55	77					-5			
...									
ED									
BF 2	20	etc.							
QD 55									
QD 66	66	77	88	90	91	92	96	87	83
QD 46	54	33	0	0	100	150	130	130	200

(8) Diversions can be a function of flow at another location (**DR** Record, field 10).

(diversion from location 55 to location 77 will be 75% of the flow at location 33)

DR	77	0	0	0	0	-6	0	.75	33

In addition to the above diversion types, “water rights” limits may also be applied (**WR** Record) in conjunction with the **DR** Record as shown in the following example:

(divert 120 acre-feet, from location 55, at the rate of 1.5 ft^3/s during Julian days 105-185)

WR370610 105 185 120									
DR 55	0	0	0	0	0	0	1.5		

4.6 Yield or Conservation Storage Determination

To assist in sizing reservoir projects for conservation purposes and in evaluating effects of reallocating storage, a procedure has been developed to automatically determine either the required storage to meet a specified demand or the maximum reservoir yield that can be obtained from a specified amount of storage. The procedure is designed for a single reservoir using average monthly flow. However, up to four reservoirs can be analyzed in a single run, provided the reservoirs being optimized operate independently (tandem reservoirs cannot be optimized at the same time). All of the conservation requirements, as well as the conservation storage, may vary monthly.

Conservation Storage. The **J7** Record is used to describe the function to be optimized for each reservoir, as explained in Appendix G. The first option determines the seasonal reservoir conservation storage required to meet all specified reservoir demands. This is determined iteratively by multiplying the reservoir storage for top of conservation (on **RL** Record) by a coefficient (which varies for each trial), operating the project for the period of flow data on the **IN** Records, determining the error in reservoir drawdown storage, and making a new estimate of the coefficient. This process is continued until the error in storage is within the allowable error defined on the **J7** Record, field 10.

Yield Determination. Given a fixed storage, the potential yield for any specified conservation purpose can be determined, while still providing for all other demands on the project. The yield can be determined for: monthly firm energy, minimum monthly desired flow, minimum monthly required flow, monthly diversions, or all of the conservation purposes. An iterative search procedure is used with a ratio adjustment of the target demands until all of the conservation storage is utilized during the critical flow period within the given data set.

Initial Estimate. The initial estimate of the variable being analyzed is normally the value specified on input. In the case of energy, a special capability has been developed to make the initial estimate of energy and capacity. The estimate is based on the power produced from the power storage and the available flow during the estimated critical drawdown period. The critical drawdown duration is estimated based on a relationship of drawdown duration (in months) to ratios of power storage to mean annual flow.

Critical Period Analysis. Unless otherwise requested, the program will operate the project for the duration of the given inflow data. If twenty years of monthly data are available and 4 or 5 iterations are required to obtain the desired results, a considerable amount of computation will be required. By using the critical period option (**J7** Record, field 8), the program will determine the starting and ending periods corresponding to either an input period or the minimum flow volume for the specified duration. Initially, only the estimated critical period data would be used for each iteration.

For program determined critical periods, an additional table can be printed that will show, for assumed critical drawdown durations of 1 - 60 months: the minimum flow volume for each duration, the starting and ending periods of the minimum flow volume, and the initial estimate of dependable capacity. The first value of capacity printed is based on the minimum flow volume only, while the second value also uses the reservoir power storage released uniformly over the number of drawdown months. The second printed value is used for the initial estimate of the dependable capacity.

Solution Cycles. If the analysis is performed for the estimated critical period first (Cycle 1), a single routing can then be made for the period of record to see if the most severe critical period has been found (Cycle 2). If a new critical period is found, then Cycles 3 and 4, and possibly 5 and 6, can be made for the new critical period and then a single routing for the period of record (see **J7** Record, field 9).

Chapter 5

Hydropower Capabilities

The application of the HEC-5 program for hydropower analysis is presented here. The sections are presented as separate program features; however, they are all dependent on the same basic power data. The basic power data are presented in the Power Reservoirs Section. The sections on System Power, Pump-Storage and Firm Energy Determination all build on the basic capabilities described below. Appendix E provides more detailed information on the program's data use and solution techniques for various hydropower options.

5.1 Power Reservoirs

This section describes the additional data required to model a hydropower reservoir. The data required for a basic reservoir model were presented in Chapter 2, and includes the total storage at each operating level, the downstream control points for which the reservoir is operated, and a storage-outflow relationship. For hydropower, both reservoir areas and elevations are provided as a function of reservoir storage. The areas are needed for evaporation computations, described in Chapter 4, and the elevations are needed for head determination. Example 7 in Appendix E is an example of power reservoir input and output.

5.1.1 Data Requirements

Power data are input with reservoir data at each hydropower reservoir. The data requirements include the installed capacity, an overload ratio, a tailwater elevation, an efficiency, and the monthly energy requirements (mW-hrs or plant factors). The primary hydropower plan data are defined on the **P1** Record and optional data is included on the **P2** Record.

Installed Capacity. The installed capacity is the nameplate capacity except for planning studies, where an assumed value is used. The capacity, times the overload ratio, defines an upper limit for power generation. If the data are available, the peaking capability can also be defined as a function of reservoir storage, reservoir outflow, or power plant head.

Overload Ratio. An overload ratio is used by the program to determine the maximum energy the power plant can produce in a time interval. The maximum production would then be a limit on how much dump energy could be generated during periods of surplus water. The program assumes a value of 1.15 if none is given.

Tailwater Elevation. The tailwater elevation can be specified as a constant value associated with full capacity operation (block loading tailwater). Tailwater elevation can also be specified as a function of reservoir releases. For most power plants, the units are on a portion of the time, however, in the program the reservoir release is an average for the simulation interval. If a downstream lake elevation could affect the tailwater elevation, the program can check that elevation to see if it is higher than the block-loading tailwater elevation or the tailwater rating curve. If it is, then the downstream lake elevation would be used. Where two or more ways are used to describe the tailwater, the higher tailwater value is used.

Power Efficiency. Power plant efficiency is the total efficiency (generator efficiency X turbine efficiency) of the power plant. No other electrical-mechanical energy loss is computed by the program. The efficiency can be a constant value (the program assumes 0.86 if none is given) or it can vary with head. An alternative to using efficiency directly is the kilowatt per discharge ($kW/ft^3/s$) coefficient as a function of reservoir storage. Often in older power studies done by hand, $kW/ft^3/s$ vs. Elevation was used as an aid to computation. These relationships, with efficiency and tailwater elevations built into them, can be used directly in the program by relating reservoir storage to elevation.

Firm Energy Requirements. The energy requirements can be defined for each hydropower plant using 12 monthly values (**PR** Records) or by using an energy requirement for every time period of the study (**PV** Records). For most planning studies, the 12 monthly values are used. The monthly energy values can be given in thousand kilowatt-hours (mW-hrs) or as plant factors. Plant factors are ratios indicating the portion of time (average per month for **PR** Records) that the plant is generating. If plant factors are given, the program computes the monthly energy requirement by multiplying the plant factor times the installed capacity times the hours in the month; the product being mW-hrs for each month.

Daily Energy Distribution. If the time interval used is less than a week, daily ratios can be given to show how the energy requirement is distributed over the seven days of the week (**PD** Records). The first value is for Sunday and the sum of the daily ratios provided must add up to 1.0. The program computes the weekly energy requirement from the given monthly requirement and then distributes the weekly total using the daily ratios. If no distribution is given, the program will use a uniform distribution. For the simulation, the program determines the day of the week based on the input starting date for the flow data (**BF** Record, field 5).

Hourly Energy Distribution. If the time interval is less than one day, a distribution within the day can be given (**PH** Records). The daily distribution should provide at least as many values as there are time intervals in a day (24 hrs/Δt). The daily distribution can be as many as 24 hourly values. If 24 values are given, and the time interval is greater than hourly, the program will sum the hourly values to compute the value for the given time interval. As with the daily ratios, the values should sum to 1.0 and if no distribution is given, a uniform distribution is used.

Power Guide Curve. An alternative to defining firm energy requirements allows input of plant factors as a function of percent power storage available (**PC** and **PF** Records). The concept provides for increased generation when water supply is high and decreased generation when supplies get low. The guide curve is not considered a firm energy option because the amount of energy generated is dependent on the amount of water available.

5.1.2 Program Operation

For hydropower operation, the program computes the energy requirements for each time period of operation. The monthly energy requirements and given distributions, or the given period-by-period energy requirements, are used for this purpose.

The program cycles through the simulation one interval at a time. For the hydropower reservoirs, the following logic is used to determine a power release:

(1) Estimate average storage. Use end of previous period's storage initially and then the average of computed and end-of-period storages. (Reservoir elevation and evaporation are both dependent on average storage.)

(2) Estimate tailwater elevation. Use highest elevation from block loading tailwater, or tailwater rating curve, or downstream reservoir elevation.

(3) Compute power head by subtracting tailwater and loss from reservoir elevation, corresponding to the estimated average storage.

(4) Compute reservoir release to meet energy requirement.

(5) Compute reservoir evaporation using reservoir area based on average reservoir storage.

(6) Solve for ending storage (S_2) using continuity equation.

(7) After the first cycle, use the new S_2 and return to step 1. On subsequent cycles, check the computed power release with the previous value for a difference less than 0.0001. Use up to five cycles to obtain a balance.

(8) Check maximum energy that could be produced during time interval using overload factor and installed capacity.

(9) Check maximum penstock discharge capacity, if given. Reduce power release to penstock capacity if computed release exceeds capacity.

The program will also determine if there is sufficient water in storage to make the power release. The buffer pool is the default minimum storage level for power; however, the user can define the inactive pool as the minimum power pool (see **J2** Record, field 4). If there is not sufficient water in storage, the program will reduce the release to just arrive at the minimum pool level.

If there is sufficient water, the power release for the reservoir establishes a minimum flow at that site. The program will evaluate every reservoir and control point in the system for each time interval. For conservation operation, it will determine if additional reservoir releases are required for some downstream requirement. If not, then the power release will be made. If additional water is needed for non-power uses, then the release will be increased. Credit for the additional energy generated by the larger release will be given to the Secondary Energy account. The Primary Energy account only shows the energy generated to meet the specified power demand.

During flood control operation, the power release may add to downstream flooding. A user specified priority determines whether the program cuts back the release to prevent downstream flooding (see **J2** Record, field 4). (The program shorts power under default priority.) If the program cuts back on the power release, there will be an energy shortage for that time period and the shortage is shown in output as Energy Shortage. A program output variable, "Case," will show the program basis for release determination. If priority is given to hydropower, then the power release will be made and some flooding due to reservoir release may occur.

5.1.3 Program Output

A description of the available output from the program is provided in Chapter 7. This section describes the hydropower output and provides some suggestions on how to check the program's results. There are 41 variables pertaining to the flow data, reservoir and control point status, and energy production. The normal sequential output provides tables of the applicable variables for each location in the system, or a user can define tables for just the variables and locations desired. The variables that deal specifically with the power reservoir are:

- Energy Required: the energy requirements specified for the reservoir
- Energy Generated: the computed energy based on the reservoir release
- Energy Shortage: the deficiencies in generated Energy
- Power Capability: either constant or variable based on input option
- Power Spill: the discharge not used for generation
- Power Head: the elevation difference between the reservoir and tailwater minus hydraulic losses
- Power Plant Factor: the ratio reflecting the percent of time the plant is generating

Summary tables also provide Primary, Secondary, and Shortages of Energy and Energy Benefits, if benefit values were provided.

Case. If the Generated energy equals the Required energy, then the Case variable should equal 0.10, showing the reservoir release was for hydropower. If generated energy was less than required, the Case variable code should show the reason (e.g., insufficient storage or flood control operation). If Generated energy was greater than Required, the program Case should indicate a release of surplus water or that a higher required flow at another control point was operated for.

Power Capability. Variable peaking capability data, if provided, are based on a Reservoir Storage, Reservoir Outflow or Reservoir Operating head (**PP** and **PS** Records). Given one of peaking capability relationships, the program computes the peaking capability for each time period of the simulation. This information can be used in conjunction with peak demand information to determine the critical peaking capability for dependable capacity. If no peaking capability function is given, the program uses the installed capacity for all periods.

Summary Tables. In the summary tables for energy, the total energy generated is shown as Primary and Secondary Energy. The Primary Energy represents energy generated to meet the primary energy demand (firm energy). The Secondary Energy is all of the surplus generated energy (dump energy). Shortage is the shortage in the firm energy for the power plant. The summary results are shown for each hydropower reservoir and for the total of all hydropower reservoirs in the system.

Energy Benefit Table. The Energy Benefits Summary Table provides the dollar value for Primary and Secondary Energy and the Purchase Cost based on Shortages. The benefits are computed using input unit values for the three categories. The Net Energy Value reflects the sum of Primary and Secondary less Purchases. A capacity value is based on the installed capacity.

5.2 System Power

Up to 35 hydropower reservoirs can be modeled as individual power projects as described in the previous section. If some of the reservoirs are delivering power into a common system, system operation might be able to produce more energy than the sum of individual projects can produce. By allocating the system load based on each project's ability to produce power, the projects could help each other during periods of low flows. This section describes the added input, program operation and output associated with the System Power capability. Everything described in the Power Reservoirs section also applies to this section. Example 9 in Appendix E of the program User's Manual shows input and output for a three-reservoir power system.

5.2.1 Data Requirements

Additional data required for system power operation consist of System Energy Requirements and an indication at each hydropower plant if it is in the system. One power system can be used; however, some of the hydropower plants may operate independently of the power system.

System Energy. System energy requirements are provided as 12 monthly values (**SM** Records) in mW-hrs or as ratios of the system power rule curve (**SC** and **SF** Records). The system energy requirements represent a demand on all projects in the hydropower system. The monthly energy requirements data start with January. The monthly system energy requirements are distributed in a similar manner as the at-site energy requirements. Seven daily ratios define the distribution of weekly energy (**SD** Record) and multi-hourly ratios define the distribution within each day (**SH** Records).

System Power Rule Curve. An alternative to defining firm system energy requirements allows for the input of plant factors (**SF** Records) as a function of total system power storage (**SC** Record). This energy definition is analogous to the application of **PC** and **PF** Records for at-site generation.

Power System Project. At each hydropower reservoir in the model, all of the power data previously described is still provided. Added input includes indication if the power plant is in the power system (**P2** Record, field 3). The indicator is zero if a power plant is not to be used for system power, and 1 if the plant is in the system.

System Plant Factor. The maximum plant factor for the project contribution to the system load is defined on the **P2** Record, field 4. The system plant factor is used to limit the extent (or percent of time) each power plant can operate to meet the system load. Generation rates greater than the system plant factor are allowed when excess water is available, but only the portion up to the maximum plant factor can be credited as meeting the system load.

At-site Energy Requirements. The monthly at-site requirements at each power plant in the system (**PR** Records) should be reduced to some minimum value to provide operational flexibility. If the at-site requirements are not reduced, the plant will operate for the at-site requirements, reducing the possibility of system flexibility. Often some low plant factor is defined for at-site requirements at system power reservoirs just to ensure their operation. However, if there are some at-site requirements for a particular project, they should be given and the other projects should be allowed the maximum flexibility.

5.2.2 Program Operation

With system energy requirements, the program will allocate the demand to all of the projects designated in the power system. The allocation is performed at the beginning of each time step of operation by determining the energy that can be produced by system reservoirs releasing down to various common levels. The program temporarily subdivides the conservation storage into a number of levels and then computes the energy that could be produced by releasing down to each level. Then, by taking the total system demand, the program can interpolate on the levels for the projects to determine releases that will keep the system balanced as much as possible. The program has provisions for checking minimum flow constraints to ensure the allocated release will also meet the reservoir's minimum flow requirement. Also, if a significant at-site requirement is given, the program will ensure the at-site requirement is met within the total system generation. Once the allocation is made, the remaining operation for the program is the same as previously described.

The reservoir release values, based on the procedure described above, may not actually produce the required system energy due to the nonlinearity of the relationship. If the sum of the project's energy production does not match system requirements, the program will cycle through the allocation procedure up to two more times in an attempt to get the generated energy to within one percent of the requirement.

The system energy operation is limited to 12 monthly energy values; period-by-period values cannot be used. Also, the system energy allocation procedure does not provide for routing between tandem reservoirs. That means the release from the upper reservoir is assumed available at the lower reservoir in the same time period. For short-interval routings with considerable travel time between tandem power reservoirs, the tandem project will not remain balanced and the actual energy generated may be lower than the system energy that was computed during the allocation period.

5.2.3 Program Output

All of the previously described output would be available plus:

- System Energy Required: the total energy required from all system plants
- System Energy Generated: the total energy generated by all system plants
- System Energy Usable: the total system energy generated, limited by the maximum plant factors for system power generation (**P2** Record, field 4)
- System Energy Shortage: the deficiencies in usable system energy

The system energy variables are displayed for the first reservoir in the system when normal sequential output is used or they can be requested using user designed output tables.

The Case variable for system power is 0.12. When a project release is based on the allocation from system power operation, a value of 0.12 is shown. When the at-site power requirement controls, a value of 0.10 will be shown.

5.3 Pump-Storage

The previous information on Power Reservoirs applies to the pump-storage model. This section describes the additional data required, the program operation, and the type of output available for pump-back operation. The pump-storage capability is applicable to either an adjacent or integral pump-back configuration. Example 8 in Appendix E of the User's Manual shows input and output for pump-back operation.

5.3.1 Data Requirements

To model a pump in a hydropower reservoir, a dummy reservoir is added just upstream from the power reservoir to input the pumping capabilities. The basic reservoir and power data described previously are required for the dummy location. For the power data, a negative installed capacity is used to indicate to the program that this is a pump and not a generator. The tailwater elevation is usually based on a lower reservoir elevation and the energy requirements data now reflect energy available for pumping. Added data include a maximum pump-back (penstock) discharge and head loss.

The program will pump to the upper reservoir until it reaches the top-of-conservation level. The maximum pump-back level can be set to a lower level by defining the pump-back level (**J1** Record, field 7).

The diversion record (**DR**) defines the source of the pump-back water. The input would indicate a diversion from the dummy location to the lower reservoir and the type of diversion would be -3 for pump-back simulation. The computed pump-back discharges are carried by the program as diversions from the lower reservoir to the dummy reservoir. Those diversions are then routed into the upper reservoir based on unlimited outlet capacity and the routing criteria from the dummy reservoir. Figure 5.1 shows the model arrangement for an on-stream pump-back system. A similar approach can be applied to an off-stream system.

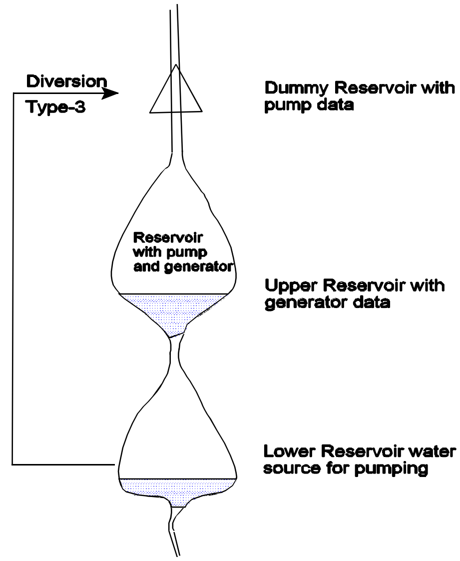

Figure 5.1 Model for on-stream pumped storage.

5.3.2 Program Operation

The initial estimate of the pump-back discharge is based on the available energy defined by input. The tailwater elevation will be based on the higher of the block loading tailwater elevation or the lower reservoir level. The upper reservoir elevation, from the end of the previous period, is used in computing the head. If pump leakage is defined, that discharge is subtracted from the pump-back discharge. If the maximum penstock capacity is defined, the program checks to see that the value is not exceeded.

The pump discharge based on available energy is reduced, if necessary, to prevent the lower reservoir from being drawn below the buffer level. The program also prevents the pump-back discharge from exceeding the storage capacity of the upper project at the top-of-conservation pool. The top of the pump-back pool can be set to a lower level by defining a pump-back level.

5.3.3 Program Output

No additional output data have been provided for pump-back operation. The discharge values for pumping are displayed as diversions at the dummy reservoir (negative values) and at the lower reservoir (positive values). The energy values are shown at the dummy reservoir. Energy Required represents the Available Energy for pumping and Shortage represents Available Energy that <u>was not used</u> for pumping.

5.4 Firm Energy Determination

Energy is one of the conservation purposes the program can maximize using the firm yield concept. The optimization procedure can determine firm energy for up to four independent reservoirs given a fixed conservation storage, or determine the required conservation storage to provide for a given at-site energy demand. Chapter 4 described the optimization capabilities of the program. This section describes the additional input requirements, the program's operation, and the type of output provided.

5.4.1 Data Requirements

The basic power reservoir model previously described would be used for the optimization procedure. The addition of one job record (**J7**) requests that optimization be performed and tells the program which reservoirs to use and the option selected. The input values for the parameters to be optimized (e.g., storage or monthly energy) are used by the program as the initial value. In the case of energy optimization, a special capability has been developed to make the initial estimate of energy and capacity. The estimate is based on the power produced from the power storage and the available flow during the estimated critical drawdown period. The critical drawdown duration is estimated by the routine based on a relationship of drawdown duration (in months) vs. ratio of power storage to mean annual flow.

Unless otherwise requested, the program will operate the project for the duration of the given inflow data. If twenty years of monthly data are available and 4 or 5 iterations are required to obtain the desired results, a considerable amount of computation will be required. By using the critical period option (**J7** Record, field 8), the program will determine the starting and ending periods corresponding to the minimum flow volume for the specified duration. Only the isolated critical period data would then be used for each of the iterative routings. With monthly data, the starting period should be January. If it is not, the program will automatically shift back to the start of the year.

5.4.2 Program Operation

The program operates the power reservoirs through a complete simulation as previously described. However, at the end of the simulation, the program checks to see if all of the power storage has been used in the routing. If not, a new estimate of the monthly energy requirements is made to provide for all fixed purposes, plus the at-site energy requirements during the critical drawdown period. The iterative search procedure uses the entire inflow data set for each cycle unless the critical period option is used to limit the simulation. The allowable error in storage can be set by the user or the default value of 100 acre-foot negative error and one percent positive error are assumed. When all demands are met and the minimum storage at the reservoir is within the allowable error, the solution is obtained.

5.4.3 Program Output

The output options previously described would normally be used with the optimization procedure. For each iteration, a special table of results is provided. For most applications using optimization, it may be desirable to just run the first half of the program, HEC-5A, and not get the sequential routings for each trial. The optimization results could then be used in a complete routing. For program determined critical periods, an additional table will show, for assumed critical drawdown durations of 1-60 months: the minimum flow volume for each duration, the starting and ending periods of the minimum flow volume, and the initial estimate of dependable capacity. The first value of capacity printed is based on the minimum flow volume only, while the second value also uses the reservoir power storage released uniformly over the number of drawdown months. The second printed value is used for the initial estimate of the dependable capacity.

5.5 Strategies for Power Studies

Strategies for using HEC-5 for project studies are similar to strategies for performing sequential routings by manual methods. The objective is to perform only those routings which are necessary to determine the amount of reservoir storage required to accomplish the desired objectives, or to determine the reservoir accomplishment possible from a given amount of reservoir storage. The relative low cost of computer solutions compared to manual methods makes it more economical to perform many more routings than before. However, it is easy to overburden a study by evaluating too many "nice to know" conditions. It is, therefore, still important to restrict the number of routings to those essential to the success of the study. The following comments may help in deciding which combination of routings is required for different types of projects.

5.5.1 Large Storage Projects

In many geographical areas, flow data are available near the project for more than 20 years. Therefore, it is usually desirable to initially limit the duration of the routings to the critical period and to use monthly flows in the analysis. Since the critical period of record can change as the demands on the system change, the full period of flow record should be used to verify that the assumed yield or firm energy can be maintained throughout the entire historical record.

The optimization procedure in HEC-5 will determine the approximate critical period and will perform sequential routings using that critical period to automatically determine either:

1. the storage for a specified annual firm energy or reservoir yield, or

2. the annual firm energy or reservoir yield that can be obtained from the specified reservoir storage.

The optimization procedure can also use the entire period of flow record to determine the storage or firm annual energy. The difference in compute time between using the flows for the entire period of record vs. the critical period only is approximately proportional to the number of months used in the routings. For 30 years of flow data and a 6-year critical period, the ratio of compute time approaches 5 to 1. In general, it is advantageous to optimize on the critical period of record and then to verify the answer on the period of record than to optimize on the entire period of record.

Once the conservation operation has been satisfactorily determined for a range of power storages and minimum power heads using monthly flows, the effect of the selected project on other project purposes should be determined. If flood control is a project purpose, the program can be set up to either:

1. perform monthly routings during non-flood periods and daily or multi-hourly routings during major flood events, or

2. perform period-of-record routings for some fixed interval such as daily flows. It is particularly important to see how the proposed hour-by-hour operation affects both the power and the flood control operations. Runs should also be made to test for the desirability of using seasonally varying storage allocations (rule curves operation).

Once a satisfactory operation for a single multi-purpose reservoir is obtained, the data should be expanded to include other reservoirs whose operation might affect the reservoir under study. In order to determine if a system operation for flood control or power is necessary or desirable, studies should be made which compare the effectiveness of the system, with and without the system rules.

5.5.2 Pumped Storage Projects

While pumped storage projects can be evaluated using some of the ideas mentioned above, the primary routings will have to be made using both daily flows and multi-hourly operations. Monthly routings for pumped storage operation would, in most cases, not be meaningful. While period-of-record runs using daily flows might be warranted, hour-by-hour operation during certain critical weeks should also be evaluated.

5.5.3 Run-of-River Projects

While run-of-river projects can be operated along with other reservoirs in the system, studies using flow duration techniques are preferable to monthly routings since short-duration high flows are important and cannot be captured by sequential analysis without going to daily or hourly operation. A daily flow sequential routing for the selected project should be made after the project's size has been determined using daily flow-duration techniques.

Chapter 6

Reservoir System Simulation

This chapter presents operation criteria for single and multiple reservoirs, system operation concepts, and multi-flood simulation. Multi-flood is the term used for options to divide a flow-data series into multiple sets for processing in HEC-5.

6.1 Reservoir System Operation Criteria

Reservoirs are operated to satisfy constraints at individual reservoirs, to maintain specified flows at downstream control points, and to keep the system in balance. The process starts with the current state of the reservoir and its requirements. Then the reservoir examines the specified downstream locations and evaluates their requirements and constraints. If more than one reservoir operates to meet the needs of a control point, the relative levels of the reservoirs are evaluated to determine which reservoir has the higher priority. If possible, the release decision will attempt to balance the levels of the reservoirs operating for a common control point, and balance levels in tandem reservoirs.

6.1.1 Operational Criteria for Individual Gated Reservoir

The reservoir first evaluates its current state to determine an initial release. Constraints at individual reservoirs with gated outlets are as follows:

(1) When the level of a reservoir is between the top of conservation pool and the top of flood pool, releases are made to attempt to draw the reservoir to the top of conservation pool without exceeding the designated channel capacity at the reservoir or at downstream control points for which the reservoir is being operated.

(2) Releases are made equal to or greater than the minimum desired flows when the reservoir storage is greater than the top of buffer storage, and equal to the minimum required flow if between level one and the top of buffer pool. No releases are made when the reservoir is below level one (top of inactive pool). Releases calculated for hydropower requirements will override minimum flows if they are greater than the controlling desired or required flows.

(3) Releases are made equal to or less than the designated channel capacity at the reservoir until the top of flood pool is exceeded, and

then all excess flood water is dumped if sufficient outlet capacity is available. If insufficient capacity exists, a surcharge routing is made. Input pre-release options permit channel capacity releases (or greater) to be made prior to the time that the reservoir level reaches the top of the flood pool if forecasted inflows are excessive.

(4) Rate-of-change criteria specifies that the reservoir release cannot deviate from the previous period release by more than a specified percentage of the channel capacity at the dam site, unless the reservoir is in surcharge operation.

6.1.2 Operational Criteria for Specified Control Points

After an initial release estimate is determined, the reservoir will “look” at the requirements and constraints at all the specified downstream control points for which it operates (**RO** Record). Constraints and considerations include:

(1) Releases are not made (as long as flood storage remains) which would contribute to flooding at one or more specified downstream locations during a predetermined number of future periods. The number of future periods considered, is the lesser of the number of reservoir release routing coefficients or the number of local flow forecast periods.

(2) Releases are made, where possible, to exactly maintain downstream flows at channel capacity (for flood operation) or for minimum desired or required flows (for conservation operation). In making a release determination, local (intervening area) flows can be multiplied by a contingency allowance (greater than 1 for flood control and less than 1 for conservation) to account for uncertainty in forecasting these flows.

6.1.3 Operation Criteria for Balancing Flood Control Reservoirs

If more than one reservoir operates to meet the needs of a control point, there is a system decision to make. Which reservoir to release from and how much? The concept of system balance, described later in the section on Equivalent Reservoirs, is used to determine priority among reservoirs. Considerations for balancing reservoirs include:

(1) Where two or more reservoirs are in parallel operation for a common control point, the reservoir that is at the highest index level, assuming no releases for the current time period, will be operated first to try to increase the flows in the downstream channel to the target flow. Then the remaining reservoirs will be operated in a priority established by index levels to attempt to fill

any remaining space in the downstream channel without causing flooding during any of a specified number of future periods.

(2) If one of two parallel reservoirs has one or more reservoirs upstream whose storage should be considered in determining the priority of releases from the two parallel reservoirs, then an equivalent index level is determined for the tandem reservoirs based on the combined storage in the tandem reservoirs.

(3) If two reservoirs are in tandem, the upstream reservoir can be operated for control points between the two reservoirs. In addition, when the upstream reservoir is being operated for the downstream reservoir, an attempt is made to bring the upper reservoir to the same index level as the lower reservoir based on index levels at the end of the previous time period.

6.1.4 Parallel Conservation Operation Procedures

Parallel conservation operation procedures are utilized when one or more gated reservoirs are operated together to serve some common downstream flow requirement. The following steps are utilized by HEC-5 to determine the reservoir releases necessary for a downstream location:

(1) Determine all reservoirs operating for the downstream location.

(2) Determine priorities of reservoirs operating for the downstream location based on index levels.

(3) Calculate table of releases to bring all other parallel reservoirs to level of each reservoir in turn.

(4) Calculate release to bring all parallel reservoirs to each target storage level. Also, determine sum of releases to bring system to top of conservation and top of buffer pools.

(5) If no upstream parallel reservoir has been operated for flood control or water supply at the downstream location and no requirement for low flow exists and no flooding will occur at the downstream location within the forecast period, skip operation for the downstream location.

(6) Check for future flooding at the downstream location within forecast period. If flooding occurs, operate for flood control.

(7) If no flooding, determine conservation releases for each parallel reservoir to bring system reservoirs to some appropriate level as follows:

(a) If the release to satisfy minimum desired flow is less than the release to bring system to top of buffer level -- then the release at each reservoir is based on the minimum DESIRED flow at the downstream location.

(b) If not, and the release required to satisfy minimum required flow is greater than the release to bring system to top of buffer level -- then the release at each reservoir is based on the minimum REQUIRED flow at the downstream location.

(c) Otherwise -- release the flow required to bring system to top of buffer level (more than required flow but less than desired flow).

(d) If release for minimum required flow exceeds discharge to bring system to level 1, only release to level 1.

6.1.5 Tandem Conservation System Operational Procedures

Tandem reservoir operation occurs when an upstream reservoir is directed to operate for a downstream reservoir (**RO** Record). Conservation system operational procedures will attempt to balance the conservation storage in the system based on storage target levels. The user, therefore, must desire to have the two reservoirs at the same relative level. If that is not the case, the upstream reservoir should not be directed to operate for the downstream reservoir. These procedures are based on the previous period's storage levels; therefore, they may not make sense when simulation is in large time steps, e.g., monthly.

When the upstream reservoir, for the previous time period, is at an index level below that of the downstream reservoir and both are below the index level for the top of conservation pool, releases from the upstream project are made to satisfy the upstream project's minimum flow requirement. When the upstream reservoir's index level, for the previous time period, is greater than the index level for the downstream reservoir, the upstream reservoir is operated to bring the upstream reservoir down to the level of the downstream reservoir for the previous time period. Two additional criteria must also be satisfied.

(1) First, the release from the upstream reservoir must not be allowed to cause the lower reservoir to spill or waste water just due to balancing levels.

(2) Second, the downstream reservoir must not be required to empty all of its conservation storage in meeting its requirements if there is still water in the upstream projects. This condition could occur due to the use of the previous time period for the balancing level. It is necessary to use the previous period's index level because the reservoir release for the downstream project, for the current time period, is not known when the upstream reservoir's release is being calculated.

6.1.6 Reservoir Operation Priority

Reservoir operation priority for different purposes is input on the **J2** Record, field 4. Table 6.1 summarizes these priorities for reservoir operation.

Table 6.1
Reservoir Operation Priority

Condition	Normal Priority	Optional Priority
During flooding at downstream location	No release for energy requirements	Release for primary power
If primary power releases can be made without increasing flooding downstream:	Release down to top of buffer pool	Release down to top of inactive (Level 1)
During flooding at downstream location:	No release for minimum flow	Release minimum flow
If minimum desired flows can be made without increasing flooding downstream:	Release minimum flow between top of conservation and top of buffer pool	Same as normal
If minimum required flows can be made without increasing flooding downstream:	Release minimum flow between top of conservation and top of inactive pool	Same as normal
Diversions from reservoirs (except when diversion is a function of storage):	Divert down to top of buffer pool	Divert down to top of inactive pool (Level 1)

6.2 System Operation Concepts

As indicated in previous paragraphs, the index levels assigned to each reservoir are used to determine priority of releases among reservoirs. The program operates to meet specified constraints throughout the system and then to keep all reservoirs in the system in balance if possible. A system is "in balance" when all reservoirs are at the same index level. To determine the reservoir index level at each time step of a simulation, the program interpolates linearly on a table of index level vs. storage (**RL** Record).

In balancing levels among reservoirs, priority for releases is governed by index levels such that reservoirs at the highest levels at the end of the current time period (assuming no releases are made) are given first priority for the current time period. The following sections show how the index levels can be used to specify operating rules for a system.

6.2.1 Equivalent Reservoirs

In determining the priority of reservoir releases among parallel reservoirs, or among subsystems of a reservoir system, where some tandem reservoirs are present, the concept of an "equivalent" reservoir is used. The concept is based on weighting the level of each reservoir in a subsystem by the storage in the reservoir to determine a storage-weighted level for the subsystem. For example, consider a situation in which two parallel reservoirs are upstream from a third, as shown in Figure 6.1.

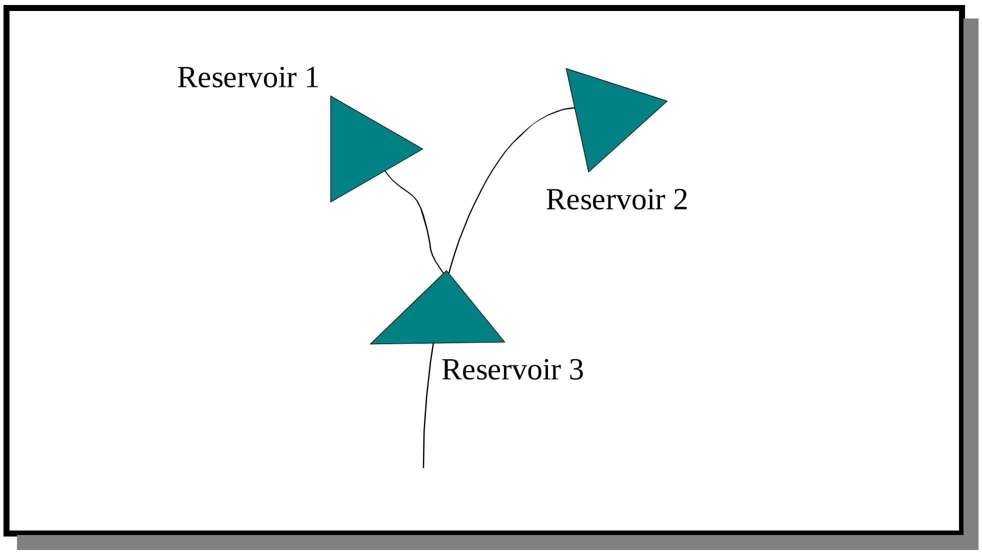

Figure 6.1 Reservoir Configuration for Equivalent Reservoir Example.

Table 6.2 shows the level-storage characteristics of the equivalent reservoir.

Table 6.2
Equivalent Reservoir Level - Storage Characteristics

Cumulative Storage - Acre Feet				
Index Level	Reservoir 1	Reservoir 2	Reservoir 3	Equivalent Reservoir
5	40	20	8	68
4	30	15	6	51
3	20	10	4	34
2	10	5	2	17
1	0	0	0	0

Suppose that it is desired to determine the amount of release to make from Reservoirs 1 and 2 and that storages in Reservoirs 1, 2 and 3 at the end of the previous time period are 35, 12.5 and 3, respectively. For these storages, the equivalent reservoir storage is 50.5. By interpolation, the equivalent level is 3.97 for the equivalent storage. (From Table 6.2, The equivalent storage of 50.5 is just below the Level 4 equivalent storage of 51). The levels of Reservoirs 1, 2, and 3 are: 4.5, 3.5 and 2.5, respectively, as shown in Table 6.3.

Table 6.3
Equivalent Level Determination

	Reservoir 1	Reservoir 2	Reservoir 3	Equivalent Reservoir
Storage	35	12.5	3	50.5
Level	4.5	3.5	2.5	3.97

The criterion used in the HEC-5 computer program is that releases will be made from an upstream reservoir if its level is above the greater of the level of downstream reservoir or the equivalent reservoir level. Therefore, a release would be made from Reservoir 1 and not from Reservoir 2 because the level of Reservoir 1 is above the equivalent reservoir level and the level of Reservoir 2 is below the equivalent reservoir level. However, the releases would also be governed by physical and other constraints that have been specified.

Figure 6.2 and Table 6.4 illustrate the use of the equivalent reservoirs concept with both parallel and tandem reservoirs operating as a system for location D. Table 6.4 shows three (3) reservoirs with the same flood control storage. Values are given in percent of storage filled.

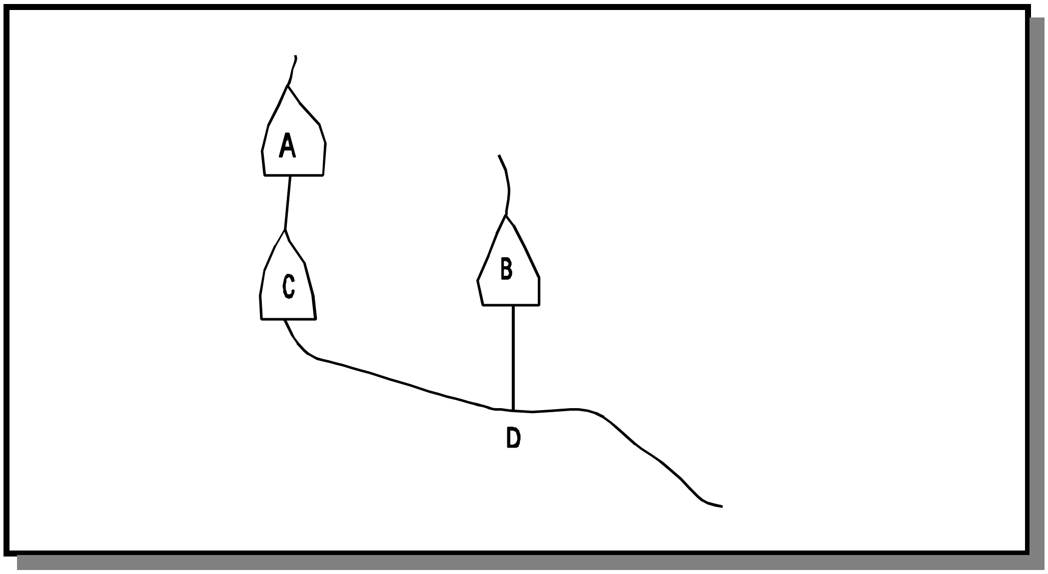

Figure 6.2 Example for Reservoirs in Parallel and Tandem.

Table 6.4
Release Priority for Tandem and Parallel Reservoirs
(Percent of Storage Filled)

A (%)	**C** (%)	**Equivalent A&C** (%)	**B** (%)	**Highest Priority B or C**	**Release from A**
60	40	50*	30	C	Yes
60	20	40*	30	C	Yes
30	20	25*	30	B	Yes
15	35*	25	30	C	No

***** Highest of C or A&C

6.3 Reservoir Priority Using Levels

Release priorities among reservoirs are an important reservoir operating criterion which must be specified for most system operations. Reservoirs first operate for their own requirements and then for downstream locations. When two or more reservoirs operate for a common location, the question is: *Which reservoir should be operated first?* The HEC-5 program uses the concept of Levels to determine reservoir release priority. The reservoir at the higher level is the priority reservoir to make a release. When all reservoirs are at the same level, the system is in balance.

Figure 6.3 shows the primary reservoir levels graphically. Additional levels can be defined within the primary levels. To illustrate the technique for setting priorities among reservoirs, the following example has been prepared:

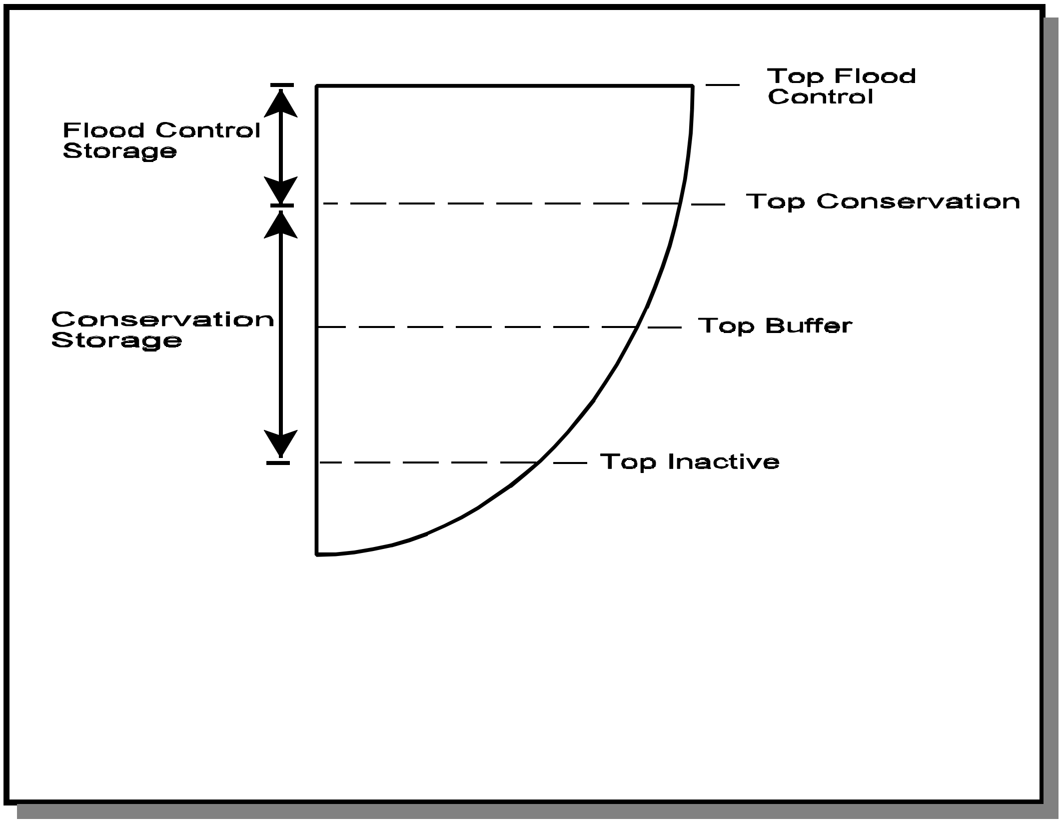

Figure 6.3 Reservoir Storage Levels.

Assume the information shown in Table 6.5 is known for each of four reservoirs which constitute a reservoir system.

Table 6.5
Reservoir Storage Levels
Cumulative Storage (acre-feet)

Reservoir Number	Top of Inactive	Top of Buffer	Top of Conservation	Top of Flood Control
11	1,000	5,000	50,000	100,000
22	5,000	10,000	100,000	200,000
33	10,000	20,000	150,000	500,000
44	50,000	100,000	200,000	700,000

It is desired to operate this example system according to the following rules:

1. Release flood control storage to top of conservation, equally.
2. Release Reservoir 11 conservation storage above top of buffer.
3. Next release Reservoirs 22 and 33 conservation storage above top of buffer.
4. Next release Reservoir 44 conservation storage above top of buffer.
5. Release conservation storage below top of buffer, equally.

To specify these operating criteria in HEC-5, each storage level in each reservoir is assigned an integer number from 1 to a maximum of 40. The number of levels used is the minimum number required to specify the desired operating rules. In this example, six levels were found to be necessary. The lowest level, Level 1, corresponds to the top of inactive pool. The highest level, Level 6, corresponds to the top of flood control pool. See Table 6.6.

The program makes releases from storage between the highest and next highest level until the water stored between these levels is exhausted; then it goes to the next lower level, and so on in descending order. All reservoirs with storage between the same successive pair of levels make releases where possible to maintain the same degree of risk. The specific criteria depends upon the system configuration.

Levels 2 through 5, in this example, are assigned in such a way that the system operates as desired. Because operating Rule 1 desires that all reservoirs release from flood control storage equally, by assigning Level 5 to the top of conservation (bottom of flood control) for all reservoirs, this rule is achieved.

Operating Rule 2 desires that all conservation storage from Reservoir 11, above the top of buffer, be released first. By assigning Level 4 to the top of buffer for Reservoir 11, and top of conservation for all other reservoirs this rule is achieved. This limits the available storage between Levels 4 and 5 to the conservation storage in Reservoir 11, thus it will be exhausted before water is released below Level 4.

Operating Rule 3 is achieved in a similar manner, by assigning Level 3 to the top of buffer for Reservoirs 22 and 33 and to the top of conservation for Reservoir 44. Conservation storage volume is provided between Levels 3 and 4 for Reservoirs 22 and 33, but not for Reservoirs 11 and 44.

Lastly, Level 2 is assigned to the top of buffer for all reservoirs. Below the top of buffer, all reservoirs are to release equally. This is achieved since Level 2 for all reservoirs is the top of buffer.

Table 6.6
Assigned Storage Levels

Level	Reservoir 11	Reservoir 22	Reservoir 33	Reservoir 44
6	100,000	200,000	500,000	700,000
5	50,000	100,000	150,000	200,000
4	5,000	100,000	150,000	200,000
3	5,000	10,000	20,000	200,000
2	5,000	10,000	20,000	100,000
1	1,000	5,000	10,000	50,000

To summarize, Figure 6.4 shows the level numbers corresponding to primary storage volumes for each reservoir. Reservoir storage volumes (corresponding to level numbers) are specified as input on the **RL** Record. During simulation, the system operates as follows: any water stored between Levels 5 and 6 is released from each reservoir. When the water stored between Levels 5 and 6 has all been released, water between Levels 4 and 5 is released. In this example, only Reservoir 11 has a storage volume between Levels 4 and 5. When the volume stored between 4 and 5 is exhausted, releases are made from storage between Levels 3 and 4, (this means from Reservoirs 22 and 33). Next, storage between Levels 2 and 3 is exhausted, therefore, Reservoir 44 releases are made. Finally, storage between Levels 1 and 2 is released. This technique for specifying reservoir operating rules has proven to be an effective way to handle most operating criteria.

Table 6.7
Reservoir System Priority of Operation (Storages and Levels)

Storage for:	Res 11	Res 22	Res 33	Res 44
Top of Flood Control	6	6	6	6
Top of Conservation	5	4, 5	4, 5	3, 4, 5
Top of Buffer	2, 3, 4	2, 3	2, 3	2
Top of Inactive	1	1	1	1

While this example treated priorities among the reservoir conservation storage, the concept applies to any component of reservoir storage. That is, the levels could be placed within the flood control or conservation storage pools. One reservoir could be drawing down one-half of its storage while another is drawing down all of its storage. In this manner, complex relationships among reservoirs, operating for a common target, can be developed.

Care must be taken when “balancing” reservoirs with large differences in their storage. If the reservoir has very little storage in a level, there will be a dramatic change in index level with small changes in storage. Because the program balances on the level, the small-storage reservoir will tend to be “out of balance” with the larger reservoirs in the system.

6.4 Alternative Reservoir Systems

When studies are being performed to evaluate proposed reservoirs, the reservoir system data set should include all proposed reservoirs, even if some of them would serve as alternatives to others. Control points should be selected and coded for all damage centers, reservoir-operational locations, and information points. Once the entire system is defined, a **J5** Record can be used to delete reservoirs from the system for each alternative system selected. The **J5** Record can be used to delete any reservoir in the system except for downstream tandem reservoirs (these reservoirs can be deleted by removing the reservoir records, while leaving the control point records).

The program has features to compute expected annual flood damage, or flood damage for a single flood. However, the preferred approach is to perform simulations with HEC-5 and write the computed regulated flows to an HEC-DSS file. The Flood Damage Analysis (HEC-FDA) and Project Benefits Accomplishments (HEC-PBA) computer programs are designed to read the flows from HEC-DSS and perform flood damage and benefit calculations based on current Corps of Engineers criteria.

The HEC-5 economic analysis capability can be evaluated at any number of control points by using **DA-DC** Records. Reservoir costs can also be evaluated by using the **R$** Record to show how the costs vary with reservoir storage (**RS** Records). The reservoir cost is based on the top of flood control storage value. If costs and expected annual flood damages are calculated, the net system flood benefits will be printed out for each alternative system operated. By careful selection of alternative systems, the system that produces the maximum net flood-damage reduction benefits can be determined by a reasonable number of separate program executions.

6.5 Non-Reservoir Alternatives

Some structural alternatives to reservoirs can also be evaluated in the system simulation. The existence of a levee or channel modification can be reflected in the reservoir system operation by changing the channel capacity (**CP** Record, field 2) and by changing the routing criteria (**RT** Records), if appropriate. The performance can be evaluated using a revised damage function. Two sets of routing criteria can be defined for each reach and thus the natural and modified routings can use different criteria. The natural flows can also be calculated by a separate program execution and entered as **NQ** Records when evaluating modified conditions.

6.6 Multi-Flood Options

In this context a flow data set is called a “flood,” even when it represents non-flooding conditions. There are several options for defining more than one flow-data set to the program. The following lists the options available:

(1) The multi-flood option may be used to operate the system for a continuous period of record with a mixture of computation intervals. A monthly operation could be used for a few years (assuming no routing is desired), and then operate for daily or hourly flows during a major flood (with detailed flood routing), and then back to a weekly or monthly routing interval, etc. A maximum of 80 events can be simulated in this manner in a single execution.

(2) Up to 10 ratios of any or all input floods can be run in a simulation operation (see **FC** Record).

(3) Each flood in a series of floods can start at different reservoir storage on **R1** Record (or **SS** Record), or from the same storages, or can be transferred using the storages from the previous flood (**BF** Record, field 3).

(4) Long floods may be simulated by dividing the flood into flow events which are less than the “Maximum Number of Periods per flow Sequence” (see HEC-5 output). This may be done by manually setting up several sets of flow data (with each less than the maximum) or by allowing the computer to generate separate floods (when the data read exceeded the maximum but is less than 2000 periods). A minimum of a 10-period overlap between floods is used to preserve continuity in channel routing.

(5) For period-of-record daily-flow simulation, it is convenient to divide the flow sequence into sets of four years (1461 periods including leap year). An overlap between flow sets is required if channel routing is used.

6.7 Automatic Flow Subdivision

Because all input arrays involving time periods are stored in the computer program's memory, each complete system operation can be made for only a certain number of periods at one time. The time period limit is variable depending on the number of reservoirs and control points in the simulation. Thus, if the number of time periods is dynamically limited to 50 and the number of flow periods read is 60, two sets of flow data must be stored in memory and operated upon separately. These two flow sets are called Floods 1 and 2, even though they may represent a single input flood event (**BF-EJ** Records).

For the example of 60 periods of flow data, HEC-5 will automatically store the data as two floods, will operate the system for the first flood, and will store the results. The program then will transfer the last 10 flows, plus a forecast period (**J2** Record, field 1) to the beginning of the next flood. Then, the program will read the second flood flows, will operate the system for the second flood and print out all the results as if it were one flood.

Chapter 7

HEC-5 Input and Output

7.1 Organization of Input

The input structure is designed to be flexible with respect to specifying characteristics of the reservoir system. Each input record is described in detail in Appendix G. Inside the back cover of Appendix G is a summary titled “Sequence of HEC-5 Input Records” that shows the order in which the records should be placed.

7.2 Types of Input Records

The various types of records used are identified by two characters in record columns 1 and 2. These characters are read by the program to identify the record. Types of records are as follows:

7.2.1 Comments - C .

Comments can be placed anywhere within the model data, but **not** within the flow data. The comments will be included in the output listing of input data.

7.2.2 Title Records - T1, T2, T3.

Three title records are required for each job. The titles specified on the records are read in alpha format and printed at the beginning of each job.

7.2.3 Job Records - J1 - JR.

These records are used to specify general information used throughout the reservoir-river system. The **J1-J3** Records are required input. The **J1** Record specifies the data units (metric of English) and the number of definition of primary storage levels for all reservoirs in the system. The **J2** Record specifies computational limits as well as policy parameters. The **J3** Record selects program output and defines the type of flow data (incremental, natural or observed) entered in the time series data. Records **J4-JR** are optional and are summarized below:

J4 Record	defines benefit and cost data
J5 Record	is for deleting reservoirs
J6 Record	represents basin evaporation
J7 Record	requests conservation optimization
J8 Record	allows for user-designed output tables
JZ Record	specifies which data are to be written to HEC-DSS
JR Record	specifies the clock times when reservoir releases will be made

7.2.4 System Energy - SM, SD, SH, SC and SF.

These records provide the system energy requirements by month (**SM**), and the daily (**SD**) and multi-hourly (**SH**) distributions for the monthly values. The **SC** and **SF** Records are used when specifying a system power rule curve.

7.2.5 Trace Records - TC, TP, TS.

These records are optional and are used to indicate the control points (**TC**), time periods (**TP**), and subroutines (**TS**) for which detailed output (trace information) is requested. Use of these records is not generally recommended since knowledge of the program is essential and the FORTRAN source code of the HEC-5 program is required for interpretation of the trace information.

7.2.6 Reservoir Records - RL, RO, RS, QQ, RQ, RA, RE, RD, R$, R1, R2, R3, and RG.

These records are used to describe characteristics of each reservoir. The **RL**, **RO**, **RS**, and **RQ** Records are required and are used to specify the reservoir storages for each index level (**RL** Record), the downstream control points that the reservoir is operated for (**RO** Record), and the reservoir storage-outflow characteristics (**RS** and **RQ** Records).

Optional records are used to describe multiple reservoir outlet capacities (**QQ** Record), reservoir areas (**RA**), elevations (**RE**), reservoir diversions (**RD**), and costs (**R$**). The optional **R1** Record is used to describe the initial storages for multiple events or for multiple ratios of the same event. The **R2** Record is to define rate-of-change variables and the **R3** Record provides monthly reservoir evaporation data for the reservoir. The **RG** Record is used to specify gate regulation curve data for induced surcharge flood routing.

7.2.7 Power Reservoir Records - P1, P2, PC, PF, PB, PR, PD, PH, PQ, PT, PL, PP, PS, and PE.

The **P1** and **PR** Records are required for a reservoir which has a power plant, but are omitted for all other reservoirs and non-reservoirs. Records **P1** and optional **P2** describe the general power characteristics. The **PR** Record specifies the monthly firm energy requirements.

The **PC**, **PF** and **PB** Records, if used, specify the rule curve power operation relating plant factor to percent of conservation storage. The optional **PD** and **PH** Records are used to specify the daily and multi-hourly distribution of power demands. The optional **PQ**, **PT** and **PL** Records describe tailwater and hydraulic loss rating curves, and the optional **PP**, **PS**, and **PE** Records describe the peaking capabilities, power storage and power efficiencies, respectively.

7.2.8 Control Point Records - CP, ID, C1, C2, RT, CR, WR, DR, QS, SQ, QD, EL, C$, CL, CC, CS, GS, CG, QM, WA, DA, DB, DF, DQ, and DC.

The **CP**, **ID**, and **RT** Records are required for each control point. They are used to identify the control point number, to specify channel capacity, to provide a name, to indicate the next downstream control point and to specify routing criteria. Control point data is required for all locations (reservoirs and non-reservoirs).

The optional **C1** and **C2** Records provide other general information for the control point. For routing with input coefficients, the optional **CR** Record defines the coefficients. For non-linear routing, the **QS** and **SQ** Records are used to input a storage-outflow table for routing to the next downstream control point.

The optional **QM** Record is used for specifying minimum desired (or required) flows that vary monthly or seasonally. When desired flows are based on ratios of natural flows, then the **WA** Record is used.

Control Point Diversion Records - WR, DR, QS, QD. Optional diversion data for a control point is primarily described by the optional **DR** Record. If water rights are considered, then the **WR** Record is used. If the diversions are a function of flow, the flow data are input on the **QS** Record. For several diversion types, the diversion schedule is input on the **QD** Record (e.g., monthly diversions).

Control Point Stage/Elevation Data - QS and EL. The optional **EL** Record contains stage or elevation data corresponding to discharge data in a similar field of the **QS** Record.

Control Point Cost Data - C$. The optional **C$** Record is used for control point costs (such as levees, etc.)

Variable Channel Capacity - CC. The optional **CC** Record allows channel capacities to vary monthly, seasonally, or be a function of the inflows or reservoir levels.

CC Record can define the monthly channel capacity
CC - **CS** Records define the seasons for the variable channel capacity.
CC - **QS** Records define the flows at another location for channel capacity.
CC - **CL** Records define reservoir levels for variable channel capacity.
CC - **CS & CG** Records define season and reservoir level or elevation (guide curves) for variable channel capacity.
CC - **CS, GS, & CG** Records define season and percent of total system flood control storage as a basis for defining variable channel capacity.

7.2.9 Damage Data Records - DA, DB, DF, DQ, and DC.

Flood damage computations in the Corps are now computed by other programs. The damage input and computations in HEC-5 have been left in the program to support older model data. These optional records are also control point records and are, for a given control point, used in computing damage for a single flood or expected annual damage. If damages are to be calculated for a given control point, all of these records except the **DB** Record are required. The **DA** Record is for predetermined expected annual damages for natural conditions while the **DB** Record is for base conditions (existing reservoir system). The **DF**, **DQ** and **DC** Records are for corresponding damage frequencies (**DF**), damage discharges (**DQ**), and damages (**DC**).

7.2.10 End of Data Record - ED.

The required **ED** Record follows the data records for the most downstream control point in the system. It indicates the end of model data. Time series data follows this record.

7.2.11 Time Series Specification - BF, FC, SS, ZR and ZW.

The **BF** Record is required to describe the conditions for the subsequent time series data records, IN-PV, such as the number of flows, the starting date of the simulation, the computational interval, etc. The optional **FC** Record specifies up to 10 ratios of the flows which will be used in up to 10 system simulations. The optional **SS** Record provides for starting storages for any of the reservoirs. The optional **ZR** and **ZW** Records allow for reading from (**ZR**) and writing to (**ZW**) an HEC-DSS file. The **JZ** Record defines which variables to write to HEC-DSS.

7.2.12 Time Series Data Records - IN, QA, NQ, MR, QD, EL, EV, PV, CC and ST.

These records are used to describe the sequential time series data for each control point. The required input is the flow data for model locations, defined on the **IN** Record. For convenience only, all of the **IN** Records for the system should be input first.

Reservoir releases can be specified with **QA** Records, which follow **IN** Records. When reservoir releases are not specified, the HEC-5 program will determine the release. Specified releases on **QA** Records will be made by the program, unless they are limited by physical constraints.

The optional **NQ** Records can be used to describe base conditions for computing expected annual damages. When this data are provided, it is treated as natural flows, instead of the computed natural flows.

Other optional records are **MR** Records to specify minimum flows, **QD** Records for diversions, **EL** Records for stages, **EV** Records for evaporation data, **PV** Records for power demands, **CC** Records for period varying channel capacities, and **ST** Records for specifying reservoir target storages (Top of Conservation storage varies each period). These optional records can be selectively used for individual control points/reservoirs on any flow sequence.

7.2.13 End of Job Record - EJ.

The **EJ** Record is read following the last data <u>for each time series set</u> (BF-EJ).

Multiple Floods. Up to eighty (80) sets of flow-data records (e.g., BF through EJ Records) can follow the ED Record.

7.2.14 End of Run Record - ER.

The **ER** Record is the required end-of-run indicator. It is the last input record in the data file.

7.3 Output

The amount of program output can be controlled by the program user. A series of pre-defined Standard Output Tables are available for selection with the **J3** Record, field 1. The Standard Output Tables are listed and described below and are presented with descriptions in Appendix F. In addition to the Standard Output Tables, the user can define User-Designed tables.

7.3.1 Standard Output Tables

The output to be provided is based on the input sum of Table Codes on the **J3** Record, field 1. As shown in the list below, items 1 through 5 are printed from the HEC-5A program. The HEC-5B program prints all the remaining output. The two programs are run sequentially in a single batch job. The input summary table names are prefaced with an " ***** " which provides a unique character string to facilitate easy location of a specific output table within a large output file. The sequence of possible output from the program is:

1. Printout of input data, including a sequential listing of the HEC-5 input data set (**T1-ER** Records) and the following summary tables: *Input Summary; *Routing Data; *Rule Curve Summary; *Operation Summary; *Map 1; *Map 2; *Reservoir Data; *Diversion Data; and, *Routing/Operation Summary.

2. Input flow data (`*FLOWS`) formatted in 10-field record image.

3. Computation of incremental local flows (`*LOCFL`)

4. Printout of optimization trials and summary (`*OPTRY` and `*OPSUM`)

5. Tables of maximum flows, levels, storages and elevations for reservoirs and non-reservoirs (Summary of Maximums)

6. Results of all variables defined and requested by input data for the system operations arranged by downstream sequence of control points (`*NORML`)

7. Results are arranged by sequence of time periods (`*ROPER`)

8. Summary of releases from reservoirs and actual flow at all other control points, arranged by period (`*RRPER` and `*RQPER`)

9. Tables of diversions and diversion shortages (`*DVPER` and `*DVSHORT`)

10. Table of percent of flood control storage utilized (`*FCPCT`)

11. User designed output based on J8/JZ Record input (`*USER5A` or `*USERS`)

12. Summary of flooding occurring during each flood event (`*SUMF1`)

13. Flood event summaries for multi-flood events (`*SUMFS` and `*SUMPO`)

14. Economic input data and damage computation (`*ECDAM`)

15. Flood frequency plots (`*EPLOT`)

16. Summary of damages or average annual damages, system costs and net benefits (`*ESUMD, *ESUMC` and `*ESUMB`)

17. Summary of discharge and stage reduction at each non-reservoir control point for each flood event (`*HYEFF`)

18. Computer check for possible errors (`*ERROR`), and

19. Listing of Case designations defining reservoir releases (`*CASES`).

7.3.2 User-Designed Output Tables

The program has a provision for creating User-Designed Output Tables using the **J8** and/or **JZ** Records. The **J8** produce period-by-period summary tables in the output file. Multiple tables are created with multiple **J8** Records. The input description for the **J8** Record in Appendix G provides a description of the options available.

There is a similar user-defined option to write results to an HEC-DSS file using the **JZ** Record. With the **JZ** Record (in conjunction with a **ZW** Record), the requested information is written to an HEC-DSS file and is also shown in the output file.

There are 41 variables available for display by time period in summary tables. The tables are defined by *Location ID***.***Variable Code* and are printed in column sequences, in the order defined.

7.3.3 Traces

In addition to ordinary output, trace information showing intermediate computations can be requested. Traces show the computation process as the program processes the information. There are several levels of trace (specified on the **TP** Record, field 10), as described in Appendix G. The choice of trace level depends on the extent and detail of information desired. Trace information can be requested at specific control points with a **TC** Record, for specific time periods with a **TP** Record and for specific subroutines with a **TS** Record. The user is cautioned to use traces sparingly because large volumes of output can be generated and a program source listing is required to interpret the information.

Appendix A

Stream Routing Methods

Channel routing in HEC-5 is accomplished by hydrologic routing methods which solve the continuity equation using some relationship between outflow and storage in the reach. The variety of routing options can be grouped into two categories: **Storage Methods** and **Coefficient Methods**.

Storage Methods are also referred to as reservoir routing because they route the inflow through a non-linear representation of reach storage. The options include: the modified Puls, modified Puls as a function of Inflow, the Working R&D method, and SSARR Time of Storage.

Coefficient options include: the Muskingum method, the Average-lag methods: Simple Lag, Successive Average-lag (Tatum) and Progressive Average-lag (Straddle-Stagger), plus the direct input of routing coefficients.

Equations used for each of these methods are given below. *Flood-Runoff Analysis*, EM 1110-2-1417, Chapter 9 is the primary Corps' reference for stream routing; however, the topic is covered in most hydrology texts.

A.1 Storage Methods

The Storage Methods operate with the basic reservoir mass balance applied to the routing reach (i.e., Inflow - Outflow = Change in Storage). The primary difference among the methods is how the storage-outflow relationship is defined. An added consideration is the number of increments (Steps) to use in the routing reach. Generally, the travel time through the Step should be equal to the computational time interval. The program will divide the reach storage by the number of Steps and route the inflow sequentially through the storage in each step. The maximum attenuation occurs with one-step routing (reservoir condition).

A.1.1 Modified Puls Routing

In this method, outflow from a routing reach is a unique function of storage. The input is a storage-outflow relationship for the routing reach. The program solves the routing problem by rearranging the terms to have future values equal to known values. The result is called the storage indication, ($S/\Delta t + O/2$). The following equations are used:

$$STRI(2) = STRI(1) + QH - O(1) \qquad (A\text{-}1)$$

where:

S	=	volume of storage in routing reach
STRI(1)	=	storage indication at beginning of time
STRI(2)	=	storage indication at end of time interval
QH	=	average inflow during time interval
O(1)	=	outflow at start of time interval
O(2)	=	outflow at the end of time interval, function of STR(2) from the Storage Indication.vs.Outflow

A.1.2 Modified Puls as a Function of Inflow

This is a variation of modified Puls which provides for multiple storage-outflow relations that are dependent on the inflow to the reach. This was added to HEC-5 because it is used in some Corps offices. However, there is a potential that continuity will not be maintained when using the procedure. Therefore, when routing with this procedure you should carefully review the results to ensure that flow is not gained or lost due to routing. An alternative is the **Working R&D Method** which provides a method to include the effect of inflow on the reach storage and maintains continuity.

A.1.3 Working R&D Method

The Working R&D uses a nonlinear storage-outflow relation, like the modified Puls method; and it permits use of wedge storage, like the Muskingum method (described under Coefficient Methods). Indeed for a linear storage-outflow relation, the Working R&D method produces results identical to the Muskingum method. For routing with no wedge storage (Muskingum X = 0), the Working R&D method produces results identical to the modified Puls method. The Working R&D method uses a "working" storage as indicated in the following equations:

$$\frac{R(2)}{\Delta t} = \frac{R(1)}{\Delta t} + QH - D(1) \qquad \text{(A-2)}$$

where:

R(2)	=	"working" storage at end of a time interval
R(1)	=	"working" storage at the beginning of a time interval
QH	=	average inflow during routing interval
D(1)	=	"working" discharge at beginning of time
D(2)	=	“working” discharge at the end of time interval, function of R(2) from the Working-storage Indication.vs.Outflow

The functional relationship described of D(2) is analogous to the storage indication-outflow relation used in the modified Puls method. Outflow is a function of "working" discharge and is determined from the following equation:

$$O(2) = D(2) - \frac{X}{(1-X)} \bullet (I(2) - D(2)) \qquad \text{(A-3)}$$

where:

X	=	Muskingum X (dimensionless)
O(2)	=	outflow at end of time interval
I(2)	=	inflow at end of time interval

A.1.4 SSARR Time of Storage Routing

This channel routing method is used in the computer program *Streamflow Synthesis & Reservoir Regulation (SSARR)*, from the Corps' North Pacific Division. The storage in the routing reach is defined by Time of Storage values (T_S), in units of hours. Therefore, the storage is defined like Muskingum K values (described below). Instead of using modified Puls storage-outflow, this method uses T_S versus outflow.

An alternative method for defining T_S is by equation 4, which defines Ts as a power function of flow.

$$T_s = \frac{KTS}{Q^n} \qquad \text{(A-4)}$$

where:

T_S	=	Time of storage per increment in hours
Q	=	Discharge in cubic meters (or feet) per hour
n	=	A coefficient usually between -1 and 1

As evident from the equation, T_S is a nonlinear function of discharge except when n = 1. It is possible to use a negative value of n if time of storage increases as discharge increases. According to the SSARR User's Manual, a value of n = 0.2 is reasonable for most streams in the Columbia River Basin.

A.2 Coefficient Methods

All coefficient methods compute outflow from a routing reach as a linear function. Equation 6 is the basic routing equation. For the direct input of coefficients, the series of 'C' values are input and their sum should equal one, to maintain continuity.

$$O_n = C_1 I_n + C_2 I_{n-1} + C_3 I_{n-2} \cdots \qquad \text{(A-5)}$$

where:

O_n	=	ordinate of outflow hydrograph at time n
I_n, I_{n-1}, etc.	=	ordinates of inflow hydrograph at times n, -1, etc.
C_1, C_2, etc.	=	routing coefficients, as coefficients of inflow

A.2.1 Muskingum Routing

The Muskingum method can be considered a storage method with the reach storage defined by the sum of *prism* and *wedge* storage. However, the storage-outflow relationship is linear and the method provides a set of constant coefficients. The equations used to determine the coefficients C_1, C_2, etc., are as follows:

$$C_1 = \frac{(\Delta t - 2XK)}{(2K(1-X) + \Delta t)} \qquad \text{(A-6)}$$

$$CC = \frac{((2K(1-X) + \Delta t) - 2\Delta t)}{(2K(1-X) + \Delta t)} \qquad \text{(A-7)}$$

$$C_2 = C_1 \bullet CC + \frac{(\Delta t + 2KX)}{(2K(1-X) + \Delta t)} \qquad \text{(A-8)}$$

$$C_i = C_{i-1} \bullet CC \quad (\text{for } i > 2) \qquad \text{(A-9)}$$

where:

Δt = routing time increment
K = Travel Time in units of time (hours)
X = Dimensionless routing parameter between 0 and .5

To avoid negative coefficients in Equation 7, the Muskingum K should be greater than or equal to (Δt) / [2 •(1-X)] and less than or equal to (Δt) / 2X.

The reach storage-outflow relationship is defined by the coefficient **K**, which can be considered the slope of the storage-outflow relationship. The *prism* storage in a reach is the product of **K** times outflow. The *wedge* storage is computed from the difference between inflow and outflow. The weighting factor on inflow is the coefficient **X**. If **X** = 0, inflow does not effect storage (like reservoir routing) and there is the maximum attenuation of outflow. If **X** =0.5, inflow has the maximum effect, and there is no attenuation of outflow (just translation based on **K** hours).

Typically, the reach is divided into steps in order to keep the step travel time approximately equal to the computational time step. For travel times significantly less than the computational time step, the reach can be treated as having no routing to avoid the computation of negative coefficients.

A.2.2 Average-Lag Methods

These methods route floods by time displacement of average inflow. The methods were developed from intuitive processes rather than mathematical equations. As such, they remain in HEC-5 because they are used in some Corps offices; however, they are not presented in the EM and their use is not encouraged. The three methods are: **Lag**, **Successive Average-Lag** (Tatum Method) and **Progressive Average-Lag** (Straddle-Stagger Method).

Lag. The inflow hydrograph can be lagged an integer number of computational time steps. This approach displaces the hydrograph in time, but does not change the shape of the routed hydrograph (no attenuation).

Successive Average-Lag averages the inflow successively through a number of subreaches (n). If there were two subreaches, the outflow for period 3 would be:

$$O_3 = \frac{1}{2}\left[\frac{I_1+I_2}{2}+\frac{I_2+I_3}{2}\right] \qquad \text{(A-10)}$$

where:

I = Inflow in increments of time
O = Outflow in increments of time

The coefficients are computed based on the number of subreaches for the successive average.

$$C_1 = \frac{1}{2^n} \tag{A-11}$$

$$C_2 = \frac{n}{2^n} \tag{A-12}$$

$$C_3 = \frac{n(n-1)}{2^n \; 2!} \tag{A-13}$$

$$C_4 = \frac{n(n-1)(n-2)}{2^n 3!} \tag{A-14}$$

$$C_n = \frac{n(n-1)(n-2)\;.\;.\;.}{2^n (n-1)!} \tag{A-15}$$

$$C_{(n+1)} = \frac{n!}{2^n n!} = \frac{1}{2^n} \tag{A-16}$$

Progressive Average-Lag Routing. This routing method is defined by the number of periods of inflow to average (Straddle) and the number of periods the average value then is lagged (Stagger). The method differs from the successive average-lag method in two respects:

(1) Equal rather than variable weight is given each inflow value in deriving an outflow, and

(2) the length of period for which inflow values are averaged to obtain an outflow value does not necessarily have any relation to the flood-wave travel time.

Generally, the length of the inflow period is determined by trial until a satisfactory agreement is obtained between the computed and actual peak outflows.

The method uses Coefficient routing equation (5) to route the inflow, with the routing coefficients determined as follows:

$$NCOEF = STAG + \frac{(STRAD + 1)}{2} \tag{A-17}$$

$$M = NCOEF - STRAD \tag{A-18}$$

$$C_i = 0 \text{ for } 1 \le i \le m \tag{A-19}$$

$$C_i = \frac{1}{STRAD} \text{ for } (M + 1) \le i \le NCOEF \tag{A-20}$$

where:

NCOEF	=	number of routing coefficients in equation (5)
STRAD	=	number of inflow ordinates to be averaged
STAG	=	number of ordinates the average value is to be lagged, from the mid-ordinate of the averaged ordinates

Appendix B

HEC-DSS use in HEC-5

HEC-5 can read and write time-series data by using the HEC Data Storage System (HEC-DSS). This Data Storage System (HEC-DSS) provides a convenient file system to transfer data from one application to another application. For example, the Flood Hydrograph Package HEC-1 could be used to develop flood hydrographs which are read by HEC-5 for reservoir system modeling. By using HEC-DSS, flow data required for simulation can be easily defined in HEC-5 by referring to the appropriate data records in the HEC-DSS file. Likewise, HEC-5 results can be stored to HEC-DSS for subsequent analysis using various HEC-DSS utility programs. This approach provides for convenient management and use of model data.

The following sections provide a brief overview of the HEC-DSS, the supporting utility programs, and the HEC-5 application. The HEC-DSS programs are documented in *HEC-DSS User's Guide and Utility Manuals* (HEC, 1994).

B.1 Introduction to the HEC-DSS

The Data Storage System (HEC-DSS) is a data base system developed by the HEC for storing hydrologic data. It consists of a set of FORTRAN subroutines that begin with the letter "Z" (e.g., ZOPEN opens a HEC-DSS file). The subroutines make it easy to add the HEC-DSS capability to a FORTRAN program that would read or write information to a HEC-DSS file. This facilitates adding the capability to a program and sharing of data among different computer programs. The library is documented in *HECLIB, Volume 2: HEC-DSS Subroutines, Programmer's Manual* (HEC, 1991).

A HEC-DSS file is a "Direct Access" (or Random) file. This allows the HEC-DSS software to access any part of the file directly, without having to read through the top of it as in a "Sequential" (normal) file. HEC-DSS files can be named like any other file, except on the DOS PC they usually have an extension of ".DSS".

The HEC-DSS stores sets, or "blocks", of data (referred to as records), each identified by a unique name, or "pathname". The HEC-DSS software uses this pathname to determine where in the HEC-DSS file its corresponding data is located. Each record consists of a header, which describes certain data attributes (such as the data units), and the actual data (which is stored as real numbers).

The HEC-DSS package includes a set of utility programs that use or manipulate data in a HEC-DSS file. The utility programs provide data management functions, graphical and tabular displays.

B.1.1 HEC-DSS Conventions

Conventions have been adopted to facilitate data exchange between programs. The records in a HEC-DSS file are defined by a pathname which contains six parts. These parts allow easy recognition of the data from the pathname. By fixing the pathname form, programs can define pathname parts from model data to provide easy access HEC-DSS data. The data are placed into "manageable" blocks. These blocks are handled automatically and provide efficient reference to time for uniform time-series data.

The HEC-DSS data types are:

- Regular Interval Time-Series Data
- Irregular Interval (No Interval) Time-Series Data
- Paired (or Curve) Data
- Text Data

HEC-5 make use of the regular interval time-series data to define input time-series data and to write user-defined output data.

B.1.2 Pathnames

The pathname for HEC-DSS records consist of 6 parts. The parts are separated by a slash (/). The parts are referenced by the letters: A, B, C, D, E, and F. For example: **/A/B/C/D/E/F/** Each part may contain from zero to 32 characters. The total pathname may contain up to a total of 80 characters.

B.1.3 Regular Interval Time-Series Conventions

The parts of the pathname should follow the naming convention:

A - Group or Basin Name (e.g., SCIOTO)

B - Location Name (e.g., CIRCLEVILLE)

C - Parameter (e.g., FLOW)

D - Block Start Date (e.g., 01MAR1959)

E - Time Interval (e.g., 3HOUR)

F - Additional Qualifiers (e.g., OBS)

An example Pathname is:

/SCIOTO/CIRCLEVILLE/FLOW/01MAR1959/3HOUR/OBS/

Time-Series data are stored in blocks with a fixed length for each time interval. For example, daily data is stored in blocks comprising one year of data. Each block will contain 365 or 366 data values, regardless of how many actual values were stored. A place holder (or missing data flag) of -901.0 is used where there are no actual values. If we have recorded only 5 daily values, there would be 360 missing data place holders (-901.0).

An example listing from a block of data for six-hour time interval would take the form:

```
/KANAWHA/BLNO7/FLOW/01MAR1977/6HOUR/OBS/
START = 01MAR1977, 0600 HRS; END = 31MAR1977, 2400 HRS; # DATA = 124
UNITS = CFS          TYPE = PER-AVER
01MAR77, 0600;    -901.   -901.   -901.   -901.   -901.   -901.
02MAR77, 1800;    -901.   -901.   -901.   -901.   -901.   -901.
04MAR77, 0600;    -901.   -901.   -901.   -901.   -901.   -901.
05MAR77, 1800;    -901.   -901.   -901.   -901.   -901.   -901.
07MAR77, 0600;    -901.   -901.   -901.   -901.   -901.   -901.
08MAR77, 1800;    -901.   -901.   -901.   -901.   -901.   -901.
10MAR77, 0600;    -901.   -901.   -901.   -901.   -901.   -901.
11MAR77, 1800;    -901.   -901.  12104.   9987.   9729.   9541.
13MAR77, 0600;    9209.   8197.   7964.   8514.   8405.   7489.
14MAR77, 1800;    7284.   8520.   8389.   7444.   7309.   8854.
16MAR77, 0600;    8328.   7706.   7628.   7300.   6066.   5526.
17MAR77, 1800;    6229.   8477.   8786.   9076.   9052.   9008.
19MAR77, 0600;    7610.   7593.   7771.   9176.   8668.   8107.
20MAR77, 1800;    8212.   8884.   7883.   6803.   6397.   6653.
22MAR77, 0600;    -901.   -901.   -901.   -901.   -901.   -901.
23MAR77, 1800;    -901.   -901.   -901.   -901.   -901.   -901.
25MAR77, 0600;    -901.   -901.   -901.   -901.   -901.   -901.
26MAR77, 1800;    -901.   -901.   -901.   -901.   -901.   -901.
28MAR77, 0600;    -901.   -901.   -901.   -901.   -901.   -901.
29MAR77, 1800;    -901.   -901.   -901.   -901.   -901.   -901.
31MAR77, 0600;    -901.   -901.   -901.   -901.
```

The valid time intervals are even subdivisions of an hour or day, plus the usual calendar increments. The valid intervals and their standard block length are:

Valid Data Intervals	Block Length
1MIN, 2MIN, 3MIN, 4MIN, 5MIN, 10MIN	One Day
15MIN, 20MIN, 30MIN, 1HOUR, 2HOUR, 3HOUR, 4HOUR, 6HOUR, 8HOUR, 12HOUR	One Month
1 DAY	One Year
1 WEEK, 1 MON	One Decade
1 YEAR	One Century

The "D" part of the pathname is the starting date of the block (not necessarily the starting date of the data). It must be a nine character military style date.

01MAY1986	O.K.
01May1986	Invalid - Lower case
01MAY86	Invalid - Must be 1986
MAY1986	Invalid - Must contain the day

01MAY1986 is a valid block start date for intervals of 5MIN through 12HOUR. It is not valid for 1DAY or above. For an interval of 1DAY, the block start date will always be 01JAN19--.

The "header" contains the units of the data (e.g. CFS, FEET), and the data type. There are 4 data types:

Period Average
Instantaneous
Period Cumulative
Instantaneous Cumulative

Period average data is stored as end-of-period data. Thus, daily period average data is typically stored at a time of 2400 hours. Instantaneous data is stored at the time it is measured.

How about daily flows measured at 8:00 a.m.? That's ok - a time offset is kept in the header. However the data must be measured at 24 hour intervals. Daily data that is measured at 7:00 a.m. one day, and 9:00 a.m. the next probably should be stored as "irregular interval time series data".

B.2 HEC-DSS Utility Programs

There are several programs written as utilities to the HEC-DSS. They include:

DSPLAY - Graphical plotting package. Plots (and tabulates) data stored in the standard conventions on a wide variety of graphical devices, the most common being Tektronix terminals.

DSSUTL - Basic data management utility program. Provides a means for tabulating, editing, copying, deleting, renaming, etc. data.

DSSMATH - Provides a wide variety of mathematical operations for HEC-DSS data.

REPGEN - Produces "publication quality" reports of HEC-DSS data.

Data Entry Programs - Many data entry programs are available for entering data into HEC-DSS from a wide variety of formats.

B.3 HEC-DSS Catalog Function

Many utility program access a HEC-DSS file's "catalog". A catalog is a list of pathnames in a separate file (at a given point in time). It is numbered and is usually ordered alphabetically by pathname parts. The catalog also provides information about the records, such as when they were last written to, by what program, and how much data the record contains.

Most utility program can use the catalog number or "reference number" to identify pathnames. For example, a DSPLAY plot may be generated by the command "PLOT 1,3,4", instead of having to specify each of three pathnames. The catalog can also be used to identify pathnames by matching pathname parts, called "selective catalog". For example, to copy all observed flow data to another HEC-DSS file in DSSUTL, the command "CO C=FLOW, F=OBS" might be given.

Example Catalog for a HEC-DSS File

```
    HECDSS Complete Catalog of Record Pathnames in File 0000DATA*MASTDB

    Catalog Created on Mar 6, 1990 at 15:24     File Created on Jan 8, 1990
    Number of Records:     30                   DSS Version 6-DA
    Sort Order: ABCFED

 Ref.                     Last Written
Number   Tag     Program   Date  Time  Type Vers Data        Record Pathname

   1  T3        DSSPD   06MAR90 15:22  RTS   1  366   /AMERICAN/AT FAIR OAKS/FLOW/01JAN1988/1DAY/OBS/
   2  T4        DSSTS   06MAR90 15:22  RTS   2  365   /AMERICAN/AT FAIR OAKS/FLOW/01JAN1989/1DAY/OBS/
   3  T11       DSSTS   06MAR90 15:22  RTS   3  365   /AMERICAN/BLUE CANYON/PRECIP-INC/01JAN1987/1DAY/OBS/
   4  T9        DSSTS   06MAR90 15:22  RTS   4  366   /AMERICAN/BLUE CANYON/PRECIP-INC/01JAN1988/1DAY/OBS/
   5  T12       DSSTS   06MAR90 15:22  RTS   1  365   /AMERICAN/BLUE CANYON/PRECIP-INC/01JAN1989/1DAY/OBS/
   6  T26       DSSTS   20FEB90 09:30  RTS   9  365   /AMERICAN/FOLSOM/ELEV/01JAN1987/1DAY/OBS/
   7  T25       DSSTS   20FEB90 09:30  RTS   4  366   /AMERICAN/FOLSOM/ELEV/01JAN1988/1DAY/OBS/
   8  T27       DSSTS   20FEB90 09:30  RTS   1  365   /AMERICAN/FOLSOM/ELEV/01JAN1989/1DAY/OBS/
   9  T21       DSSTS   20FEB90 09:30  RTS   4  365   /AMERICAN/FOLSOM/EVAP-PAN/01JAN1986/1DAY/OBS/
  10  T18       DSSTS   20FEB90 09:30  RTS   1  365   /AMERICAN/FOLSOM/EVAP-PAN/01JAN1987/1DAY/OBS/
  11  T16       DSSTS   20FEB90 09:30  RTS   1  366   /AMERICAN/FOLSOM/EVAP-PAN/01JAN1988/1DAY/OBS/
  12  T23       DSSTS   20FEB90 09:30  RTS   1  365   /AMERICAN/FOLSOM/FLOW-OUTLET/01JAN1987/1DAY/OBS/
  13  T22       DSSTS   20FEB90 09:30  RTS   6  366   /AMERICAN/FOLSOM/FLOW-OUTLET/01JAN1988/1DAY/OBS/
  14  T24       DSSTS   20FEB90 09:30  RTS   2  365   /AMERICAN/FOLSOM/FLOW-OUTLET/01JAN1989/1DAY/OBS/
  15  T19       DSSTS   20FEB90 09:30  RTS   1  365   /AMERICAN/FOLSOM/FLOW-POWER/01JAN1987/1DAY/OBS/
  16  T17       DSSTS   20FEB90 09:30  RTS   2  366   /AMERICAN/FOLSOM/FLOW-POWER/01JAN1988/1DAY/OBS/
  17  T20       DSSTS   20FEB90 09:30  RTS   1  365   /AMERICAN/FOLSOM/FLOW-POWER/01JAN1989/1DAY/OBS/
  18  T1        DSSPD   06MAR90 15:22  PD    1   52   /CALAVERAS/NEW HOGAN/STAGE-FLOW///USGS/
  19  T2        DSSPD   06MAR90 15:22  PD    1   52   /CALAVERAS/NEW HOGAN/STAGE-FLOW/RT #13/30JUN1980/USGS/
  20  T6        DSSPD   06MAR90 15:22  PD    1   46   /DRY CR/NR GEYSERVILLE/STAGE-FLOW/RT #34/07MAR1986/USGS/
  21  T5        DSSPD   06MAR90 15:22  PD    1   66   /DRY CR/NR GEYSERVILLE/STAGE-FLOW/RT #38/30SEP1987/USGS/
  22  T8        DSSPD   06MAR90 15:22  PD    1   60   /DRY CR/NR LEMONCOVE/STAGE-FLOW///USGS/
  23  T15       DSSPD   06MAR90 15:22  PD    1   14   /DRY CR/WARM SPRINGS/ELEV-AREA//01OCT1983/POLY/
  24  T7        DSSPD   06MAR90 15:22  PD    1   62   /DRY CR/WARM SPRINGS/STAGE-FLOW///USGS/
  25  T29       DSSTS   06MAR90 15:22  RTS   3  365   /FEATHER/QUINCY/PRECIP-INC/01JAN1982/1DAY/OBS/
  26  T28       DSSTS   06MAR90 15:22  RTS   2  365   /FEATHER/QUINCY/PRECIP-INC/01JAN1983/1DAY/OBS/
  27  T30       DSSTS   06MAR90 15:22  RTS   2  366   /FEATHER/QUINCY/PRECIP-INC/01JAN1984/1DAY/OBS/
  28  T14       DSSTS   06MAR90 15:22  RTS   1  365   /FEATHER/SIERRAVILLE/PRECIP-INC/01JAN1986/1DAY/OBS/
  29  T13       DSSTS   06MAR90 15:22  RTS   1  365   /FEATHER/SIERRAVILLE/PRECIP-INC/01JAN1987/1DAY/OBS/
  30  T10       DSSTS   06MAR90 15:22  RTS   1  366   /FEATHER/SIERRAVILLE/PRECIP-INC/01JAN1988/1DAY/OBS/
```

B.4 Entering Data into a HEC-DSS file

B.4.1 DSSTS

This program provides general data entry for regular-interval time-series data. The program can be run interactively as a DOS program. The required information is prompted for, with the user entering the data in response. The program can also be run with an input file created with a text editor.

When data values are input, several values can be input on one line. Missing data can be entered as M, or -901. As data are entered, the date and time for each value is given as a prompt (see example below).

DSSTS logs a copy of your input. If you "blow it" (press the break key instead of the return key). You can use the log file (workfile W2) as input to return to where you left off.

The program documentation is included in: *HEC-DSS User's Guide and Utility Program Manuals.*

Example Data Entry with DSSTS

```
DSSTS
ENTER DSS FILE NAME
FILE = DATABAS
        -----DSS---ZOPEN; CREATED RANDOM FILE:  DATABAS
        -----DSS---ZOPEN      NEW FILE OPENED   71  DATABAS

ENTER PATHNAME, OR PATHNAME PART(S), OR FINISH
I>/SCIOTO/WALDO/FLOW/01JAN1988/1DAY/OBS/
/SCIOTO/WALDO/FLOW/01JAN1988/1DAY/OBS/
ENTER UNITS OF DATA (E.G. CFS, FEET)
I>CFS
ENTER DATA TYPE (E.G. PER-AVER, INST-VAL)
I>INST-VAL
ENTER THE DATE AND TIME FOR THE FIRST DATA VALUE
I>23DEC1987 0700
Enter data values.
Enter END at the beginning of the line when done.
23DEC87, 0700 >933
24DEC87, 0700 >933.5 934 935 938 M 940
30DEC87, 0700 >944.3
31DEC87, 0700 >M
01JAN88, 0700 >942.1 944 946 949
05JAN88, 0700 >END
---DSS---ZWRITE FILE 71, VERS. 1  /SCIOTO/WALDO/FLOW/01JAN1987/1DAY/OBS/
---DSS---ZWRITE FILE 71, VERS. 1  /SCIOTO/WALDO/FLOW/01JAN1988/1DAY/OBS/
ENTER PATHNAME, OR PATHNAME PART(S), OR FINISH
I>B=DUBLIN C=STAGE
/SCIOTO/DUBLIN/STAGE/01JAN1988/1DAY/OBS/
ENTER UNITS OF DATA (E.G. CFS, FEET)
I>FEET
ENTER DATA TYPE (E.G. PER-AVER, INST-VAL)
I>INST-VAL
ENTER THE DATE AND TIME FOR THE FIRST DATA VALUE
I>27DEC87 0800
Enter data values.
Enter END at the beginning of the line when done.
27DEC87, 0800 >10.73
28DEC87, 0800 >10.88
29DEC87, 0800 >11.02 11.21
31DEC87, 0800 >M
01JAN88, 0800 >11.20 11.22 11.22
04JAN88, 0800 >11.24
05JAN88, 0800 >END
---DSS---ZWRITE FILE 71, VERS. 1  /SCIOTO/DUBLIN/STAGE/01JAN1987/1DAY/OBS/
---DSS---ZWRITE FILE 71, VERS. 1  /SCIOTO/DUBLIN/STAGE/01JAN1988/1DAY/OBS/

ENTER PATHNAME, OR PATHNAME PART(S), OR FINISH
I>FINISH
           -----DSS---ZCLOSE FILE   71
                  NO. RECORDS=       4
                  FILE SIZE=      3686 WORDS,     33 SECTORS
                  PERCENT INACTIVE=  0.00
STOP
```

B.4.2 WATDSS

This is a specialized program to load daily streamflow data from a WATSTORE file. It is easy to use; no preprocessing of the data is necessary. WATDSS can substitute station names for the B part of the Pathname instead of using a USGS gage number. The program source code is often modified to create a program to read other specialized (local) formats. Program documentation is included in: *HEC-DSS User's Guide and Utility Program Manuals.*

Sample WATSTORE file:

```
3        1447800192710 1   166.   119.   147.  1406.  1281.   864    684.   558.
3        1447800192710 2   579.   441.   369.   423.  2851.  2263.  1540.  1164.
3        1447800192710 3  1111.  2263.  5131.  4795.  3437.  2343.  1817.  1674.
3        1447800192710 4  1227.   958.   864.   774.   729.   639.   599.     0.
3        1447800192711 1   579.   579.   958.  1674.  1603.  1343.  1057.   904.
3        1447800192711 2   819.   729.   729.   684.   684.   639.   599.   558.
3        1447800192711 3  1003.  4795.  2931.  1746.  1674.  1478.  1227.  1164.
3        1447800192711 4  1164.   958.  1057.  1164.  1111.  1057.     0.     0.
3        1447800192712 1  1003.  1003.  1406.  1227.  1057.   958.   958.  3615.
3        1447800192712 2  2771.  1960.  1674.  1540.  1960.  2263.  1817.  1674.
3        1447800192712 3  1674.  1281.  1164.  1057.   958.   864.   729.   579.
3        1447800192712 4   498.   477.   477.   498.   579.   729.   864.     0.
3        14478001928 1 1  1111.   864.   639.   579.   558.   518.   498.   477.
3        14478001928 1 2   518.   558.   477.   477.   459.   477.   459.   459.
3        14478001928 1 3   441.   423.   405.   423.   353.   290.   290.   274.
```

B.5 Use of HEC-DSS with HEC-5

B.5.1 HEC-DSS File Specification

Typically the HEC-DSS file (and other files) are specified on the execution line. Data can be “read from” and results “written to” the same HEC-DSS file by specifying DSSFILE=*filename*. For example:

HEC5 INPUT=MYIN.DAT OUTPUT=MYOUT.OUT DSSFILE=MYDSS.DSS

Alternatively, data can be “read from” one HEC-DSS file (DSSIN=*filename*) and results “written to” a different HEC-DSS file (DSSOUT=*filename*). For example:

HEC5 INPUT=MYIN.DAT OUTPUT=MYOUT.OUT DSSIN=MYIN.DSS DSSOUT=MYOUT.DSS

When the HEC-5 menu is used, the HEC-DSS file names are given as menu input items.

B.5.2 HEC-DSS Read and Write

Generally, to have an application program read or write to a HEC-DSS file a **ZR** and/or **ZW** Record is inserted into the input file. The **ZR** Record indicates which data should be read from HEC-DSS, and the **ZW** Record indicates that data are to be written to HEC-DSS. The **JZ** Record is used to specify the HEC-5 data to write to HEC-DSS.

Several of the HEC-DSS Pathname parts are specified on the **ZR** and **ZW** Records. This is done by using the part letter followed by an equal sign then the Pathname part. For example:

ZR=IN A=SCIOTO, C=FLOW, F=OBS

HEC5 obtains inflows to a river or reservoir on **IN** Records. Instead of defining all the flow data on **IN** Records, the flow can be read from HEC-DSS using a **ZR** Record, which follows the date/time data on the **BF** Record. Note, in the above example the data read from HEC-DSS is for the **IN** Records. When reading data from HEC-DSS, the format code (**BF** Record, field 2) must be 2.

Without HEC-DSS, the input form is:

. . .
BF *date and time information* . . .
IN *period by period flow values*. . .
IN . . .
IN . . .
. . .

Example Without HEC-DSS:

```
. . .
ED
BF     2      50      50       22010100            24           1900
IN    31
IN    72     111     209     111      94      99     106      90     146     282
IN   133     109     112     116     121     170     257     147     136     177
IN   161     180     187     175     162     147     125     107     104      99
IN    95     102     110     115     145     148     123     113     125     150
IN   109      99     102     105      94     175     325     139     102      94
IN    42
IN   122     193     203     268     315     434     662     652     509     405
IN   290     209     277     349     358     243     360     562     553     560
IN   539     540     581    1823    6480   12896   14766    9182    5425    3648
IN  2662    2117    1816    1803    2074    2553    2174    1686    1391    1243
IN  1153    1084    1239    4325    5961    5104    3761    8096   26933   29171
EJ
ER
```

With HEC-DSS, the input form is:

```
. . .
BF    2  . . . date and time information . . .
ZR=IN  A=RED RIVER,  C=FLOW,  F=OBS
```

Data is retrieved for each location specified in the input, using the name on the Identification (**ID**) Records as the B part of the Pathname, unless the B part is specified on the **ZR** Record.

Example of Reading Time Series Data from HEC-DSS:

```
. . .
ED
BF    2    50    50     22010100          24
ZR=IN    A=RED RIVER C=FLOW F=OBS
EJ
ER
```

To write data computed by HEC-5 to HEC-DSS, two changes are made to the input data file:

1. Insert a **JZ** Record (after the **J1 - J8** Records). The **JZ** Record specifies what variables and locations data is to be stored. The **JZ** Record specifications are generally the same as the **J8** Record for user defined output.

2. Insert a **ZW** Record following the **BF** Record.

Example of Writing to HEC-DSS:

```
. . .
BF . . .
ZR=IN  A=RED RIVER  C=FLOW  F=OBS
ZW A=RED RIVER, F=COMPUTED
EJ
ER
```

The remaining parts of the Pathname (other than the **A** and **F** Parts specified on **ZW**) come from the model data, or from HEC-5. The **B** Part comes from the location name on the **ID** Record. The parameter (**C** Part) is determined by HEC-5 (the labels used are shown with the **JZ** input description). The date (**D** Part) and the time interval (**E** Part) come from the **BF** Record.

Appendix C

Reservoir Flood Operation

Many of the flood control features and options described in this appendix are illustrated with a single reservoir model (shown in Examples 1 and 2). Flood control operation may also apply to multi-reservoir systems. A four-reservoir system is used to explain options useful in flood control system operation (shown in Example 3).

To simulate the operation of a single flood control reservoir or a system of reservoirs operating to reduce downstream flooding, the basic components of the surface water system must first be defined. These include: streamflow data (including local inflow between control points), physical and operational characteristics of the reservoirs, and operational channel capacities for the reservoir and downstream control points in the system.

C.1 Single Reservoir Model

The first example is a single reservoir model which illustrates the default HEC-5 operation to reduce flooding at downstream locations.

C.1.1 Basic Reservoir Model Data

Figure C.1 shows a schematic of a single flood control reservoir (Reservoir 44) and a downstream control point (CP 40). The reservoir is operated to reduce flooding at CP 40. The basic reservoir storage data 1, are shown in Table C.1 and are further described in the following paragraphs. The data listing is shown in Table C.2.

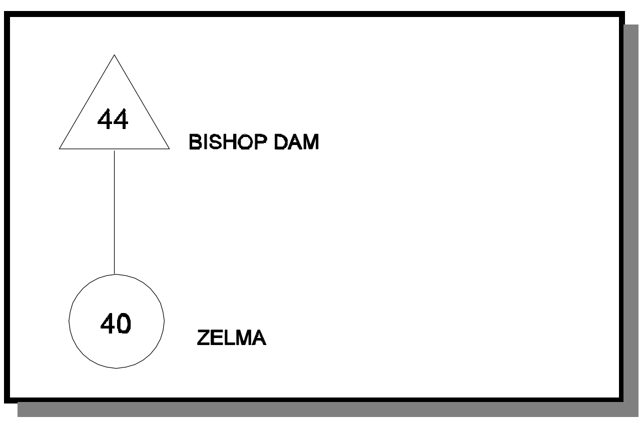

Figure C.1 Single Flood Control Reservoir
(Examples 1 and 2)

Table C.1 Reservoir Storage Levels, Volumes & Elevations (Example 1)

Storage Level Top of:	Level Number	Cumulative Storage (1000 m^3)	Elevation (meters)
Inactive Pool	1	131,438	250.2
Buffer Pool	2	134,000	250.4
Conservation	3	146,480	251.5
Flood Control	4	562,248	283.2
Dam	5	630,063	286.8

Reservoir Levels. In the first example (EXAMPLE1.DAT), five reservoir index levels (see **J1** Record, field 3) are defined at Reservoir 44. Table C.1 shows the cumulative storage for each of these index levels. The cumulative storage values are input on the **RL** record.

Reservoir Operation Criteria. The **RO** Record specifies the downstream control points that the reservoir operates for. A reservoir can operate for any or all of the locations that are dendritically located downstream. By default, each reservoir operates for itself. In Example 1, this means that the reservoir will operate to meet the minimum desired (80 m^3/s) and required (3 m^3/s) flows specified on the **CP** Record (fields 3 and 4) for Reservoir 44 while not exceeding its own channel capacity of 425 m^3/s (**CP** Record, field 2). In addition to itself, Reservoir 44 operates for one downstream location, Control Point 40, where the non-damaging channel capacity is specified as 450 m^3/s (**CP** Record, field 2).

R**eservoir Storage-Outflow-Elevation Data.** The reservoir's storage-outflow capacity are defined on the **RS** and **RQ** Records. The outflow data on the **RQ** Record should be the maximum outflow capability, which is an important constraint in flood operations. If the reservoir pool level rises above the top-of-flood control, the reservoir outflow will be based on the **RS-RQ** relation. This would represent operation of the emergency spillway. Below top-of-flood, the **RQ** data serves as the maximum value for the computation of reservoir releases. Therefore, release will be less than, or equal to the limiting capacity defined on the **RQ** Records.

The optional **RE** Record defines water surface elevation and is used in gated spillway and other options. Reservoir surface area is given on the **RA** Record and is used in computing evaporation, if given. Evaporation is not used in these flood operation examples.

Table C.2 Single Reservoir Input Data (Example 1)

```
T1      HEC-5 Example 1, Basic Flood Regulation   (EXAMPLE1.DAT)
T2      SI Units, 24 Hrs Foresight with 20% Contingency
T3      Rocky River, Bishop Dam Site to Zelma, 9-13 Nov 1973 Flood
J1     1       1       5       3       4       2
J2    24     1.2               0       0       0
J3     5                      -1               1
J8 44.09   44.10   44.12   44.13   40.04   40.02   40.24
JZ-44.10   44.13   44.22   40.04   40.02   40.17   44.09   44.24   40.24

C  ============== Bishop Dam Site =============
RL    44  146480  131438  134000  146480  562248  630063
RO     1      40
RS    13       0  124113  131438  134000  146480  253628  362008  417740  465211
RS546342  562248  589251  630063
RQ    13       0     333     665     668     681     796     872     912    2322
RQ  5664    6457    7646    9629
RE    13   209.7   249.6   250.2   250.4   251.5   262.1   270.5   274.3   277.4
RE 282.2   283.2   284.7   286.8
CP    44     425      80       3
IDBISHOP DAM
RT    44      40     1.2     0.3     3.0

C  =============== Zelma ===============
CP    40     450
IDZELMA
RT    40
ED

C    ------------------- Flood of Nov 9-13 1973 ----------------------------
BF     2      32             73110906               3
C    ----------- Local Flow at Bishop Dam Site -----------------------
IN    44
IN    67      78     159     215     309     473     605     704     960    1022
IN  1133    1378    1696    1787    2405    2616    2150    1974    1796    1660
IN  1396    1167     918     861     704     548     384     235     199     157
IN   226     197
C    ----------- Local Flow at Zelma -------------------------
IN    40
IN    52      62      78     197     231     289     473     460     509     608
IN   756     934    1036     882     715     529     374     326     217     106
IN    97      80      77      75      73      70      67      65      63      61
IN    59      57
ZW   A=EXAMPLE 1   F=BASIC FLOOD REGULATION
EJ
ER
```

Channel Capacity. The maximum channel capacity at the reservoir is used to control releases during flood operations. The channel capacity at Reservoir 44 is 425 m^3/s and is specified in the second field of the **CP** Record. Additionally, because Reservoir 44 operates for Control Point 40, the channel capacity of 450 m^3/s (**CP** Record, field 2 at Control Point 40) will also be considered when determining the reservoir releases.

Channel Routing. Seven channel routing methods are available in HEC-5. The routing sequence and the routing information are given on the **RT** Record. In this example, CP 44 routes water to CP 40 using one sub-reach with the Muskingum method (field 3). The Muskingum X is 0.3 and the travel time (K) for the sub-reach is 3 hours (**RT** Record, fields 4 and 5).

Streamflow. Inflows into the reservoir and incremental local flows into CP 40 are defined on **IN** Records. Each flow represents the average inflow for a three hour time interval (**BF** Record, field 7). The alternative to reading in flow values on **IN** Records would be to define a HEC-DSS file and use the **ZR** Record to equate the **IN** Records to pathnames in the HEC-DSS file. Example 2 will demonstrate reading flow data from an HEC-DSS file. The **ZW** Record, in conjunction with the **JZ** Record, is used for writing HEC-5 results to HEC-DSS.

The HEC-5 input for Example 1 is shown in Table C.2. For a detailed description of the input format and data requirements, see Appendix G, Input Description.

C.1.2 HEC-5 Results for Example 1

Example 1 is a single reservoir model where the reservoir operates to reduce flooding at a downstream location. A contingency factor of 20% (applied to local flows) and a 24-hour foresight (used in conjunction with the routing coefficients) are used in determining releases from the reservoir that would not contribute to flooding. Excerpts from the output file (EXAMPLE1.ANS) are shown in various tables and are discussed in detail using numbered references.

The routing coefficients resulting from using the Muskingum routing method in Example 1 (for the reach from Reservoir 44 to Control Point 40) are shown in Table C.3. For discussion purposes, let's assume that the reservoir release is being determined for the first period (9 Nov 73, 6:00-9:00 a.m.). Whatever release is made from reservoir 44 for period 1 ("current" period), then:

① 16.7% of period 1's release will reach CP 40 in period 1;
② 69.5% of period 1's release will reach CP 40 in period 2;
③ 11.6% of period 1's release will reach CP 40 in period 3;
④ 1.9% of period 1's release will reach CP 40 in period 4;
⑤ 0.3% of period 1's release will reach CP 40 in period 5.

Table C.3 Muskingum Method Routing Coefficients (Example 1)

```
*Routing/Operation Summary  (Coefficients Based on   3 Hours)


ROUTING COEFFICIENTS from Reservoir 44 to Downstream Location(s):
Loc=   40  0.1668  0.6949  0.1158  0.0193  0.0032
             ①       ②       ③       ④       ⑤
```

A summary of pertinent input data for Example 1 is shown in Table C.4. For flood control operation, the primary items of interest are the channel capacities and the flood control storage at the reservoir.

Table C.4 Summary of Pertinent Input Data (Example 1)

```
*Map 2

          HEC-5 Example 1, Basic Flood Regulation   (EXAMPLE1.DAT)


          Channel    Flood    Conserv.  Min Des.  Min Req. Divert  Map   Location
          Capacity  Storage   Storage     Flow      Flow     to   Number Name

44R BISHOP   425.    415768.    15042.      80.       3.      0     44    BISHOP
40  ZELMA    450.         0.       0.        0.       0.      0     40    ZELMA
```

Table C.5 is a User Designed Output table resulting from the **J8** Record input for Example 1. This table shows four major items of interest at Reservoir 44 and three items of interest at Control Point 40:

①	Inflow	- Inflow into Reservoir 44;
②	Outflow	- Release from Reservoir 44;
③	Case	- The "reason" for making the reservoir release;
④	Level	- An indication of how full the reservoir is; e.g., in this example, Level 3 is the Top-of-Conservation Pool;
⑤	Flow Reg	- The regulated flow at the downstream location, CP 40;
⑥	Natural	- The unregulated flow at the downstream location, CP 40;
⑦	Loc Incr	- The Incremental Local Flow between Reservoir 44 and the downstream location CP 40.

Notice that Reservoir 44 begins the simulation (period 1) by operating for its own desired flow goal of 80 m^3/s (CP Record, field 3). Starting in period 2, the reservoir begins to cut back its release(to prevent flooding at location 40) but the Rate-of-change (CASE=0.02) limits the change in its release. This was due to the input Rate-of-Change (J2 Record, field 3) being set to the default value of .04 times the channel capacity at the reservoir (425 m^3/s) times 3 hours (simulation time interval) = 51 m^3/s. Therefore, since the release in period 1 is 80 m^3/s and the maximum change in release is 51 m^3/s (for a 3 hour time interval), then the release for period 2 is determined to be 29 m^3/s.

During periods 3 through 17, no reservoir release is made because any routed release would contribute to the flow at location 40, exceeding its channel capacity within the foresight of 24 hours (the number of hours of foresight was input on the J2 Record, field 1 as 24 hours). The CASE values indicate that the "reason" for the zero release is based on flooding at location 40 during future periods. In the third period for instance, the CASE is 40.04 which indicates forecast flooding at location 40 four periods in the future. In periods 18 through 24, the reservoir determines that there is space downstream for additional water and begins to evacuate the water stored in the flood pool (reservoir level is above Level 3). However, once again the release is limited by the Rate-of-Change constraint

(CASE=0.02) and the reservoir increases its releases in steps of 51 m^3/s until it determines that the forecasted flow at the downstream location will again exceed its channel capacity. At that time (period 25) the reservoir begins cutting back its release.

Table C.5 User Designed Output Table Resulting from J8 Record (Example 1)

```
*USERS. 1    User Designed Output    (Dates shown are for END-of-Period)
                                                Summary by Period   Flood=       1
```

Location No=				44.	44.	44.	44.	40.	40.	40.
J8/JZ Codes=				44.090	44.100	44.120	44.130	40.040	40.020	40.240
				BISHOP DA	BISHOP DA	BISHOP DA	BISHOP DA	ZELMA	ZELMA	ZELMA
Per	Date:	Hr	Day	Inflow	Outflow	Case	Level	Flow Reg	Natural	Loc Incr
1	9Nov73	9	Fri	67.00	80.00	0.00	2.99	132.00	119.00	52.00
2	9Nov73	12	Fri	78.00	29.00	0.02	3.00	133.50	130.83	62.00
3	9Nov73	15	Fri	159.00	0.00	40.04	3.01	109.25	167.97	78.00
4	9Nov73	18	Fri	215.00	0.00	40.03	3.01	202.21	353.83	197.00
5	9Nov73	21	Fri	309.00	0.00	40.04	3.02	231.87	451.97	231.00
6	9Nov73	24	Fri	473.00	0.00	40.04	3.03	289.15	610.66	289.00
7	10Nov73	3	Sat	605.00	0.00	40.04	3.05	473.03	942.78	473.00
8	10Nov73	6	Sat	704.00	0.00	40.04	3.06	460.01	1058.96	460.00
9	10Nov73	9	Sat	960.00	0.00	40.04	3.09	509.00	1238.16	509.00
10	10Nov73	12	Sat	1022.00	0.00	40.03	3.12	608.00	1539.86	608.00
11	10Nov73	15	Sat	1133.00	0.00	40.02	3.15	756.00	1781.48	756.00
12	10Nov73	18	Sat	1378.00	0.00	40.01	3.18	934.00	2089.91	934.00
13	10Nov73	21	Sat	1696.00	0.00	40.00	3.23	1036.00	2429.99	1036.00
14	10Nov73	24	Sat	1787.00	0.00	40.00	3.27	882.00	2542.83	882.00
15	11Nov73	3	Sun	2405.00	0.00	40.00	3.33	715.00	2583.97	715.00
16	11Nov73	6	Sun	2616.00	0.00	40.00	3.40	529.00	2879.83	529.00
17	11Nov73	9	Sun	2150.00	0.00	40.00	3.46	374.00	2868.14	374.00
18	11Nov73	12	Sun	1974.00	51.00	0.02	3.51	334.50	2504.02	326.00
19	11Nov73	15	Sun	1796.00	102.00	0.02	3.55	269.42	2195.34	217.00
20	11Nov73	18	Sun	1660.00	153.00	0.02	3.59	208.24	1909.72	106.00
21	11Nov73	21	Sun	1396.00	204.00	0.02	3.62	250.04	1736.95	97.00
22	11Nov73	24	Sun	1167.00	255.00	0.02	3.65	284.01	1478.49	80.00
23	12Nov73	3	Mon	918.00	306.00	0.02	3.66	332.00	1241.08	77.00
24	12Nov73	6	Mon	861.00	357.00	0.02	3.68	381.00	1024.51	75.00
25	12Nov73	9	Mon	704.00	378.92	40.01	3.68	425.15	922.59	73.00
26	12Nov73	12	Mon	548.00	328.16	40.00	3.69	436.00	772.26	70.00
27	12Nov73	15	Mon	384.00	379.16	0.02	3.69	409.97	613.38	67.00
... Periods 28-31 not shown ...										
32	13Nov73	6	Tue	197.00	346.89	40.00	3.67	438.60	269.81	57.00
			Sum =	30179.00	4469.73	880.53	108.10	13873.92	39723.82	9678.00
			Max =	2616.00	395.73	40.04	3.69	1036.00	2879.83	1036.00
			Min =	67.00	0.00	0.00	2.99	109.25	119.00	52.00
			PMax=	16.00	31.00	3.00	27.00	13.00	16.00	13.00
			Avg =	943.09	139.68	27.52	3.38	433.56	1241.37	302.44

In summary, the following can be concluded about the simulation results in Example 1:

① The maximum inflow to Reservoir 44 was 2616 m^3/s (period 16) and the maximum outflow was 396 m^3/s (period 31).

② The channel capacity of 450 m^3/s at the downstream location (Location 40) was exceeded due to its uncontrolled local flow (not due to releases from Reservoir 44).

③ Without the operation of Reservoir 44, the maximum flow at Location 40 would have peaked at 2880 m^3/s (during period 16). With the operation of Reservoir 44, the peak flow at Location 40 was reduced to 1036 m^3/s (during period 13).

Since it may be useful to see the results of an HEC-5 simulation displayed in graphical form and/or perform statistical or mathematical operations on the results, then the option of storing data to HEC-DSS may be used. Table C.6 shows the JZ and ZW Records that were used in Example 1 to specify which results (JZ Record) and which pathnames (ZW Record) are to be written to HEC-DSS.

Table C.6 Storing HEC-5 Simulation Results to HEC-DSS (Example 1)

```
JZ-44.10   44.13   44.22   40.04   40.02   40.17   44.09   44.24   40.24

ZW   A=EXAMPLE 1   F=BASIC FLOOD REGULATION


   -----DSS---ZOPEN:  New File Opened,  File: EXAMPLE1.DSS
                      Unit:  72;  DSS Version: 6-JE

    ----- Flood Number  1 -----

---DSS---ZWRITE Unit 72; Vers. 1:/EXAMPLE 1/BISHOP DAM/FLOW-RES OUT/01NOV1973/3HOUR/BASIC FLOOD REGULATION/
---DSS---ZWRITE Unit 72; Vers. 1:/EXAMPLE 1/BISHOP DAM/LEVEL-RES/01NOV1973/3HOUR/BASIC FLOOD REGULATION/
---DSS---ZWRITE Unit 72; Vers. 1:/EXAMPLE 1/BISHOP DAM/ELEV/01NOV1973/3HOUR/BASIC FLOOD REGULATION/
---DSS---ZWRITE Unit 72; Vers. 1:/EXAMPLE 1/ZELMA/FLOW-REG/01NOV1973/3HOUR/BASIC FLOOD REGULATION/
---DSS---ZWRITE Unit 72; Vers. 1:/EXAMPLE 1/ZELMA/FLOW-NAT/01NOV1973/3HOUR/BASIC FLOOD REGULATION/
---DSS---ZWRITE Unit 72; Vers. 1:/EXAMPLE 1/ZELMA/FLOW-CHAN CAP/01NOV1973/3HOUR/BASIC FLOOD REGULATION/
---DSS---ZWRITE Unit 72; Vers. 1:/EXAMPLE 1/BISHOP DAM/FLOW-RES IN/01NOV1973/3HOUR/BASIC FLOOD REGULATION/
---DSS---ZWRITE Unit 72; Vers. 1:/EXAMPLE 1/BISHOP DAM/FLOW-LOC INC/01NOV1973/3HOUR/BASIC FLOOD REGULATION/
---DSS---ZWRITE Unit 72; Vers. 1:/EXAMPLE 1/ZELMA/FLOW-LOC INC/01NOV1973/3HOUR/BASIC FLOOD REGULATION/

----- OUTPUT Data Written to DSS -----

   -----DSS---ZCLOSE Unit:  72,   File: EXAMPLE1.DSS
              Pointer Utilization:  0.25
              Number of Records:      9
              File Size:     21.8  Kbytes
              Percent Inactive:   0.0
```

C.1.3 Single Reservoir with Gated Spillway

The capability to simulate the regulation of large floods with "gate regulation curves" is an important HEC-5 flood regulation option. A typical application for this feature would be the routing of the spillway design flood or large historic flood which is larger than the flood storage design flood. The data required to define the induced storage zone, physical characteristics of the gated spillway and operation criteria are input on the **RG** Record. Example 2 demonstrates the regulation of a large flood with the gate regulation curve procedure. The input data for Example 2 (Table C.7) is basically the same as in Example 1, except for the following four items:

Table C.7 HEC-5 Input for Single Reservoir Gate Regulation (Example 2)

```
T1      HEC-5 Example 2, Gated Spillway Simulation (EXAMPLE2.DAT)
T2      Low Flow Release During Flooding, Rate of Change Constraints
T3      Rocky River, Bishop Dam Site to Zelma, 20-28 Dec 1964 Flood
J1     1       1       5       3       4       2
J2    24     1.2               8       0       0
J3     5                      -1               1
J8 44.09   44.10   44.36   44.12   44.13   44.22   40.04   40.02   40.24   40.19
JZ-44.10   44.36   44.13   44.22   40.04   40.02   40.17

C  ============== Bishop Dam Site =============
RL    44  146480  131438  134000  146480  562248  630063
RO     1      40
RS    13       0  124113  131438  134000  146480  253628  362008  417740  465211
RS546342  562248  589251  630063
RQ    13       0     333     665     668     681     796     872     912    2322
RQ  5664    6457    7646    9629
RE    13   209.7   249.6   250.2   250.4   251.5   262.1   270.5   274.3   277.4
RE 282.2   283.2   284.7   286.8
R2    70     225
RG 284.7   283.2     425    28.6    64.8   270.5      90     872     3.0   282.5
CP    44     425      80       3
IDBISHOP DAM
RT    44      40     1.2     0.3     3.0

C  ============== Zelma ==============
CP    40     450
IDZELMA
RT    40
ED

C    ------------------- Flood of Dec 20-28 1964 ----------------------------
BF     2      72       0       64122000      0       3                  1900
ZR   A=EXAMPLE 2  C=FLOW-LOC INC  F=MAXIMUM HISTORIC FLOOD
ZR=IN44  B=BISHOP DAM
ZR=IN40  B=ZELMA
ZW   A=EXAMPLE 2     F=GATED SPILLWAY SIMULATION
EJ
```

① A **RG** Record has been added to the reservoir data to indicate a gate regulation operation. Also, **J8**/**JZ** Records were revised to contain output code 44.36 which will tabulate gate regulation discharges.

② A priority has been input that specifies that low-flow releases will be made eventhough they may contribute to flooding (**J2** Record, field 4 = 8).

③ Rising and falling rate-of-change constraints have been specified at the reservoir (**R2** Record, fields 1 and 2).

④ Time Series Data: a historic flood similar to the spillway design flood event is used; flow values are read from HEC-DSS (see **ZR** Records); and, the Century of 1900 is input on the **BF** Record, Field 10.

C.1.4 Gate Regulation Results

The results of Example 2 (using the **RG** Record to invoke the Gate Regulation Operation), can best be illustrated by comparing the results with the Example 1 model (without the **RG** Record). The Example 1 model is referred to as a Method A operation, while the model with the **RG** Record is referred to as a Gated Spillway operation. Figure C.2 shows the Reservoir releases (at Bishop Dam) from the two models and Figure C.3 shows the downstream regulated flow (at Zelma) from the two models. For detailed discussion, excerpts from the HEC-5 output files are shown in Tables C.8 thru C.11. The following observations can be made from reviewing these figures and tables:

① In Figure C.2, the Method A operation (without the RG Record) indicates that the reservoir delays its release (to reduce downstream flooding) until the reservoir fills to the top-of-flood pool. At that time, releases equal to the inflow are made (unless the capacity of the release facilities is exceeded). The Gated Spillway operation shows that the reservoir begins releasing the flood flows earlier; the maximum release is reduced approximately 40 percent (from 1900 m^3/s to 1160 m^3/s); and, the maximum release occurs later in time.

② In Figure C.3, the maximum downstream regulated flow was reduced approximately 35 percent (from 2430 m^3/s to 1560 m^3/s) by using a Gated Spillway operation.

③ Table C.8 and Table C.9 show for each type of operation a Summary of Maximums (at the Bishop Dam reservoir and at the downstream channel control point location Zelma). Comparison of these tables shows that during the Gated Spillway operation (Table C.9), the Bishop Dam reservoir stored water in the surcharge pool (maximum HEC-5 level = 4.169, where the top-of-flood pool is level 4.0). However, during the Method A operation (Table C.8), water was not stored above the top-of-the flood pool (a surcharge pool was not defined). By storing water above the top-of-flood pool and making earlier releases, the maximum release was reduced and consequently the maximum downstream regulated flow was reduced by using the Gated Spillway operation.

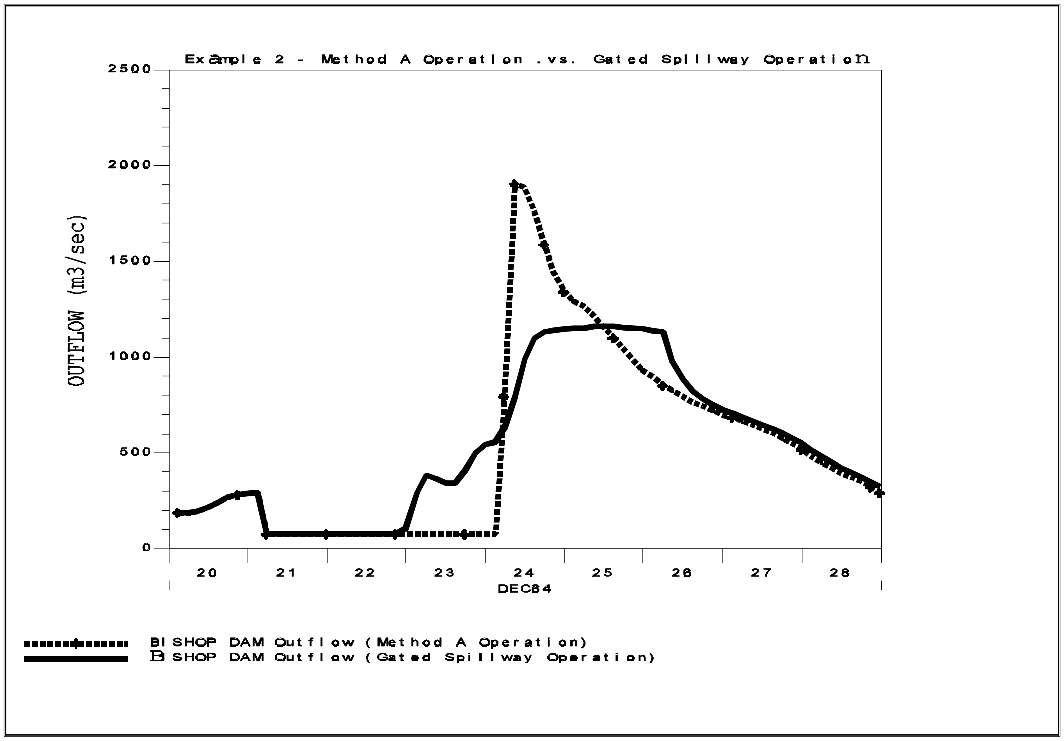

Figure C.2 Bishop Dam: With and Without Gate Regulation (Example 2)

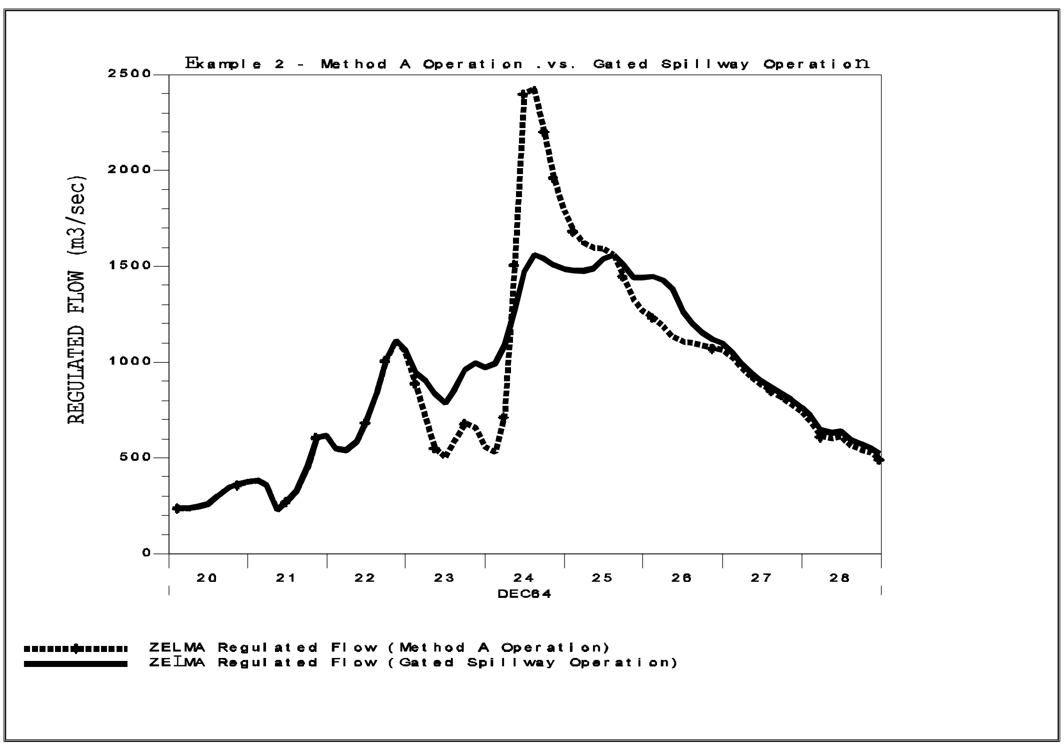

Figure C.3 Zelma: With and Without Gate Regulation (Example 2)

④ Table C.10 is a User Designed Output table resulting from the **J8** Record for the Method A operation (without **RG** Record). The pertinent reservoir operation information is shown in the first four columns: the inflow to Bishop Dam (Inflow); the release from Bishop Dam (Outflow); the HEC-5 "reason" for the release (Case); and, the HEC-5 level number (Level). By looking at these columns, it can be seen that the reservoir starts with a full conservation pool (Level 3) and releases inflow through time period 9. At that time, it is determined that the flow at the downstream location, Zelma, will exceed its channel capacity of 450 m^3/s (**CP** Record, field 2) within the forecast time of 24 hours (**J2** Record, field 1). Therefore, HEC-5 determines that the reservoir releases should be cut back. However, due to the input priority (**J2** Record, field 4), the reservoir releases the minimum flow of 80 m^3/s (even though flooding is occurring) during periods 10 through 33. The default Method A operation will cause the program to store water until flood storage is completely filled. When flood storage is exhausted, HEC-5 will make emergency releases (Case = 0.04) up to the capacity of the discharge facilities. In period 34 the reservoir releases 801 m^3/s and for the remainder of the simulation, the reservoir continues to release inflow and remains at the top-of-flood pool.

⑤ Table C.11 is a User Designed Output table resulting from the **J8** Record for the Gated Spillway operation (with **RG** Record). The pertinent reservoir operation information is shown as it was Table C.10 except an additional column has been included to show the releases determined during the Gate Regulation operation (Q-Gate R). By comparing these results with the results in Table C.10, it can be seen that the operations are exactly the same through period 23. At that time, the Gate Regulation criteria becomes the controlling factor and the reservoir releases are determined based on the **RG** Record input.

Table C.8 Summary of Maximums (Method A Operation: without RG Record)

```
                                                 --------------
                   Summary of Maximums for    RESERVOIRS
                                 --------      --------------

        HEC-5 Example 2, METHOD A Operation (WITHOUT Gated Spillway)
        Low Flow Release During Flooding, Rate of Change Constraints
        Rocky River, Bishop Dam Site to Zelma, 20-28 Dec 1964 Flood

             -------------------------------------------------------
             Period of Analysis:  STARTING :  20DEC64 - 0000 Hrs
                                  ENDING   :  28DEC64 - 2400 Hrs
                                  DURATION :  9 Days,  0 Hrs,  0 Min

                  Time Interval:    3 Hours,  0 Minutes
             -------------------------------------------------------

******************************************************************************
*    Reservoir    *     Max    *     Max    *    Max             *     Max    *
*                 *   Inflow   *   Outflow  *  Storage    Elev   *    HEC-5   *
*  ID    Name     *   (m3/s)   *   (m3/s)   * (1000m3)  (Meters)*    Levels  *
*                 *            *            *                    *            *
******************************************************************************
*                 *            *            *                    *            *
*  44 BISHOP DAM  *       3087 *       1912 *   562248   283.20 *       4.000 *
*                 * 22DEC-2400 * 24DEC-0900 *    24DEC-0600      * 24DEC-0600 *
*                 *            *            *                    *            *
******************************************************************************

             Maximum System Storage Used =   562248.  (24DEC-0600)

                                            -----------------------------------
           Summary of Maximums for    CHANNEL CONTROL POINT LOCATIONS
                      --------      -----------------------------------

        HEC-5 Example 2, METHOD A Operation (WITHOUT Gated Spillway)
        Low Flow Release During Flooding, Rate of Change Constraints
        Rocky River, Bishop Dam Site to Zelma, 20-28 Dec 1964 Flood

             -------------------------------------------------------
             Period of Analysis:  STARTING :  20DEC64 - 0000 Hrs
                                  ENDING   :  28DEC64 - 2400 Hrs
                                  DURATION :  9 Days,  0 Hrs,  0 Min

                  Time Interval:    3 Hours,  0 Minutes
             -------------------------------------------------------

******************************************************************************
*  Channel Location  *  Channel     Max     Q from *  Max Cum.  *    Max     *
*                    * Capacity  Reg. Flow    Res. *  Local Q   * Natural Q  *
*  ID    Name        *  (m3/s)    (m3/s)    (m3/s) *  (m3/s)    *  (m3/s)    *
******************************************************************************
*                    *                             *            *            *
*  44 BISHOP DAM     *     425       1912        0 *     3087   *     3087   *
*                    *          24DEC-0900         * 22DEC-2400 * 22DEC-2400 *
*                    *                             *            *            *
*  40 ZELMA          *     450       2430     1394 *     1036   *     3852   *
*                    *          24DEC-1500         * 22DEC-2100 * 23DEC-0300 *
*                    *                             *            *            *
******************************************************************************
```

Table C.9 Summary of Maximums (Gated Spillway Operation with RG Record)

```
                                          --------------
                 Summary of Maximums for    RESERVOIRS
                                --------  --------------

      HEC-5 Example 2, Gated Spillway Simulation (EXAMPLE2.DAT)
      Low Flow Release During Flooding, Rate of Change Constraints
      Rocky River, Bishop Dam Site to Zelma, 20-28 Dec 1964 Flood

           -------------------------------------------------------
           Period of Analysis:  STARTING :  20DEC64 - 0000 Hrs
                                ENDING   :  28DEC64 - 2400 Hrs
                                DURATION :  9 Days,  0 Hrs,  0 Min

                Time Interval:    3 Hours,  0 Minutes
           -------------------------------------------------------

******************************************************************************
*    Reservoir    *     Max    *     Max    *    Max             *     Max    *
*                 *   Inflow   *   Outflow  *  Storage    Elev   *    HEC-5   *
*  ID    Name     *   (m3/s)   *   (m3/s)   * (1000m3)  (Meters)*    Levels  *
*                 *            *            *                    *            *
******************************************************************************
*                 *            *            *                    *            *
*  44 BISHOP DAM  *       3087 *       1164 *   573676   283.83 *      4.169 *
*                 * 22DEC-2400 * 25DEC-0900 *    25DEC-0900      * 25DEC-0900 *
*                 *            *            *                    *            *
******************************************************************************

           Maximum System Storage Used =   573676.  (25DEC-0900)

                                   -----------------------------------
         Summary of Maximums for    CHANNEL CONTROL POINT LOCATIONS
                        --------   -----------------------------------

      HEC-5 Example 2, Gated Spillway Simulation (EXAMPLE2.DAT)
      Low Flow Release During Flooding, Rate of Change Constraints
      Rocky River, Bishop Dam Site to Zelma, 20-28 Dec 1964 Flood

           -------------------------------------------------------
           Period of Analysis:  STARTING :  20DEC64 - 0000 Hrs
                                ENDING   :  28DEC64 - 2400 Hrs
                                DURATION :  9 Days,  0 Hrs,  0 Min

                Time Interval:    3 Hours,  0 Minutes
           -------------------------------------------------------

******************************************************************************
*  Channel Location  *  Channel     Max     Q from *  Max Cum.  *    Max     *
*                    * Capacity  Reg. Flow    Res. *  Local Q   * Natural Q  *
*  ID    Name        *  (m3/s)    (m3/s)    (m3/s) *  (m3/s)    *  (m3/s)    *
******************************************************************************
*                    *                             *            *            *
*  44 BISHOP DAM     *     425       1164        0 *     3087   *      3087  *
*                    *          25DEC-0900         * 22DEC-2400 * 22DEC-2400 *
*                    *                             *            *            *
*  40 ZELMA          *     450       1563      526 *     1036   *      3852  *
*                    *          25DEC-1500         * 22DEC-2100 * 23DEC-0300 *
*                    *                             *            *            *
******************************************************************************
```

Table C.10 HEC-5 User Designed Output Table for Method A Operation (Example 2 without **RG** Record)

*USERS. 1   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood=   1

Per	Date:	Hr	Day	BISHOP DA Inflow	BISHOP DA Outflow	BISHOP DA Case	BISHOP DA Level	BISHOP DA EOP Elev	ZELMA Flow Reg	ZELMA Natural	ZELMA Loc Incr	ZELMA Q by US
Location No=				44.	44.	44.	44.	44.	40.	40.	40.	40.
J8/JZ Codes=				44.090	44.100	44.120	44.130	44.220	40.040	40.020	40.240	40.190
1	20Dec64	3	Sun	192.58	192.58	0.03	3.00	251.50	241.85	241.85	49.27	192.58
2	20Dec64	6	Sun	192.58	192.58	0.03	3.00	251.50	241.85	241.85	49.27	192.58
3	20Dec64	9	Sun	198.24	198.24	0.03	3.00	251.50	247.09	247.09	53.57	193.52
4	20Dec64	12	Sun	216.64	216.64	0.03	3.00	251.50	263.09	263.09	62.57	200.52
5	20Dec64	15	Sun	242.14	242.14	0.03	3.00	251.50	306.84	306.84	88.64	218.20
6	20Dec64	18	Sun	271.87	271.87	0.03	3.00	251.50	345.51	345.51	102.40	243.11
7	20Dec64	21	Sun	286.03	286.03	0.03	3.00	251.50	363.92	363.92	94.48	269.44
8	20Dec64	24	Sun	290.28	290.28	0.03	3.00	251.50	378.07	378.07	94.10	283.97
9	21Dec64	3	Mon	297.36	297.36	0.03	3.00	251.50	385.16	385.16	94.75	290.41
10	21Dec64	6	Mon	297.36	80.00	0.00	3.01	251.73	361.67	397.90	101.70	259.97
11	21Dec64	9	Mon	297.36	80.00	0.00	3.01	251.96	231.97	419.14	121.97	110.00
12	21Dec64	12	Mon	417.72	80.00	0.00	3.02	252.33	277.37	509.76	192.37	85.00
13	21Dec64	15	Mon	559.32	80.00	0.00	3.03	252.84	328.83	672.60	248.00	80.83
14	21Dec64	18	Mon	715.08	80.00	0.00	3.05	253.52	447.63	930.32	367.49	80.14
15	21Dec64	21	Mon	909.07	80.00	0.00	3.07	254.40	611.14	1253.16	531.12	80.02
16	21Dec64	24	Mon	972.79	80.00	0.00	3.09	255.36	618.81	1427.33	538.81	80.00
17	22Dec64	3	Tue	1005.36	80.00	0.00	3.12	256.34	553.07	1437.24	473.07	80.00
18	22Dec64	6	Tue	1104.48	80.00	0.00	3.14	257.44	540.46	1475.48	460.46	80.00
19	22Dec64	9	Tue	1260.24	80.00	0.00	3.18	258.70	588.63	1624.16	508.63	80.00
20	22Dec64	12	Tue	1522.20	80.00	0.00	3.21	260.24	687.75	1887.53	607.75	80.00
21	22Dec64	15	Tue	1932.84	80.00	0.00	3.26	262.19	836.43	2306.67	756.43	80.00
22	22Dec64	18	Tue	2478.00	80.00	0.00	3.32	264.20	1014.37	2894.30	934.37	80.00
23	22Dec64	21	Tue	2895.72	80.00	0.00	3.40	266.56	1116.24	3497.52	1036.24	80.00
24	22Dec64	24	Tue	3086.88	80.00	0.00	3.47	269.08	1062.19	3837.36	982.19	80.00
25	23Dec64	3	Wed	3016.08	80.00	0.00	3.55	271.41	895.06	3851.52	815.06	80.00
26	23Dec64	6	Wed	2704.56	80.00	0.00	3.62	273.34	709.08	3596.64	629.08	80.00
27	23Dec64	9	Wed	2400.12	80.00	0.00	3.68	275.02	554.19	3171.84	474.19	80.00
28	23Dec64	12	Wed	2173.56	80.00	0.00	3.73	276.49	505.72	2837.67	425.72	80.00
29	23Dec64	15	Wed	2095.68	80.00	0.00	3.79	277.87	596.99	2717.30	516.99	80.00
30	23Dec64	18	Wed	2060.28	80.00	0.00	3.84	279.13	685.84	2713.06	605.84	80.00
31	23Dec64	21	Wed	1947.00	80.00	0.00	3.89	280.33	657.46	2626.68	577.46	80.00
32	23Dec64	24	Wed	1791.24	80.00	0.00	3.93	281.42	560.45	2418.53	480.45	80.00
33	24Dec64	3	Thu	1748.76	80.00	0.00	3.97	282.50	534.14	2262.77	454.14	80.00
34	24Dec64	6	Thu	1826.64	801.30	0.04	4.00	283.20	716.76	2288.26	516.54	200.22
35	24Dec64	9	Thu	1911.60	1911.60	0.04	4.00	283.20	1512.70	2458.18	626.53	886.17
36	24Dec64	12	Thu	1890.36	1890.36	0.04	4.00	283.20	2406.80	2564.37	669.64	1737.16
37	24Dec64	15	Thu	1762.92	1762.92	0.04	4.00	283.20	2430.50	2456.76	586.91	1843.59

Table C.10 HEC-5 User Designed Output Table for Method A Operation (without **RG** Record, continued)

Location No=				44.	44.	44.	44.	44.	40.	40.	40.	40.
				BISHOP DA	BISHOP DA	BISHOP DA	BISHOP DA	BISHOP DA	ZELMA	ZELMA	ZELMA	ZELMA
Per	Date:	Hr	Day	Inflow	Outflow	Case	Level	EOP Elev	Flow Reg	Natural	Loc Incr	Q by US
38	24Dec64	18	Thu	1593.00	1593.00	0.04	4.00	283.20	2207.41	2211.79	459.37	1748.04
39	24Dec64	21	Thu	1437.24	1437.24	0.04	4.00	283.20	1970.34	1971.07	377.46	1592.88
40	24Dec64	24	Thu	1345.20	1345.20	0.04	4.00	283.20	1793.95	1794.07	346.11	1447.84
41	25Dec64	3	Fri	1295.64	1295.64	0.04	4.00	283.20	1689.27	1689.29	335.22	1354.05
42	25Dec64	6	Fri	1267.32	1267.32	0.04	4.00	283.20	1625.56	1625.57	324.91	1300.65
43	25Dec64	9	Fri	1217.76	1217.76	0.04	4.00	283.20	1600.08	1600.08	335.46	1264.62
44	25Dec64	12	Fri	1161.12	1161.12	0.04	4.00	283.20	1594.42	1594.42	378.29	1216.13
45	25Dec64	15	Fri	1104.48	1104.48	0.04	4.00	283.20	1560.43	1560.43	399.58	1160.85
46	25Dec64	18	Fri	1047.84	1047.84	0.04	4.00	283.20	1454.23	1454.23	349.80	1104.43
47	25Dec64	21	Fri	984.12	984.12	0.04	4.00	283.20	1332.45	1332.45	285.80	1046.65
48	25Dec64	24	Fri	934.56	934.56	0.04	4.00	283.20	1274.40	1274.40	288.12	986.28
49	26Dec64	3	Sat	899.16	899.16	0.04	4.00	283.20	1237.58	1237.58	300.30	937.28
50	26Dec64	6	Sat	856.68	856.68	0.04	4.00	283.20	1186.61	1186.61	288.18	898.43
51	26Dec64	9	Sat	825.53	825.53	0.04	4.00	283.20	1134.22	1134.22	275.77	858.45
52	26Dec64	12	Sat	797.21	797.21	0.04	4.00	283.20	1108.73	1108.73	282.43	826.30
53	26Dec64	15	Sat	767.47	767.47	0.04	4.00	283.20	1105.89	1105.89	308.79	797.10
54	26Dec64	18	Sat	746.23	746.23	0.04	4.00	283.20	1090.32	1090.32	321.45	768.87
55	26Dec64	21	Sat	722.16	722.16	0.04	4.00	283.20	1077.57	1077.57	331.58	745.99
56	26Dec64	24	Sat	700.92	700.92	0.04	4.00	283.20	1067.66	1067.66	345.07	722.59
57	27Dec64	3	Sun	686.76	686.76	0.04	4.00	283.20	1025.18	1025.18	323.01	702.17
58	27Dec64	6	Sun	666.93	666.93	0.04	4.00	283.20	971.37	971.37	285.35	686.02
59	27Dec64	9	Sun	647.11	647.11	0.04	4.00	283.20	923.23	923.23	256.42	666.81
60	27Dec64	12	Sun	631.54	631.54	0.04	4.00	283.20	886.42	886.42	238.62	647.80
61	27Dec64	15	Sun	608.88	608.88	0.04	4.00	283.20	853.85	853.85	223.38	630.47
62	27Dec64	18	Sun	580.56	580.56	0.04	4.00	283.20	817.03	817.03	209.27	607.76
63	27Dec64	21	Sun	552.24	552.24	0.04	4.00	283.20	780.21	780.21	199.84	580.37
64	27Dec64	24	Sun	522.51	522.51	0.04	4.00	283.20	740.57	740.57	188.60	551.97
65	28Dec64	3	Mon	487.10	487.10	0.04	4.00	283.20	695.26	695.26	173.74	521.52
66	28Dec64	6	Mon	453.12	453.12	0.04	4.00	283.20	615.95	615.95	128.78	487.17
67	28Dec64	9	Mon	424.80	424.80	0.04	4.00	283.20	604.64	604.64	150.56	454.08
68	28Dec64	12	Mon	396.48	396.48	0.04	4.00	283.20	614.55	614.55	189.59	424.96
69	28Dec64	15	Mon	375.24	375.24	0.04	4.00	283.20	564.99	564.99	167.30	397.69
70	28Dec64	18	Mon	354.00	354.00	0.04	4.00	283.20	547.99	547.99	172.55	375.44
71	28Dec64	21	Mon	325.68	325.68	0.04	4.00	283.20	529.58	529.58	176.73	352.85
72	28Dec64	24	Mon	297.36	297.36	0.04	4.00	283.20	498.43	498.43	172.94	325.49
			Sum =	76684.89	38187.85	1.83	264.38	19672.70	63596.00	102093.05	25518.57	38077.43
			Max =	3086.88	1911.60	0.04	4.00	283.20	2430.50	3851.52	1036.24	1843.59
			Min =	192.58	80.00	0.00	3.00	251.50	231.97	241.85	49.27	80.00
			PMax=	24.00	35.00	34.00	34.00	34.00	37.00	25.00	23.00	37.00
			Avg =	1065.07	530.39	0.03	3.67	273.23	883.28	1417.96	354.42	528.85
			PMin=	1.00	10.00	10.00	1.00	1.00	11.00	1.00	1.00	16.00

Table C.11 HEC-5 User Designed Output Table for Gated Spillway Operation (Example 2 with **RG** Record)

*USERS. 1 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

Location No=	44.	44.	44.	44.	44.	44.	40.	40.	40.	40.
J8/JZ Codes=	44.090	44.100	44.360	44.120	44.130	44.220	40.040	40.020	40.240	40.190

Per	Date:	Hr	Day	BISHOP DA Inflow	BISHOP DA Outflow	BISHOP DA Q-Gate R	BISHOP DA Case	BISHOP DA Level	BISHOP DA EOP Elev	ZELMA Flow Reg	ZELMA Natural	ZELMA Loc Incr	ZELMA Q by US
1	20Dec64	3	Sun	192.58	192.58	0.00	0.03	3.00	251.50	241.85	241.85	49.27	192.58
2	20Dec64	6	Sun	192.58	192.58	0.00	0.03	3.00	251.50	241.85	241.85	49.27	192.58
3	20Dec64	9	Sun	198.24	198.24	0.00	0.03	3.00	251.50	247.09	247.09	53.57	193.52
4	20Dec64	12	Sun	216.64	216.64	0.00	0.03	3.00	251.50	263.09	263.09	62.57	200.52
5	20Dec64	15	Sun	242.14	242.14	0.00	0.03	3.00	251.50	306.84	306.84	88.64	218.20
6	20Dec64	18	Sun	271.87	271.87	0.00	0.03	3.00	251.50	345.51	345.51	102.40	243.11
7	20Dec64	21	Sun	286.03	286.03	0.00	0.03	3.00	251.50	363.92	363.92	94.48	269.44
8	20Dec64	24	Sun	290.28	290.28	0.00	0.03	3.00	251.50	378.07	378.07	94.10	283.97
9	21Dec64	3	Mon	297.36	297.36	0.00	0.03	3.00	251.50	385.16	385.16	94.75	290.41
10	21Dec64	6	Mon	297.36	80.00	0.00	0.00	3.01	251.73	361.67	397.90	101.70	259.97
11	21Dec64	9	Mon	297.36	80.00	0.00	0.00	3.01	251.96	231.97	419.14	121.97	110.00
12	21Dec64	12	Mon	417.72	80.00	0.00	0.00	3.02	252.33	277.37	509.76	192.37	85.00
13	21Dec64	15	Mon	559.32	80.00	0.00	0.00	3.03	252.84	328.83	672.60	248.00	80.83
14	21Dec64	18	Mon	715.08	80.00	0.00	0.00	3.05	253.52	447.63	930.32	367.49	80.14
15	21Dec64	21	Mon	909.07	80.00	0.00	0.00	3.07	254.40	611.14	1253.16	531.12	80.02
16	21Dec64	24	Mon	972.79	80.00	0.00	0.00	3.09	255.36	618.81	1427.33	538.81	80.00
17	22Dec64	3	Tue	1005.36	80.00	0.00	0.00	3.12	256.34	553.07	1437.24	473.07	80.00
18	22Dec64	6	Tue	1104.48	80.00	0.00	0.00	3.14	257.44	540.46	1475.48	460.46	80.00
19	22Dec64	9	Tue	1260.24	80.00	0.00	0.00	3.18	258.70	588.63	1624.16	508.63	80.00
20	22Dec64	12	Tue	1522.20	80.00	0.00	0.00	3.21	260.24	687.75	1887.53	607.75	80.00
21	22Dec64	15	Tue	1932.84	80.00	0.00	0.00	3.26	262.19	836.43	2306.67	756.43	80.00
22	22Dec64	18	Tue	2478.00	80.00	0.00	0.00	3.32	264.20	1014.37	2894.30	934.37	80.00
23	22Dec64	21	Tue	2895.72	80.00	0.00	0.00	3.40	266.56	1116.24	3497.52	1036.24	80.00
24	22Dec64	24	Tue	3086.88	104.75	104.75	0.20	3.47	269.05	1066.32	3837.36	982.19	84.13
25	23Dec64	3	Wed	3016.08	283.26	283.26	0.20	3.54	271.24	946.13	3851.52	815.06	131.07
26	23Dec64	6	Wed	2704.56	383.47	383.47	0.20	3.60	272.95	903.68	3596.64	629.08	274.60
27	23Dec64	9	Wed	2400.12	370.09	370.09	0.20	3.66	274.44	837.29	3171.84	474.19	363.10
28	23Dec64	12	Wed	2173.56	345.27	345.27	0.20	3.71	275.73	790.51	2837.67	425.72	364.79
29	23Dec64	15	Wed	2095.68	344.79	344.79	0.20	3.75	276.96	865.44	2717.30	516.99	348.45
30	23Dec64	18	Wed	2060.28	412.79	412.79	0.20	3.79	278.06	962.57	2713.06	605.84	356.73
31	23Dec64	21	Wed	1947.00	500.73	500.73	0.20	3.83	278.98	995.56	2626.68	577.46	418.10
32	23Dec64	24	Wed	1791.24	546.42	546.42	0.20	3.86	279.78	975.02	2418.53	480.45	494.57
33	24Dec64	3	Thu	1748.76	561.30	561.30	0.20	3.89	280.54	994.40	2262.77	454.14	540.26
34	24Dec64	6	Thu	1826.64	636.76	636.76	0.20	3.92	281.30	1086.91	2288.26	516.54	570.37
35	24Dec64	9	Thu	1911.60	796.90	796.90	0.20	3.95	282.01	1278.91	2458.18	626.53	652.38
36	24Dec64	12	Thu	1890.36	982.45	982.45	0.20	3.98	282.61	1473.38	2564.37	669.64	803.74
37	24Dec64	15	Thu	1762.92	1099.13	1099.13	0.20	3.99	283.06	1559.02	2456.76	586.91	972.11

Table C.11 HEC-5 User Designed Output Table for Gated Spillway Operation (with **RG** Record, continued)

Location No=	44.	44.	44.	44.	44.	44.	40.	40.	40.	40.
	BISHOP DA	BISHOP DA	BISHOP DA	BISHOP DA	BISHOP DA	BISHOP DA	ZELMA	ZELMA	ZELMA	ZELMA
Per Date: Hr Day	Inflow	Outflow	Q-Gate R	Case	Level	EOP Elev	Flow Reg	Natural	Loc Incr	Q by US
38 24Dec64 18 Thu	1593.00	1134.57	1134.57	0.20	4.04	283.35	1543.24	2211.79	459.37	1083.87
39 24Dec64 21 Thu	1437.24	1142.69	1119.45	0.21	4.09	283.53	1504.93	1971.07	377.46	1127.47
40 24Dec64 24 Thu	1345.20	1148.09	1093.50	0.21	4.12	283.65	1487.16	1794.07	346.11	1141.05
41 25Dec64 3 Fri	1295.64	1152.01	1096.68	0.21	4.14	283.74	1482.79	1689.29	335.22	1147.57
42 25Dec64 6 Fri	1267.32	1155.07	1121.44	0.21	4.16	283.80	1476.69	1625.57	324.91	1151.78
43 25Dec64 9 Fri	1217.76	1163.61	1163.61	0.20	4.17	283.83	1491.40	1600.08	335.46	1155.94
44 25Dec64 12 Fri	1161.12	1163.54	0.00	0.21	4.17	283.83	1540.61	1594.42	378.29	1162.32
45 25Dec64 15 Fri	1104.48	1161.97	0.00	0.21	4.16	283.80	1562.66	1560.43	399.58	1163.08
46 25Dec64 18 Fri	1047.84	1158.93	0.00	0.21	4.14	283.73	1511.45	1454.23	349.80	1161.65
47 25Dec64 21 Fri	984.12	1154.25	0.00	0.21	4.11	283.63	1444.40	1332.45	285.80	1158.60
48 25Dec64 24 Fri	934.56	1148.35	0.00	0.21	4.08	283.50	1442.12	1274.40	288.12	1154.00
49 26Dec64 3 Sat	899.16	1141.62	0.00	0.21	4.04	283.36	1448.47	1237.58	300.30	1148.17
50 26Dec64 6 Sat	856.68	1133.82	0.00	0.21	4.00	283.19	1429.59	1186.61	288.18	1141.41
51 26Dec64 9 Sat	825.53	979.67	0.00	0.22	4.00	283.08	1385.16	1134.22	275.77	1109.39
52 26Dec64 12 Sat	797.21	888.44	0.00	0.22	3.99	283.02	1268.52	1108.73	282.43	986.09
53 26Dec64 15 Sat	767.47	827.96	0.00	0.22	3.99	282.98	1203.43	1105.89	308.79	894.64
54 26Dec64 18 Sat	746.23	787.09	0.00	0.22	3.99	282.95	1153.71	1090.32	321.45	832.26
55 26Dec64 21 Sat	722.16	754.63	0.00	0.22	3.99	282.93	1120.79	1077.57	331.58	789.21
56 26Dec64 24 Sat	700.92	727.77	0.00	0.22	3.99	282.91	1100.98	1067.66	345.07	755.91
57 27Dec64 3 Sun	686.76	707.27	0.00	0.22	3.99	282.90	1052.06	1025.18	323.01	729.05
58 27Dec64 6 Sun	666.93	687.10	0.00	0.22	3.99	282.89	992.89	971.37	285.35	707.54
59 27Dec64 9 Sun	647.11	667.10	0.00	0.22	3.99	282.87	943.59	923.23	256.42	687.17
60 27Dec64 12 Sun	631.54	649.32	0.00	0.22	3.99	282.86	906.11	886.42	238.62	667.49
61 27Dec64 15 Sun	608.88	629.10	0.00	0.22	3.99	282.85	872.36	853.85	223.38	648.98
62 27Dec64 18 Sun	580.56	604.83	0.00	0.22	3.99	282.83	837.64	817.03	209.27	628.37
63 27Dec64 21 Sun	552.24	578.54	0.00	0.22	3.99	282.81	804.21	780.21	199.84	604.37
64 27Dec64 24 Sun	522.51	550.52	0.00	0.22	3.98	282.79	766.77	740.57	188.60	578.17
65 28Dec64 3 Mon	487.10	518.81	0.00	0.22	3.98	282.77	723.59	695.26	173.74	549.85
66 28Dec64 6 Mon	453.12	485.97	0.00	0.22	3.98	282.75	647.29	615.95	128.78	518.51
67 28Dec64 9 Mon	424.80	455.38	0.00	0.22	3.98	282.73	636.85	604.64	150.56	486.29
68 28Dec64 12 Mon	396.48	425.93	0.00	0.22	3.98	282.71	645.22	614.55	189.59	455.63
69 28Dec64 15 Mon	375.24	400.59	0.00	0.22	3.98	282.69	593.96	564.99	167.30	426.66
70 28Dec64 18 Mon	354.00	377.29	0.00	0.22	3.98	282.68	573.60	547.99	172.55	401.05
71 28Dec64 21 Mon	325.68	351.49	0.00	0.22	3.98	282.66	553.68	529.58	176.73	376.95
72 28Dec64 24 Mon	297.36	324.42	0.00	0.22	3.98	282.64	524.16	498.43	172.94	351.22
Sum =	76684.89	39013.56	14097.36	10.62	264.99	19657.26	64394.97	102093.05	25518.57	38876.41
Max =	3086.88	1163.61	1163.61	0.22	4.17	283.83	1562.66	3851.52	1036.24	1163.08
Min =	192.58	80.00	0.00	0.00	3.00	251.50	231.97	241.85	49.27	80.00
PMax=	24.00	43.00	43.00	51.00	43.00	43.00	45.00	25.00	23.00	45.00
Avg =	1065.07	541.86	195.80	0.15	3.68	273.02	894.37	1417.96	354.42	539.95
PMin=	1.00	10.00	1.00	10.00	1.00	1.00	11.00	1.00	1.00	16.00

C.2 Multiple Reservoir System Simulation

A four-reservoir system is used to demonstrate flood control system operation in HEC-5. Flood control simulations are accomplished by balancing the reservoir levels above a common downstream control point according to the user specified target levels on the **RL** Records. The four-reservoir system is also used to illustrate reservoir guide curve options, varying channel capacity options and the various channel routing techniques available. These options may also be used for single reservoirs.

C.2.1 Four-Reservoir System Model (Example 3)

Figure C.4 is a schematic of four reservoirs operating as a system to reduce flooding at three common downstream locations.

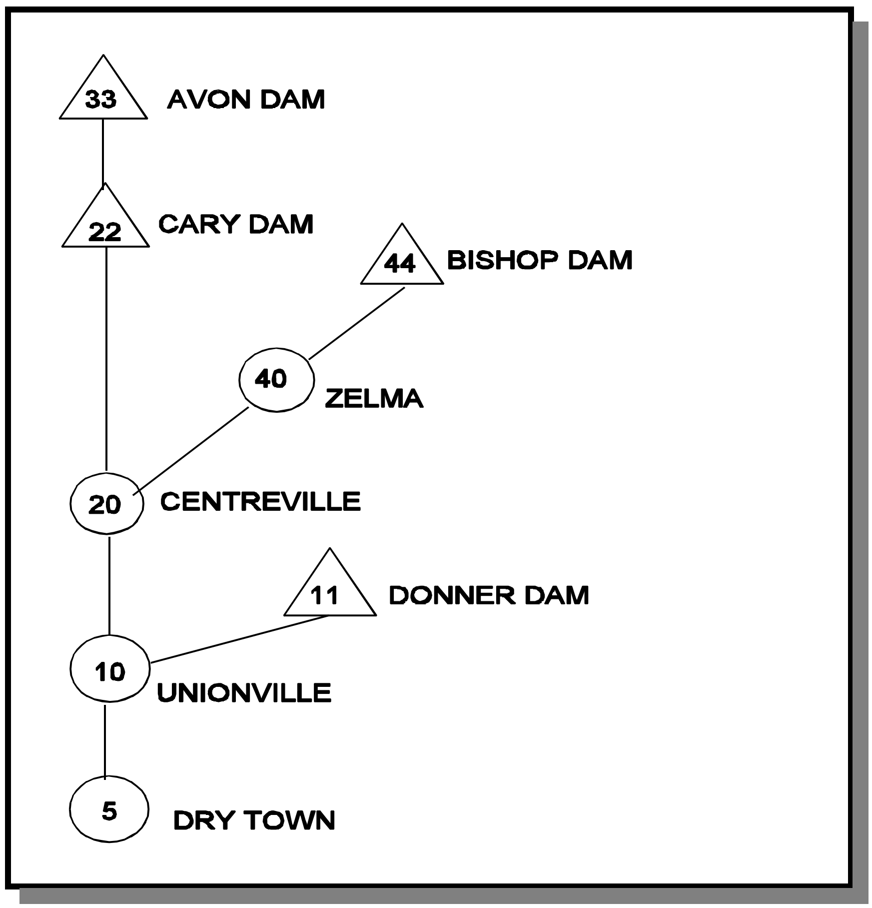

Figure C.4 Four-Reservoir System (Example 3)

Reservoir storage allocations, storage-outflow-elevation relationships, operational criteria and routing criteria (**RL-RT** Records) are given for each of the four reservoirs. The general rule for ordering the input data is simply described as adding reservoirs and control points to the data in a "top-to- bottom" sequence. However, when developing an input model such as Example 3, with both tandem and parallel reservoirs, a more thoughtful approach is beneficial. In this example, the order of input was guided by two additional rules: the outer tandem reservoirs should be added first (reservoir 33); and, the most complex (e.g., operationally constrained) branches (44 and 40) should have a high priority for addition. The input sequence for Example 3 is: 33, 44, 40, 22, 20, 11, 10, and 5. The **RO** Records, which define the locations reservoirs consider, are especially important in multi-reservoir operation. Rules for use of the **RO** Record are described in Appendix G, Input Description. In this example, reservoir 33 operates for reservoir 22 (tandem operation). Reservoirs 22, 44 and 11 each operate for all of their downstream control points. By default, each reservoir operates for itself and need not be specified on the **RO** Record.

Daily incremental local flows (**J3** Record, field 6 = 1) are being read from HEC-DSS (**ZR** Record) at all locations. Natural flows are being calculated for comparison purposes (**J2** Record, field 4 = -1).

Table C.12 lists the HEC-5 input file (EXAMPLE3.DAT) of the four-reservoir system and Table C.13 shows two schematic maps that are produced in the output file. *Map 1 summarizes the locations being operated for by upstream reservoirs. *Map 2 is a summary of pertinent input data including channel capacities and flood storage allocations.

In Example 3, all levels remain the same during the year except for the top-of-conservation pool (level 3) which varies as follows:

Reservoir 33 varies seasonally (9 seasons)
Reservoir 22 varies seasonally (6 seasons)

Table C.12 HEC-5 Input for a Basic Four-Reservoir System (Example 3)

```
T1      HEC-5 Example 3, Four Reservoir System     (EXAMPLE3.DAT)
T2      Tandem and Parallel Reservoir System with Variable Channel Capacities
T3      Rocky River Basin, Avon Dam to Dry Town
J1      1       1       5       3       4       2
J2     24     1.2               8       0      10
J3      5                      -1              -1
J8 44.10   44.12   44.13   22.13   22.12   22.10   20.18   40.18   10.18    5.18
J8 33.10   33.12   33.13   22.13   22.12   22.10   22.17   22.22   20.04   10.04
J8 44.10   22.10   11.10   44.13   22.13   11.13   44.12   22.12   11.12    5.04
JZ-44.13   33.13   22.13   11.13   44.10   33.10   22.10   11.10   40.17   20.17
JZ 40.04   20.04   10.04    5.04   40.02   20.02   10.02    5.02   10.17    5.17
JR      0     1.7     600    1200    1800
JR     33     1.7     600    1800

C  ============== Avon Dam =============
RL     33  151400   31100   34050  151400  350550  375000
RL      1      33      -1       0   31100
RL      2      33      -1       0   34050
RL      3      33       9       0  151400  151400  197000  310330  310330  254050
RL                                 210500  151400  151400
RL      4      33      -1       0  350550
RL      5      33      -1       0  375000
RO      1      22
RS     11       0   31100   34050   53000  100240  151400  201100  256350  297100
RS350550  375000
RQ     11       0      11     145     178     212     240     452     664    1457
RQ  1646    1829
RE     11     309   349.6     351   362.1     370   374.3   377.4     382     383
RE 384.7   386.8
R2     20      60
CP     33     150       3     1.5
IDAVON DAM
RT     33      22     2.2    0.25     3.2
CS      9       1     105     135     151     250     274     305     331     365

C  ============== Bishop Dam Site =============
RL     44  146480  131438  134000  146480  562248  630063
RO      4      40      20      10       5
RS     13       0  124113  131438  134000  146480  253628  362008  417740  465211
RS546342  562248  589251  630063
RQ     13       0     333     665     668     681     796     872     912    2322
RQ  5664    6457    7646    9629
RE     13   209.7   249.6   250.2   250.4   251.5   262.1   270.5   274.3   277.4
RE 282.2   283.2   284.7   286.8
R2     10      60
CP     44     425      20       2
IDBISHOP DAM
RT     44      40     1.2     0.3     3.0

C  ============== Zelma ===============
CP     40     450
IDZELMA
RT     40      20     1.9
CR      3     .10     .65     .25
```

... Continued ...

Table C.12 HEC-5 Input for Four Reservoir System (Example 3, Continued)

... Continuation of Example 3 ...

```
C  ============== Cary Dam =============
RL    22  255480   21438  134000  255480  389190  435563
RL     1      22      -1       0   21438
RL     2      22      -1       0  134000
RL     3      22       6       0  255480  255480  362008  362008  255480  255480
RL     4      22      -1       0  389248
RL     5      22      -1       0  435563
RO     3      20      10       5
RS     9       0   21438  134000  255480  362008  375600  378300  389190  435563
RQ     9       0     657     681     796     872     892     896     912    2322
RE     9     259   309.6   302.5   312.1   320.5   322.4   322.8   324.3   327.4
R2    15      30
CP    22     100     2.2       1
IDCARY DAM
RT    22      20     2.2    0.45     3.1
CC  22.5     100     100     150     150
CS     6       1     105     151     250     305     365
CG -4.10     309     309     309     309     309     309
CG -4.11   312.1   312.1   320.5   320.5   312.1   312.1
CG -2.25   317.1   317.1   325.5   325.5   317.1   317.1
CG -4.35   327.4   327.4   327.4   327.4   327.4   327.4

C  ============== Centerville ==============
CP    20     550
IDCENTERVILLE
RT    20      10     1.2    0.35     3.0

C  ============== Donner Reservoir =============
RL    11   56480    1638    4000   56480  150200  215000
RO     2      10       5
RS     8       0    1638    4000   56480   93008  112740  150200  215000
RQ     8       0     657     681     796     872     912    2322    5664
RE     8    59.7    99.6   101.5   112.1   120.5   124.3   127.4   132.2
R2   100     100
CP    11     100     1.1      .5
IDDONNER DAM
RT    11      10     3.2     0.2     3.0
CL     6     1.0     3.0     3.1    3.59     3.8     5.0
CC  11.4      25      25     100     100     150     150

C  ============== Unionville ==========
CP    10     870
IDUNIONVILLE
RT    10       5     1.4     0.2       0
QS     9       0     200     300     540     740     920    1150    1480    3000
SQ     9       0     400     640    1050    1550    1850    3250    4500    6200

C  ============== Dry Town ============
CP     5     950
IDDRY TOWN
RT     5

ED
C    ------------------- Flood of Jan 21-29 1955 ------------------------------
BF     2      72       0        55012100       0       3
ZR=IN   A=EXAMPLE 3    C=FLOW-LOC INC   F=COMPUTED FLOWS
ZW      A=EXAMPLE 3         F=SYSTEM OPERATION
EJ
ER
```

Table C.13 Schematic Maps from Output File Showing Pertinent Input Data (Example 3)

```
*Map 1

         HEC-5 Example 3, Four Reservoir System     (EXAMPLE3.DAT)

                               Upstream Reservoirs Operating for Each Location

    33R              AVON DAM
    22R              CARY DAM          33
     |     .----44R  BISHOP DAM
     .----40         ZELMA             44
    20               CENTERVILL        44      22
     .----11R        DONNER DAM
    10               UNIONVILLE        44      22      11
     5               DRY TOWN          44      22      11


--------------------------------------------------------------------------------------------------------------


*Map 2

         HEC-5 Example 3, Four Reservoir System     (EXAMPLE3.DAT)

                                 Channel    Flood    Conserv.  Min Des.  Min Req.  Divert    Map  Location
                                 Capacity  Storage   Storage     Flow      Flow      to    Number   Name

    33R              AVON DAM        150.   199150.   120300.        3.        2.       0      33 AVON DAM
    22R              CARY DAM        100.   133768.   234042.        2.        1.       0      22 CARY DAM
     |     .----44R  BISHOP DAM      425.   415768.    15042.       20.        2.       0      44 BISHOP DAM
     .----40         ZELMA           450.        0.        0.        0.        0.       0      40 ZELMA
    20               CENTERVILL      550.        0.        0.        0.        0.       0      20 CENTERVILLE
     .----11R        DONNER DAM       25.    93720.    54842.        1.        1.       0      11 DONNER DAM
    10               UNIONVILLE      870.        0.        0.        0.        0.       0      10 UNIONVILLE
     5               DRY TOWN        950.        0.        0.        0.        0.       0       5 DRY TOWN
```

Additional **RL** Records are required for Reservoir 33 and Reservoir 22, for each level. However, for those levels that remain constant throughout the year (levels 1, 2, 4 and 5), a value of -1 is specified in field 3 of the **RL** Record and the storage value for that level is input in field 5. For the level that varies by season (level 3 in this example), a **CS** Record is required to define the seasons that correspond to the input storage values on the **RL** Record for level 3. HEC-5 uses linear interpolation between storage values. Table C.14 contains the "*Rule Curve Summary" produced in the Example 3 output file. It shows the season dates and the corresponding storage values for the five reservoir levels at all of the reservoirs. Figure C.5 shows an HEC-DSS plot of the reservoir guide curves at the two reservoirs where the top-of-conservation varies seasonally.

Channel Capacity Options. The channel capacity at any location can be constant or vary as shown in Table C.15. In Example 3, Reservoir 11 illustrates channel capacity at the reservoir based on reservoir level alone (option 4). The reservoir level can be at any specified reservoir; however, in this example it is the same reservoir. Table C.16 shows the input records for specifying the channel capacity for Reservoir 11 based on its Level. The program uses linear interpolation between the six points defining the reservoir levels (on **CL** Record) and the channel capacities (on **CC** Record).

Channel capacity varying seasonally with reservoir level or elevation (option 5) is used for Reservoir 22. A discussion of the channel capacity rule curve operation and its variations is given in Appendix G, Input Description for the **CG** Record. Table C.17 shows the input records for Reservoir 22. Six seasons are input on the **CS** Record, four channel capacities are entered on the **CC** Record, and one **CG** Record is given for each of the four values specified on the **CC** Record. The **CG** Records are input in the same order as the values on the **CC** Record. The code (to the left of the decimal point) in the first field of the **CG** Record determines the method by which the channel capacity is to be interpolated within reservoir zones. A negative value indicates reservoir elevations (instead of reservoir levels) are being specified in the remaining fields of the **CG** Record. The value of -4.10 for the first **CG** Record signifies that the top-of-the zone is used to define the channel capacity for the reservoir elevations given on the remainder of the **CG** Record.

Table C.14 Summary of Input Reservoir Storage Values for Five Levels (Example 3)

```
*Rule Curve Summary

   Initial   Cum     Start              Storage for Level:
   Storage   Days    Date        1         2         3         4         5


          -----------------------------------------
          Reservoir Number =   33     AVON DAM
          -----------------------------------------

   151400.     1    01 JAN    31100.    34050.   151400.   350550.   375000.

Season = 2   105    15 APR    31100.    34050.   151400.   350550.   375000.

         3   135    15 MAY    31100.    34050.   197000.   350550.   375000.

         4   151    31 MAY    31100.    34050.   310330.   350550.   375000.

         5   250    07 SEP    31100.    34050.   310330.   350550.   375000.

         6   274    01 OCT    31100.    34050.   254050.   350550.   375000.

         7   305    01 NOV    31100.    34050.   210500.   350550.   375000.

         8   331    27 NOV    31100.    34050.   151400.   350550.   375000.

         9   365    31 DEC    31100.    34050.   151400.   350550.   375000.


          -----------------------------------------
          Reservoir Number =   44     BISHOP DAM
          -----------------------------------------

   146480.     1    01 Jan   131438.   134000.   146480.   562248.   630063.


          -----------------------------------------
          Reservoir Number =   22     CARY DAM
          -----------------------------------------

   255480.     1    01 JAN    21438.   134000.   255480.   389248.   435563.

Season = 2   105    15 APR    21438.   134000.   255480.   389248.   435563.

         3   151    31 MAY    21438.   134000.   362008.   389248.   435563.

         4   250    07 SEP    21438.   134000.   362008.   389248.   435563.

         5   305    01 NOV    21438.   134000.   255480.   389248.   435563.

         6   365    31 DEC    21438.   134000.   255480.   389248.   435563.


          -----------------------------------------
          Reservoir Number =   11     DONNER DAM
          -----------------------------------------

    56480.     1    01 Jan     1638.     4000.    56480.   150200.   215000.
```

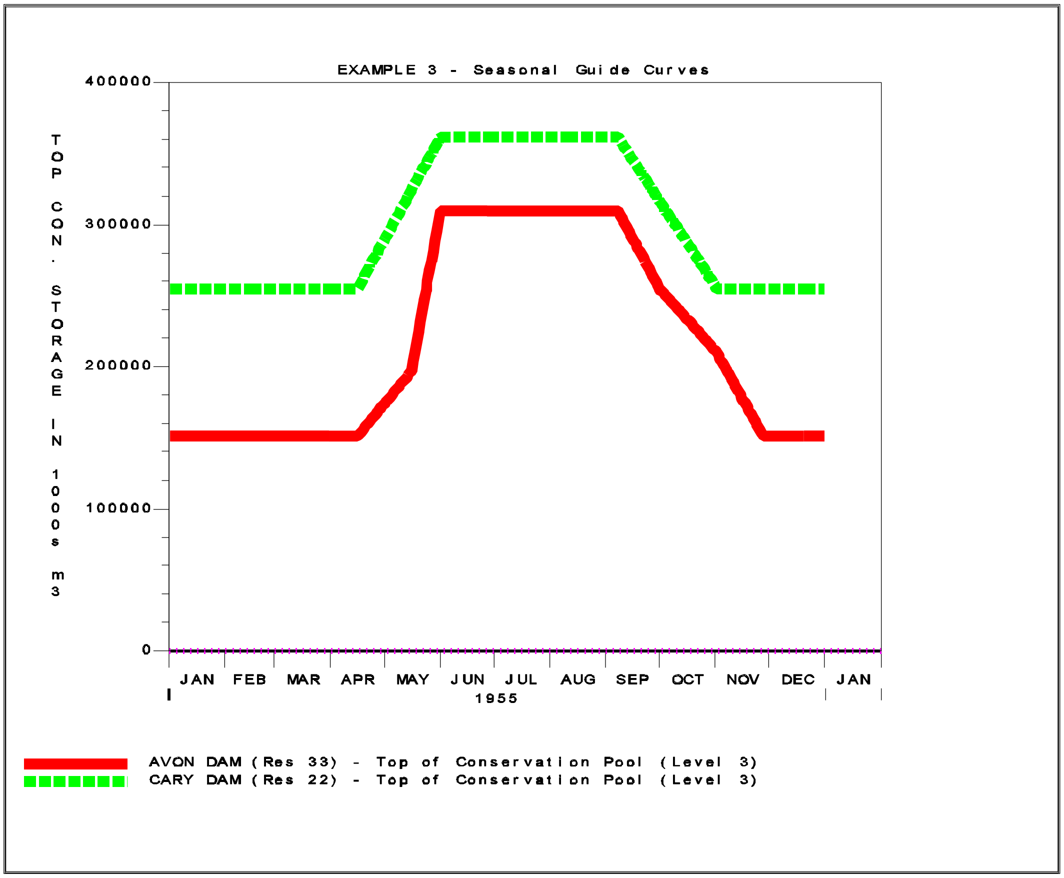

Figure C.5 Seasonal Guide Curves for Reservoirs 33 and 22 (Example 3)

Table C.15 Options for Varying Channel Capacities

Option	Description	Records
1	Monthly	CC
2	Seasonally	CC, CS
3	Function of flow at another location	CC, QS
4	Function of reservoir level	CC, CL
5	Function of season and level	CC, CS, CG
6	Function of season and percent system flood control storage	CC, CS, CG, GC
7	Varies with rising or falling inflow	CC

Table C.16 Channel Capacity Based on Reservoir Level (Reservoir 11)

CL	6	1.0	3.0	3.1	3.59	3.8	5.0
CC	11.4	25	25	100	100	150	150

Table C.17 Channel Capacity Based on Seasons and Reservoir Elevation (Reservoir 22)

```
The following are input records for Specifying Channel Capacity for Reservoir 22:

 CC  22.5     100     100     150     150
 CS     6       1     105     151     250     305     365
 CG -4.10     309     309     309     309     309     309
 CG -4.11   312.1   312.1   320.5   320.5   312.1   312.1
 CG -2.25   317.1   317.1   325.5   325.5   317.1   317.1
 CG -4.35   327.4   327.4   327.4   327.4   327.4   327.4

The following summary is produced in the Output file:

                                   --------------
 Channel Capacity GUIDE CURVE for: Location =  22  Based on: REFERENCE Location = 22
================                  --------------

Seasons (in Days Since 31 Dec):        1.    105.    151.    250.    305.    365.
                 Starting Date:    01 JAN  15 APR  31 MAY  07 SEP  01 NOV  31 DEC
       .... CODE  ....
 Zone  Rising  Falling   Chan Cap    Reservoir  ELEVATION  Data for Zones
 ---------------------
   1     4        4
 ---------------------      100.   309.00  309.00  309.00  309.00  309.00  309.00
   2     4        4
 ---------------------      100.   312.10  312.10  320.50  320.50  312.10  312.10
   3     2        2
 ---------------------      150.   317.10  317.10  325.50  325.50  317.10  317.10
   4     4        4
 ---------------------      150.   327.40  327.40  327.40  327.40  327.40  327.40
```

C.2.2 HEC-5 Results for Example 3

Example 3 is a four-reservoir system model which illustrates the operation of reservoirs to reduce flooding at downstream locations while maintaining specified low-flow requirements. To analyze HEC-5 flood system simulation results, the HEC-5 output features which are the most useful are: (1) the "Summary of Maximums" tables; (2) the **J8**/**JZ** User Designed Output tables; and (3) graphical plots generated using the HEC-DSS program DSPLAY.

The "Summary of Maximums" tables (requested by **J3** Record, field 1) are shown in Table C.18 and Table C.19.

Table C.18 Summary of Maximum Values for Reservoirs (Example 3)

```
                                          --------------
                 Summary of Maximums for    RESERVOIRS
                            --------      --------------


      HEC-5 Example 3, Four Reservoir System     (EXAMPLE3.DAT)
      Tandem and Parallel Reservoir System with Variable Channel Capacities
      Rocky River Basin, Avon Dam to Dry Town

           -------------------------------------------------------

           Period of Analysis:  STARTING :  21JAN55 - 0000 Hrs
                                ENDING   :  29JAN55 - 2400 Hrs
                                DURATION :  9 Days,  0 Hrs,  0 Min

                Time Interval:    3 Hours,  0 Minutes

           -------------------------------------------------------

******************************************************************************
*    Reservoir    *     Max    *     Max    *    Max             *     Max    *
*                 *   Inflow   *   Outflow  *  Storage    Elev   *    HEC-5   *
*  ID    Name     *   (m3/s)   *   (m3/s)   * (1000m3)  (Meters)*    Levels   *
*                 *            *            *                    *            *
******************************************************************************
*                 *            *            *                    *            *
*  33 AVON DAM    *        741 *        150 *   315714   383.59 *      3.825 *
*                 * 22JAN-2100 * 22JAN-0600 *    29JAN-1500      * 29JAN-1500 *
*                 *            *            *                    *            *
*  44 BISHOP DAM  *       1544 *        333 *   493315   279.06 *      3.834 *
*                 * 22JAN-2100 * 29JAN-1800 *    28JAN-0600      * 28JAN-0600 *
*                 *            *            *                    *            *
*  22 CARY DAM    *        623 *        150 *   366517   321.13 *      3.830 *
*                 * 23JAN-0600 * 26JAN-1800 *    29JAN-0300      * 29JAN-0300 *
*                 *            *            *                    *            *
*  11 DONNER DAM  *        355 *        113 *   117025   124.65 *      3.646 *
*                 * 23JAN-1800 * 26JAN-1200 *    26JAN-1200      * 26JAN-1200 *
*                 *            *            *                    *            *
******************************************************************************


           Maximum System Storage Used =  1281593.  (28JAN-0300)
```

Table C.19 Summary of Maximum Values for Control Point Locations (Example 3)

Summary of Maximums for CHANNEL CONTROL POINT LOCATIONS

HEC-5 Example 3, Four Reservoir System (EXAMPLE3.DAT)
Tandem and Parallel Reservoir System with Variable Channel Capacities
Rocky River Basin, Avon Dam to Dry Town

Period of Analysis: STARTING : 21JAN55 - 0000 Hrs
ENDING : 29JAN55 - 2400 Hrs
DURATION : 9 Days, 0 Hrs, 0 Min

Time Interval: 3 Hours, 0 Minutes

Channel Location ID	Name	**Channel Capacity** (m3/s)	**Max Reg. Flow** (m3/s)	Q from Res. (m3/s)	Max Cum. Local Q (m3/s)	Max Natural Q (m3/s)
33	AVON DAM	150	150 22JAN-0600	0	741 22JAN-2100	741 22JAN-2100
44	BISHOP DAM	425	333 29JAN-1800	0	1544 22JAN-2100	1544 22JAN-2100
22	CARY DAM	150	150 26JAN-1800	0	494 23JAN-0600	1193 23JAN-0600
11	DONNER DAM	113	113 26JAN-1200	0	355 23JAN-1800	355 23JAN-1800
40	ZELMA	450	538 23JAN-1200	20	518 23JAN-1200	1788 23JAN-0300
20	**CENTERVILLE**	**550**	**771** 23JAN-1800	22	748 23JAN-1800	3055 23JAN-1200
10	UNIONVILLE	870	909 23JAN-2100	23	886 23JAN-2100	3340 23JAN-1500
5	DRY TOWN	950	1036 23JAN-2100	23	1013 23JAN-2100	3447 23JAN-1800

Table C.18 shows Reservoir maximum values of storages, elevations, and levels, as well as maximum inflow and outflow values. In Example 3, the flood control storage zone is defined as being between level 3 and level 4 (see **J1** Record, fields 4 and 5). A review of Table C.18 indicates that the maximum flood control storage level in each of the three upper reservoirs (Avon, Bishop, and Cary) was 3.83 (flood storage 83% full). The fact that each of the three upper reservoirs achieved the same utilization of their flood storage is indicative of a strong integrated system operation. The lowest reservoir in the system (Donner), however, utilized only 65% (level 3.65) of its flood control storage.

To answer why Donner utilized significantly less flood storage and reached its maximum level several days earlier, additional output must be reviewed. The output listed in Table C.19 suggests that flooding in the system was the most severe at Centerville, which had a maximum regulated flow of 771 m^3/s and a channel capacity of 550 m^3/s. We can surmise that since Donner is in the lower portion of the basin and it does not operate for Centerville, it was able to make releases to evacuate its flood storage pool more frequently; or, perhaps runoff in the lower basin was significantly less than in the upper basin. The "Summary of Maximums" tables do not provide definitive answers to these operation questions.

The most informative output are the "User Designed" output tables which show selected program results for each time period of the simulation. Program users may create these tables by choosing from 41 output variable codes. These tables are created using the **J8** and/or **JZ** Records where location numbers and codes are specified (e.g., 44.10 requests reservoir 44's outflow). Table C.20 is an example of a thoughtfully developed user designed table. The three most essential reservoir output items (Outflow, Case and Level), which explain reservoir release decisions, are shown for the two *parallel* reservoirs (Bishop and Cary) in the upper basin. Also shown are the available flood space (Q Space) at the four downstream locations for which the reservoirs operate.

The second user designed table (Table C.21) shows similar information for the two *tandem* reservoirs (Avon and Cary). Because the channel capacity at Cary Dam varies with elevation, this table also shows its elevation and channel capacity along with the regulated flows at Centerville and Unionville. Table C.22 shows Outflow, Level and Case for all three of the *parallel* reservoirs (Bishop, Cary and Donner) as well as the regulated flow at Dry Town, their common operation point.

Because Bishop and Cary Dams operate for a common downstream location (Centerville), an analysis of their operation can be made by reviewing Table C.20. Notice that in Period 12 the Cary Dam Outflow was reduced from 103.2 m^3/s to 69.19 m^3/s. The Cary Dam Case shown for this period is 20.03 which indicates the decision was based on a forecast of flooding at location 20 (Centerville) three periods in the future. Release from Bishop Dam was increased during period 12 from 28.5 m^3/s to 58.5 m^3/s. The Bishop Dam Case for this period is 0.02 which indicates it was based on the rate-of-change for increasing releases (see **R2** Record, field 1).

Table C.20 User Designed Output: Parallel Operation of Bishop Dam and Cary Dam for Centerville (Example 3)

*USERS. 1   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood=   1

Location No=				44.	44.	44.	22.	22.	22.	20.	40.	10.	5.
J8/JZ Codes=				44.100	44.120	44.130	22.130	22.120	22.100	20.180	40.180	10.180	5.180
				BISHOP D	**BISHOP D**	**BISHOP D**	**CARY DAM**	**CARY DAM**	**CARY DAM**	**CENTERVIL**	ZELMA	UNIONVILL	DRY TOWN
Per	Date:	Hr	Day	**Outflow**	**Case**	**Level**	**Level**	**Case**	**Outflow**	**Q Space**	Q Space	Q Space	Q Space
1	21Jan55	3	Fri	148.50	0.03	3.00	3.00	0.01	100.02	257.73	270.00	546.36	616.86
2	21Jan55	6	Fri	148.50	0.03	3.00	3.00	0.01	100.02	255.18	257.00	545.00	614.17
3	21Jan55	9	Fri	148.50	-0.01	3.00	3.00	-0.01	100.02	243.83	250.50	541.19	609.72
4	21Jan55	12	Fri	178.50	0.02	3.00	3.00	0.01	100.02	229.76	249.50	529.93	600.16
5	21Jan55	15	Fri	178.50	-0.01	3.01	3.00	-0.01	100.02	222.15	228.67	515.36	583.79
6	21Jan55	18	Fri	208.50	0.02	3.02	3.00	0.01	100.02	209.46	219.69	503.98	571.84
7	21Jan55	21	Fri	208.50	-0.01	3.02	3.01	-0.01	100.02	195.93	194.78	485.92	555.06
8	21Jan55	24	Fri	208.50	-0.01	3.03	3.02	-0.01	100.02	175.88	181.21	468.57	535.11
9	22Jan55	3	Sat	208.50	-0.01	3.04	3.03	-0.01	100.02	155.53	145.62	450.38	515.64
10	22Jan55	6	Sat	28.50	0.02	3.05	3.04	0.01	103.02	124.18	147.52	428.44	487.03
11	22Jan55	9	Sat	**28.50**	-0.01	**3.07**	**3.05**	-0.01	**103.02**	106.22	221.32	399.47	455.53
12	22Jan55	12	Sat	**58.50**	**0.02**	**3.10**	**3.07**	**20.03**	**69.19**	138.30	221.99	384.66	439.96
13	22Jan55	15	Sat	58.50	-0.01	3.13	3.09	-0.01	69.19	125.88	189.46	402.50	456.33
14	22Jan55	18	Sat	**20.00**	0.00	3.17	3.12	0.00	**2.20**	90.64	177.83	382.02	443.80
15	22Jan55	21	Sat	20.00	-0.01	3.20	3.16	-0.01	2.20	**82.16**	194.75	352.32	405.79
16	22Jan55	24	Sat	20.00	-0.01	3.24	3.20	-0.01	2.20	160.25	174.62	348.15	396.59
17	23Jan55	3	Sun	20.00	-0.01	3.28	3.25	-0.01	2.20	156.84	125.85	398.45	424.36
18	23Jan55	6	Sun	20.00	0.00	3.31	3.30	0.00	2.20	101.15	51.98	387.52	408.94
19	23Jan55	9	Sun	20.00	-0.01	3.34	3.35	-0.01	2.20	7.34	**-37.00**	324.43	329.27
20	23Jan55	12	Sun	20.00	0.00	3.36	3.39	0.00	2.20	**-111.06**	**-88.00**	222.99	227.47
21	23Jan55	15	Sun	20.00	-0.01	3.39	3.43	-0.01	2.20	**-208.25**	**-61.00**	101.06	88.88
22	23Jan55	18	Sun	20.00	0.00	3.41	3.46	0.00	2.20	**-220.60**	22.50	0.40	**-31.38**
23	23Jan55	21	Sun	20.00	-0.01	3.44	3.49	-0.01	2.20	**-136.78**	115.50	**-38.88**	**-86.43**
24	23Jan55	24	Sun	20.00	-0.01	3.46	3.52	-0.01	2.20	**-11.95**	133.00	2.50	**-59.01**
25	24Jan55	3	Mon	20.00	-0.01	3.48	3.55	-0.01	2.20	30.58	147.00	89.95	13.96
26	24Jan55	6	Mon	20.00	0.00	3.51	3.57	0.00	2.20	52.25	141.50	149.08	39.98
27	24Jan55	9	Mon	20.00	-0.01	3.53	3.59	-0.01	2.20	63.72	137.00	186.30	28.51
28	24Jan55	12	Mon	20.00	0.00	3.55	3.62	0.00	2.20	67.13	141.50	205.53	26.54
29	24Jan55	15	Mon	20.00	-0.01	3.57	3.64	-0.01	2.20	88.52	160.00	223.40	55.20
30	24Jan55	18	Mon	20.00	0.00	3.59	3.66	0.00	2.20	99.22	163.00	251.11	93.73
31	24Jan55	21	Mon	20.00	-0.01	3.61	3.69	-0.01	2.20	108.90	171.50	277.78	128.11
32	24Jan55	24	Mon	20.00	-0.01	3.62	3.71	-0.01	2.20	114.17	176.50	291.16	152.45
33	25Jan55	3	Tue	20.00	-0.01	3.64	3.73	-0.01	2.20	116.65	185.00	300.65	162.99
34	25Jan55	6	Tue	41.43	20.02	3.66	3.74	0.02	47.20	121.67	192.93	306.67	187.21
35	25Jan55	9	Tue	41.43	-0.01	3.67	3.75	-0.01	47.20	117.44	182.05	304.94	194.25
36	25Jan55	12	Tue	21.81	5.01	3.68	3.76	0.02	92.20	79.17	213.84	276.42	177.78
37	25Jan55	15	Tue	21.81	-0.01	3.70	3.77	-0.01	92.20	95.59	252.55	230.62	137.44

Table C.21 User Designed Output: Tandem Operation of Avon Dam for Cary Dam (Example 3)

*USERS. 2 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

Location No=				33.	33.	33.	22.	22.	22.	22.	22.	20.	10.
J8/JZ Codes=				33.100	33.120	33.130	22.130	22.120	22.100	22.170	22.220	20.040	10.040
Per	Date:	Hr	Day	**AVON DAM Outflow**	**AVON DAM Case**	**AVON DAM Level**	**CARY DAM Level**	CARY DAM Case	CARY DAM Outflow	CARY DAM QMax-Tar	CARY DAM EOP Elev	CENTERVIL Flow Reg	UNIONVILL Flow Reg
1	21Jan55	3	Fri	71.28	0.03	3.00	3.00	0.01	100.02	100.02	312.11	292.27	323.64
2	21Jan55	6	Fri	45.76	0.05	3.00	3.00	0.01	100.02	100.02	312.12	294.82	325.00
3	21Jan55	9	Fri	45.76	-0.01	3.00	3.00	-0.01	100.02	100.02	312.13	306.17	328.81
4	21Jan55	12	Fri	45.76	-0.01	3.01	3.00	0.01	100.02	100.02	312.13	320.24	340.07
5	21Jan55	15	Fri	45.76	-0.01	3.02	3.00	-0.01	100.02	100.02	312.12	327.85	354.64
6	21Jan55	18	Fri	105.76	0.02	3.02	3.00	0.01	100.02	100.02	312.13	340.54	366.02
7	21Jan55	21	Fri	105.76	-0.01	3.03	3.01	-0.01	100.02	100.02	312.17	354.07	384.08
8	21Jan55	24	Fri	105.76	-0.01	3.04	3.02	-0.01	100.02	100.02	312.26	374.12	401.43
9	22Jan55	3	Sat	105.76	-0.01	3.04	3.03	-0.01	100.02	101.02	312.38	394.47	419.62
10	22Jan55	6	Sat	150.00	0.01	3.05	3.04	0.01	103.02	103.02	312.51	425.82	441.56
11	22Jan55	9	Sat	150.00	-0.01	3.06	3.05	-0.01	103.02	104.02	312.65	443.78	470.53
12	22Jan55	12	Sat	150.00	-0.01	3.08	3.07	20.03	69.19	106.02	312.86	411.70	485.34
13	22Jan55	15	Sat	150.00	-0.01	3.11	3.09	-0.01	69.19	108.02	313.10	424.12	467.50
14	22Jan55	18	Sat	150.00	0.01	3.14	3.12	0.00	2.20	110.02	313.41	459.36	487.98
15	22Jan55	21	Sat	150.00	-0.01	3.17	3.16	-0.01	2.20	114.02	313.80	467.84	517.68
16	22Jan55	24	Sat	150.00	-0.01	3.20	3.20	-0.01	2.20	118.02	314.26	389.75	521.85
17	23Jan55	3	Sun	**150.00**	-0.01	**3.23**	**3.25**	-0.01	2.20	123.02	314.78	393.16	471.55
18	23Jan55	6	Sun	**58.62**	**0.05**	**3.25**	3.30	0.00	2.20	128.02	315.31	448.85	482.48
19	23Jan55	9	Sun	58.62	-0.01	3.28	3.35	-0.01	2.20	133.02	315.82	542.66	545.57
20	23Jan55	12	Sun	58.62	-0.01	3.30	3.39	0.00	2.20	139.02	316.25	661.06	647.01
21	23Jan55	15	Sun	58.62	-0.01	3.33	3.43	-0.01	2.20	143.02	316.64	758.25	768.94
22	23Jan55	18	Sun	**3.00**	0.00	3.35	3.46	0.00	2.20	147.02	316.97	770.60	869.60
23	23Jan55	21	Sun	3.00	-0.01	3.38	3.49	-0.01	2.20	150.04	317.29	686.78	908.88
24	23Jan55	24	Sun	3.00	-0.01	3.40	3.52	-0.01	2.20	150.04	317.59	561.95	867.50
25	24Jan55	3	Mon	3.00	-0.01	3.42	3.55	-0.01	2.20	150.04	317.86	519.42	780.05
26	24Jan55	6	Mon	3.00	0.00	3.45	3.57	0.00	2.20	150.04	318.10	497.75	720.92
27	24Jan55	9	Mon	3.00	-0.01	3.47	3.59	-0.01	2.20	150.04	318.34	486.28	683.70
28	24Jan55	12	Mon	3.00	-0.01	3.49	3.62	0.00	2.20	150.04	318.59	482.88	664.47
29	24Jan55	15	Mon	3.00	-0.01	3.51	3.64	-0.01	2.20	150.04	318.85	461.48	646.60
30	24Jan55	18	Mon	3.00	0.00	3.53	3.66	0.00	2.20	150.04	319.11	450.78	618.89
31	24Jan55	21	Mon	3.00	-0.01	3.55	3.69	-0.01	2.20	150.04	319.35	441.10	592.22
32	24Jan55	24	Mon	3.00	-0.01	3.57	3.71	-0.01	2.20	150.04	319.57	435.83	578.84
33	25Jan55	3	Tue	3.00	-0.01	3.58	3.73	-0.01	2.20	150.04	319.76	433.35	569.35
34	25Jan55	6	Tue	3.00	0.00	3.60	3.74	0.02	47.20	150.04	319.91	428.33	563.33
35	25Jan55	9	Tue	3.00	-0.01	3.61	3.75	-0.01	47.20	150.04	320.05	432.56	565.06
36	25Jan55	12	Tue	3.00	-0.01	3.63	3.76	0.02	92.20	150.04	320.15	470.83	593.58
37	25Jan55	15	Tue	3.00	-0.01	3.64	3.77	-0.01	92.20	150.04	320.24	454.41	639.38

To understand why one of the two parallel reservoirs (Cary) was reducing its outflow while the other (Bishop) was increasing its outflow, it is necessary to compare the Levels for both reservoirs. The Levels for Bishop and Cary have been tabulated next to each other to facilitate an easy comparison. The decision for Bishop to increase outflow was based on the fact that its flood pool was fuller at the beginning of period 12 (level 3.07 for period 11 compared to Cary's level of 3.05) . Therefore, Bishop had the priority to make use of the available space at Centerville. In period 14 both reservoirs reduced their releases to their respective minimum flows, which they maintained until period 34. The default operation would be to not release flow that would contribute to flooding downstream. However, recall that in this example, a priority was given to release minimum flows even though the releases might contribute to flooding (**J2** Record, field 4). In the last four columns, the space available for upstream reservoirs to fill with releases (Q Space) for Centerville, Zelma, Unionville, and Dry Town is shown. The negative values shown in these columns indicate both the timing and magnitude of flooding.

A detailed review of Table C.21 explains the operation of the Avon and Cary *tandem* reservoir sub-system. Of interest in this table is the operation of Avon in period 18, during which the outflow from Avon is reduced from 150.0 m^3/s to 58.62 m^3/s. Avon's Case for period 18 is 0.05, which indicates a *tandem* reservoir operation. In this example, Avon does not operate for a limiting channel capacity at a downstream control point; rather, it operates to balance levels with a downstream reservoir (Cary). At the end of period 17, Cary's level was 3.25 and Avon's level was 3.23. Therefore, Avon reduces its outflow in period 18 in order to match Cary's level in the previous period. Since Cary's level continued to rise, Avon reduced outflow to its minimum value at the next decision time (period 22).

The operation of the three *parallel* reservoirs (Bishop, Cary, and Donner) is shown in Table C.22. The operation of Donner shows that its release was reduced from 30.44 m^3/s to 3.35 m^3/s to decrease flooding at Dry Town (location 5) eight periods in the future (period 12 Case for Donner = 5.08). The flood reduction operation of Bishop and Cary was previously reviewed in Table C.20. However, they are presented in Table C.22 to illustrate that all three of these parallel reservoirs cut back their outflows to minimum flows by period 14 in order to reduce downstream flooding. By period 34, the downstream flows had receded and larger releases from the reservoirs were resumed in order to evacuate their flood control storage.

In summary, it may be said that the operation of the upper three reservoirs of the system (Avon, Bishop, and Cary) was based on reducing flows at Centerville (even though Avon did not directly operate for Centerville, its operation was impacted by Cary's operation for Centerville). The operation of the lowest reservoir in the system (Donner) was based on reducing flows at Dry Town.

Table C.22 User Designed Output: Operation of System Parallel Reservoirs (Example 3)

*USERS. 3 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

Location No=				44.	22.	11.	44.	22.	11.	44.	22.	11.	5.
J8/JZ Codes=				44.100	22.100	11.100	44.130	22.130	11.130	44.120	22.120	11.120	5.040
				BISHOP DA	**CARY DAM**	**DONNER D**	BISHOP D	CARY DAM	DONNER DA	BISHOP DA	CARY DAM	**DONNER D**	**DRY TOWN**
Per	Date:	Hr	Day	**Outflow**	**Outflow**	**Outflow**	Level	Level	Level	Case	Case	**Case**	**Flow Reg**
1	21Jan55	3	Fri	148.50	100.02	22.77	3.00	3.00	3.00	0.03	0.01	0.03	333.14
2	21Jan55	6	Fri	148.50	100.02	24.95	3.00	3.00	3.00	0.03	0.01	0.03	335.83
3	21Jan55	9	Fri	148.50	100.02	24.95	3.00	3.00	3.00	-0.01	-0.01	-0.01	340.28
4	21Jan55	12	Fri	178.50	100.02	25.78	3.00	3.00	3.00	0.02	0.01	0.01	349.84
5	21Jan55	15	Fri	178.50	100.02	25.78	3.01	3.00	3.00	-0.01	-0.01	-0.01	366.21
6	21Jan55	18	Fri	208.50	100.02	26.95	3.02	3.00	3.00	0.02	0.01	0.01	378.16
7	21Jan55	21	Fri	208.50	100.02	26.95	3.02	3.01	3.00	-0.01	-0.01	-0.01	394.94
8	21Jan55	24	Fri	208.50	100.02	26.95	3.03	3.02	3.00	-0.01	-0.01	-0.01	414.89
9	22Jan55	3	Sat	208.50	100.02	26.95	3.04	3.03	3.01	-0.01	-0.01	-0.01	434.36
10	22Jan55	6	Sat	28.50	103.02	30.44	3.05	3.04	3.01	0.02	0.01	0.01	462.97
11	22Jan55	9	Sat	28.50	103.02	30.44	3.07	3.05	3.01	-0.01	-0.01	-0.01	494.47
12	22Jan55	12	Sat	58.50	69.19	**3.35**	3.10	3.07	3.02	0.02	20.03	**5.08**	510.04
13	22Jan55	15	Sat	58.50	69.19	3.35	3.13	3.09	3.03	-0.01	-0.01	-0.01	493.67
14	22Jan55	18	Sat	**20.00**	**2.20**	**1.10**	3.17	3.12	3.04	0.00	0.00	0.00	506.20
15	22Jan55	21	Sat	20.00	2.20	1.10	3.20	3.16	3.06	-0.01	-0.01	-0.01	544.21
16	22Jan55	24	Sat	20.00	2.20	1.10	3.24	3.20	3.07	-0.01	-0.01	-0.01	553.41
17	23Jan55	3	Sun	20.00	2.20	1.10	3.28	3.25	3.09	-0.01	-0.01	-0.01	525.64
18	23Jan55	6	Sun	20.00	2.20	1.10	3.31	3.30	3.11	0.00	0.00	0.00	541.06
19	23Jan55	9	Sun	20.00	2.20	1.10	3.34	3.35	3.13	-0.01	-0.01	-0.01	620.73
20	23Jan55	12	Sun	20.00	2.20	1.10	3.36	3.39	3.17	0.00	0.00	0.00	**722.53**
21	23Jan55	15	Sun	20.00	2.20	1.10	3.39	3.43	3.21	-0.01	-0.01	-0.01	861.12
22	23Jan55	18	Sun	20.00	2.20	1.10	3.41	3.46	3.25	0.00	0.00	0.00	981.38
23	23Jan55	21	Sun	20.00	2.20	1.10	3.44	3.49	3.29	-0.01	-0.01	-0.01	1036.43
24	23Jan55	24	Sun	20.00	2.20	1.10	3.46	3.52	3.32	-0.01	-0.01	-0.01	1009.01
25	24Jan55	3	Mon	20.00	2.20	1.10	3.48	3.55	3.35	-0.01	-0.01	-0.01	936.04
26	24Jan55	6	Mon	20.00	2.20	1.10	3.51	3.57	3.38	0.00	0.00	0.00	910.02
27	24Jan55	9	Mon	20.00	2.20	1.10	3.53	3.59	3.41	-0.01	-0.01	-0.01	921.49
28	24Jan55	12	Mon	20.00	2.20	1.10	3.55	3.62	3.44	0.00	0.00	0.00	923.46
29	24Jan55	15	Mon	20.00	2.20	1.10	3.57	3.64	3.46	-0.01	-0.01	-0.01	894.80
30	24Jan55	18	Mon	20.00	2.20	1.10	3.59	3.66	3.49	0.00	0.00	0.00	856.27
31	24Jan55	21	Mon	20.00	2.20	1.10	3.61	3.69	3.51	-0.01	-0.01	-0.01	821.89
32	24Jan55	24	Mon	20.00	2.20	1.10	3.62	3.71	3.53	-0.01	-0.01	-0.01	797.55
33	25Jan55	3	Tue	20.00	2.20	1.10	3.64	3.73	3.56	-0.01	-0.01	-0.01	787.01
34	25Jan55	6	Tue	**41.43**	**47.20**	**100.00**	3.66	3.74	3.57	20.02	0.02	0.01	762.79
35	25Jan55	9	Tue	41.43	47.20	100.00	3.67	3.75	3.58	-0.01	-0.01	-0.01	755.75
36	25Jan55	12	Tue	21.81	92.20	1.10	3.68	3.76	3.60	5.01	0.02	0.00	772.22
37	25Jan55	15	Tue	21.81	92.20	1.10	3.70	3.77	3.62	-0.01	-0.01	-0.01	812.56

Tabular output can be very useful in a detailed analysis of a simulation. However, for a complex reservoir system, a graphical review is also helpful. Therefore, use of the HEC-DSS graphics program DSPLAY can be most useful. Computed results can be written to an HEC-DSS file by using the **JZ** and **ZW** Records. HEC-5 simulation was complete. These graphical presentations are extremely helpful in illustrating the flood situation at Centerville. In Figure C.6 Centerville's channel capacity, regulated flow and the flow from upstream reservoirs are shown. From this plot it may be concluded that the reservoirs contributed only a minor portion of flow during the period of flooding at Centerville. From earlier review of Table C.20, we know that both reservoirs (Bishop and Gary) operating for Centerville only released their minimum flows during the time of flooding. In Figure C.7, Centerville's channel capacity, regulated flow and uncontrolled local flows are shown. This plot also leads to the conclusion that the uncontrolled runoff below Bishop and Cary is responsible for the excess flow at Centerville.

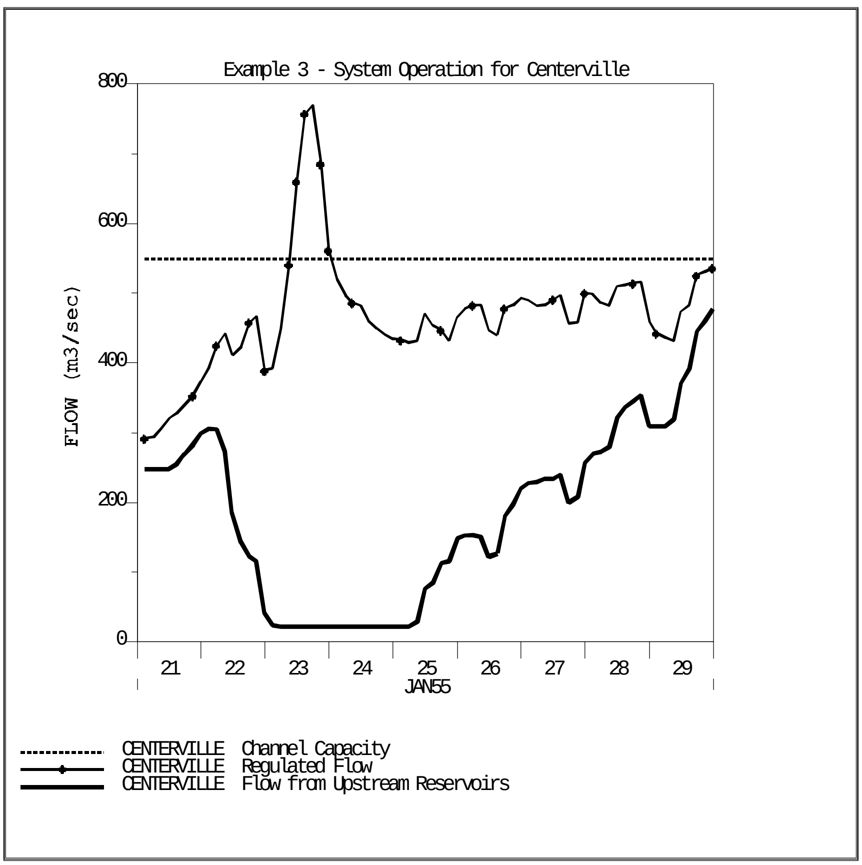

Figure C.6 Effect of Reservoir Releases on Centerville Regulated Flow (Example 3)

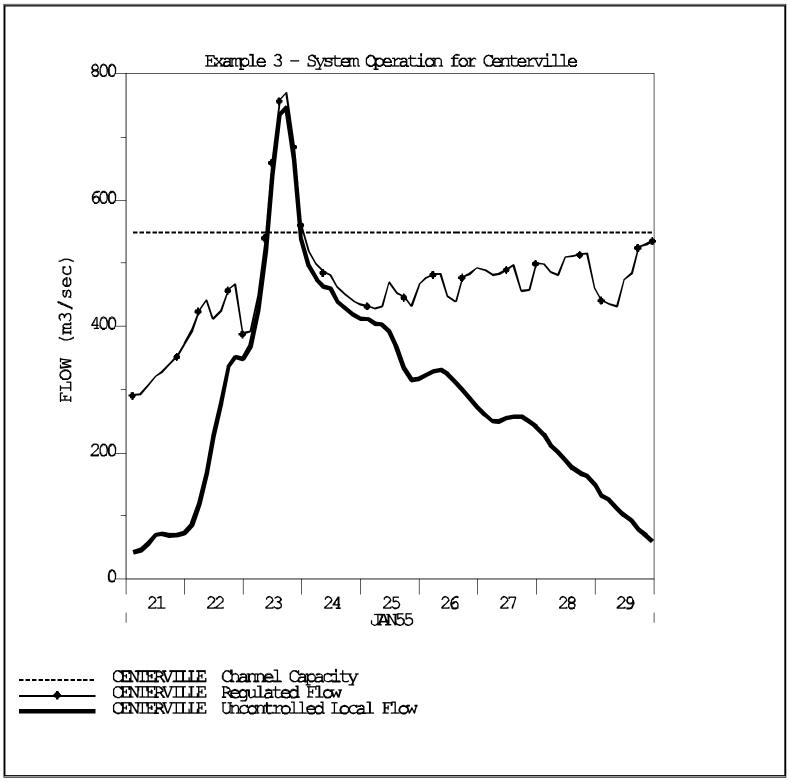

Figure C.7 Effect of Uncontrolled Local Flows on Centerville Regulated Flow (Example 3)

Appendix D

Water Supply Simulation

The principal components of a surface-water reservoir operation are common regardless of purpose. What differs with each purpose is the nature of the stream flow, operational criteria, and demand. For water supply, low-flow periods are of special concern because it is during these periods that the possibility of not meeting water supply needs is greatest.

Low flows normally have the characteristic that they are relatively constant over a week or month period. Therefore, monthly stream flows are commonly used in water supply simulations. Also, low flows are commonly within channel. Consequently, routing criteria and water surface elevations, which are significant in flood control simulation, are less important in water supply. Low flows can be significantly affected by local inflow, effluent discharge from waste-water treatment plants, seepage to or from a river, evaporation and other phenomena.

Operating criteria for water supply is principally concerned with meeting demands over prolonged low-flow periods (droughts). In HEC-5, water supply demands are primarily simulated with low-flow targets and diversion schedules defined at model control points. System simulations illustrate the ability of the reservoirs to meet target demands with available storage allocation and specified flows. Additionally, HEC-5 can perform sequential analysis to determine the storage required to meet a specified demand or the scale of demand (yield) that can be met with a specified storage.

This appendix illustrates HEC-5 program features that apply to water supply simulation. Many options exist; however, the examples used should be sufficient to illustrate the input and expected output. Three example models are presented: Example 4 is a single reservoir model demonstrating seasonally varying storage, reservoir diversions and evaporation, and operation for downstream locations that contain diversions and minimum flow requirements; Example 5 is a three-reservoir system with seasonal-pool level goals and parallel operation for a downstream location; and Example 6 demonstrates the application of a firm-yield determination.

D.1 Single Reservoir Model

The single reservoir model (Example 4) illustrates reservoir data usually associated with low-flow studies. The reservoir has seasonally varying storage, evaporation, and operates for downstream diversions and low-flow targets. Several options for specifying demands are demonstrated.

D.1.1 Reservoir Model Data

The reservoir model has five levels, with top of Buffer at level 2, top of Conservation at level 3, and top of Flood Control at level 4. All monthly data start with January. Figure D.1 shows a schematic diagram of a single reservoir system. The reservoir data are shown in Table D.1.

The reservoir storage for Level 2 and Level 3 is seasonally varying. To do this, there is a **RL** Record for each reservoir level. To indicate a constant level, -1 is entered in the third field. To indicate the nine seasons, a 9 is entered in the third field. The nine seasons are defined in days on the **CS** Record, with 1 equal to January 1. The seasons must be defined to the end of the year, with 365 equal to December 31.

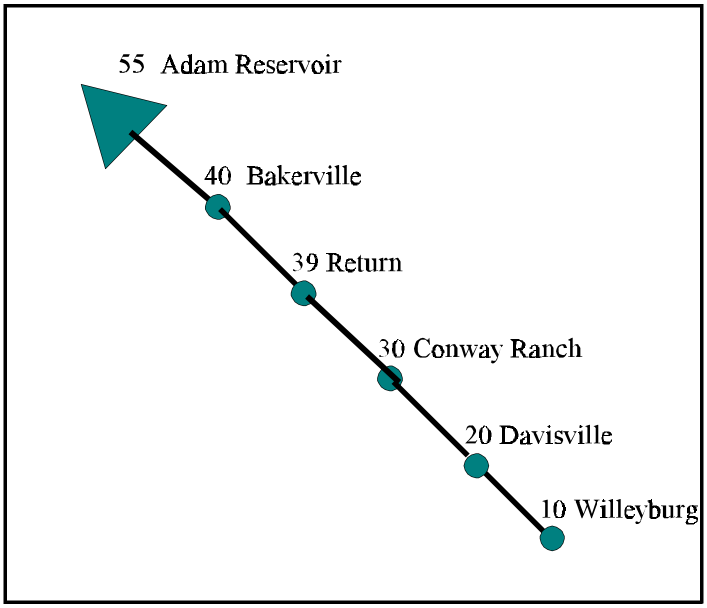

Figure D.1 Example 4 System Diagram

The reservoir operates for four downstream locations, as shown on the **RO** Record. Diversions and minimum flow requirements will be considered at those locations when making reservoir release determinations.

The storage in the reservoir is defined with 39 values from 0 to 3,070,000. The negative value (-39) in field 1 indicates that storage values are entered in 1000 acre-feet. Following the storage values are associated reservoir outflow capacity (**RQ**), reservoir area (**RA**), reservoir elevation (**RE**), and reservoir diversion (**RD**). The **DR** Record indicates the diversions from the reservoir leave the system (no divert to location). The diversion option (-2) indicates the diversion is a function of reservoir storage.

Reservoir net-evaporation is defined for the 12 months on **R3** Records. The first month for all monthly data is January. Minus evaporation values indicate a net gain for those months when precipitation is greater than evaporation. Evaporation data requires reservoir area data to compute the volume gained or loss during each simulation interval.

Control point data (**CP** Record), at the reservoir, indicates the minimum Desired flow is 450 and the Required flow is 230. The minimum reservoir release should be the Desired flow when the reservoir is above top-of-buffer level, and the Required flow when below top-of-buffer pool level. At level 1, inactive storage level, no releases are made and evaporation is the only loss from storage.

Table D.1. **Example 4 Reservoir Data**

```
RL    55 1957000
RL     1      55      -1          867600
RL     2      55       9         1369772 1400771 1400771 1400771 1400771 1400771
RL                               1400771 1400771 1369772
RL     3      55       9         1957000 1957000 1957000 1957000 1995200 1995200
RL                               1995200 1957000 1957000
RL     4      55      -1         2554000
RL     5      55      -1         3070000
RO     4      40      30      20      10
RS   -39       0     760     867     913     960    1009    1059    1085    1112
RS  1139    1166    1194    1222    1251    1280    1309    1339    1370    1401
RS  1432    1464    1496    1529    1561    1595    1629    1663    1698    1733
RS  1769    1805    1842    1879    1917    1957    1994    2034    2554    3070
RQ    39       0    1000    9750    9820    9870    9920    9970   10010   10050
RQ  9000    9000   10190   10230   10270   10300   10330   10370   10410   10450
RQ 10490   10530   10570   10610   10650   10690   10730   10770   10800   10830
RQ 10870   10910   10940   10980   11020   11060    9500    9500   11580   21850
RA    39       0   20508   22442   23217   24008   24833   25701   26159   26619
RA 27079   27535   27983   28432   28861   29291   29721   30153   30587   31023
RA 31461   31901   32343   32789   33238   33690   34147   34610   35079   35555
RA 36036   36522   37015   37515   38024   38542   39078   39638   47182   53300
RE    39    1420    1530    1535    1537    1539    1541    1543    1544    1545
RE  1546    1547    1548    1549    1550    1551    1552    1553    1554    1555
RE  1556    1557    1558    1559    1560    1561    1562    1563    1564    1565
RE  1566    1567    1568    1569    1570    1571    1572    1573    1585    1595
RD     0       0       0       0      10      10      10      10      10      10
RD    10      10      10      10      10      10      10      10      10      45
RD    45      45      45      45      67      67      67      67      67      67
RD    67      67      67      67      80      80      80      80      80      80
R3  -2.7    -2.0    -1.6     0.3     3.4     2.5     2.0     0.9     1.9     1.6
R3  -0.8    -1.6
CP    55   10000     450     230
IDADAM RESERVOIR
RT    55      40
DR    55                                              -2
CS     9       1      32      60      90     121     181     273     335     365
```

D.1.2 Control Point Data

There are five downstream control points and Table D.2 shows a listing of their data. The reservoir operates (**RO** Record) for all locations except for control point 39 (Return). Looking at the data for control points, shown in Table D-2, the first location is CP 40, Bakerville. The **CP** Record shows no minimum flow requirements. The **RT** Record shows the flow transfers to location 39 without routing. The diversion (**DR** Record) indicates a diversions from location 40 to location 39. Field 6 (0.70) shows 70% of the diversion returns to location 39, field 7 (0) indicates that the diversion will be constant, and field 8 (75) is the constant diversion rate.

Location 39 (Return) shows no minimum requirements or diversions. Seventy percent of the flow diverted from 40 will return here and be added to the local flow and routed upstream flow. Again, the reservoir does not operate for this location because there are no requirements because there are no requirements.

Table D.2. Example 4 Downstream Control Point Data

```
C **************** Green River at Bakerville ***********************************
CP    40   11000
IDBAKERVILLE
RT    40      39
DR    40      39                           0.70       0      75

C **************** Bakerville Return Flows *************************************
CP    39   11000
IDRETURN
RT    39      30

C **************** Conway Ranch ************************************************
CP    30  100000
IDCONWAY RANCH
RT    30      20
DR    30      20                           0.40       1
QD    12     5.3     5.1     5.8     7.3    40.3    89.5   122.0   135.2   118.0
QD  22.1     7.7     4.9

C **************** Green River at Davisville ***********************************
CP    20   17000     750     750
IDDAVISVILLE
C1    30    0.67
RT    20      10

C **************** Green River at Willeyburg ***********************************
CP    10  999999
IDWILLEYBURG
RT    10
QM   755     925     950    1030    1050    1100    1250    1150     755     755
QM   755     755

ED
```

Conway Ranch (CP 30) is the next location. There are no minimum flow requirments (**CP** Record) and the flow is transferred to location 20 (**RT** Record) with no routing. The Diversion data (**DR** Record) indicates a diversion from location 30 to location 20, with a monthly diversion schedule (field 7 = 1) and a 40% return flow (field 6 = 0.40). The monthly diversion schedule is provided on **QD** Records. The first field indicates that there are 12 values and the monthly schedule follows, with 5.3 ft^3/s specified for the month of January.

Davisville (CP 20) data indicates a minimum desired and required flow target of 750 ft^3/s (**CP** Record, fields 3 and 4). The **C1** Record (fields 1 and 2) indicates the local flow for this location will be set equal to 67% of the local flow at location 30. Flow transfers from this location to 10 without routing (**RT** Record).

The last control point (CP 10) is Willeyburg. The large channel capacity (999999) usually indicates there are no flood control limits here. The **RT** Record indicates this is the last location because the flow is not routed to another location. The monthly minimum desired-flow targets are defined on **QM** Records, starting with January.

The **ED** Record indicates the end of the system model.

D.1.3 Time-series Data

Time series data begins with the **BF** Record, as shown in Table D.3. The flow format, number of simulation periods, starting date and time and time interval are all defined. The tenth field (1900) provides for the century definition, because the date format only provides for two digits for the year. This example will simulate one year (365 periods) of daily (24 hour) data, starting at 0000 hour on 1 January 1986. The first output will be for 2400 hours on that date.

Table D.3. **Example 4 Time-series Input Data**

```
BF     2     365               086010100             24                    1900
ZR=IN55    A=EXAMPLE 4  B=ADAM RESERVOIR   C=LOCAL FLOW   F=ESTIMATED
ZR=IN40    A=EXAMPLE 4  B=BAKERVILLE       C=LOCAL FLOW   F=ESTIMATED
ZR=IN30    A=EXAMPLE 4  B=CONWAY RANCH     C=LOCAL FLOW   F=ESTIMATED
ZR=IN10    A=EXAMPLE 4  B=WILLEYBURG     C=FLOW-LOC-INC   F=ESTIMATED
ZW     A=EXAMPLE 4     F=BASIC WATER SUPPLY
EJ
ER
```

Because the flow data are read from a DSS file, the filename must be specified on the execution command line along with input and output filenames. The **ZR** Record format (**ZR=IN##**) associates the data in the DSS Record to **IN** Record input for model control point ##.

The **ZW** Record indicates writing results to the DSS file with pathname A-part as EXAMPLE 4, and pathname F-part as BASIC WATER SUPPLY. The Records to write are defined on the **JZ** Records, shown below. The negative values in the first field indicates that this data will not be printed. The default (without the minus sign) is to print the data table defined by the **JZ** Records in the same format as the **J8** Records (***USER** Tables).

Table D.4 Output Data to Write to DSS

```
JZ-55.22   55.10   40.03   30.03   20.04   10.04   10.05
```

D.1.4 Single Reservoir Simulation Output

The Example 4 output can be obtained by running the data set. Samples of the output are presented here to illustrate the program's operation with the specified demand data. Note, after the output listing of the input data including the flow data extracted from the DSS file, there are warning notes that there are negative flow values in the data set. HEC-5 can use negative values; however, in an actual study, the user would review the flow data to determine the cause for negative flow. The output then presents summary tables for the input data (`*Input Summary`). One should review these tables to ensure that the input data are appropriate.

After HEC-5A has completed the simulation, the requested output is written to DSS. A series of ZWRITE lines indicate each Record written. Review those lines to ensure the desired output is written.

The HEC-5B performs an analysis of the run for errors. The output for this option should always be requested (**J3** Record, field 1, code 4). Only one output table was defined by **J8** Record input. The output of **JZ** Record data was not printed.

The output for the beginning of the simulation is shown in Table D.5. The first 10 periods indicate that the reservoir is at top-of-conservation (Level = 3.0). The "ideal" state for the reservoir is to remain there as long as passing inflow does not cause flooding and the specified demands are all met by passing the inflow amount. The Case for this condition is 0.03. A review of the downstream demands would indicate that diversions and minimum flow targets are being met during these periods.

The simulation continues passing inflow until period 91 (1 April 1986). On that period the reservoir Case indicates 10.00, which means the reservoir is releasing to meet the target at location 10, Willeyburg. Looking at the regulated flow at location 10 (Flow Reg) shows a value of 1030.00 and the shortage at that location (DeQ-Shor) is 0.00. Reviewing the input data shows a monthly minimum flow schedule for Willeyburg to be 1030 ft^3/s for April.

The simulation continues to operate for location 10 for all of April and most of May. Table D.6 shows the output starting at period 135 (15 May 1986). The May target is 1050 ft^3/s and the output shows Adam Reservoir is operating to meet that target up to period 145, when the Case changes to 0.00 indicating the reservoir is operating for itself to meet minimum desired flow. For eight days, the outflow is 450 ft^3/s to meet the reservoir minimum. (Note that during this time the Willeyburg regulated flow is greater than the 1050 ft^3/s minimum.) By June 2, the release is increased to meet the target of 1100 ft^3/s at Willeyburg.

Table D.5 User Output Table for the Initial Periods

*USERS. 1 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

Period	Date:	Day	ADAM RESE EOP Elev	ADAM RESE Level	ADAM RESE Case	ADAM RESE Outflow	BAKERVILL Diversio	CONWAY RA Diversio	DAVISVILL Flow Reg	WILLEYBUR Flow Reg	WILLEYBUR DeQ-Shor
Location No=			55.	55.	55.	55.	40.	30.	20.	10.	10.
J8/JZ Codes=			55.220	55.130	55.120	55.100	40.030	30.030	20.040	10.040	10.060
1	1Jan86	Wed	1571.00	3.00	0.03	1286.29	75.00	5.30	1710.10	1763.36	0.00
2	2Jan86	Thu	1571.00	3.00	0.03	1236.81	75.00	5.30	1685.34	1744.41	0.00
3	3Jan86	Fri	1571.00	3.00	0.03	1206.08	75.00	5.30	1689.83	1716.32	0.00
4	4Jan86	Sat	1571.00	3.00	0.03	1024.40	75.00	5.30	1446.48	1478.01	0.00
5	5Jan86	Sun	1571.00	3.00	0.03	898.90	75.00	5.30	1310.10	1334.99	0.00
6	6Jan86	Mon	1571.00	3.00	0.03	821.26	75.00	5.30	1217.82	1243.53	0.00
7	7Jan86	Tue	1571.00	3.00	0.03	870.17	75.00	5.30	1234.89	1259.50	0.00
8	8Jan86	Wed	1571.00	3.00	0.03	764.82	75.00	5.30	1130.59	1143.19	0.00
9	9Jan86	Thu	1571.00	3.00	0.03	831.59	75.00	5.30	1195.47	1212.08	0.00
10	10Jan86	Fri	1571.00	3.00	0.03	827.67	75.00	5.30	1198.76	1222.55	0.00
:											
11 - 89 Omitted											
:											
90	31Mar86	Mon	1571.00	3.00	0.03	882.61	75.00	5.80	1319.90	1362.31	0.00
91	1Apr86	Tue	1571.01	3.00	10.00	591.04	75.00	7.30	994.35	1030.00	0.00
92	2Apr86	Wed	1571.03	3.00	10.00	570.61	75.00	7.30	1005.15	1030.00	0.00
93	3Apr86	Thu	1571.04	3.00	10.00	604.84	75.00	7.30	1010.29	1030.00	0.00
94	4Apr86	Fri	1571.05	2.99	10.00	607.36	75.00	7.30	1012.80	1030.00	0.00
95	5Apr86	Sat	1571.07	2.99	10.00	604.98	75.00	7.30	1008.21	1030.00	0.00
96	6Apr86	Sun	1571.10	2.99	10.00	603.90	75.00	7.30	1007.77	1030.00	0.00
97	7Apr86	Mon	1571.12	2.99	10.00	546.16	75.00	7.30			

Table D.6 User Output Table for the Middle of the Simuation

Period	Date:	Day	ADAM RESE EOP Elev	ADAM RESE Level	ADAM RESE Case	ADAM RESE Outflow	BAKERVILL Diversio	CONWAY RA Diversio	DAVISVILL Flow Reg	WILLEYBUR Flow Reg	WILLEYBUR DeQ-Shor
Location No=			55.	55.	55.	55.	40.	30.	20.	10.	10.
:											
135	15May86	Thu	1570.92	2.93	10.00	694.71	75.00	40.30	1007.78	1050.00	0.00
136	16May86	Fri	1570.92	2.93	10.00	617.96	75.00	40.30	987.83	1050.00	0.00
137	17May86	Sat	1570.93	2.93	10.00	570.32	75.00	40.30	982.72	1050.00	0.00
138	18May86	Sun	1570.94	2.93	10.00	550.30	75.00	40.30	984.08	1050.00	0.00
139	19May86	Mon	1570.94	2.93	10.00	545.44	75.00	40.30	986.63	1050.00	0.00
140	20May86	Tue	1570.94	2.93	10.00	546.68	75.00	40.30	984.69	1050.00	0.00
141	21May86	Wed	1570.94	2.93	10.00	528.46	75.00	40.30	977.74	1050.00	0.00
142	22May86	Thu	1570.94	2.93	10.00	506.50	75.00	40.30	975.48	1050.00	0.00
143	23May86	Fri	1570.94	2.93	10.00	559.64	75.00	40.30	994.07	1050.00	0.00
144	24May86	Sat	1570.94	2.93	10.00	492.74	75.00	40.30	969.47	1050.00	0.00
145	25May86	Sun	1570.97	2.93	0.00	450.00	75.00	40.30	1148.56	1298.82	0.00
146	26May86	Mon	1571.00	2.94	0.00	450.00	75.00	40.30	1449.41	1675.35	0.00
147	27May86	Tue	1571.04	2.94	0.00	450.00	75.00	40.30	1505.10	1711.13	0.00
148	28May86	Wed	1571.08	2.94	0.00	450.00	75.00	40.30	1511.64	1701.40	0.00
149	29May86	Thu	1571.12	2.94	0.00	450.00	75.00	40.30	1493.58	1677.15	0.00
150	30May86	Fri	1571.16	2.95	0.00	450.00	75.00	40.30	1491.29	1674.60	0.00
151	31May86	Sat	1571.19	2.95	0.00	450.00	75.00	40.30	1425.08	1578.12	0.00
152	1Jun86	Sun	1571.20	2.95	0.00	450.00	75.00	89.50	1167.42	1251.60	0.00
153	2Jun86	Mon	1571.19	2.95	10.00	683.61	75.00	89.50	1093.14	1100.00	0.00
154	3Jun86	Tue	1571.17	2.95	10.00	714.67	75.00	89.50	1074.12	1100.00	0.00
155	4Jun86	Wed	1571.16	2.95	10.00	699.76	75.00	89.50	1065.56	1100.00	0.00
156	5Jun86	Thu	1571.14	2.94	10.00	662.14	75.00	89.50	1058.73	1100.00	0.00
:											
157 - 365 Omitted											
		Sum =	573100.88	1061.53	1783.72	334423.41	27375.00	17221.38	528253.13	548595.25	0.00
		Max =	1571.22	3.00	20.00	5536.51	75.00	135.20	7695.86	7996.30	0.00
		Min =	1567.72	2.73	0.00	450.00	75.00	4.90	750.00	755.00	0.00
		PMax=	112.00	1.00	255.00	333.00	1.00	213.00	333.00	333.00	1.00
		Avg =	1570.14	2.91	4.89	916.23	75.00	47.18	1447.27	1503.00	0.00
		PMin=	280.00	279.00	145.00	145.00	1.00	335.00	255.00	259.00	1.00

The flow goal at Willeyburg continues to "control" the release determination for most of the periods, with an occasional release for the reservoir minimum and a few days in September operating for location 20, Davisville.

D.2 Multiple Reservoir System Model

Example 5 is a three reservoir system. Two storage reservoirs (Allen and James) operate in parallel to meet a downstream flow goals and the third (Brenda Lake) is a flow-through reservoir. Additionally, James Reservoir has seasonally varying minimum flow goals that are based on pool elevation. Figure D.2 is a diagram of the system. The input data are shown in two parts: Table D.7 shows the beginning of the input along with the data for the East Branch (Allen Reservoir to Dougville); and Table D.8 lists the input for the West Branch (James Reservoir to Dry Town) along with the time-series input data.

The job data define 5 reservoir levels, with level 3 as top-of-conservation, level 4 as top-of-flood control, and level 2 as top-of-buffer pool (**J1** Record). Net evaporation data are defined for all reservoirs in the system (**J6** Record). User designed tables are defined on the **J8** Records and are discussed in D.2.2 Reservoir System Output.

D.2.1 Reservoir System Data

Allen Reservoir data (location 444) provides monthly storage for the top of conservation (level 3) and constant storage values for the other 4 levels (**RL** Records). The starting storage is defined as an elevation (-1060.5). Allen Reservoir operates for three downstream locations (**RO** Record).

Note that the operation of Allen Reservoir through the downstream reservoir 440 can be accomplished only because the downstream reservoir is defined as a "flow-through reservoir." That is,

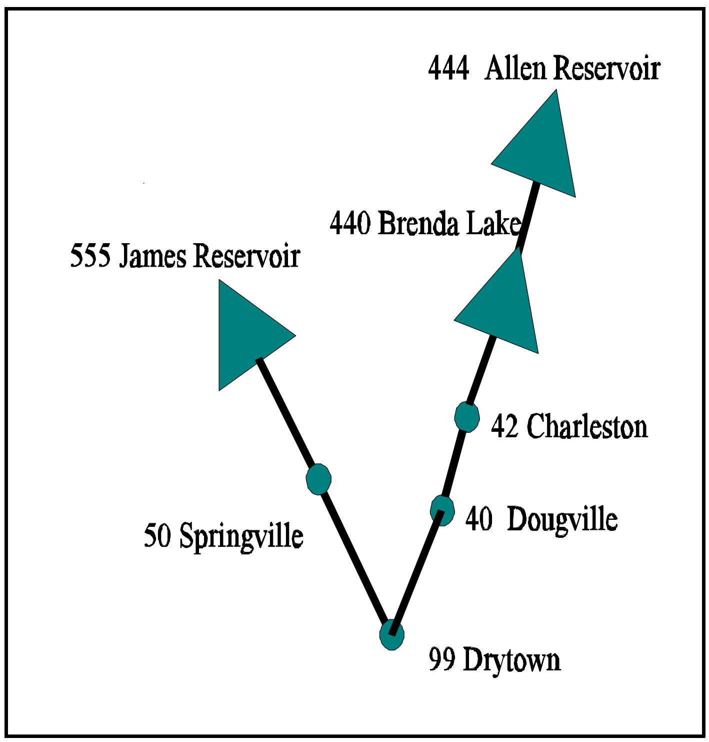

Figure D.2 Example 5 System Diagram

reservoir 440 does not store water and the releases from Allen will flow through to the downstream locations. If reservoir 440 were a operating storage reservoir, the upper reservoir should only operate to the lower reservoir (tandem operation) and the lower reservoir would then operate for the downstream locations.

Table D.7 Example 5 Input Data - First Half (East Branch)

```
T1      EXAMPLE 5, Reservoir System Operating for Flow Augmentation
T2      3 Reservoir System, 2 Storage Reservoirs and 1 Flow-Thru Reservoir
T3      Flow Goals Based on Season and Reservoir Elevation (EXAMPLE5.DAT)
J1     0       1       5       3       4       2
J2    24     1.0       0       0       0       0       0
J3     4       0       0      -1       0      -1
J6  -8.4    -6.7    -6.1    -3.7     1.9     3.8     5.8     6.1     4.3     1.5
J6  -2.3    -5.1
J8444.10  444.12  444.13  555.13  555.12  555.10   99.04   99.02
J8444.12  444.10  400.12  400.10   42.04   40.04   99.04
J8555.12  555.13  555.22  555.06  555.10   50.03   99.04
J8444.12  444.10  400.24  400.03  400.21  400.12  400.10   99.04
C
RL   444 -1060.5
RL     1     180      -1          237810
RL     2     180      -1          242163
RL     3     180       0          377073  377073  377073  377073  438869  438869
RL                                438869  438869  438869  383564  383564  377073
RL     4     180      -1          472757
RL     5     180      -1          500000
RO     3      42      40      99
RS    17  237810  242164  260355  284879  311402  339972  355050  370670  377073
RS383564  403588  420922  438869  457441  472757  491029  500000
RQ    17   30400   31480   31700   31795   32064   32064   32390   32495   34310
RQ 37603   55100   69442  103500  137500  164684  181300  198000
RA    17    2158    2196    2353    2552    2754    2962    3060    3179    3230
RA  3275    3402    3530    3651    3770    3880    4030    4170
RE    17    1020    1022    1030    1040    1050    1060    1065    1070    1072
RE  1074    1080    1085    1090    1095    1099    1105    1110
CP   444   12600
IDALLEN RES
RT   444     400

RL  -400   17500     290    1500   17500   17500   19300
RO
RS     6     290     750    4000   11000   17501   19300
RQ     6       0   11900   46900   72749   85905   87400
RA     6      50      80     610     787     870     890
CP   400   99999
IDBRENDA LAKE
RT   400      42
DR   400                                               0     125

CP    42   15000     600     320
IDCHARLESTON
RT    42      40

CP    40  999999     650     370
IDDOUGVILLE
RT    40      99
```

At Allen Reservoir, seventeen values define the basic storage-outflow-area relationship defined on the **RS, RQ, RA**, **RE** Records. The control point data for Allen Reservoir indicates a channel capacity of 12,600 ft^3/s, but no minimum flow requirements. Releases are transferred to location 444 without routing (**RT** Record).

Brenda Lake, location 400, is defined as a "flow-through" reservoir with the minus sign on the control point number (**RL** Record). Constant storage values are defined for the five levels. The reservoir cannot operate for a downstream location (**RO** Record) and six values define the storage-outflow-area relationship. The control point data indicates a constant diversion of 125 ft^3/s from the reservoir (**DR** Record).

Location 42, Charleston, has a channel capacity limit of 15,000 ft^3/s, a minimum desired flow goal of 600 ft^3/s and a minimum required goal of 320 ft^3/s (**CP** Record). Flow transfer to location 40 with no routing (**RT** Record).

Location 40, Dougville, has no channel capacity limit (99,999 ft^3/s), a minimum desired flow goal of 650 ft^3/s and a minimum required goal of 370 ft^3/s (**CP** Record). Flow transfers from location 40 to location 99 with no routing (**RT** Record). At this point, the data for the West Branch are entered because all upstream data must be defined before the data at location 99.

The input data for the second half of the model is shown in Table D-8. The data defines the West Branch from James Reservoir down to location 99, Drytown. James Reservoir, control point 555, starts at elevation 820.44 (**RL** Records). The storage for each level is defined with a separate (**RL** Record) and the top of conservation is seasonally varying, with the seven seasons defined on **CS** Record. The storage for the other four levels is constant. The reservoir operates for locations 50 and 99 (**RO** Record). Twenty-nine values define the storage-outflow-area-elevation relationships (**RS**, **RQ**, **RA**, and **RE** Records).

The reservoir's control point data indicates a minimum flow goal dependent on the reservoir pool elevation, **Guide Curve Operation** with **CG** Records. In this example, the operation is for minimum flow defined on the **QM** Record. A **CG** Record is required for each minimum flow defined. The first **CG** Record applies to the first minimum flow on the **QM** Record, etc. The first field indicates the data are elevations (minus sign) and the code 4 (left of decimal) indicates the data are specified for the top of the zone, while the code 2 indicates a linear transition between elevations. In this application, the decimal value is not used by the program but is defined to indicate the minimum flow value the **CG** data applies. For example, the first **CG** Record value -4.10 indicates that elevation data follow, that the top of the zone applies, and this input relates to the first 100 ft^3/s minimum flow (**QM** Record, field 2). The seven values of 725 are the elevations for this zone over the seven seasons (**CS** Record). The first field of the **QM** Record (-555) indicates minimum flow goals are based on location 555 elevation or level.

Table D.8 Example 5 Input Data - Second Half (West Branch)

```
RL   555 -820.44
RL     1     555      -1           10373
RL     2     555      -1           82891
RL     3     555       7          210492  210492  391749  391749  391749  210492
RL                                210492
RL     4     555      -1          471559
RL     5     555      -1          597164
RO     2      50      99
RS    29   10373   82884   89647  104879  113447  122709  132705  143514  155137
RS167612  181000  195280  210492  226656  243772  261860  280940  301031  322154
RS344288  367473  391749  417136  443713  471559  500734  531317  563427  597164
RQ    29     420    1200    1250    1310    1380    1460    1560    1670    1880
RQ  2000    2130    2270    2400    2540    2690    2830    2990    3110    4680
RQ  9800   15000   26000   37000   50000   66000   82000  100000  120000  140000
RA    29     182    3251    3516    4116    4452    4812    5196    5602    6024
RA  6462    6913    7373    7841    8317    8801    9293    9793   10298   10808
RA 11329   11862   12411   12988   13599   14246   14933   15665   16449   17293
RE    29     725     800     802     806     808     810     812     814     816
RE   818     820     822     824     826     828     830     832     834     836
RE   838     840     842     844     846     848     850     852     854     856
CP   555   11000
IDJAMES RES
RT   555      50
CS     7       1      15     121     182     274     350     365
CG -4.10     725     725     725     725     725     725     725
CG -4.10     790     790     820     820     820     790     790
CG -2.40     819     819     837     837     837     819     819
CG -4.48     824     824     842     842     842     824     824
QM  -555     100     100     400     480

CP    50  999999
IDSPRINGVILLE
RT    50      99
DR    50                                             1
QD    12      15      15      15      37      37      45      45      35      25
QD    20      15      15

CP    99   15000    1850
IDDRY TOWN
RT    99

ED
BF     2      40              86010100              24
ZR IN444  A=ROCKY RIVER B=ALLEN RES   C=FLOW-LOC INC F=COMPUTED
ZR IN400  A=ROCKY RIVER B=BRENDA LAKE C=FLOW-LOC INC F=COMPUTED
ZR IN42   A=ROCKY RIVER B=CHARLESTON  C=FLOW-LOC INC F=COMPUTED
ZR IN40   A=ROCKY RIVER B=DOUGVILLE   C=FLOW-LOC INC F=COMPUTED
ZR IN555  A=FALL RIVER  B=JAMES RES   C=FLOW-LOC INC F=COMPUTED
ZR IN50   A=FALL RIVER  B=SPRINGVILLE C=FLOW-LOC INC F=COMPUTED
ZR IN99   A=FALL RIVER  B=DRY TOWN    C=FLOW-LOC INC F=COMPUTED
EJ
ER
```

The downstream location, 50, does not have a limiting channel capacity (999,999 ft^3/s). Even though there are no minimum flow goals specified, there is a diversion from location 50 to location 99 (**DR** and **QD** Records). The **DR** Record indicates that the diversion schedule is monthly (filed 7) and that 100% of the diversion is returned (filed 6) to location 99. The monthly schedule is defined on the **QD** Records.

The last location, 99, requires a "system operation." Up to this point, the reservoirs are operating for the downstream locations that only they can serve. For location 99, Dry Town, both storage reservoirs can make releases to meet the defined maximum channel capacity of 15,000 ft^3/s and the minimum desired flow of 1,850 ft^3/s (**CP** Record). When there is a choice between the reservoirs, the additional releases will be made from the reservoir with the higher index level at the end of the previous period.

The **ED** Record defines the end of the system data and the **BF** Record defines the start of the time-series data. Forty periods, starting on 1 January 1986, of average daily flow (24 hours) will be used. Again, the flow data are read from a DSS file. No output will be written to a DSS file, because no **JZ** or **ZW** Records are input.

D.2.2 Reservoir System Output

The summary tables for the input data should be reviewed first to ensure that the data are appropriate. The summary tables of seasonal data (*Rule Curve Summary) are helpful because the days are converted to starting date and all storage values are listed. The Guide-Curve data are also summarized showing dates, zones, and operation codes.

The first output table (*USERS. 1) is defined by the first **J8** Record and shown in Table D.9. This table lists the Outflow, Case, and Level for the two storage reservoirs along with the Regulated and Natural Flow at Dry Town. This output arrangement shows the releases and the basis for the release and the resulting pool level. At the start, Allen is releasing to meet a flow goal at location 40 (Case = 40.00) and James is releasing for the goal at Dry Town (99). Looking at the reservoir Levels, one sees that James is at a higher Level than Allen; therefore, it should be making the additional release to meet Dry Town’s flow goal of 1,850 ft^3/s. The ‘Flow Reg’ column shows that value is met. Allen continues to release for locations 40 or 42 until period 7. At periods 7 and 8, both reservoirs are operating for location 99 and their Levels are equal. The system allocation for release is meeting the downstream target and keeping the reservoirs "balanced" during these periods.

During periods 9 through 12, the local requirement of 480 ft^3/s controls the release from James (Case = 0.00), while Allen continues to release for location 99. During periods 13 through 15, both reservoirs again have a joint operation to meet the goal at location 99. Then, for the remainder of the simulation, the local requirement controls the release from James, and Allen operates to meet the target at location 99. Because the local requirement at James is based on the pool elevation, the minimum flow requirement starts decreasing from 480 ft^3/s after period 17. This would indicate the flow goal is on the linear transition zone 2. It drops from zone 4 into zone 2 because the elevation for zone 3 starts increasing from 819 to 837 feet on January 15 and the reservoir is near elevation 819.

Table D.9 Parallel System Operation for Dry Town (Example 5)

*USERS. 1 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

Location No=	444.	444.	444.	555.	555.	555.	99.	99.
J8/JZ Codes=	444.100	444.120	444.130	555.130	555.120	555.100	99.040	99.020
	ALLEN RES	ALLEN RES	ALLEN RES	JAMES RES	JAMES RES	JAMES RES	DRY TOWN	DRY TOWN
Period Date: Day	Outflow	Case	Level	Level	Case	Outflow	Flow Reg	Natural
1 1Jan86 Wed	180.19	40.00	2.75	2.79	99.00	653.30	1850.00	2335.42
2 2Jan86 Thu	141.16	40.00	2.75	2.79	99.00	633.29	1850.00	2121.43
3 3Jan86 Fri	186.66	40.00	2.76	2.78	99.00	592.52	1850.00	2036.40
4 4Jan86 Sat	339.26	42.00	2.76	2.78	99.00	605.56	1850.00	1848.07
5 5Jan86 Sun	401.06	40.00	2.77	2.77	99.00	622.93	1850.00	1713.82
6 6Jan86 Mon	409.00	40.00	2.77	2.77	99.00	628.77	1850.00	1658.18
7 7Jan86 Tue	561.37	99.00	2.77	2.77	99.00	499.95	1850.00	1570.21
8 8Jan86 Wed	627.81	99.00	2.76	2.76	99.00	498.15	1850.00	1499.64
9 9Jan86 Thu	627.60	99.00	2.76	2.76	0.00	480.00	1850.00	1522.47
10 10Jan86 Fri	641.65	99.00	2.76	2.76	0.00	480.00	1850.00	1515.90
11 11Jan86 Sat	670.05	99.00	2.75	2.75	0.00	480.00	1850.00	1480.25
12 12Jan86 Sun	680.85	99.00	2.75	2.75	0.00	480.00	1850.00	1485.42
13 13Jan86 Mon	708.83	99.00	2.75	2.75	99.00	507.22	1850.00	1390.11
14 14Jan86 Tue	671.27	99.00	2.74	2.74	99.00	540.53	1850.00	1416.29
15 15Jan86 Wed	666.75	99.00	2.74	2.74	99.00	535.71	1850.00	1421.33
16 16Jan86 Thu	713.31	99.00	2.74	2.73	0.00	480.00	1850.00	1501.42
:								
17 - 37 Omitted								
:								
38 7Feb86 Fri	623.30	99.00	2.65	2.57	0.00	361.25	1850.00	1798.48
39 8Feb86 Sat	684.69	99.00	2.65	2.56	0.00	359.29	1850.00	1740.80
40 9Feb86 Sun	763.36	99.00	2.64	2.56	0.00	357.40	1850.00	1589.80
Sum =	25584.93	3608.00	108.62	107.32	1089.00	17908.91	73999.98	65786.95
Max =	861.01	99.00	2.77	2.79	99.00	653.30	1850.00	2335.42
Min =	141.16	40.00	2.64	2.56	0.00	357.40	1849.99	1390.11
PMax=	34.00	7.00	6.00	1.00	1.00	1.00	1.00	1.00
Avg =	639.62	90.20	2.72	2.68	27.23	447.72	1850.00	1644.67
PMin=	2.00	1.00	40.00	40.00	9.00	40.00	33.00	13.00

The second output table (*USERS. 2) shows the operation down the East Branch, from Allen Reservoir down to Dry Town. Only the first 10 periods are shown in Table D.10. The results for Allen reservoir are the same as previously discussed (*USER. 1). Brenda Reservoir shows a Case of 0.03 for all periods. Because it was defined as a flow-through reservoir, the pool level stays at the starting top of conservation and the reservoir passes inflow. The reason the outflow form Brenda is more than the release from Allen Reservoir is the addition of incremental local flow between the two reservoirs. During the first six periods, Allen operates for locations 40 and 42. For those periods, notice that the regulated flow at those locations is the target minimum desired flow (650 ft^3/s for location 40 and 600 ft^3/s for location 42). Allen Reservoir then operates for location 99 for the remaining periods, as discussed above and shown in Table D.9.

Table D.10 East Branch Operation (Example 5)

```
 *USERS. 2    User Designed Output    (Dates shown are for END-of-Period)

                                      Summary by Period   Flood=       1
Location No=          444.     444.     400.     400.      42.      40.     99.
J8/JZ Codes=          444.120  444.100  400.120  400.100   42.040   40.040  99.040

                   ALLEN RES ALLEN RES BRENDA  BRENDA   CHARLEST DOUGVILL DRY TOWN
Period  Date:  Day    Case   Outflow   Case    Outflow  Flow Reg Flow Reg Flow Reg

     1  1Jan86 Wed    40.00   180.19     0.03   260.82   604.35   650.00  1850.00
     2  2Jan86 Thu    40.00   141.16     0.03   231.99   602.94   650.00  1850.00
     3  3Jan86 Fri    40.00   186.66     0.03   248.49   600.54   650.00  1850.00
     4  4Jan86 Sat    42.00   339.26     0.03   367.09   600.00   657.46  1850.00
     5  5Jan86 Sun    40.00   401.06     0.03   416.49   612.25   650.00  1850.00
     6  6Jan86 Mon    40.00   409.00     0.03   416.43   601.40   650.00  1850.00
     7  7Jan86 Tue    99.00   561.37     0.03   562.60   734.91   787.23  1850.00
     8  8Jan86 Wed    99.00   627.81     0.03   625.05   796.12   844.73  1850.00
     9  9Jan86 Thu    99.00   627.60     0.03   622.03   791.22   835.03  1850.00
    10 10Jan86 Fri    99.00   641.65     0.03   633.48   797.96   841.02  1850.00
     :
   11-40 Omitted
```

The third output table (*USER. 3) shows the operation on the West Branch, from James Reservoir down to Dry Town. Table D.11 lists the output for the first 20 periods (the output for Dry Town is not shown because it is the same as Table D.10). James Reservoir operates for location 99 (Case = 99.00) and for the minimum desired flow requirement defined at the reservoir (Case = 0.00). There is only a 15 ft^3/s diversion specified at location 50, which is far less than the minimum flow targets. During periods 9 through 12, the Guide Curve minimum flow is 480 based on the season and pool elevation. That is also true for periods 16 and 17. After January 15, the Guide Curve elevation is increasing causing the reservoir's operation Zone to shift from Zone 4, with the 480 ft^3/s target, to Zone 2 with a transition from 400 ft^3/s to 100 ft^3/s based on pool elevation.

Table D.11 West Branch Operation (Example 5)

```
 *USERS. 3    User Designed Output    (Dates shown are for END-of-Period)

                                            Summary by Period   Flood=      1
Location No=           555.      555.      555.      555.       555.       50.
J8/JZ Codes=           555.120   555.130   555.220   555.060    555.100    50.030

                     JAMES RES JAMES RES JAMES RES  JAMES RES  JAMES RES SPRINGVIL

  Period  Date:  Day   Case      Level   EOP Elev   DeQ-Shor   Outflow    Diversio

      1  1Jan86 Wed    99.00      2.79     820.36       0.00     653.30      15.00
      2  2Jan86 Thu    99.00      2.79     820.29       0.00     633.29      15.00
      3  3Jan86 Fri    99.00      2.78     820.23       0.00     592.52      15.00
      4  4Jan86 Sat    99.00      2.78     820.16       0.00     605.56      15.00
      5  5Jan86 Sun    99.00      2.77     820.08       0.00     622.93      15.00
      6  6Jan86 Mon    99.00      2.77     820.00       0.00     628.77      15.00
      7  7Jan86 Tue    99.00      2.77     819.93       0.00     499.95      15.00
      8  8Jan86 Wed    99.00      2.76     819.87       0.00     498.15      15.00
      9  9Jan86 Thu     0.00      2.76     819.81       0.00     480.00      15.00
     10 10Jan86 Fri     0.00      2.76     819.76       0.00     480.00      15.00
     11 11Jan86 Sat     0.00      2.75     819.70       0.00     480.00      15.00
     12 12Jan86 Sun     0.00      2.75     819.66       0.00     480.00      15.00
     13 13Jan86 Mon    99.00      2.75     819.59       0.00     507.22      15.00
     14 14Jan86 Tue    99.00      2.74     819.53       0.00     540.53      15.00
     15 15Jan86 Wed    99.00      2.74     819.46       0.00     535.71      15.00
     16 16Jan86 Thu     0.00      2.73     819.44       0.00     480.00      15.00
     17 17Jan86 Fri     0.00      2.72     819.41       0.00     480.00      15.00
     18 18Jan86 Sat     0.00      2.71     819.42       0.00     399.13      15.00
     19 19Jan86 Sun     0.00      2.70     819.44       0.00     397.45      15.00
     20 20Jan86 Mon     0.00      2.69     819.45       0.00     395.80      15.00
      :
   21-40 Omitted
```

User Tables 3 and 4, not shown, provide more detail for the reservoirs including elevation, evaporation, and diversions. For a review of those data, run the example data set and review the entire output file. The concluding error check indicates no errors for the simulation.

D.3 Firm Yield Determination

In water supply planning it is often desired to know the minimum conservation storage required to meet reservoir or downstream flow and diversion requirements. The solution is an iterative process of assuming different storage volumes until the minimum storage is found that will meet the requirements. The inverse is also common. Given a fixed storage volume, what is the maximum desired flow, required flow, or diversion which the reservoir will yield? In this case two of the three requirements are held fixed while the third is varied until the maximum is reached for a given reservoir storage. The maximum desired flow, for example, can be determined while holding the required flow and diversion constant.

The foregoing task of finding minimum conservation storage or maximum yield (desired flow, required flow or diversion) is handled in HEC-5 through its yield determination capability. In addition to water supply yield, the program can determine monthly firm energy and monthly plant factors for hydropower. The time interval of inflow for these options must be monthly. Also, only a single reservoir or up to four independent reservoirs in a system, can be analyzed. Each reservoir must be processed for its own independent set of flow requirements or conservation storage. An upstream reservoir's yield, operating for a downstream control point can be accomplished, but tandem reservoir operation yield cannot be determined.

D.3.1 Firm Yield Options

Time-period options. The standard selection of the simulation periods are available using this capability. These are period-of-record, partial record, and critical period. Period-of-record and partial record options are specified using the **BF** Record, discussed previously. For the critical period, the options are specified on the **J7** Record, Field 8. These options include: specifying the time periods desired for the simulation run; specifying a monthly reservoir drawdown duration; and specifying a duration equal to 70 times the ratio of conservation storage to mean annual flow. These are referred to as the "critical period" options. In addition, there also exists the capability to simulate using several combinations of critical period and period-of-records simulations. For this option, a code is input in field 9, **J7** Record. However, two basic approaches are suggested: Use the entire period-of-record (field 9 = 0 or 1); or use the multiple series of critical-period analysis followed by the period-of-record simulation (field 9 = 6).

Using the critical period analysis with the **J7** Record, field 9 = 6 allows for both critical period and period-of-record simulation. A check is made to see if the storage (or flow, or diversion) computed for the assumed critical period can be maintained for the period-of-record. If the assumed critical period is in fact, the true critical period, then the firm yield can be maintained for the period-of-record. If the drawdown using the period-of-record is greater than the drawdown using the assumed critical period, and not within the specified allowable error, then a new critical period is selected and the storage optimized. This capability also applies to desired flow, required flow and diversions.

Reservoir conservation storage. To determine required conservation storage to meet specified demands, the **J7** Record, field 1 is set to the location number (control point number) and the conservation storage above the top of buffer pool will be determined by specifying .0, (e.g., 55.0 would determine storage for reservoir 55). In field 8 specify 2 to start with an initial critical duration equal to 70 times the ratio of conservation storage to mean annual flow. An allowable error ratio (positive and negative) is specified in field 10. This is the ratio of the storage error (difference between the target drawdown storage and the minimum storage in the simulation) to the total conservation storage above the target drawdown storage. When reservoir storage is being determined, the desired and required flow requirements may be specified for either the reservoir or a downstream control point. When determining any yield (required or desired flow or diversions), the water yield must be <u>at</u> the reservoir unless the downstream control point (**J7** Record, field 5) is specified.

Maximum desired flow. This option determines the maximum desired flow available during the critical period or period-of-record given a specified volume of conservation storage. Other system requirements such as diversions and required flow are met as specified. Note however, that required flow is not competitive with desired flow because it is not drawn upon until the storage reaches the top of buffer at which time desired flow is no longer met. In field 1 of the **J7** Record a 55.2 would indicate that the maximum desired flow (.2) at control point 55 will be determined. The other input on the **J7** Record are the same as used for the storage determination. The pattern for the monthly varying desired flow is specified using the **QM** Record. Also, a constant or period varying desired flow may also be utilized. The desired flows are required as input on the **MR** Records in order to provide an initial estimate of the flows that vary by period.

Maximum required flow. This option determines the maximum required flow for the critical period or period-of-record that can be maintained through the period of historical flow data given a specified volume of conservation storage. Other system requirements such as diversions and desired flows are met as specified. Again, the **J7** Record specifies this option with a control point number plus a .3 in field 1. The other input on the **J7** Record are the same as for the storage determination. An initial estimate for a constant required flow is input on the **CP** Record, field 4. Monthly and period varying required flow may also be determined.

Maximum monthly diversion. This option determines the maximum diversion flow for the critical period or period-of-record. A given volume of conservation storage, with other system requirements being met, is specified. Both desired and required flow requirements may be competitive with diversions since the diversion requirement applies to storage above and below the buffer level. The required input on the **J7** Record is a control point number plus .4 input on field 1, where the control point number is the location for the diversion. The other input data on the **J7** Record are the same as previously described. An initial estimate of the monthly varying diversion is input on the **QD** Record.

Maximum value of all reservoir yields. By specifying a control point number plus .9 in field 1 of the **J7** Record, all yields (i.e., desired flow, required flow and diversion) are determined for a given storage at the reservoir. Each of the yields is multiplied iteratively by the same constant until the drawdown storage is within the target error specified. All yields must be at the reservoir.

Maximum yield at a downstream control point. In addition to determining maximum reservoir yields, the maximum yield can also be determined at a downstream control point. This option is accomplished by defining the downstream control point number to be analyzed in field 5 of the **J7** Record.

D.3.2 Firm Yield Model Data

Example 6 provides a firm-yield determination of diversions from reservoir location 111. Table D.12 lists the input data file. Andrew Reservoir has a specified monthly diversion and minimum flow schedule. The reservoir also operates for location 99, Zola, which has a minimum desired flow goal of 65 ft^3/s.

Table D.12 Firm Yield Determination (Example 6)

```
T1        HEC-5 Example 6, Firm Yield Determination    (EXAMPLE6.DAT)
T2        Firm Yield Determination of Diversion, DR and QD (J7.1 = 111.4)
T3        Blue River, Andrew Reservoir to Zola, Monthly Flow Data 1980-92
J1     0       1       5       3       4       2
J2    24     1.0               0
J3     4       0       0       0       0      -1
J7 111.4                                                       2       6       0
JZ111.11  111.13  111.03  111.10  111.05  111.06   99.04   99.05   99.06

C ===================== Andrew Reservoir ======================
RL   111  218000    7500    9500  218000  361800  552600
RO     1      99
RS    10    7500    9500   46900   66120  111800  218000  350000  361800  445200
RS552600
RQ    10    2700    2740    3800    4060    4400    4800    5200    5200   55000
RQ118700
RA    10     402     410    1390    1830    2790    4670    6520    6930    8294
RA  9498
R3  -2.6    -1.4    -1.2     -.6    -1.5     2.3     4.5     4.7     3.1     0.5
R3  -1.9    -2.5
CP   111    4800              10
IDANDREW RES
RT   111      99
DR   111                                         1
QD    12    10.5    10.5    10.5    15.2    25.7    43.3    43.3    43.3    25.7
QD  15.2    10.5    10.5
QM    20      20      20      20      25      35      50      50      45      30
QM    20      20

C ===================== Zola ===================
CP    99   14500      65
IDZOLA
RT    99

ED
BF     2     144       0       80010100             720                     1900
ZR=IN  A=BLUE RIVER  C=FLOW-LOC INC  F=COMPUTED FLOWS
ZW     A=BLUE RIVER  F=FIRM YIELD RESULTS
EJ
ER
```

The added **J7** Record calls for a yield determination and defines the objectives. The first field indicates location 111, the reservoir, and the decimal value indicates the target demand to process (i.e., .4 requests maximize diversions based on the schedule defined on the **QD** Record). Field 8 value is 2, requesting a critical period determination, based on the reservoir storage to mean annual flow ratio, and an output table showing the critical flow periods for 1 to 60 months. Field 9 has the recommended value 6, indicating that after the critical period results are determined there will be a test with the full flow sequence. And, if the full-record simulation finds another critical period, a subsequent analysis would be performed and tested. Up to three sequences will be performed, first analyzing the critical period and then testing with the full record. The last field defines the error tolerance. A zero input accepts the default of a 100 acre-ft negative error and a 1% of storage positive error. This allows the minimum storage to be 100 acre-feet below the minimum pool and up to .01 times the conservation storage as an acceptable minimum storage.

The remainder of the model data is similar to the previous examples. The program will simulate the operation with the defined data. After the first simulation, the program will adjust the diversion schedule by a ratio in an attempt to meet the maximum diversions while keeping the minimum storage within the storage error tolerance. The simulation output is described in the following section.

D.3.3 Firm Yield Output

As with the other examples, the output provides an input listing, followed by a summary of input. Unique to this example is the tabulation of the flow data read from the DSS file. With the firm-yield application, the data are formatted into the standard card-image format. Following the input listing is the table of flow-duration used to define the initial estimate of critical period. The output table is shown in Table D.13. The table is provided for 1 to 60 periods (months), showing the minimum volume and associated periods, the average flow, the average flow plus conservation storage, and the estimated storage for durations of 1 to 11 months, and dependable capacity if determination of installed capacity is desired.

The critical period is then estimated by the program based on the conservation storage to average annual flow ratio, shown at the end of the table. Based on the Ratio 0.693, the program estimated a critical duration of 49 months and the data for that duration is shown in the last line of the table, after the 60 month duration line. While the minimum flow for that duration begins in period 38, the program roles the start date back to the beginning of a year, period 25. The first cycle to find the maximum diversion schedule will be processed with the flow data from period 25 to 91.

Table D.13 Flow-Duration Table to Define Critical Period

DUR	VOL-DUR	PER-START	PER-END	Q-RIVER	Q+QSTOR	EST-STG	DEP CAP
1.	0.	47.	47.	0.	3454.	3115.	0.
2.	0.	46.	47.	0.	1727.	6230.	0.
3.	3.	46.	48.	1.	1152.	9165.	0.
4.	5.	46.	49.	1.	865.	12159.	0.
5.	10.	45.	49.	2.	693.	14972.	0.
6.	25.	44.	49.	4.	580.	17182.	0.
7.	67.	43.	49.	10.	503.	17762.	0.
8.	74.	42.	49.	9.	441.	20454.	0.
9.	158.	42.	50.	18.	401.	18498.	0.
10.	296.	41.	50.	30.	375.	13282.	0.
11.	702.	40.	50.	64.	378.	0.	0.
12.-30. *OMITTED*							
:							
31.	5850.	29.	59.	189.	300.	0.	0.
32.	6130.	29.	60.	192.	299.	0.	0.
33.	6596.	29.	61.	200.	305.	0.	0.
34.	7529.	28.	61.	221.	323.	0.	0.
35.	8001.	27.	61.	229.	327.	0.	0.
36.	8480.	26.	61.	236.	331.	0.	0.
37.	8963.	37.	73.	242.	336.	0.	0.
38.	9144.	36.	73.	241.	332.	0.	0.
39.	9444.	35.	73.	242.	331.	0.	0.
40.	9786.	29.	68.	245.	331.	0.	0.
41.	9874.	31.	71.	241.	325.	0.	0.
42.	9906.	31.	72.	236.	318.	0.	0.
43.	9974.	30.	72.	232.	312.	0.	0.
44.	10077.	30.	73.	229.	308.	0.	0.
45.	10208.	29.	73.	227.	304.	0.	0.
46.	10511.	41.	86.	229.	304.	0.	0.
47.	10729.	41.	87.	228.	302.	0.	0.
48.	11135.	40.	87.	232.	304.	0.	0.
49.	11483.	38 .	86.	234.	305.	0.	0.
50.	11701.	38.	87.	234.	303.	0.	0.
51.	11949.	36.	86.	234.	302.	0.	0.
52.	12167.	36.	87.	234.	300.	0.	0.
53.	12467.	35.	87.	235.	300.	0.	0.
54.	12726.	31.	84	236.	300.	0.	0.
55.	12765.	31.	85.	232.	295.	0.	0.
56.	12814.	31.	86.	229.	290.	0.	0.
57.	12882.	30.	86.	226.	287.	0.	0.
58.	13013.	29.	86.	224.	284.	0.	0.
59.	13231.	29.	87.	224.	283.	0.	0.
60.	14086.	29.	88.	235.	292.	0.	0.
49.	11483.	38.	86.	234.	305.	0.	0.

START-PER	END-PER	DATE
25	91	82010100

CON-STG	QMEAN	RAT-STG/Q	DRAW-DUR	APPROX. DEP CAP.
208500.	415.	0.693	49.	0.

The routing cycles and trial runs are summarized in the output table labeled "*OPTRY." The descriptions of the output data are provided in Appendix F. At the end of each trial, the minimum storage achieved is evaluated to determine if the demand can be increased or needs to be decreased. The program temporarily adds 500,000 acre-feet to the minimum storage to support demands greater than the available water supply can. If the minimum storage is below the adjusted target minimum (TAR-MIN-STG), the program can use the storage deficit to estimate how much to adjust the demand. Likewise, when the minimum is above the target, the increase in demand can be estimated based on the surplus water in storage distributed over the draw-down duration. The program computes the adjustment factor, shown as "MULTIPLIER= x.xxx" where x.xxx is the adjustment. Then the program performs another cycle with the adjusted demand.

The output for the ninth, and final, cycle is shown in Table D.14. (Note, the format has been slightly modified to fit the page.) The ninth cycle summary shows that the minimum storage was 77 acre-ft. above the minimum (509577 vs. 509500), within the minimum positive storage error of 100 acre-feet. Therefore, this cycle result is considered accepted and the next phase of analysis begins. The estimated diversion schedule is shown under "Firm Yield Optimization Results" and the final multiplier is shown as "DIVRAT(NDIV) = 9.895099" near the end of the summary. The program will now apply the determined diversion schedule with the period-of-record data, 144 periods.

Table D.15 shows "ROUTING CYCLE= 2.," the summary table for the simulation using the entire period-of-record. (Again, the format has been slightly modified.) The output is similar to that shown in Table D.14. The primary purpose for this iteration is to ensure that the results from the critical period analysis does reflect the most critical flow sequence. If it does, the results for the entire period-of-record should be the same. However, there is always a chance that a more critical period exists in the flow set. Reviewing the data near the end of the table shows the same results were obtained with the period-of-record. That is, the minimum storage was only 77 acre-ft. above minimum pool and the diversion multiplying factor is the same. One can verify this result by running a simulation using the multiplying factor in the ninth field of the diversion record (**DR**), or the diversion data (**QD** Records) can be changed to the values shown in the output labeled "Optimized Monthly Diversions." A test run with the multiplying factor confirmed the results.

Table D.14 Output for the Last Cycle of Trial 1

```
*********************************************************************************

 ROUTING CYCLE=       1   OPT TRIAL=       9

         AVG. CRITICAL DRAW DOWN RESULTS FROM PER       5  TO      34

      INFLOW      POW-REL      EL-BTW     DRAW-RAT      DIV-Q      EVAP-P
      -59.70        0.00        0.00        1.00       239.10        2.17
RELEASE     STORAGE       ELEV       EN-REQ
52.50     593602.38       0.00        0.00

         AVG. ROUTING PERIOD RESULTS FROM PER       1  TO      67

      INFLOW      POW-REL      HEAD      DRAW-RAT     QSPILL    TAILWATER
      52.91        0.00        0.00        1.00       52.65        0.00
RELEASE      H.TOP-C     H-BOT-C
  81.98        0.01        0.00

  OP TRIAL  ERROR-RAT ERR-STG  TAR-MIN-STG MIN-STG PER-MIN-STG TOP-STG   LOC.TYP
         9  0.000368       77.   509500.    509577.        34   718000.   111.40

                            *******************

 ANN DES Q  ANN REQ Q  ANN DIV Q     INS CAP  ANN FIRM E   AVG ANN E
      29.6      10.00     217.86          0.          0.          0.


   ITYOPT=   4  MULTIPLIER=       1.000180    DIVRAT(NDIV)=       9.895099

      ASSUMED   NEXT-ASSUM         PTWO         EST3   ER-IMPROVE   EST-BOUND
       103.90      103.92      103.92      103.91       305.19       103.92
BNDMAX       BNDMIN   ERR-BN-MAX   ERR-BN-MIN
104.01       103.90      -380.81        76.63

  =================== Firm Yield Optimization Results ====================
  Location: 111      Optimized Monthly Diversions:
                     103.90    103.90    103.90    150.41    254.30    428.46
                     428.46    428.46    254.30    150.41    103.90    103.90


           DUR       VOL-DUR         PER-START         PER-END         Q-RIVER
          115.        39459.             29.            143.            343.
Q+QSTOR        EST-STG         DEP CAP
  447.             0.             0.


      START-PER        END-PER          DATE
              1            144      80010100

        CON-STG          QMEAN      RAT-STG/Q       DRAW-DUR   APPROX. DEP CAP.
        718000.           415.         2.386          115.              0.
```

Table D.15 Summary Table for Cycle 2

```
**********************************************************************************
 *OPTRY

 ROUTING CYCLE=       2   OPT TRIAL=       1

ALL. PERC NEGATIVE ERROR= 0.950  POSITIVE ERROR= 0.9500  IND FOR ONE MORE TRY= 0

       AVG. CRITICAL DRAW DOWN RESULTS FROM PER      29  TO      58

      INFLOW      POW-REL      EL-BTW     DRAW-RAT      DIV-Q      EVAP-P
       -59.70        0.00        0.00        1.00      239.10        2.17

RELEASE     STORAGE       ELEV       EN-REQ
 52.50   593602.38        0.00        0.00

       AVG. ROUTING PERIOD RESULTS FROM PER       1  TO     144

      INFLOW      POW-REL      HEAD      DRAW-RAT     QSPILL    TAILWATER
       197.57        0.00        0.00        1.00      165.34        0.00

    RELEASE      H.TOP-C     H-BOT-C
 194.92        0.01        0.00

  OP TRIAL  ERROR-RAT ERR-STG  TAR-MIN-STG  MIN-STG PER-MIN-STG TOP-STG   LOC.TYP
         1   0.000368     77.       509500.  509577.         58   718000.   111.40

                            *******************

 ANN DES Q ANN REQ Q ANN DIV Q     INS CAP  ANN FIRM E   AVG ANN E
      29.6     10.00    217.86          0.          0.          0.

   ITYOPT=   4  MULTIPLIER=       1.000143    DIVRAT(NDIV)=       9.895099


      ASSUMED   NEXT-ASSUM         PTWO         EST3   ER-IMPROVE   EST-BOUND

       103.90       103.91         0.00       103.91         1.00         0.00

       BNDMAX       BNDMIN   ERR-BN-MAX   ERR-BN-MIN
 100000000.00       103.90         0.00        76.63

  ==================== Firm Yield Optimization Results =====================
  Location: 111     Optimized Monthly Diversions:
                    103.90    103.90    103.90    150.41    254.30    428.46
                    428.46    428.46    254.30    150.41    103.90    103.90

 New Critical Period=   -28.064     0.000     0.000
```

Appendix E

Hydropower Simulation

The basic operation of HEC-5 hydropower routines is to find the necessary release to generate a specified energy requirement. This exhibit describes HEC-5 hydropower operation and the data required for the various program options. The basic hydropower reservoir is described first, followed by additional program features for: pump-storage, hydropower optimization, system power, added turbine units, energy benefits.

E.1 Power Operation

For hydropower operation, the program computes the energy requirements for each time period-of-operation. The monthly energy requirements and distributions or the period-by-period energy requirements are used for this purpose.

The program cycles through the simulation one interval at a time. For the hydropower reservoirs, the following logic is used to determine a power release:

1. Estimate average storage. Use end of previous period's storage initially and then the average of computed and end-of-period storages. (Reservoir elevation and evaporation are both dependent on average storage.)

2. Estimate tailwater elevation. Use highest elevation from block loading tailwater, or tailwater rating curve, or downstream reservoir elevation.

3. Compute gross head by subtracting tailwater from reservoir elevation corresponding to estimated average storage.

4. Compute reservoir release to meet energy requirement.

$$Q = \frac{Ec}{eht} \qquad \textbf{(E-1)}$$

where:

E	=	required energy (kWh)
c	=	conversion factor - (11.815 English or 0.102 metric)
e	=	plant efficiency
h	=	gross head (feet English or meters)
t	=	time (hours)
Q	=	reservoir release

5. Compute reservoir evaporation (EVAP) using reservoir area based on average reservoir storage.

6. Solve for ending storage (S_2) using continuity equation:

$$S_2 = S_1 - EVAP + (INFLOW - OUTFLOW) \bullet CQS \qquad \textbf{(E-2)}$$

where:

S_1	=	end-of-period storage
EVAP	=	evaporation during time interval
OUTFLOW	=	power release and leakage
CQS	=	discharge to storage conversion

7. On the first cycle, use the new S_2 and return to 1. On subsequent cycles, check the computed power release with the previous value for a difference less than 0.0001. Use up to five cycles to obtain a balance.

8. Check maximum energy that could be produced during time interval using overload factor and installed capacity.

9. Check maximum penstock discharge capacity, if given. Reduce power release to penstock capacity if computed release exceeds capacity.

The program will also determine if there is sufficient water in storage to make the power release. The buffer pool is the default minimum storage level for power; however, the user can define the inactive pool as the minimum power pool. If there is not sufficient water in storage, the program will reduce the release to just arrive at the minimum pool level. If there is sufficient water, the power release for the reservoir establishes a minimum flow at that site. Other considerations are described in the section on Hydropower Limits.

E.2 Hydropower Data

Power data are input with reservoir data at each hydropower reservoir. The basic data requirements include: energy requirements, installed capacity, an overload ratio, a combined turbine-generator efficiency, tailwater elevation, and optional losses and penstock capacity. Example data are shown in Section E.3.

E.2.1 Energy Requirement Options

At-site energy requirements may be expressed by two basic methods: firm energy or non-firm energy. Firm energy requirements are generally given in thousand kilowatt-hours (MW-hr) per month or as monthly plant factors (ratios of the portion of the month the plant is generating). If the simulation is daily or multi-hourly, the ratio of the monthly value is given for each time interval.

An alternative to the firm energy method of operation is the use of project guide curve. The curve defines the plant factor as a function of the percent of power storage occupied in the reservoir during any time period.

Monthly Firm Energy Requirements. The conventional way to express an energy requirement is to specify a monthly at-site firm energy requirement in MW-hr. The first monthly value is for the starting month, typically January (**J1**, field 2). The monthly energy requirements are defined sequentially on the **PR** Records.

For run-of-river projects there is typically no energy requirement; however, the **PR** Records are still required. For a run-of-river model, the monthly energy requirement data on the two **PR** Records would be set to zero.

Monthly Plant Factors. An alternate means of specifying an energy requirement is by monthly plant factors. The plant factor is based on operating at installed capacity for a portion of time. The energy requirement in kWh is computed as follows:

$$\text{Energy (kWh)} = \text{Plant Factor} * \text{Installed Capacity (kW)} * \Delta\text{Time (hours)}$$

Monthly plant factors are specified on the **PR** Records as negative decimal values. The negative sign indicates that these values are plant factors and not fixed energy requirements (in MW-hr).

Note: When plant factors are input and a variable capacity is defined (**PP** and **PS** Records), the program will used the *Installed Capacity* to determine the *Energy Required*; however, the *Energy Generated* will be limited to the *Plant Factor* times the *Current Capacity*. Therefore, there will be energy shortages when the capacity drops below the installed value. The use of plant factors assumes a "Peaking" operation where the plant is on a fixed length of time in the day.

The output values of plant factor, labeled "PLANT FA", are the plant factor computed from the final release, and may differ from the required plant factor for a particular period. During the periods the reservoir is operating for at-site power (Case = .10) the plant factor shown in the output should be the same as that given in the input (**PR** data). However, during periods when a higher reservoir release is made to draw to the top-of-conservation pool (e.g., Case = .03) the plant factor is computed as follows:

$$\text{Plant Factor (Final)} = \frac{\text{Energy generated (kWh)}}{\text{Capacity (kW)} \times \text{time (hours)}}$$

Higher reservoir release generates more energy resulting in a higher plant factor.

E.2.2 At-Site Energy Distribution

Monthly energy requirements can be distributed on a daily schedule and an hourly schedule. The daily schedule is given on the **PD** Record and it indicates the ratio of weekly energy required each day of the week, Sunday through Saturday. The sum of the ratios should equal one. The daily energy is computed by the following:

Weekly Energy = Monthly Energy * [(7 days/week) / (days in month)]

Daily Energy = Weekly Energy * Day Ratio

The daily distribution would be used for simulation time intervals of 24 hours, or less. The simulation interval is given on the **BF** Record in field seven.

Multi-hourly simulations are useful to obtain a more detailed simulation of project operation. The **PD** Record specifies the daily ratios and the **PH** Record specifies ratios of the daily energy requirement for each time interval within a day. The **PH** Record contains the number of values necessary to cover the number of simulation periods in one day (e.g., four ratios for each six-hour simulation interval). The first value represents the period starting at midnight. The sum of the values equals one.

A maximum of 24 hourly values can be input on the **PH** Record. If the simulation time interval is greater than the **PH** time increment, the program will sum the **PH** values to equal the simulation interval. Therefore, an hourly distribution of daily energy can be used with any even multiple-hour subdivision of a day.

E.2.3 Power Guide Curve

Another style of operation is to apply a power guide curve which relates plant factor to the percent of power storage remaining in the reservoir. This method is an alternative method to firm energy operation. Figure E.1 demonstrates this option graphically. The plant factors are in percent.

The power guide curve relates the power storage occupied at any given time to the plant factor. The end-of-period storage from the previous period will be used to find the required plant factor for the present period.

In Figure E.1, the power pool is defined as the storage between the top-of-the buffer pool (level 2) and the top-of-the conservation pool (level 3). The storage in levels 2 and 3 can remain constant with time, or vary monthly or seasonally. Between levels 2 and 3, the power plant is operated according to the power guide curve. As the pool level increases, the energy requirement increases from a plant factor of 0.1 to a value of 1.0 at full pool, the factors are shown as percent.

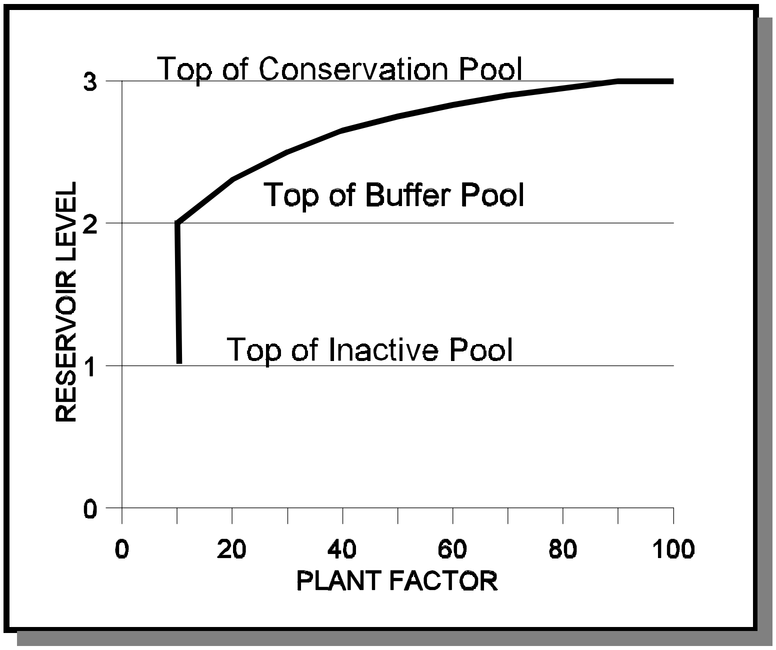

Figure E.1. Power Guide Curve

The reservoir storage between the inactive and buffer levels (levels 1 and 2) will also be used to generate power, but at a minimum plant factor corresponding to 0% power storage on the guide curve, unless the Power Drawdown Priority is used. Above level 2, the operation will be governed by the guide curve.

The HEC-5 input requirements for this option are described below:

Power guide curve. The percent of power storage occupied (expressed as a decimal) is entered on the **PC** Record and the corresponding plant factors are entered on the **PF** Record. Percent power storage should not exceed 1.0 as flood storage will not be counted toward computing an energy requirement for guide curve operation. For this option, the monthly ratios input on the **PR** Record are multiplied by this factor.

Power drawdown priority: The **J2** Record field 4 value includes a 2. This allows the reservoir to draw down to level 1 to generate power.

E.2.4 Power Guide Curve Factor

It is sometimes desired to increase the energy requirements (either firm energy or power guide curve options) when there is sufficient storage in the reservoir to meet the increased requirement. This is handled in HEC-5 through a power guide curve factor. A reservoir power index level may be specified on the **J1** Record in field 9. This is usually the same as the top-of-the buffer pool (level 2), but may be different. Energy requirements can be given as monthly energy requirements (on the **PR** Records) or power guide curve requirements (on the **PC-PF** Records).

The power guide curve factor is entered on field 14 of the **PR** Record. The input energy requirements are multiplied by the factor when the reservoir level, in the previous time period, is above the index level (**J1**.9). For example **PR**.14 = 1.25, then the energy requirement would be multiplied by 1.25 when the reservoir level in the previous period is above the power index level. When the reservoir level drops below the index level, the energy requirements are taken directly from the plant factor specified on the **PC-PF** Records or the energy requirement on the **PR** Records.

E.2.5 Peaking Capability

Hydropower peaking capability may be defined for HEC-5 use in four ways: as a constant capacity value, or a function of: reservoir storage, reservoir release, or power head. The variable peaking capability is used with plants with substantial power storage and provides important information on peaking capability vs. time plus a more accurate estimate of energy.

Constant Capacity. The installed capacity is given on field 2 of the **P1** Record.

Peaking vs. Reservoir Storage. The turbine-generator capability vs. reservoir storage function is input on the **PP** and **PS** Records. A value of 1 is specified in field 4 of the **P1** Record to define this type of relationship. This option is used when head fluctuations are primarily dependent upon the headwater elevation. Note that the end-of-period storage of the previous period is used to determine the peaking capability of the current period. The variable peaking capability in kW is shown in output as "PEAK CAP".

Peaking vs. Reservoir Release. Field 4 of the **P1** Record is changed to 2 to describe the peaking capability vs. reservoir release on the **PP** and **PS** Records. The **PP** and **PS** Records are changed accordingly. This option is used when head fluctuations are primarily dependent upon changes in tailwater. The variation in peaking capability is shown in the column labeled "PEAK CAP".

Peaking vs. Operating Head. Peaking capability vs. reservoir operating head will be read on Records **PP** and **PS** when a 3 is specified in field 4 of the **P1** Record. This option reflects changes in headwater and tailwater elevations, and may be more accurate if both change significantly.

E.2.6 Overload Ratio

An overload ratio is used along with the installed capacity to determine the maximum energy the power plant can produce in a time interval. Many older plants have been designed with an overload ratio of 1.15, meaning that the plant can generate at 15% over installed (nameplate) capacity. The overload ratio is input in field 3 of the **P1** Record. Current Corps' specifications and modern electrical design permit new plants to have a 1.0 overload ratio.

E.2.7 Efficiency Options

There are four ways to express the turbine-generator efficiency in HEC-5. In preliminary studies to determine the hydropower potential at a reservoir, a constant turbine-generator efficiency of 86% is often used. In actual operation, however, the turbine-generator efficiency varies throughout its range of operation. There are three ways to specify a variable efficiency.

Constant Efficiency. The constant value is input on field 7 of the **P1** Record.

Efficiency vs. Reservoir Storage. A value of -1 is coded in field 7 of the **P1** Record to indicate that the efficiencies on the **PE** Record will be used with the reservoir storages on the **RS** Record. Note that the efficiencies are specified in decimal form (50% efficiency = .50).

Efficiency vs. Operating Head. For this option, a value of -1 is also coded in field 7 of the **P1** Record. However, this time the values on the **PE** Record are greater than 1 (an impossible efficiency). Both the head and corresponding efficiency are input on the **PE** Record. The value to the left of the decimal point represents the head corresponding to the efficiency which is entered to the right of the decimal point. (e.g., 144.87 would indicate that the power efficiency is 87% at a head of 144.)

Efficiency in kW/ft^3/s vs. Reservoir Storage. A value of -2 is specified in field 7 of the **P1** Record to indicate an efficiency in kW/ft^3/s coefficients are entered on the **PE** Record. Values of kW/ft^3/s are computed for a project by repetitive solution of the energy equation for assumed elevations in the reservoir. This approach was often used for convenient hand calculations of energy. These coefficients correspond to the reservoir storages on the **RS** Record. Energy is calculated as follows:

$$\text{Energy (kWh)} = \text{Flow (ft}^3\text{/s)} * \text{Coefficient (kW/ft}^3\text{/s)} * \text{Time (hours)}$$

E.2.8 Power Head

In computing the energy that can be generated in any time period, the available head is a critical factor. The headwater is determined by averaging the end-of-period (EOP) storage for the current period and the previous period. The storage in a particular time period, t, is determined from the equation:

$$\text{Storage}_t = \text{Storage}_{t-1} - \text{EVAP} + [(\text{Inflow} - \text{Outflow}) * \text{CQS}]$$

where:

EVAP = Net evaporation for the time step
CQS = Discharge to storage conversion factor

The headwater elevation thus must be determined by a trial and error method because it is based on the outflow, which is also unknown. To compute head, the tailwater must be known. There are three ways to define the tailwater elevation in HEC-5. If more than one method is given, the program uses the highest of those specified.

E.2.9 Tailwater

Block-loading Tailwater. The tailwater elevation may be given as a constant. This is often called block-loading because it represents the tailwater elevation based on the discharge required to produce 100% of the installed capacity. For peaking plants, block-loading is the average "on-line" tailwater that would be expected during power generation. The block-loading tailwater elevation is specified in field 5 of the **P1** Record.

Tailwater Rating Curve. For hydropower analysis it is often necessary to specify tailwater elevation as a function of the reservoir release. Usually, the block-loading tailwater elevation is omitted and a rating curve is entered on the **PQ** and **PT** Records. The hydropower release is an average value for the time interval and the rating curve usually represents an instantaneous value. Therefore, the program adjusts the computed power release by dividing it by the plant factor for the time interval to estimate an instantaneous discharge. The estimated instantaneous value is used to determine the tailwater elevation from the input rating.

Downstream Reservoir. Reservoirs are in tandem when they are on the same stream and consecutive. A downstream reservoir's headwater elevation can affect the tailwater elevation of the upper reservoir. The control point number of the downstream reservoir is input in field 6 on the upstream reservoir's **P1** Record. For each period in the simulation, the elevation of the downstream reservoir pool is compared with the tailwater from block-loading or rating curve and the higher of the two is used to compute the head for the upstream reservoir in that period.

Combination Tailwater Data. All the tailwater options can be used at a site. If more than one option is used, the highest elevation in each period is used to compute the head. Combinations may be required for peaking plants to account for high tailwater elevations during flood conditions, or inundation from downstream reservoir pool.

E.2.10 Losses

Efficiency reflects the "losses" in the electrical-mechanical operation for energy generation. Hydraulic losses reflect the hydraulic head loss and the water losses at the site. Hydraulic loss may be expressed as a constant, or varying with reservoir outflow. In addition, a constant leakage (in ft^3/s) may be specified.

Fixed Hydraulic Losses. A constant hydraulic loss is specified in field 8 of the **P1** Record. The input value is subtracted from the final net head calculated during each period. This hydraulic loss option is comparable to the Block-Loading tailwater option. The output "POWER HE" will include the subtracted loss value.

Losses Varying With Release. Hydraulic losses in feet corresponding to power release are specified on the **PQ** and **PL** Records, respectively. The releases are input in increasing order on the **PQ** Record.

Leakage. Water which continuously passes through the wicket gates or under the dam, or through fish ladders or low flow outlets, but cannot be used for power generation is specified as leakage (in flow units) on the **P2** Record in field 1. The leakage will continue even when no power releases are made. Leakage will occur through the entire range of reservoir levels, until Level 1 is reached.

E.2.11 Hydropower Limits

After the energy-release determination has been made, the program will check limitations in the penstock capacity (if defined) the power capability, and the available water for generation. If any of these considerations cause a reduction in the power release, the energy generated will be less than the specified energy requirement. There is no output *Case* to indicate this situation, so the program may still indicate it is operating for hydropower requirement (*Case* = 0.10). The user should check the following limits when there is a power shortage and the *Case* = 0.10.

Capacity Limit. A variable capacity can limit energy production in a time step. The application of that limit depends on how the energy requirement, **PR** data, is defined.

> <u>If the energy requirement is given (MW-hrs)</u>, then the entire simulation time interval is available to generate the required energy. The capacity will be applied for the entire time interval to meet the energy requirement.
>
> <u>If the energy requirement is defined by plant factors</u>, then only the ratio of the time interval is available to generate the required energy.

Penstock Capacity. The penstock conveys water from the outlet at the reservoir into the turbine. For existing plants, the maximum discharge capacity for the penstock must be considered in estimating energy generation. For proposed plants, there may be a design discharge capacity to consider. If no value is specified, the penstock capacity will not be a constraint on power releases.

The penstock capacity is input on the **P2** Record, field 2. The program converts the penstock capacity to an average discharge over the simulation time interval based on the plant factor for that time period. The following equation is used:

Average Power Release (ft^3/s) = Plant Factor x Penstock Capacity (ft^3/s)

If the computed power release exceeds the penstock capacity, another computational iteration is made for that period limited by the penstock capacity.

Overload Capacity. The overload ratio is only used when there is a surplus of water to be released and the program determines the maximum energy that can be produced in the simulation time interval. Any release greater than the flow required to generate the maximum energy is assumed to be Spill. The Maximum energy is computed by:

$$\text{Maximum Energy} = \text{Capacity} * \text{Overload} * \Delta\text{Time (hours)}$$

The capacity is usually the installed capacity. However, if a variable capacity is defined, the current value of the capacity will be used for this computation.

E.2.12 Priority Options

A primary question in the study of a hydropower system is how much energy can be generated. In a multi-purpose system, many variables can create conflicts in operation. There is the available storage for power generation and the use of that storage for other purposes. Then, during high flows, there may be the need to reduce reservoir releases to minimize flooding at downstream locations. A useful feature in HEC-5 is to allow the user to define priorities between competing project purposes.

Normal Priority. In a multi-purpose system that operates for both hydropower and flood control. the "normal priority" is for reservoirs to operate for flood protection first, and to meet conservation flows second. Conservation flows include minimum required flows, minimum desired flows, and primary energy releases.

Power releases from the reservoir will be cutback (shorting energy requirements) when any control point in the system which the reservoir operates for is flooding.

Power releases are assumed to meet minimum flow requirements. If the power release is insufficient, the release will be increased to meet the specified minimum requirement. Also, the extra release will be used to generate hydropower up to defined physical limits.

Power Priority. The "priority" variable is on the **J2** Record, field 4. The priority code of 1 specifies preference of primary power releases over flood control releases. With this option, releases are made to meet energy requirements even though the release contributes to downstream flooding.

Power Drawdown Priority. In HEC-5, power releases are normally made as long as the reservoir is above the buffer level (usually level 2). The "drawdown priority" option allows releases to be made down to level 1 to generate primary energy. No energy shortages occur as long as there is sufficient water and capacity.

E.2.13 Additional Hydropower Features

This section describes options that may be very helpful in specialized hydropower studies requiring additional modeling and analysis. Items include adding an additional turbine, energy benefits, pump-storage, optimization, and system power.

Headwater Option. HEC-5 can be used to model the addition of a turbine on a second outlet of an existing hydropower reservoir. For example, if a constant 50 ft^3/s is being released through a low flow outlet, and a second turbine is to be placed at the outlet, the "headwater" option can be used to model the second turbine.

First, a dummy reservoir (e.g., Res. 25) is added to the input data for the second plant. Reservoir data for the dummy reservoir describe a reservoir with the same storage as the power reservoir (e.g., Res. 20). Power data describing characteristics of the second turbine are input at the dummy reservoir. A value of -20 is coded in field 6 of the **P1** Record which tells the dummy reservoir to use the headwater elevation from Reservoir 20. A diversion record is added to reservoir 20 to divert the constant 50 ft^3/s from reservoir 20 to the power plant at reservoir 25. See the **DR** Record for input description. This effectively creates a system with a single operating reservoir and two power outlets.

Energy Benefits. Analyzing the economics of a hydropower plant can be aided by the HEC-5 options which allow project benefits to be computed. The **J4** Record provides capability for energy (fields 7 and 8) and capacity (field 6) benefits for a firm energy operation while the **PB** Record allows energy benefits for the power rule curve type of operation. Given the energy benefit values (in mills/kWh) and the corresponding plant factors, the benefit in dollars is computed for the rule curve operation for each period. Required records are the **PC**, **PF**, and **PB**. Data on the records are the percent conservation storage remaining, plant factor and the corresponding benefit rate, respectively.

E.3 Hydropower Modeling

The hydropower model (Example 7) is a three-reservoir system illustrating three types of hydropower modeling: power guide curve, peaking requirements and run-of-river. The first reservoir, on the west branch, operates based on a power guide curve that defines energy required as a function of conservation storage. The upper reservoir on the east branch only operates for its hydropower based on a monthly energy demand schedule, labeled "Peaking Hydropower". The lower reservoir on the east branch has no energy requirement and operates for low-flow demand, labeled "Run-of-river" hydropower. The following sections described each reservoir’s hydropower input data and then the hydropower operation.

The reservoirs have six levels, with top-of-conservation at level 5 and top-of-buffer pool at level 2. The intermediate level 3 is used to favor one reservoir over the other when operating for downstream low-flow goals. (This is described in the note following Table E.3.) Monthly net-evaporation depths are defined for all reservoirs on the **J6** Records.

E.3.1 Power Guide Curve Data

An alternative to specified energy requirements is the power guide curve data used with Andrew Reservoir, location 80. The data are listed in Table E.1. The reservoir data define a seasonally varying storage for levels 3 and 4 (**RL** Records). The **RO** Record indicates the reservoir operates for downstream location 33. Reservoir outflow capacity (**RQ**), reservoir area (**RA**) and elevation (**RE**) are all defined as a function of storage (**RS**). The **R2** Record indicates a rate-of-change of 10,000 ft^3/s for both increasing and decreasing reservoir releases. The seven seasons are defined on the **CS** Record, at the bottom of the input series.

The power data (**P1** Record, fields 2 - 8) define a 82,000 MW plant, with no overload, peaking capability is a function of operating head, no minimum tailwater or downstream reservoir effecting tailwater, efficiency defined by kW versus release based on reservoir storage, and a hydraulic head loss of 1.2 feet. The optional **P2** Record indicates a leakage of 1.5 ft^3/s and a penstock capacity of 9,800 ft^3/s.

Following the **P1** and **P2** Records, are the power rule curve data. This approach defines the energy required as a function of storage available. The **PC** Record defines the percent of power (conservation) storage for the associated power requirements, defined as plant factors on **PF** Records. The first field indicates the number of values, 8. Then the ratios of power storage, from 0 to 1.0 are defined on the **PC** Record and the associated plant factors are defined on the **PF** Record. For example, for a power-storage ratio from 0.0 to 0.45, the energy required is a minimum 0.045 which is equivalent to one hour of generation per day.

Table E.1 Power Guide Curve Input Data (Example 7, beginning of file)

```
T1      HEC-5 Example 7, Basic Hydropower Model   (EXAMPLE7.DAT)
T2      2 Peaking Plants and a Reregulation Reservoir with Run-of-River Power
T3      Green River, Adam Reservoir to Willeyburg, Hourly Flow Data 1986-1987
J1     0       1       6       4       5       2
J2    24       1
J3     4                                       1
J6  -2.7    -2.0    -1.6     0.3     3.4     2.5     2.0     0.9     1.9     1.6
J6  -0.8    -1.6
J8 80.12   80.10   55.12   55.10   50.12   50.10   33.04   33.05
J8 80.12   80.10   80.13   80.16   80.15   80.35
J8 55.12   55.10   55.13   55.16   55.15   55.35
J8 50.12   50.10   50.13   50.16   50.15   50.35
C =================== Andrew Reservoir (Peaking Project) =====================
RL    80  345000
RL     1      80      -1           82890
RL     2      80      -1           95000
RL     3      80       7          210400  210400  379600  379600  379600  210400
RL                                210400
RL     4      80       7          210492  210492  379611  379611  379611  210492
RL                                210492
RL     5      80      -1          670052
RL     6      80      -1          804006
RO     1      33
RS    32   10373   82884   89647  104879  113447  122709  132705  143514  155137
RS167612  181000  195280  210492  226656  243772  261860  280940  301031  322154
RS344288  367473  391749  417136  443713  471559  500734  531317  563427  597164
RS632646  670052  804006
RQ    32    9800    9800    9800    9800    9800    9800    9800    9800    9800
RQ  9800    9800    9800    9800    9800    9800    9800    9800    9800    9800
RQ  9800   15000   26000   37000   50000   66000   82000  100000  120000  140000
RQ160000  185000  300000
RA    32     182    3251    3516    4116    4452    4812    5196    5602    6024
RA  6462    6913    7373    7841    8317    8801    9293    9793   10298   10808
RA 11329   11862   12411   12988   13599   14246   14933   15665   16449   17293
RA 18206   19201   24200
RE    32     725     800     802     806     808     810     812     814     816
RE   818     820     822     824     826     828     830     832     834     836
RE   838     840     842     844     846     848     850     852     854     856
RE   858     860     870
R2 10000   10000
C  == Andrew Power Plant == 2 41 mW Generators, Operate 4hrs/day Monday-Friday
P1    80   82000       1       3       0       0      -2     1.2
P2   1.5    9800
PC     8       0     .45     .60     .65     .88     .92     .94     1.0
PF     8    .042    .042    .083    .083    .125    .167    .208     .25
PR     1       1       1       1       1     1.2     1.5     1.5     1.2       1
PR     1       1
PD     0       1       1       1       1       1       0
PH    24       0       0       0       0       0       0    .125    .125    .125
PH  .125    .125    .125    .125    .125       0       0       0       0       0
PH     0       0       0       0       0
PQ     0     203    4200    7500    9500   11600   32100   45000
PT   685     690   692.6   694.7   696.5   697.9   733.1     735
PP 28000   58000   68000   82000   82000   82000   82000
PS    80     100     115     125     130     145     200
C    PLANT EFFICIENCY RATIO IS (KW/CFS)
PE  6.75    6.75    6.97    7.42    7.64    7.86    8.08     8.3    8.52    8.75
PE  8.97    9.19    9.37     9.5     9.7     9.9   10.23   10.49   10.66   10.83
PE 11.00   11.16   11.31   11.47   11.62   11.78   11.93   12.09   12.24   12.40
PE 12.55   12.55
CP    80    9800
IDANDREW RESERVOIR
RT    80      70
CS     7       1      15     121     182     274     350     365
:
: Continued in Table E.2
```

Note that **PR** Records are also given. In this application, the **PR** data define monthly ratios to apply to the computed energy requirement defined by the storage-plant factor input. In this example, the ratio of one will be used from January to May, the first five months. Then in June, the ratio will be 1.2 and in July, 1.5. This allows for a seasonal increase, or decrease, in the energy requirements defined by the hydropower rule.

The **PD** Record distributes the weekly energy over the seven day. The input indicates a uniform demand over Monday through Friday. The **PH** Records serve to distribute the energy requirement over the block-hours of the day, 24 in this example. *Note, the number of hourly values must be the same for all power reservoirs in the model.* This input indicates a uniform demand from 7:00 AM to 2:00 PM.

The **PQ** and **PT** data defined the tailwater rating curve, flow versus tailwater. The data should define the entire range of potential releases, from low to high. The tailwater elevation will be computed by linear interpolation based on the average outflow for the time interval.

The **PP** and **PS** Records define the peaking capability as a function of storage, flow, or head, based on the code in field 4 of the **P1** Record. For this example, the data are based on head. The head, or storage, data should cover the entire range of operation.

The **PE** Records define hydropower efficiency as a function of storage defined on the **RS** Records. Based on the code in field 7 of the **P1** Record, either efficiency or kW per release (ft^3/s) is defined. In this example, it is the latter. For the 32 values of reservoir storage, the **PE** Record defines the $kW/ft^3/s$ factors. These factors are often computed to simplify hydropower calculations by hand. Given a power capacity, the required flow can be computed by dividing with the factor.

E.3.2 Peaking Energy Requirements

The input data for the east branch begins with Adam Reservoir illustrating specified energy requirements for a peaking hydropower project. The input data are shown in Table E.2. The reservoir (location 55) has seasonally varying storage for top-of-conservation, level 4. The nine seasons are defined on the **CS** Record, shown at the bottom of the table. Reservoir data includes area (**RA**), required for evaporation, and elevation (**RE**), required for hydropower computations. The maximum rate-of-change for releases, both increasing and decreasing, are defined on the **R2** Record.

Table E.2 Peaking Energy Requirements Data (continued from Table E.1)

```
: continued from Table E.1
:
C **************** Adam Reservoir **********************************************
RL    55 -1557.3
RL     1      55      -1        867600
RL     2      55      -1       1369772
RL     3      55      -1       1956000
RL     4      55       9       1957000 1957000 1957000 1957000 1995200 1995200
RL                             1995200 1957000 1957000
RL     5      55      -1       2554000
RL     6      55      -1       3070000
RO
RS   -39       0     760     867     913     960    1009    1059    1085    1112
RS  1139    1166    1194    1222    1251    1280    1309    1339    1370    1401
RS  1432    1464    1496    1529    1561    1595    1629    1663    1698    1733
RS  1769    1805    1842    1879    1917    1957    1994    2034    2554    3070
RQ    39       0    1000    9750    9820    9870    9920    9970   10010   10050
RQ  9000    9000   10190   10230   10270   10300   10330   10370   10410   10450
RQ 10490   10530   10570   10610   10650   10690   10730   10770   10800   10830
RQ 10870   10910   10940   10980   11020   11060    9500    9500   11580   21850
RA    39       0   20508   22442   23217   24008   24833   25701   26159   26619
RA 27079   27535   27983   28432   28861   29291   29721   30153   30587   31023
RA 31461   31901   32343   32789   33238   33690   34147   34610   35079   35555
RA 36036   36522   37015   37515   38024   38542   39078   39638   47182   53300
RE    39    1420    1530    1535    1537    1539    1541    1543    1544    1545
RE  1546    1547    1548    1549    1550    1551    1552    1553    1554    1555
RE  1556    1557    1558    1559    1560    1561    1562    1563    1564    1565
RE  1566    1567    1568    1569    1570    1571    1572    1573    1585    1595
R2 12000   12000

C  == Adam Power Plant == 4 20 mW Generators, Operate 4hrs/day Monday-Friday
P1    55   80000    1.15       0  1433.6      50     .87     1.5
P2   2.3    9000
PR-.0595  -.0595  -.0595  -.1192  -.1192  -.1192  -.1192   -.089   -.089   -.089
PR-.0595  -.0595
PD     0      .2      .2      .2      .2      .2       0
PH    24       0       0       0       0       0       0     .25     .25     .25
PH   .25       0       0       0       0       0       0       0       0       0
PH     0       0       0       0       0
CP    55   15000
IDADAM RESERVOIR
RT    55      50
CS     9       1      32      60      90     121     181     273     335     365
:
: Continued in Table E.3
```

The hydropower data begin with the **P1** Record, which defines for location 55: the installed capacity, the overload ratio, and a constant capacity will be used (fields 1 through 4, respectively). Following those are: the tailwater elevation, the downstream reservoir for tailwater consideration, the efficiency, and a fixed head loss in feet. When the tailwater is multiply defined, the program will use the higher value for each time step. That is, the input tailwater elevation of 1433.6 will be used if higher than the pool elevation at location 50. The **P2** Record defines the leakage as 2.3 ft^3/s and the penstock capacity as 9000 ft^3/s.

The monthly energy requirements are defined on the **PR** Records. The negative sign indicates that the input is plant factor rather than energy. The energy requirements are computed by multiplying the plant factor times installed capacity times the duration of the month, in hours. The **PD** Record defines the daily distribution, Sunday through Saturday. The daily data indicates a uniform distribution of energy for Monday through Friday and no power requirements for the weekend. For the hourly simulation, the **PH** Records define the distribution during the day, starting with the number of values, 24. This indicates the following data is hourly, starting from midnight. *(Note for* **PH** *Records, all power reservoirs must have the same number of values.)* The hourly data define four hours of operation from 1 to 4 PM each weekday, as the comment information (**C** Record) states. The monthly plant factor 0.1192 is equivalent to operating the full 80,000 KW plant capacity for four hours per week day. (This will be shown in the output review for this example.)

E.3.3 Run-of-river Hydropower Data

The run-of-river data and the remainder of the input file are listed in Table E.3. The re-regulation dam, location 50, regulates the flow from Adam Reservoir and operates to meet flow goals at location 33 (**RO** Record). The lower reservoir has the same basic reservoir data as the others, with fewer data points and a constant storage for each level. The power data are similar too, except this project has a tailwater rating curve (**PQ** and **PT** Records) and there are no energy requirements on the **PR** Records.

The power data (**P1** Record) define a 6,000 MW capacity with a 1.2 overload factor, an 0.85 efficiency, and a 1.1 foot head loss. There is no **P2** Record, which is optional. The **PR** Records are required; however, the blank fields indicate that there are no energy requirements. This means that the reservoir will make releases for other purposes and the energy resulting from the release will be computed.

Looking at the reservoir **RO** Record indicates the reservoir operates for itself and downstream location 33. At the reservoir, there is a minimum desired flow requirement of 130 ft^3/s and a required flow of 25 ft^3/s (**CP** Record). The downstream location, Willeyburg, has a monthly minimum-flow schedule (**QM** Records). This means that the primary operation for the re-regulation reservoir will be to ensure that the minimum flow target at Willeyburg is met and to generate energy, up to the limit of its capacity, with the reservoir releases.

Table E.3 Run-of-river Hydropower Data (continued from Table E.2)

```
: continued from Table E.2
:

C ***************** Reregulation Dam below Adam Reservoir *********************
RL    50   11400     290    1500    1600   17500   18500   19300
RO     1      33
RS     6     290     750    4000   11000   17500   19300
RQ     6       0   11900   46900   72749   85905   87400
RA     6      50      80     610     787     870     890
RE     6    1407    1414    1424    1434    1442    1444
R2  3000    4000
C  == Reregulation Dam Power Plant, 6,000 kW, Run of River Operation ===========
P1    50    6000     1.2                             .85     1.1
PR
PR
PQ    20     100     400     800    1200    2000    5000   10000   20000
PT1400.2 1400.55 1401.27 1401.92 1402.45 1403.33 1405.75  1408.7 1413.11
CP    50   16000     120      35
IDREREG
RT    50      33

CP    70  999999
IDOTTOVILLE
RT    70      33

C **************** Green River at Willeyburg ***********************************
CP    33  999999
IDWILLEYBURG
RT    33
QM   755     925     950    1550    1600    1650    1700    1450    1400    1400
QM   755     755

ED
BF     2      48               86073100               1                     1900
ZR=IN80  A=ROCK RIVER   B=ANDREW RESERVOIR C=LOCAL FLOW  F=COMPUTED
ZR=IN70  A=ROCK RIVER   B=OTTOVILLE        C=LOCAL FLOW  F=COMPUTED
ZR=IN55  A=GREEN RIVER  B=ADAM RESERVOIR   C=LOCAL FLOW  F=COMPUTED
ZR=IN50  A=GREEN RIVER  B=REREG RESERVOIR  C=LOCAL FLOW  F=COMPUTED
ZR=IN33  A=GREEN RIVER  B=WILLEYBURG       C=LOCAL FLOW  F=COMPUTED
EJ
ER
```

*Note: Both this reservoir and Andrew Reservoir, location 80, operate for the downstream flow goal at location 33. When two reservoirs operate for the same downstream location, the reservoir at the higher level is given the priority to meet the downstream goal. This reservoir only has 1,000 acre-feet of storage between levels 4 and 5 (***RL** *Record). Location 80 has a variable storage allocation; however, it is always over 290,000 acre-feet. With the larger storage between Levels 4 and 5 at location 80, that reservoir will tend to provide more of the flow required to meet the downstream goal at 33. In system operations, the reservoirs are considered balanced when they are at the same level. To be balanced from Levels 5 to 4, Adam Reservoir would draw-down 290,000 acre-feet while the re-regulation reservoir draws down 1,000 acre-feet. The output review in Section E.3.6 describes this reservoirs operation.*

The flow data indicates 48 periods of one-hour flow will be processed, starting on 31 July 1986. Note: the century input is in field 10 of the **BF** Record. The flow data will be read from a DSS file based on the defined pathnames parts defined on the **ZR** Records.

E.3.4 Power Guide Curve Output

The first user table provides an overview of the entire reservoir system. Reservoir Case and Outflow shows the releases and the controlling purpose. For the two storage projects, the Case is mostly leakage (Case = 0.13) and hydropower generation based on energy requirement (Case = 0.10). And exception is Case - 0.14 for Adam Reservoir at 0800 and 0900 on 31 July. That indicates that the penstock capacity is limiting. Adam Reservoir operation is reviewed in Section E.3.5. The re-regulation operation is either for downstream flow goal (Case = 33.00) or at-site minimum flow (Case = 0.00) The re-regulation reservoir is reviewed in Section E.3.6.

Andrew Reservoir operation is presented in User Table 2, Figure E.5. Along with Case and Outflow are: Level, Energy Generated, Energy Required and Plant Factor. The hourly distribution for energy was for eight hours per week-day, starting at 0700. The input plant factor (**PF** Record) for 0.88 storage (Level = 2.88) is 0.125. However, the monthly multiplier (**PR** Records) is 1.25 for July and August. Therefore, the energy requirement is the product of the two values, making the required plant factor 0.1875. The output Plant Factor shows 0.19 for the eight periods a day of energy generation. When there is no energy requirement, the release is 1.50 ft^3/s and the Case is 0.13. Both consistent with the input leakage of 1.5 ft^3/s. The energy requirement gradually decreases for each period because the reservoir is at a lower storage level. The program interpolates the plant factor based on the power storage for each period. By the second day, the power storage is 87% (Level = 2.87).

Table E.4 Hydropower Example User Table 1

```
*USERS. 1    User Designed Output    (Dates shown are for END-of-Period)

                                                Summary by Period   Flood=       1
 Location No=             80.        80.        55.        55.        50.        50.        33.        33.
 J8/JZ Codes=             80.120     80.100     55.120     55.100     50.120     50.100     33.040     33.050

                       ANDREW RE  ANDREW RE  ADAM RESE  ADAM RESE  REREG      REREG      WILLEYBUR  WILLEYBUR
  Per  Date:  Hr Day    Case       Outflow    Case       Outflow    Case       Outflow    Flow Reg   Min Desi
    1 31Jul86  1 Thu       0.13       1.50       0.13       2.30      33.00    1441.05    1700.00    1700.00
    2 31Jul86  2 Thu       0.13       1.50       0.13       2.30      33.00    1440.26    1699.98    1700.00
    3 31Jul86  3 Thu       0.13       1.50       0.13       2.30      33.00    1439.49    1700.00    1700.00
    4 31Jul86  4 Thu       0.13       1.50       0.13       2.30      33.00    1438.72    1700.00    1700.00
    5 31Jul86  5 Thu       0.13       1.50       0.13       2.30      33.00    1437.91    1699.98    1700.00
    6 31Jul86  6 Thu       0.13       1.50       0.13       2.30      33.00    1437.13    1699.97    1700.00
    7 31Jul86  7 Thu       0.10    1416.74       0.10    8897.90       0.00     120.00    1798.86    1700.00
    8 31Jul86  8 Thu       0.10    1415.99       0.10    8966.13       0.00     120.00    1798.89    1700.00
    9 31Jul86  9 Thu       0.10    1415.25       0.14    9002.30       0.00     120.00    1798.93    1700.00
   10 31Jul86 10 Thu       0.10    1414.50       0.14    9002.30       0.00     120.00    1798.96    1700.00
   11 31Jul86 11 Thu       0.10    1413.75       0.13       2.30       0.00     120.00    1798.99    1700.00
   12 31Jul86 12 Thu       0.10    1413.01       0.13       2.30       0.00     120.00    1799.02    1700.00
   13 31Jul86 13 Thu       0.10    1412.27       0.13       2.30       0.00     120.00    1799.07    1700.00
   14 31Jul86 14 Thu       0.10    1411.53       0.13       2.30       0.00     120.00    1799.10    1700.00
   15 31Jul86 15 Thu       0.13       1.50       0.13       2.30      33.00    1430.14    1699.99    1700.00
   16 - 23 deleted.  The operation stays the same for the remainder of the day
    :
   24 31Jul86 24 Thu       0.13       1.50       0.13       2.30      33.00    1423.13    1700.00    1700.00
   25  1Aug86  1 Fri       0.13       1.50       0.13       2.30      33.00    1173.19    1449.99    1450.00
   26  1Aug86  2 Fri       0.13       1.50       0.13       2.30      33.00    1172.71    1449.98    1450.00
   27  1Aug86  3 Fri       0.13       1.50       0.13       2.30      33.00    1172.25    1450.00    1450.00
   28  1Aug86  4 Fri       0.13       1.50       0.13       2.30      33.00    1171.76    1450.00    1450.00
   29  1Aug86  5 Fri       0.13       1.50       0.13       2.30      33.00    1171.27    1449.98    1450.00
   30  1Aug86  6 Fri       0.13       1.50       0.13       2.30      33.00    1170.81    1450.00    1450.00
   31  1Aug86  7 Fri       0.10    1410.74       0.10    6730.70       0.00     120.00    1808.91    1450.00
   32  1Aug86  8 Fri       0.10    1410.01       0.10    6730.70       0.00     120.00    1808.65    1450.00
   33  1Aug86  9 Fri       0.10    1409.28       0.10    6730.70       0.00     120.00    1808.41    1450.00
   34  1Aug86 10 Fri       0.10    1408.56       0.10    6730.70       0.00     120.00    1808.17    1450.00
   35  1Aug86 11 Fri       0.10    1407.83       0.13       2.30       0.00     120.00    1807.91    1450.00
   36  1Aug86 12 Fri       0.10    1407.11       0.13       2.30       0.00     120.00    1807.67    1450.00
   37  1Aug86 13 Fri       0.10    1406.38       0.13       2.30       0.00     120.00    1807.41    1450.00
   38  1Aug86 14 Fri       0.10    1405.66       0.13       2.30       0.00     120.00    1807.18    1450.00
   39  1Aug86 15 Fri       0.13       1.50       0.13       2.30      33.00    1166.50    1450.00    1450.00
   40 - 47 deleted.  The operation stays the same for the remainder of the day
   48  1Aug86 24 Fri       0.13       1.50       0.13       2.30      33.00    1162.20    1450.00    1450.00
```

Table E.5 Andrew Reservoir Operation, User Table 2

```
*USERS. 2    User Designed Output    (Dates shown are for END-of-Period)

                                             Summary by Period   Flood=      1
Location No=         80.        80.        80.        80.        80.        80.
J8/JZ Codes=         80.120     80.100     80.130     80.160     80.150     80.350

                  ANDREW RE  ANDREW RE  ANDREW RE  ANDREW RE  ANDREW RE  ANDREW RE
 Per  Date:  Hr Day   Case     Outflow    Level      Energy G   Energy R   Plant Fa

   1 31Jul86  1 Thu   0.13        1.50       2.88       0.00       0.00       0.00
   2 31Jul86  2 Thu   0.13        1.50       2.88       0.00       0.00       0.00
   3 31Jul86  3 Thu   0.13        1.50       2.88       0.00       0.00       0.00
   4 31Jul86  4 Thu   0.13        1.50       2.88       0.00       0.00       0.00
   5 31Jul86  5 Thu   0.13        1.50       2.88       0.00       0.00       0.00
   6 31Jul86  6 Thu   0.13        1.50       2.88       0.00       0.00       0.00
   7 31Jul86  7 Thu   0.10     1416.74       2.88   15333.75   15333.75       0.19
   8 31Jul86  8 Thu   0.10     1415.99       2.88   15324.44   15324.44       0.19
   9 31Jul86  9 Thu   0.10     1415.25       2.88   15315.13   15315.13       0.19
  10 31Jul86 10 Thu   0.10     1414.50       2.88   15305.83   15305.83       0.19
  11 31Jul86 11 Thu   0.10     1413.75       2.88   15296.53   15296.53       0.19
  12 31Jul86 12 Thu   0.10     1413.01       2.88   15287.24   15287.24       0.19
  13 31Jul86 13 Thu   0.10     1412.27       2.88   15277.95   15277.95       0.19
  14 31Jul86 14 Thu   0.10     1411.53       2.88   15268.66   15268.66       0.19
  15 31Jul86 15 Thu   0.13        1.50       2.88       0.00       0.00       0.00
  16 31Jul86 16 Thu   0.13        1.50       2.88       0.00       0.00       0.00
  17 31Jul86 17 Thu   0.13        1.50       2.88       0.00       0.00       0.00
  18 31Jul86 18 Thu   0.13        1.50       2.88       0.00       0.00       0.00
  19 31Jul86 19 Thu   0.13        1.50       2.88       0.00       0.00       0.00
  20 31Jul86 20 Thu   0.13        1.50       2.88       0.00       0.00       0.00
  21 31Jul86 21 Thu   0.13        1.50       2.88       0.00       0.00       0.00
  22 31Jul86 22 Thu   0.13        1.50       2.88       0.00       0.00       0.00
  23 31Jul86 23 Thu   0.13        1.50       2.88       0.00       0.00       0.00
  24 31Jul86 24 Thu   0.13        1.50       2.88       0.00       0.00       0.00
  25  1Aug86  1 Fri   0.13        1.50       2.88       0.00       0.00       0.00
  26  1Aug86  2 Fri   0.13        1.50       2.88       0.00       0.00       0.00
  27  1Aug86  3 Fri   0.13        1.50       2.88       0.00       0.00       0.00
  28  1Aug86  4 Fri   0.13        1.50       2.88       0.00       0.00       0.00
  29  1Aug86  5 Fri   0.13        1.50       2.88       0.00       0.00       0.00
  30  1Aug86  6 Fri   0.13        1.50       2.88       0.00       0.00       0.00
  31  1Aug86  7 Fri   0.10     1410.74       2.87   15258.74   15258.74       0.19
  32  1Aug86  8 Fri   0.10     1410.01       2.87   15249.61   15249.61       0.19
  33  1Aug86  9 Fri   0.10     1409.28       2.87   15240.50   15240.50       0.19
  34  1Aug86 10 Fri   0.10     1408.56       2.87   15231.39   15231.39       0.19
  35  1Aug86 11 Fri   0.10     1407.83       2.87   15222.30   15222.30       0.19
  36  1Aug86 12 Fri   0.10     1407.11       2.87   15213.22   15213.22       0.19
  37  1Aug86 13 Fri   0.10     1406.38       2.87   15204.14   15204.14       0.19
  38  1Aug86 14 Fri   0.10     1405.66       2.87   15195.08   15195.08       0.19
  39  1Aug86 15 Fri   0.13        1.50       2.87       0.00       0.00       0.00
  40  1Aug86 16 Fri   0.13        1.50       2.87       0.00       0.00       0.00
  41  1Aug86 17 Fri   0.13        1.50       2.87       0.00       0.00       0.00
  42  1Aug86 18 Fri   0.13        1.50       2.87       0.00       0.00       0.00
  43  1Aug86 19 Fri   0.13        1.50       2.87       0.00       0.00       0.00
  44  1Aug86 20 Fri   0.13        1.50       2.87       0.00       0.00       0.00
  45  1Aug86 21 Fri   0.13        1.50       2.87       0.00       0.00       0.00
  46  1Aug86 22 Fri   0.13        1.50       2.87       0.00       0.00       0.00
  47  1Aug86 23 Fri   0.13        1.50       2.87       0.00       0.00       0.00
  48  1Aug86 24 Fri   0.13        1.50       2.87       0.00       0.00       0.00

              Sum =   5.76    22626.61     137.99  244224.50  244224.50       3.04
              Max =   0.13     1416.74       2.88   15333.75   15333.75       0.19
              Min =   0.10        1.50       2.87       0.00       0.00       0.00
              PMax=   1.00        7.00       1.00       7.00       7.00       7.00
              Avg =   0.12      471.39       2.87    5088.01    5088.01       0.06
              PMin=   7.00        1.00      38.00       1.00       1.00       1.00
```

E.3.5 Peaking Hydropower Output

Users Table 3 shows the operation of Adam Reservoir for hydropower demands. The output is shown in Table E.6, with minor editing to fit the page. Recalling that the reservoir operates four hours each week-day for hydroelectric energy, the initial six periods (hours) show an outflow of 2.30 ft^3/s and a case of 0.13. The case indicates the release is for leakage, as defined. There is no energy required.

For periods 7 through 10, the release is to meet hydropower demand. The Case = 0.10 indicates hydropower release. However, for periods 9 and 10, the Case is 0.14 indicating that the penstock capacity (9,000 ft^3/s) is limiting hydropower release. The outflow is 9,002.3 ft^3/s, which represents the penstock capacity plus the leakage of 2.3 ft^3/s. (Leakage is assumed to be continuous.) After the four hours of hydropower operation, the release is zero plus leakage.

The other data in Users. 3 are: Reservoir Level, Energy Generated, Energy Required, and Plant Factor. You can see by the Energy Generated during periods 9 and 10 did not equal requirement due to the penstock-limited release. The cause is the decrease in power head, due to the low pool level.

The second day of the simulation, August 1, has a different energy requirement and downstream low-flow goal. Again the reservoir operates for hydropower, starting at 7:00 am. With the lower energy demand, the reservoir is able to meet the demand with releases from 6,733 to 6,851 ft^3/s. Because these releases are well within the penstock limit, the cases all indicate 0.10 for these four periods and the energy required is met. Also, the plant factors indicate 0.75, which is consistent with three of the four units running.

When the hydropower requirements are zero, the reservoir release is zero and the only outflow is the leakage value of 2.3 ft^3/s and the Case is 0.13 for the rest of the day.

Table E.6 Adam Reservoir Operation, User Table 3

*USERS. 3   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood=   1

Location No=				55.	55.	55.	55.	55.	55.
J8/JZ Codes=				55.120	55.100	55.130	55.160	55.150	55.350
				ADAM RES	ADAM RES	ADAM RES	ADAM RES	ADAM RES	ADAM RES
Per	Date:	Hr	Day	Case	Outflow	Level	Energy G	Energy R	Plant Fa
1	31Jul86	1	Thu	0.13	2.30	2.18	0.00	0.00	0.00
2	31Jul86	2	Thu	0.13	2.30	2.18	0.00	0.00	0.00
3	31Jul86	3	Thu	0.13	2.30	2.18	0.00	0.00	0.00
4	31Jul86	4	Thu	0.13	2.30	2.18	0.00	0.00	0.00
5	31Jul86	5	Thu	0.13	2.30	2.18	0.00	0.00	0.00
6	31Jul86	6	Thu	0.13	2.30	2.18	0.00	0.00	0.00
7	31Jul86	7	Thu	0.10	8897.90	2.18	80000.00	80000.00	1.00
8	31Jul86	8	Thu	0.10	8966.13	2.17	80000.00	80000.00	1.00
9	31Jul86	9	Thu	0.14	9002.30	2.17	79711.48	80000.00	1.00
10	31Jul86	10	Thu	0.14	9002.30	2.17	79097.59	80000.00	0.99
11	31Jul86	11	Thu	0.13	2.30	2.17	0.00	0.00	0.00
12	31Jul86	12	Thu	0.13	2.30	2.17	0.00	0.00	0.00
13	31Jul86	13	Thu	0.13	2.30	2.17	0.00	0.00	0.00
14	31Jul86	14	Thu	0.13	2.30	2.17	0.00	0.00	0.00
15	31Jul86	15	Thu	0.13	2.30	2.17	0.00	0.00	0.00
16	31Jul86	16	Thu	0.13	2.30	2.17	0.00	0.00	0.00
17	31Jul86	17	Thu	0.13	2.30	2.17	0.00	0.00	0.00
18	31Jul86	18	Thu	0.13	2.30	2.17	0.00	0.00	0.00
19	31Jul86	19	Thu	0.13	2.30	2.17	0.00	0.00	0.00
20	31Jul86	20	Thu	0.13	2.30	2.17	0.00	0.00	0.00
21	31Jul86	21	Thu	0.13	2.30	2.17	0.00	0.00	0.00
22	31Jul86	22	Thu	0.13	2.30	2.17	0.00	0.00	0.00
23	31Jul86	23	Thu	0.13	2.30	2.17	0.00	0.00	0.00
24	31Jul86	24	Thu	0.13	2.30	2.17	0.00	0.00	0.00
25	1Aug86	1	Fri	0.13	2.30	2.17	0.00	0.00	0.00
26	1Aug86	2	Fri	0.13	2.30	2.17	0.00	0.00	0.00
27	1Aug86	3	Fri	0.13	2.30	2.17	0.00	0.00	0.00
28	1Aug86	4	Fri	0.13	2.30	2.17	0.00	0.00	0.00
29	1Aug86	5	Fri	0.13	2.30	2.17	0.00	0.00	0.00
30	1Aug86	6	Fri	0.13	2.30	2.17	0.00	0.00	0.00
31	1Aug86	7	Fri	0.10	6733.80	2.17	59808.00	59808.00	0.75
32	1Aug86	8	Fri	0.10	6772.42	2.17	59808.01	59808.00	0.75
33	1Aug86	9	Fri	0.10	6811.72	2.17	59808.01	59808.00	0.75
34	1Aug86	10	Fri	0.10	6851.71	2.17	59808.01	59808.00	0.75
35	1Aug86	11	Fri	0.13	2.30	2.17	0.00	0.00	0.00
36	1Aug86	12	Fri	0.13	2.30	2.17	0.00	0.00	0.00
37	1Aug86	13	Fri	0.13	2.30	2.17	0.00	0.00	0.00
38	1Aug86	14	Fri	0.13	2.30	2.17	0.00	0.00	0.00
39	1Aug86	15	Fri	0.13	2.30	2.17	0.00	0.00	0.00
40	1Aug86	16	Fri	0.13	2.30	2.17	0.00	0.00	0.00
41	1Aug86	17	Fri	0.13	2.30	2.17	0.00	0.00	0.00
42	1Aug86	18	Fri	0.13	2.30	2.17	0.00	0.00	0.00
43	1Aug86	19	Fri	0.13	2.30	2.17	0.00	0.00	0.00
44	1Aug86	20	Fri	0.13	2.30	2.17	0.00	0.00	0.00
45	1Aug86	21	Fri	0.13	2.30	2.17	0.00	0.00	0.00
46	1Aug86	22	Fri	0.13	2.30	2.17	0.00	0.00	0.00
47	1Aug86	23	Fri	0.13	2.30	2.17	0.00	0.00	0.00
48	1Aug86	24	Fri	0.13	2.30	2.17	0.00	0.00	0.00
			Sum =	6.08	63130.30	104.26	558041.06	559232.00	6.99
			Max =	0.14	9002.30	2.18	80000.00	80000.00	1.00
			Min =	0.10	2.30	2.17	0.00	0.00	0.00
			PMax=	9.00	9.00	1.00	7.00	7.00	7.00
			Avg =	0.13	1315.21	2.17	11625.86	11650.67	0.15
			PMin=	7.00	1.00	34.00	1.00	1.00	1.00

E.3.6 Run-of-river Hydropower Output

The Re-Regulation Reservoir output is shown in Users. 4, listed in Table E.7. Again, the upper reservoir, Adam, only operates for hydropower four hours during the five week-days. The lower, re-regulation, reservoir operates for downstream flow goals and incidently produces hydropower. There is no required energy at this site.

The Case variable shows 33.00 or 0.00 for all periods. Location 33 is the downstream location Willeyburg. The reservoir is operating for the downstream location and, during July, the flow goal is 1,700 ft^3/s and in August the goal is 1,450 ft^3/s. Looking back to User 1, Table E.4, during the first six periods the Flow Regulated at Willeyburg is 1700 ft^3/s. Then during the next eight periods the regulated flow is greater than 1700 ft^3/s. Also note, during those periods Andrew reservoir is releasing for hydropower. With that information, the release schedule for the re-regulation reservoir makes sense. When Andrew Reservoir operates for hydropower, the re-regulation reservoir only needs to make a small release to meet the flow goal at Willeyburg. However, the minimum release is 120 ft^3/s. Therefore, during the eight hours of power releases on the West Branch, the reservoir operates for its minimum release. The remaining hours, the re-regulation reservoir operates for location 33 because there are no power releases on the other branch.

The Level and Energy Generated shows the affect of the hydropower cycle on the East Branch. The inflow to the re-regulation reservoir comes exclusively from the upper reservoir release. Therefore, the inflow is the leakage value of 2.3 ft^3/s until the hydropower is generated for four hours. During generation, the inflow exceed the required outflow to meet downstream demand and the pool level rises. Then, with the higher pool level, the energy generated is greater for approximately the same release. During the remaining time, the release draws the pool level down. As the pool draws down, the energy generated decreases. The weekend operation, with no hydropower release, will be most critical for the re-regulation dam to meet the downstream demand with essentially no inflow. This simulation does not extend into the weekend.

Table E.7 Re-Regulation Reservoir Operation, User Table 4

*USERS. 4 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

Location No=				50.	50.	50.	50.	50.	50.
J8/JZ Codes=				50.120	50.100	50.130	50.160	50.150	50.350
				REREG	REREG	REREG	REREG	REREG	REREG
Per	Date:	Hr	Day	Case	Outflow	Level	Energy G	Energy R	Plant Fa
1	31Jul86	1	Thu	33.00	1441.05	3.61	3171.36	0.00	0.53
2	31Jul86	2	Thu	33.00	1440.26	3.60	3154.53	0.00	0.53
3	31Jul86	3	Thu	33.00	1439.49	3.59	3137.78	0.00	0.52
4	31Jul86	4	Thu	33.00	1438.72	3.59	3120.71	0.00	0.52
5	31Jul86	5	Thu	33.00	1437.91	3.58	3101.49	0.00	0.52
6	31Jul86	6	Thu	33.00	1437.13	3.57	3082.35	0.00	0.51
7	31Jul86	7	Thu	0.00	120.00	3.62	279.26	0.00	0.05
8	31Jul86	8	Thu	0.00	120.00	3.66	286.99	0.00	0.05
9	31Jul86	9	Thu	0.00	120.00	3.71	294.77	0.00	0.05
10	31Jul86	10	Thu	0.00	120.00	3.76	302.57	0.00	0.05
11	31Jul86	11	Thu	0.00	120.00	3.75	306.41	0.00	0.05
12	31Jul86	12	Thu	0.00	120.00	3.75	306.31	0.00	0.05
13	31Jul86	13	Thu	0.00	120.00	3.75	306.20	0.00	0.05
14	31Jul86	14	Thu	0.00	120.00	3.75	306.10	0.00	0.05
15	31Jul86	15	Thu	33.00	1430.14	3.75	3423.40	0.00	0.57
16	31Jul86	16	Thu	33.00	1429.36	3.74	3406.67	0.00	0.57
17	31Jul86	17	Thu	33.00	1428.58	3.73	3389.97	0.00	0.56
18	31Jul86	18	Thu	33.00	1427.80	3.72	3373.29	0.00	0.56
19	31Jul86	19	Thu	33.00	1427.00	3.72	3356.59	0.00	0.56
20	31Jul86	20	Thu	33.00	1426.25	3.71	3340.02	0.00	0.56
21	31Jul86	21	Thu	33.00	1425.47	3.70	3323.42	0.00	0.55
22	31Jul86	22	Thu	33.00	1424.69	3.69	3306.84	0.00	0.55
23	31Jul86	23	Thu	33.00	1423.89	3.69	3290.25	0.00	0.55
24	31Jul86	24	Thu	33.00	1423.13	3.68	3273.74	0.00	0.55
25	1Aug86	1	Fri	33.00	1173.19	3.67	2711.36	0.00	0.45
26	1Aug86	2	Fri	33.00	1172.71	3.67	2700.26	0.00	0.45
27	1Aug86	3	Fri	33.00	1172.25	3.66	2689.20	0.00	0.45
28	1Aug86	4	Fri	33.00	1171.76	3.65	2678.10	0.00	0.45
29	1Aug86	5	Fri	33.00	1171.27	3.65	2667.03	0.00	0.44
30	1Aug86	6	Fri	33.00	1170.81	3.64	2656.00	0.00	0.44
31	1Aug86	7	Fri	0.00	120.00	3.68	290.26	0.00	0.05
32	1Aug86	8	Fri	0.00	120.00	3.71	296.06	0.00	0.05
33	1Aug86	9	Fri	0.00	120.00	3.75	301.86	0.00	0.05
34	1Aug86	10	Fri	0.00	120.00	3.78	307.66	0.00	0.05
35	1Aug86	11	Fri	0.00	120.00	3.78	310.51	0.00	0.05
36	1Aug86	12	Fri	0.00	120.00	3.78	310.41	0.00	0.05
37	1Aug86	13	Fri	0.00	120.00	3.78	310.30	0.00	0.05
38	1Aug86	14	Fri	0.00	120.00	3.78	310.20	0.00	0.05
39	1Aug86	15	Fri	33.00	1166.50	3.77	2858.28	0.00	0.48
40	1Aug86	16	Fri	33.00	1166.03	3.77	2847.24	0.00	0.47
41	1Aug86	17	Fri	33.00	1165.55	3.76	2836.19	0.00	0.47
42	1Aug86	18	Fri	33.00	1165.07	3.75	2825.16	0.00	0.47
43	1Aug86	19	Fri	33.00	1164.59	3.75	2814.14	0.00	0.47
44	1Aug86	20	Fri	33.00	1164.11	3.74	2803.12	0.00	0.47
45	1Aug86	21	Fri	33.00	1163.63	3.73	2792.13	0.00	0.47
46	1Aug86	22	Fri	33.00	1163.13	3.73	2781.08	0.00	0.46
47	1Aug86	23	Fri	33.00	1162.66	3.72	2770.13	0.00	0.46
48	1Aug86	24	Fri	33.00	1162.20	3.72	2759.23	0.00	0.46
			Sum =	056.00	43496.33	177.83	101266.91	0.00	16.87
			Max =	33.00	1441.05	3.78	3423.40	0.00	0.57
			Min =	0.00	120.00	3.57	279.26	0.00	0.05
			PMax=	1.00	1.00	34.00	15.00	1.00	15.00
			Avg =	22.00	906.17	3.70	2109.73	0.00	0.35
			PMin=	7.00	7.00	6.00	7.00	1.00	7.00

E.4 Pumped-Storage

The pumped storage capability in HEC-5 is applicable to either an adjacent (off stream) or integral (pump-back) configuration. The energy available for pumping is input. Based on the available energy, the program computes the pumped discharge for each time step, subject to storage capacity, available water and flow constraints. Example 8 modifies the re-regulation reservoir from Example 7 into a pump-back reservoir model operating with the upstream Adam Reservoir. The following sections describe the data input and output.

E.4.1 Pumped-Storage Data

To model a pump in a hydropower system, a dummy reservoir is added, just upstream from the upper reservoir, to describe the pumping capabilities. The pump data from Example 8 are shown in Table E.8. Basic reservoir and control point data are required for dummy reservoir (as shown for Reservoir 155). The reservoir has no storage allocated, operates for no downstream locations, and has an unlimited outlet capacity.

Table E.8. Pump-back Data from Example 8

```
T1      HEC-5 Example 8, Pumped Storage Hydropower Model   (EXAMPLE8.DAT)
T2      Pumped Storage with Re-Regulation Reservoir and Downstream Flow Goal
T3      Green River, Adam Reservoir to Willeyburg, 3-Hour Flow Data
J1     0       1       5       3       4       2
J2    24       1
J3     4                                      -1
J8 55.16   55.15   55.35   55.13   55.12   55.10   50.13   50.12   50.10   10.04
J8155.15  155.16  155.00  155.03   55.09   55.10   50.09   50.10
JZ 55.13   50.13   55.16   55.23  155.15  155.16   55.10   50.10   10.04
C =================== Pumpback at Adam Reservoir ==============================
RL   155
RO
RS     2       1     100
RQ     2     100      -1
RE     2       1      10
C  == Adam Reservoir Pumpback == 1 24 mW Pump Unit ============================
P1   155  -24000       1                      50     .75     2.1
P2     0    5500
PR -.375   -.375   -.375   -.375   -.375   -.375   -.375   -.375   -.375   -.375
PR -.375   -.375
C  ==  Energy Available 9hrs/day (8 pm - 5 am) Sunday - Saturday ===============
PD  .142    .143    .143    .143    .143    .143    .143
PH     8  0.3333  0.2223       0       0       0       0  0.1111  0.3333
CP   155  999999
IDPUMPBACK
RT   155      55
DR   155      50       0       0       0       0      -3
C =================== Adam Reservoir (Pumped Storage Project) =================
```

The power data for a pump is indicated by a negative capacity (-24,000 kW) in the second field of the **P1** Record for the pump-back data. The program "knows" that the input power data are for pumping, not generation. The tailwater should be based on the lower reservoir (the pumping supply source), which is the re-regulation reservoir at location 50, defined in field 6. (The minimum tailwater elevation can be specified in field 5.) The efficiency is the pumping efficiency (e.g., 0.75 input in field 7). A fixed head loss for pumping is input in field 8 (e.g., 2.1 feet). The optional **P2** Record, in fields 1 and 2, defines no leakage and a pumping penstock capacity of 5,500 ft^3/s.

The energy available to pump is input to the program as monthly plant factors on the **PR** Records. The plant factors are based on the number of hours per day that energy is available for pumping. For pumped-storage simulation with daily or multiple-hourly time intervals, **PD** and **PH** Records should also be used. In Example 8, the daily distribution is uniform, **PD** Records. The eight three-hour blocks of hourly distribution, on the **PH** Record, show energy is available during the first two and last two blocks of time. The ratios represent 0.3333 for all three hours, 0.22223 for two hours and 0.1111 for one hour. Thus, the data suggests that energy is available from 8 PM to 5 AM, as stated on the Comment Record.

Control point data include the **RT** Record, which indicates the dummy routes to the upper reservoir (e.g., Reservoir 55) with no routing lag. A diversion record (**DR**) is required to convey the pump-back discharge into the upper reservoir. The diversion record is input with the dummy reservoir data. The diversion is indicated from the dummy (Reservoir 155) to the downstream source of water (Reservoir 50). The diversion type is -3 (**DR** Record, field 7) for pump-back simulation. The computed pump-back discharges are carried by the program as diversions from Reservoir 50 to Reservoir 155. The diversions are then routed into Reservoir 55 based on an unlimited outlet capacity and zero lag routing criteria.

In the HEC-5 simulation, water will be pumped to the upper reservoir using all the available energy; however pumping will stop if the upstream pool reaches the top-of-conservation level or the lower pool draws below the buffer level. The maximum pump-back level can be set to a lower level than the top-of-conservation pool by defining an intermediate pump-back level on the **J1** Record, field 7.

The pump-back reservoir's data, for the power generation cycle of operation, follows the pumping data defined at the "dummy" reservoir. Adams Reservoir, location 55, data are the same as the data in Example 7, described in the previous Hydropower Model. The input is shown in Table E.8. Minor differences include the hourly distribution of power requirements are defined in eight 3-hour blocks instead of 24 hourly values. Remember that all **PH** Records must have the same number of values in an HEC-5 model. Also, while the starting storage is input in the **RL** Record, the actual starting storage is input with the time-series data on **SS** Records, shown at the end of Table E.10.

Table E.9. Pump-back Data from Example 8 (continued)

```
: Continued from Table E.8
:
C =================== Adam Reservoir (Pumped Storage Project) =================
RL    55 1995200
RL     1      55      -1         867600
RL     2      55       9        1369772 1400771 1400771 1400771 1400771 1400771
RL                              1400771 1400771 1369772
RL     3      55       9        1957000 1957000 1957000 1957000 1995200 1995200
RL                              1995200 1957000 1957000
RL     4      55      -1        2554000
RL     5      55      -1        3070000
RO
RS   -39       0     760     867     913     960    1009    1059    1085    1112
RS  1139    1166    1194    1222    1251    1280    1309    1339    1370    1401
RS  1432    1464    1496    1529    1561    1595    1629    1663    1698    1733
RS  1769    1805    1842    1879    1917    1957    1994    2034    2554    3070
RQ    39       0    1000    9750    9820    9870    9920    9970   10010   10050
RQ  9000    9000   10190   10230   10270   10300   10330   10370   10410   10450
RQ 10490   10530   10570   10610   10650   10690   10730   10770   10800   10830
RQ 10870   10910   10940   10980   11020   11060    9500    9500   11580   21850
RA    39       0   20508   22442   23217   24008   24833   25701   26159   26619
RA 27079   27535   27983   28432   28861   29291   29721   30153   30587   31023
RA 31461   31901   32343   32789   33238   33690   34147   34610   35079   35555
RA 36036   36522   37015   37515   38024   38542   39078   39638   47182   53300
RE    39    1420    1530    1535    1537    1539    1541    1543    1544    1545
RE  1546    1547    1548    1549    1550    1551    1552    1553    1554    1555
RE  1556    1557    1558    1559    1560    1561    1562    1563    1564    1565
RE  1566    1567    1568    1569    1570    1571    1572    1573    1585    1595
R2 12000   12000
R3  -2.7    -2.0    -1.6     0.3     3.4     2.5     2.0     0.9     1.9     1.6
R3  -0.8    -1.6
C  == Adam Power Plant == 4 20 MW Generators ==================================
P1    55   80000    1.15       0  1433.6      50     .87     1.5
P2   2.3    9000
PR-.0893  -.0893  -.0893  -.1786  -.1786  -.1786  -.1786   -.134   -.134   -.134
PR-.0893  -.0893
C  ==  Required Generation 6hrs/day (6am - 12 noon) Monday - Friday ============
PD     0      .2      .2      .2      .2      .2       0
PH     8       0       0      .5      .5       0       0       0       0
CP    55   15000
IDADAM RESERVOIR
RT    55      50
CS     9       1      32      60      90     121     181     273     335     365
 :
```

The re-regulation reservoir, location 50, is immediately below Adam Reservoir, the pump-back reservoir. This reservoir is the source for pump-back water, as described above. The data are listed in Table E.10. As in Example 7, the reservoir does not have specified power requirements, the **PR** Records are blank. The reservoir operates for its own minimum flow of 100 ft^3/s and the downstream location 10 flow-goal of 1,100 ft^3/s. The energy generated will be computed based on the releases made for other purposes.

Table E.10. Pump-back Data from Example 8 (continued)

```
: Continued from Table E.9
:

C ***************** Re-Regulation Dam below Adam Reservoir ********************
RL    50    1500     290    1500   17500   18500   19300
RO     1      10
RS     6     290     750    4000   11000   17500   19300
RQ     6       0   11900   46900   72749   85905   87400
RA     6      50      80     610     787     870     890
RE     6    1407    1414    1424    1434    1442    1444
R3  -2.7    -2.0    -1.6     0.3     3.4     2.5     2.0     0.9     1.9     1.6
R3  -0.8    -1.6
C  == Re-Regulation Dam Power Plant, 6,000 kW, Run of River Operation ==========
P1    50    6000     1.2                             .85     1.1
PR
PR
PQ    20     100     400     800    1200    2000    5000   10000   20000
PT1400.2 1400.55 1401.27 1401.92 1402.45 1403.33 1405.75  1408.7 1413.11
CP    50   17500     100
IDREREG
RT    50      10

C **************** Green River at Willeyburg ************************************
CP    10  999999    1100
IDWILLEYBURG
RT    10

ED
BF     2      56            86050500              3                   1900
SS    55-1571.35
SS    50 -1428.1
ZR=IN55  A=GREEN RIVER  B=ADAM RESERVOIR   C=LOCAL FLOW  F=COMPUTED
ZR=IN50  A=GREEN RIVER  B=REREG            C=LOCAL FLOW  F=COMPUTED
ZR=IN10  A=GREEN RIVER  B=WILLEYBURG       C=LOCAL FLOW  F=COMPUTED
ZW      A=EXAMPLE 8  F=PUMPED STORAGE SIMULATION
EJ
ER
```

The downstream location, Willeyburg, has the target flow of 1,100 ft^3/s. This location ends the reservoir model.

The time-series data (**BF**) indicates 56 periods starting on 5 May 1986 with 3-hour data. The starting storage for locations 55 and 50 is defined with **SS** Records and the negative values indicate reservoir elevation, rather than storage. The flow data are read from DSS records, as defined by input pathnames. Output data written to DSS will have EXAMPLE 8 as the A-part and PUMPED STORAGE SIMULATION as the F-Part, **ZW** Record.

E.4.2 Pumped-Storage Output

The User. 1 table shows the operation of Adam Reservoir and the re-regulation reservoir. The first three days, 24 periods, are listed in Table E.11. The output shows Adam Reservoir operating for hydropower two periods each day, the re-regulation reservoir operating for location 10, and 1,100 ft^3/s at that location.

Table E.11 Pump-back Operation, Users Table 1

*USERS. 1   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood= 1

Location No=			55.	55.	55.	55.	55.	55.	50.	50.	50.	10.
J8/JZ Codes=			55.160	55.150	55.350	55.130	55.120	55.100	50.130	50.120	50.100	10.040
			ADAM RES	ADAM RES	ADAM RES	ADAM RES	ADAM RES	ADAM RES	REREG	REREG	REREG	WILLEYBUR
Per	Date:	Hr Day	Energy G	Energy R	Plant Fa	Level	Case	Outflow	Level	Case	Outflow	Flow Reg
1	5May86	3 Mon	0.00	0.00	0.00	2.96	0.13	2.30	2.30	10.00	955.31	1100.00
2	5May86	6 Mon	0.00	0.00	0.00	2.96	0.13	2.30	2.27	10.00	958.14	1100.00
3	5May86	9 Mon	240000.02	240000.00	1.00	2.96	0.10	7980.21	2.38	10.00	965.59	1100.00
4	5May86	12 Mon	240000.00	240000.00	1.00	2.95	0.10	7983.28	2.49	10.00	973.03	1100.00
5	5May86	15 Mon	0.00	0.00	0.00	2.95	0.13	2.30	2.48	10.00	980.47	1100.00
6	5May86	18 Mon	0.00	0.00	0.00	2.95	0.13	2.30	2.46	10.00	987.92	1100.00
7	5May86	21 Mon	0.00	0.00	0.00	2.95	0.13	2.30	2.44	10.00	995.36	1100.00
8	5May86	24 Mon	0.00	0.00	0.00	2.95	0.13	2.30	2.40	10.00	995.26	1100.00
9	6May86	3 Tue	0.00	0.00	0.00	2.95	0.13	2.30	2.36	10.00	995.16	1100.00
10	6May86	6 Tue	0.00	0.00	0.00	2.95	0.13	2.30	2.33	10.00	995.06	1100.00
11	6May86	9 Tue	240000.00	240000.00	1.00	2.95	0.10	7984.25	2.44	10.00	993.63	1100.00
12	6May86	12 Tue	240000.02	240000.00	1.00	2.95	0.10	7987.33	2.55	10.00	992.20	1100.00
13	6May86	15 Tue	0.00	0.00	0.00	2.95	0.13	2.30	2.54	10.00	990.77	1100.00
14	6May86	18 Tue	0.00	0.00	0.00	2.95	0.13	2.30	2.52	10.00	989.34	1100.00
15	6May86	21 Tue	0.00	0.00	0.00	2.95	0.13	2.30	2.50	10.00	987.91	1100.00
16	6May86	24 Tue	0.00	0.00	0.00	2.95	0.13	2.30	2.47	10.00	989.04	1100.00
17	7May86	3 Wed	0.00	0.00	0.00	2.95	0.13	2.30	2.43	10.00	990.17	1100.00
18	7May86	6 Wed	0.00	0.00	0.00	2.95	0.13	2.30	2.40	10.00	991.31	1100.00
19	7May86	9 Wed	240000.02	240000.00	1.00	2.95	0.10	7988.27	2.51	10.00	986.33	1100.00
20	7May86	12 Wed	240000.00	240000.00	1.00	2.94	0.10	7991.35	2.62	10.00	981.35	1100.00
21	7May86	15 Wed	0.00	0.00	0.00	2.94	0.13	2.30	2.60	10.00	976.37	1100.00
22	7May86	18 Wed	0.00	0.00	0.00	2.94	0.13	2.30	2.59	10.00	971.39	1100.00
23	7May86	21 Wed	0.00	0.00	0.00	2.94	0.13	2.30	2.57	10.00	966.41	1100.00
24	7May86	24 Wed	0.00	0.00	0.00	2.94	0.13	2.30	2.53	10.00	959.94	1100.00

:

: *Periods 25 - 56 omitted*

The pump-back operation and the continuity of flow is shown in User. 2, with the first 24 periods shown in Table E.12. There is no special output for pump-back operation; the basic hydropower variables and diversion are used. Looking at Table E.12, the "`PUMPBACK Energy R`" is the energy available for pumping. The "`Energy G`" is the energy used, not generated. The "`Change`" column is the difference between the preceding two columns. That column shows that the available energy was used for pumping. The water pumped back is shown as a negative diversion, "`PUMPBACK Diveriso`." A negative diversion indicates a gain instead of loss to the reservoir.

The Inflow to Adam Reservoir is the reservoir inflow plus the diversion. The outflow from Adam reflects the leakage value of 2.3 ft^3/s or the hydropower release for two periods each day.

The Inflow to the re-regulation reservoir is both negative and positive. The inflow is the net value, reflecting pump-back "diversions," local flow, and releases from Adam Reservoir. The outflow for the re-regulation dam is the release to meet the downstream flow goal, as noted in the review of User 1.

The third user table shows the reservoir levels, energy generated, energy used, the outflows and the resulting downstream regulated flow. The first 24 periods are listed in Table E.13. The Adam Reservoir level shows the advantage of pump-back operation. The releases for energy lower the pool level; however, the pump-back operation tends to recover the water and resupply Adam Reservoir.

The complement operation is shown in the re-regulation level. Releases from Adam raise the regulation reservoir level, while pump-back diversions and outflow lower the level. By balancing the pumping and generation cycles, the reservoir can maintain the downstream flow goal at Willeyburg and have sufficient water supply to pump to the limit of available energy. The critical time comes during the weekend when there are no power releases from Adam Reservoir. While not shown in the tables here, the re-regulation reservoir was able to meet the weekend operation for the simulation period. Review the complete output for Example 8 to see the full week operation.

Table E.12 Pump-back Operation, Users Table 2

*USERS. 2 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

Location No=				155.	155.	155.	155.	55.	55.	50.	50.
J8/JZ Codes=				155.150	155.160	155.000	155.030	55.090	55.100	50.090	50.100
				PUMPBACK	PUMPBACK	PUMPBACK	PUMPBACK	ADAM RESE	ADAM RESE	REREG	REREG
Per	Date:	Hr	Day	Energy R	Energy G	Change	Diversio	Inflow	Outflow	Inflow	Outflow
1	5May86	3	Mon	72000.00	72000.00	0.00	-1463.82	1801.53	2.30	-1392.26	955.31
2	5May86	6	Mon	48064.82	48062.09	2.73	-971.51	1308.69	2.30	-900.08	958.14
3	5May86	9	Mon	0.00	0.00	0.00	0.00	336.97	7980.21	8049.21	965.59
4	5May86	12	Mon	0.00	0.00	0.00	0.00	336.76	7983.28	8052.17	973.03
5	5May86	15	Mon	0.00	0.00	0.00	0.00	336.55	2.30	71.09	980.47
6	5May86	18	Mon	0.00	0.00	0.00	0.00	336.34	2.30	70.99	987.92
7	5May86	21	Mon	24021.60	24021.31	0.29	-498.51	834.64	2.30	-427.60	995.36
8	5May86	24	Mon	72000.00	71997.48	2.52	-1488.78	1825.44	2.30	-1417.95	995.26
9	6May86	3	Tue	72000.00	71997.49	2.51	-1479.81	1816.99	2.30	-1409.05	995.16
10	6May86	6	Tue	48064.82	48063.72	1.10	-981.99	1319.70	2.30	-911.30	995.06
11	6May86	9	Tue	0.00	0.00	0.00	0.00	338.45	7984.25	8052.58	993.63
12	6May86	12	Tue	0.00	0.00	0.00	0.00	339.18	7987.33	8055.60	992.20
13	6May86	15	Tue	0.00	0.00	0.00	0.00	339.92	2.30	70.51	990.77
14	6May86	18	Tue	0.00	0.00	0.00	0.00	340.66	2.30	70.46	989.34
15	6May86	21	Tue	24021.60	24021.31	0.29	-503.90	845.29	2.30	-433.50	987.91
16	6May86	24	Tue	72000.00	71997.39	2.61	-1504.84	1847.97	2.30	-1434.49	989.04
17	7May86	3	Wed	72000.00	71997.41	2.59	-1495.62	1840.49	2.30	-1425.32	990.17
18	7May86	6	Wed	48064.82	48063.67	1.15	-992.40	1339.00	2.30	-922.16	991.31
19	7May86	9	Wed	0.00	0.00	0.00	0.00	348.34	7988.27	8056.14	986.33
20	7May86	12	Wed	0.00	0.00	0.00	0.00	350.08	7991.35	8059.15	981.35
21	7May86	15	Wed	0.00	0.00	0.00	0.00	351.81	2.30	70.02	976.37
22	7May86	18	Wed	0.00	0.00	0.00	0.00	353.55	2.30	69.93	971.39
23	7May86	21	Wed	24021.60	24021.30	0.29	-509.45	864.74	2.30	-439.62	966.41
24	7May86	24	Wed	72000.00	71997.36	2.64	-1521.39	1876.57	2.30	-1451.67	959.94

:

: *Periods 25 - 56 omitted*

Table E.13 Pump-back Operation, Users Table 3

*USERS. 3 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

Per	Date:	Hr	Day	ADAM RESE Level	REREG Level	ADAM RESE Energy G	ADAM RESE Energy S	PUMPBACK Energy R	PUMPBACK Energy G	ADAM RESE Outflow	REREG Outflow	WILLEYBUR Flow Reg
Location No=				55.	50.	55.	55.	155.	155.	55.	50.	10.
J8/JZ Codes=				55.130	50.130	55.160	55.230	155.150	155.160	55.100	50.100	10.040
1	5May86	3	Mon	2.96	2.30	0.00	0.00	72000.00	72000.00	2.30	955.31	1100.00
2	5May86	6	Mon	2.96	2.27	0.00	0.00	48064.82	48062.09	2.30	958.14	1100.00
3	5May86	9	Mon	2.96	2.38	240000.02	0.00	0.00	0.00	7980.21	965.59	1100.00
4	5May86	12	Mon	2.95	2.49	240000.00	0.00	0.00	0.00	7983.28	973.03	1100.00
5	5May86	15	Mon	2.95	2.48	0.00	0.00	0.00	0.00	2.30	980.47	1100.00
6	5May86	18	Mon	2.95	2.46	0.00	0.00	0.00	0.00	2.30	987.92	1100.00
7	5May86	21	Mon	2.95	2.44	0.00	0.00	24021.60	24021.31	2.30	995.36	1100.00
8	5May86	24	Mon	2.95	2.40	0.00	0.00	72000.00	71997.48	2.30	995.26	1100.00
9	6May86	3	Tue	2.95	2.36	0.00	0.00	72000.00	71997.49	2.30	995.16	1100.00
10	6May86	6	Tue	2.95	2.33	0.00	0.00	48064.82	48063.72	2.30	995.06	1100.00
11	6May86	9	Tue	2.95	2.44	240000.00	0.00	0.00	0.00	7984.25	993.63	1100.00
12	6May86	12	Tue	2.95	2.55	240000.02	0.00	0.00	0.00	7987.33	992.20	1100.00
13	6May86	15	Tue	2.95	2.54	0.00	0.00	0.00	0.00	2.30	990.77	1100.00
14	6May86	18	Tue	2.95	2.52	0.00	0.00	0.00	0.00	2.30	989.34	1100.00
15	6May86	21	Tue	2.95	2.50	0.00	0.00	24021.60	24021.31	2.30	987.91	1100.00
16	6May86	24	Tue	2.95	2.47	0.00	0.00	72000.00	71997.39	2.30	989.04	1100.00
17	7May86	3	Wed	2.95	2.43	0.00	0.00	72000.00	71997.41	2.30	990.17	1100.00
18	7May86	6	Wed	2.95	2.40	0.00	0.00	48064.82	48063.67	2.30	991.31	1100.00
19	7May86	9	Wed	2.95	2.51	240000.02	0.00	0.00	0.00	7988.27	986.33	1100.00
20	7May86	12	Wed	2.94	2.62	240000.00	0.00	0.00	0.00	7991.35	981.35	1100.00
21	7May86	15	Wed	2.94	2.60	0.00	0.00	0.00	0.00	2.30	976.37	1100.00
22	7May86	18	Wed	2.94	2.59	0.00	0.00	0.00	0.00	2.30	971.39	1100.00
23	7May86	21	Wed	2.94	2.57	0.00	0.00	24021.60	24021.30	2.30	966.41	1100.00
24	7May86	24	Wed	2.94	2.53	0.00	0.00	72000.00	71997.36	2.30	959.94	1100.00

:
: *Periods 25 - 56 ommited*

E.5 System Power Operation

When individual hydropower reservoirs deliver energy and capacity into a common power system, operating the projects as a system can often produce more energy or more firm energy than the sum of the individual projects operating independently. Many of the options available for at-site power are available for the system as well. Additional data requirements for the system power routines consist of system energy requirements and an indication at each hydropower plant if it is in the system.

At the beginning of each time-step of the simulation, the energy potential of all reservoirs in the system is estimated. This is accomplished by subdividing each reservoir in the system into multiple levels within the power pool. Then the energy produced by drawing each reservoir drawn to each level is computed and summed for all. Then the system energy required is compared to the total energy produced at each level to estimate the common level where all the reservoirs would meet the system energy requirement. By this method the system energy is allocated to the reservoirs in the system. If no other constraint applies, the reservoirs will each operate to meet the allocated system load and their storage should be at the same level at the end of the time step. By this approach, the system energy load is allocated to the projects most able to meet the demand for each time step.

The system power computations do not consider the time delay of water moving through the system. Therefore, the allocation of system energy may not balance with the actual flow releases when channel routing is used. Therefore, channel routing should not be used with system power options.

E.5.1 System Energy Data

System Energy Requirements. System requirements are defined for the entire system. Monthly system energy requirements are given in MWh on the **SM** Records. An alternative is to input monthly ratios and indicate the total annual system energy on the thirteenth field of the **SM** Record (third field of second record).

System energy requirements for each day of the week may be specified as a ratio on the **SD** Record. The program computes the weekly requirements based on the monthly energy requirement (**SM** Records) and then computes the daily values from the weekly requirements based on the **SD** Records. Seven daily ratios which must total 1.0 are given on the **SD** Record.

For simulations time-steps of less than one day, the multi-hourly system energy requirements are given on the **SH** Record. As with at-site power, the hourly distribution can be defined for an even interval of a day, up to 24 values for hourly. For example, if 6-hour flows were provided, four ratios are given on the **SH** Record, one for each six-hour routing interval of the day.

System Power Guide Curve. The power guide curve approach for a single reservoir can be applied to a system of reservoirs. The power storage in the system is the sum of each of the individual reservoir's power storage. The percent of the total power storage occupied in the reservoir system is entered on the **SC** Record as a ratio. The corresponding system plant factor is entered on the **SF** Record. When the cumulative storage in the system is between levels 2 and 3 (top-of-buffer to top-of-conservation pool), the guide curve will control operation. When the system storage is below level 2, the system will operate at the minimum plant factor corresponding to 0% power storage on the guide curve. (The power priority can be changed on the **J2**, field 4 to operate to Level 1.) When the **SC** Record is used, the **SM** Records are read as usual, but they represent monthly adjustment ratios of the plant factors on the **SF** Records. This method is an alternative method to firm system energy operation.

Firm Monthly Energy Requirements. At each hydropower reservoir in the model, all of the power data previously described are still provided plus an indication if the power plant is in the power system (**P2** Record, field 3) and the maximum plant factor for the project which can be used to meet the system load (**P2** Record, field 4).

E.5.2 System Energy Model

The system power model is Example 9. A listing of the first part of the input data file, including system energy data and the first reservoir in the system, is shown in Table E.14. This model is a modification of Example 7, the first hydropower example. Note the first **J8** record with system energy variables, 80.28, 80.26, and 80.29. The system energy output is associated with the first reservoir in the data model, reservoir 80 in this example.

The system power data are provided before the first reservoir. The general format is similar to at-site power requirements. The **SM** data provide the monthly energy requirements, in MWh, for all the reservoirs in the system. The thirteenth entry can be used as a multiplying factor, 1.0 in this example. The daily distribution of the system energy is defined on the **SD** Records, Sunday through Saturday. In this example, the daily distribution is uniform over the weekdays and none on the weekend.

The data for Reservoir 80 is the same as Example 7, except the at-site energy requirements were eliminated allowing the reservoir complete freedom to operate for the system load. If at-site requirements are defined, the reservoir will have to operate to meet those requirements as well as the allocated system demand. The additional input is the indicator that Andrew Reservoir is in the system (**P2** Record, field 3 = 1). Hydropower reservoirs do not have to be in the system.

The data for Adam Reservoir is the same as Example 7. The at-site power requirements were left, which means that Adam will operate to meet those requirements. The **P2** Record was modified (field 3 = 1) indicating that Adam is

Table E.14 System Hydropower Model (Example 9)

```
T1      HEC-5 Example 9, System Hydropower Model, Daily Flow Data (EXAMPLE9.DAT)
T2      2 Peaking Plants and a Re-Regulation Reservoir with Run-of-River Power
T3      Green and Rocky Rivers, Adam and Andrew Reservoirs to Willeyburg
J1     0       1       5       3       4       2
J2    24       1
J3     4                                       1
J6  -2.7    -2.0    -1.6     0.3     3.4     2.5     2.0     0.9     1.9     1.6
J6  -0.8    -1.6
J8 80.13   55.13   50.13   80.16   55.16   50.16   80.28   80.26   80.00   80.29
J8 80.12   80.16   80.10   55.12   55.16   55.10   50.12   50.16   50.10   80.28
JZ-80.13   55.13   50.13   80.28   80.26   80.16   55.16   50.16
SM 12000   11500   10450   10500   10100   10500   15500   15700   12000   12500
SM 12500   12000     1.0
SD     0      .2      .2      .2      .2      .2       0

C ==================== Andrew Reservoir (Peaking Project) ======================
RL    80  210492
RL     1      80      -1           82890
RL     2      80      -1           95000
RL     3      80       7          210492  210492  379611  379611  379611  210492
RL                                210492
RL     4      80      -1          670052
RL     5      80      -1          804006
RO
RS    32   10373   82884   89647  104879  113447  122709  132705  143514  155137
RS167612  181000  195280  210492  226656  243772  261860  280940  301031  322154
RS344288  367473  391749  417136  443713  471559  500734  531317  563427  597164
RS632646  670052  804006
RQ    32    9800    9800    9800    9800    9800    9800    9800    9800    9800
RQ  9800    9800    9800    9800    9800    9800    9800    9800    9800    9800
RQ  9800   15000   26000   37000   50000   66000   82000  100000  120000  140000
RQ160000  185000  300000
RA    32     182    3251    3516    4116    4452    4812    5196    5602    6024
RA  6462    6913    7373    7841    8317    8801    9293    9793   10298   10808
RA 11329   11862   12411   12988   13599   14246   14933   15665   16449   17293
RA 18206   19201   24200
RE    32     725     800     802     806     808     810     812     814     816
RE   818     820     822     824     826     828     830     832     834     836
RE   838     840     842     844     846     848     850     852     854     856
RE   858     860     870
R2 10000   10000
C  == Andrew Power Plant == 2 41 mW Generators,
P1    80   82000       1       3   696.8       0      -1     1.2
P2   1.5    9800       1
PR
PR
PQ     0     203    4200    7500    9500   11600   32100   45000
PT   685     690   692.6   694.7   696.5   697.9   733.1     735
PP 28000   58000   68000   82000   82000   82000   82000
PS    80     100     115     125     130     145     200
PE   .80     .81     .82     .82     .83     .83     .84     .84     .84     .84
PE   .85     .85     .85     .85     .85     .85     .86     .86     .86     .87
PE   .87     .87     .88     .88     .87     .86     .85     .85     .84     .84
PE   .84     .83
CP    80    9800
IDANDREW RESERVOIR
RT    80      70
CS     7       1      15     121     182     274     350     365
 : data model continues, see file Example9.dat
```

part of the system. Therefore, the program will consider the energy generated to meet at-site requirements as part of the system energy. If there is a limit on a reservoir's contribution to meet system load, the fourth field of the **P2** Record can be used to limit the maximum contribution for any hydropower project.

The re-regulation reservoir is also part of the system. There were no power requirements at that location in Example 7, so the reservoir generated power based on operation for low-flow goals. Now, being part of the system, the reservoir will operate to meet system goals as well as low-flow goals.

The flow data and simulation runs one-year of average daily flow. The following output review focuses on the first month; however, you can run the data and review the entire year.

E.5.3 System Energy Output

The output table for system energy is associated with the first reservoir in the hydropower system. Output options include system energy requirement, generation, usable energy and system shortage. The usable energy can be less than the system generated energy if the maximum system plant factor for each individual project (**P2** Record, field 4) is less than the maximum at-site plant factor for the project (overload ratio, **P1** Record, field 3).

Case output for hydropower operation shows Case = .10 when the reservoir is operating for at-site energy, and Case = .12 when the reservoir is generating for system energy production.

Table E.15 lists the first month from Example 9 Users Table 1. The output lists the reservoir Levels, Energy Generated for each reservoir, System Energy Generated and Required, plus the difference between and System Energy Shortage. While the last two columns are similar, the Shortage only shows deficiency from requirements while the difference shows any difference. For example, there is no energy required on Saturday and Sunday so there is no shortage. You can see from the shortages that the energy allocation process is not exact; however, the sum of the project energy production is very close to the target.

Looking at the first three columns of Level, shows the two storage reservoirs at nearly the same level while the re-regulation reservoir tends to be lower. Recall that the re-regulation reservoir also operates to meet downstream flow goals. A review of the Case variable should show the bases for releases. Table E.16 shows the Case, Energy Generated, and Outflow for each reservoir.

Table E.15 System Energy Operation, Users Table 2

*USERS. 2   User Designed Output   (Dates shown are for END-of-Period)

Summary by Period   Flood=   1

Location No=			80.	80.	80.	55.	55.	55.	50.	50.	50.	80.
J8/JZ Codes=			80.120	80.160	80.100	55.120	55.160	55.100	50.120	50.160	50.100	80.280
			ANDREW RE	ANDREW RE	ANDREW RE	ADAM RES	ADAM RES	ADAM RES	REREG	REREG	REREG	ANDREW RE
Period	Date:	Day	Case	Energy G	Outflow	Case	Energy G	Outflow	Case	Energy G	Outflow	Sys En G
1	1Jan86	Wed	0.12	228.39	1051.91	0.12	223.29	993.85	0.12	89.39	1369.99	541.07
2	2Jan86	Thu	0.12	172.80	796.49	0.12	260.81	1152.59	0.12	105.44	1679.67	539.05
3	3Jan86	Fri	0.12	163.72	754.99	0.12	268.10	1173.47	0.12	105.34	1745.53	537.16
4	4Jan86	Sat	0.03	15.83	74.31	0.13	0.00	2.30	0.00	7.58	120.00	23.40
5	5Jan86	Sun	0.03	112.58	519.23	0.13	0.00	2.30	0.00	7.52	120.00	120.10
6	6Jan86	Mon	0.12	220.44	1015.80	0.12	254.25	1096.63	0.12	63.97	1074.05	538.66
7	7Jan86	Tue	0.12	147.84	682.26	0.12	298.11	1286.49	0.12	90.14	1551.20	536.09
8	8Jan86	Wed	0.12	147.10	679.12	0.12	305.30	1311.60	0.12	83.68	1456.91	536.07
9	9Jan86	Thu	0.12	147.04	679.18	0.12	318.94	1367.09	0.12	71.52	1236.54	537.50
10	10Jan86	Fri	0.12	149.04	688.69	0.12	330.46	1420.50	0.12	59.69	1002.71	539.18
11	11Jan86	Sat	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.55	120.00	7.55
12	12Jan86	Sun	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.49	120.00	7.49
13	13Jan86	Mon	0.12	302.23	1394.17	0.12	202.92	876.45	0.12	35.31	577.18	540.46
14	14Jan86	Tue	0.12	150.88	697.63	0.12	358.31	1555.13	0.12	32.68	508.92	541.86
15	15Jan86	Wed	0.12	140.19	648.64	0.12	305.29	1352.48	0.12	95.84	1501.93	541.31
16	16Jan86	Thu	0.13	0.00	1.50	0.12	457.84	2022.67	0.12	166.35	2777.44	624.18
17	17Jan86	Fri	0.13	0.00	1.50	0.12	453.48	1976.52	0.12	151.06	2646.07	604.54
18	18Jan86	Sat	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.33	120.00	7.33
19	19Jan86	Sun	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.27	120.00	7.27
20	20Jan86	Mon	0.13	0.00	1.50	0.12	437.18	1874.87	0.12	98.78	1753.08	535.97
21	21Jan86	Tue	0.13	0.00	1.50	0.12	450.20	1936.28	0.12	87.95	1517.71	538.15
22	22Jan86	Wed	0.13	0.00	1.50	0.12	482.10	2091.00	0.12	59.81	958.83	541.92
23	23Jan86	Thu	0.13	0.00	1.50	0.12	407.13	1805.58	0.12	133.58	2164.02	540.71
24	24Jan86	Fri	0.13	0.00	1.50	0.12	378.78	1669.65	0.12	155.66	2676.95	534.45
25	25Jan86	Sat	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.37	120.00	7.37
26	26Jan86	Sun	0.13	0.00	1.50	0.13	0.00	2.30	0.00	7.32	120.00	7.32
27	27Jan86	Mon	0.13	0.00	1.50	0.12	429.19	1848.98	0.12	106.73	1903.00	535.92
28	28Jan86	Tue	0.13	0.00	1.50	0.12	423.65	1824.56	0.12	111.46	2012.25	535.11
29	29Jan86	Wed	0.13	0.00	1.50	0.12	452.23	1942.07	0.12	85.91	1510.80	538.13
30	30Jan86	Thu	0.13	0.00	1.50	0.12	482.70	2091.01	0.12	59.19	965.94	541.90
31	31Jan86	Fri	0.13	0.00	1.50	0.12	411.68	1823.22	0.12	129.17	2124.43	540.85

32 - *end of run not listed.*

Table E.16 System Energy Operation, Users Table 1

*USERS. 1 User Designed Output (Dates shown are for END-of-Period)

Summary by Period Flood= 1

			ANDREW RE	ADAM RES	REREG	ANDREW RE	ADAM RES	REREG	ANDREW RE	ANDREW RE	ANDREW RE	ANDREW RE
Location No=			80.	55.	50.	80.	55.	50.	80.	80.	80.	80.
J8/JZ Codes=			80.130	55.130	50.130	80.160	55.160	50.160	80.280	80.260	80.000	80.290
Period	Date:	Day	Level	Level	Level	Energy G	Energy G	Energy G	Sys En G	Sys En R	Change	Sys En S
1	1Jan86	Wed	3.00	3.00	2.95	228.39	223.29	89.39	541.07	541.94	-0.87	0.87
2	2Jan86	Thu	3.00	3.00	2.89	172.80	260.81	105.44	539.05	541.94	-2.88	2.88
3	3Jan86	Fri	2.99	2.99	2.82	163.72	268.10	105.34	537.16	541.94	-4.77	4.77
4	4Jan86	Sat	3.00	2.99	2.80	15.83	0.00	7.58	23.40	0.00	23.40	0.00
5	5Jan86	Sun	3.00	2.99	2.79	112.58	0.00	7.52	120.10	0.00	120.10	0.00
6	6Jan86	Mon	2.99	2.99	2.79	220.44	254.25	63.97	538.66	541.94	-3.27	3.27
7	7Jan86	Tue	2.99	2.99	2.76	147.84	298.11	90.14	536.09	541.94	-5.84	5.84
8	8Jan86	Wed	2.98	2.98	2.74	147.10	305.30	83.68	536.07	541.94	-5.86	5.86
9	9Jan86	Thu	2.98	2.98	2.76	147.04	318.94	71.52	537.50	541.94	-4.44	4.44
10	10Jan86	Fri	2.98	2.98	2.81	149.04	330.46	59.69	539.18	541.94	-2.75	2.75
11	11Jan86	Sat	2.98	2.98	2.80	0.00	0.00	7.55	7.55	0.00	7.55	0.00
12	12Jan86	Sun	2.99	2.98	2.78	0.00	0.00	7.49	7.49	0.00	7.49	0.00
13	13Jan86	Mon	2.97	2.97	2.82	302.23	202.92	35.31	540.46	541.94	-1.48	1.48
14	14Jan86	Tue	2.97	2.97	2.95	150.88	358.31	32.68	541.86	541.94	-0.07	0.07
15	15Jan86	Wed	2.97	2.97	2.93	140.19	305.29	95.84	541.31	541.94	-0.62	0.62
16	16Jan86	Thu	2.96	2.96	2.84	0.00	457.84	166.35	624.18	541.94	82.25	0.00
17	17Jan86	Fri	2.95	2.95	2.76	0.00	453.48	151.06	604.54	541.94	62.60	0.00
18	18Jan86	Sat	2.95	2.96	2.74	0.00	0.00	7.33	7.33	0.00	7.33	0.00
19	19Jan86	Sun	2.95	2.96	2.73	0.00	0.00	7.27	7.27	0.00	7.27	0.00
20	20Jan86	Mon	2.94	2.95	2.74	0.00	437.18	98.78	535.97	541.94	-5.97	5.97
21	21Jan86	Tue	2.94	2.95	2.80	0.00	450.20	87.95	538.15	541.94	-3.79	3.79
22	22Jan86	Wed	2.93	2.94	2.94	0.00	482.10	59.81	541.92	541.94	-0.02	0.02
23	23Jan86	Thu	2.93	2.93	2.89	0.00	407.13	133.58	540.71	541.94	-1.23	1.23
24	24Jan86	Fri	2.92	2.93	2.77	0.00	378.78	155.66	534.45	541.94	-7.49	7.49
25	25Jan86	Sat	2.92	2.93	2.75	0.00	0.00	7.37	7.37	0.00	7.37	0.00
26	26Jan86	Sun	2.91	2.93	2.74	0.00	0.00	7.32	7.32	0.00	7.32	0.00
27	27Jan86	Mon	2.91	2.93	2.73	0.00	429.19	106.73	535.92	541.94	-6.01	6.01
28	28Jan86	Tue	2.91	2.92	2.71	0.00	423.65	111.46	535.11	541.94	-6.83	6.83
29	29Jan86	Wed	2.90	2.92	2.76	0.00	452.23	85.91	538.13	541.94	-3.80	3.80
30	30Jan86	Thu	2.90	2.91	2.90	0.00	482.70	59.19	541.90	541.94	-0.04	0.04
31	31Jan86	Fri	2.89	2.90	2.87	0.00	411.68	129.17	540.85	541.94	-1.09	1.09

32 - *end of run not listed.*

The simulation starts on Wednesday and the first three Case values are 0.12 for the three reservoirs. This indicates that the three were operating for system power on Wednesday through Friday. On the weekend, with no system energy requirement, the reservoirs tend to operate for their local demands: Andrew Reservoir spilled (Case = 0.03), Adam Reservoir outflow is leakage (Case = 0.13) and the re-regulation reservoir released minimum flow (Case = 0.00). The pattern is the same for the following week.

During the third week, the pattern persists until period 16, when the case for Andrew changes to leakage (Case = 0.13). Referring back to User Table 1, the Levels for Andrew and Adam look balanced (equal). However, looking several periods later you can see that Adam's Level is higher than Andrew's. Because Adam is higher, the system energy is being allocated to it and Andrew's energy is being set to zero, only leakage. Recall that Andrew has no at-site power requirements so the energy production can go to zero.

The Case for the re-regulation reservoir indicates that it too is operating for the system load; however, the Level is not balanced with Adam. Two things are contributing to the imbalance: the minimum releases on the weekend and the relative small size of the re-regulation reservoir. With less storage, the re-regulation reservoir Level changes quickly with releases while the larger storage reservoirs change more slowly. It is difficult to balance a small storage reservoir with large reservoirs. However, the Levels remain fairly close.

For a more complete review of Example 9, run the data and review the output file. Generally, the energy requirements were met through the year and the minimum pool level was above 2.0 for all reservoirs.

E.6 Hydropower Determination

The objective of many hydropower planning studies is to determine how much firm energy can be produced given a reservoir of fixed size and installed capacity with a specified flow sequence (critical period). The solution is an iterative process of assuming different firm energy requirements until the maximum is found that can be generated with no shortages during the critical period. The inverse problem is also common. Given a fixed energy requirement, what is the minimum storage which will produce this amount? In this case, the storage is varied until a minimum is reached which will produce the required energy.

The HEC-5 optimization routines can handle the above tasks as well as a variety of water supply planning problems. Up to four reservoir locations not in tandem may be optimized in a single run. The time interval is normally monthly, but can be weekly or daily as long as the number of periods (NPER, **BF** Record, field 2) will fit into the HEC-5 program's memory as a single flow sequence. The number of periods that the routines can handle is a function of the program's Dynamic Dimension DM array size, which is set at compilation time, and the size of the data set (i.e., number of reservoirs and control points). The program will put an explanatory message specifying the maximum number of periods (NPER) which can be handled by the optimization routines if an insufficient memory situation occurs.

Options available for selecting the simulation period include: period-of-record, partial record and critical period. Unless otherwise requested in the input, the program simulates system operation for the entire period of the given inflow data. Refer to HEC-5 Users Manual Input Description for **J7** Record, field 8..

E.6.1 Capacity and Energy Determination

Capacity and energy determination is similar to yield determination, described in Section 4.6 and demonstrated in Section D.3. Job Record **J7** requests the optimization routine. Field 1 tells the program which reservoir to use (entered to the left of the decimal) and the optimization option selected (entered to the right of the decimal). The monthly energy requirements and the installed capacity of the power plant can be optimized for the given power storage. For example, at Reservoir 20, a value of 20.1 is coded in field 1 of the **J7** Record.

The values for optimization variables CRITPR, IFLAG, and OPTERR, are input on the **J7** Record in fields 8, 9, and 10 respectively. These variables deal with defining the critical period used in the optimization routine, checking to see if this is the true critical period, and the allowable error in the solution (usually 5%). The recommended values should normally be used.

The energy generated is proportioned according to the monthly plant factors on the **PR** Records. The program makes the initial estimate of capacity if the **P1** Record, field 2 equals 1. This indicates that this project is a proposed plant and not an existing plant. The estimate of capacity is based on the energy which could be produced from the power storage and the inflow during the estimated critical drawdown period. The length of the critical drawdown period is estimated by a routine based on an empirical relationship between drawdown, duration (in months) and the ratio of power storage to mean annual flow.

Alternately, the initial value of the capacity may be input in field 2 of the **P1** Record.

A summary output table shows the result from each optimization trial. First the results are shown for each iteration with the initial estimated critical period. Once an answer is found, the program will test it with the entire record. If it fails to meet energy production for the entire record, a new critical period is determined and the cycle continues with that period. Up to three full cycles can be performed. In the final trial, if the computed error ratio for the critical drawdown period is less than the specified allowable error, then no more iterations are needed.

E.6.2 Maximum Energy Determination

To request the maximum energy for the existing installed capacity, a value of 20.5 (reservoir 20 and option .5) is coded in field 1 of the **J7** Record. The existing capacity is given in field 2 of the **P1** Record. In the optimization, the capacity is held fixed while the firm energy is optimized. The final computed error ratio is below the specified allowable error (5%).

E.6.3 Power Storage Determination

To optimize power storage, field 1 is coded with a 20.0 (reservoir 20 and option 0). The installed capacity and energy requirements as plant factors are given as previously described on the power records.

In this option, the top-of-buffer pool remains fixed and the top-of-the conservation storage is varied until the maximum energy is produced for the given installed capacity.

The optimization routine will converge on a solution within the specified tolerance. The optimization routine adds 500,000 acre-feet to all storages to eliminate working with negative storage values. The true storage is equal to the storage shown in the output at level 3.0 less 500,000 acre-feet. A negative value of allowable error (**J7** Record, field 10) would perform one more simulation and remove the added 500,000 acre-feet and provide correct reservoir storages and levels.

E.6.4 Short-interval Analysis

A weekly, daily, or multi-hourly optimization of plant capacity and energy can be performed, similar to the monthly simulation. The flow data would be in the appropriate time interval. All other input data would be the same as monthly optimization. Given the shorter time interval, the results should be more accurate than those from a monthly simulation.

Appendix F

Description of Program Output

The sequence of possible output[1] from the HEC-5 program is:

1. Printout of input data (*Input Summary, *Routing Data, *Rule Curve Summary, *Operation Summary, *Map 1, *Map 2, *Reservoir Data, *Diversion Data, and *Routing / Operation Summary, *FLOWS)

2. Computation of incremental local flows (*LOCFL)

3. Printout of optimization trials and summary (*OPTRY and *OPSUM)

4. Results of all variables defined and requested by input data for the system operations arranged by downstream sequence of control points (*NORML)

5. Reservoir operation results arranged by sequence of time periods (*ROPER)

6. Results displayed in sequential time series: releases from reservoirs (*RRPER), regulated flows at all non-reservoir control points (*RQPER), diversion flows (*DVPER) and diversion shortages (*DVSHORT) at all locations, and percent flood control storage used by reservoirs (*FCPCT)

7. User-designed output based on **J8/JZ** Record input (*USERS)

8. Single flood summary of maximums for reservoirs and non-reservoirs

9. Multi-event summaries for flood control (*SUMFS) and conservation (*SUMPO)

10. Economic input data and damage computation (*ECDAM)

11. Flood frequency plots (*EPLOT)

12. Summary of damages or average annual damages, system costs and net benefits (*ESUMD, *ESUMC and *ESUMB)

13. Summary of discharge and stage reduction at each non-reservoir control point for each flood event (*HYEFF)

14. Computer check for possible errors (*ERROR), and

15. Listing of case designations defining reservoir releases (*CASES).

---

[1] Most of the output that is generated in the output file is controlled by the user (see the **J3** Record, field 1). The first 3 items in the above list are displayed from the HEC-5A program. The HEC-5B program displays all of the remaining output. The two programs are run sequentially in a single batch job.

The following sections provide a detailed description of the items that appear in an output file.

F.1 Printout of Input Data (*Input, *Routing, *Rule, *Operation, *Map, *Reservoir, *Diversion, *Routing/Operation, *FLOWS)

In addition to an "echo display" of the input data records (**T1-EJ**), the following summary information is "automatically" displayed in the output file:

***Input Summary** - a reflection of the Job Records (**J1-J4**) with the record's variable names and default values in instances where the values were not input. Also included in this section is a summary of control point locations along with their Channel Capacities and Minimum Flow requirements (from **CP** Records). Table F.1 is an excerpt from an example output file showing the input summary information.

Table F.1 Example Output Showing **Input Summary*

```
*Input Summary


J1 METRIC  ISTMO   NULEV  LEVCON  LEVTFC  LEVBUF  LEVPUM  NOADLV  LEVPRC
        1      1       5       3       4       2       3       0       2
J2 IFCAST  CFLOD  RATCHG   IPRIO   IOPMD  ISCHED   NCPTR  NCYCLE
        8   1.20    0.04       8       0      10       0       1
J3 IPRINT  PRCOL  IPLOTJ  FLONAT  CRITPR  ILOCAL  NOROUT  INTYPE  NOOPTS
        5   130.       0     -1.      0.      -1      24       0       0
J4 IANDAM  ECFCT  IPRECN  BCRFAC  COSFAC   PCVAL  PEPVAL  PESVAL  PEBVAL    J410
        0    1.0       0    1.00    1.00     0.0     0.0     0.0     0.0     0.0

Location:   ChCap    QMRatio  QMinD    QMinR  LQCP  QRatio QLag Location:


      33      150.   1.000     3.0      1.5     0   1.000    0. AVON DAM

      44      425.   1.000    20.0      2.0     0   1.000    0. BISHOP DAM

      40      450.   1.000     0.0      0.0     0   1.000    0. ZELMA

      22      100.   1.000     2.2      1.0     0   1.000    0. CARY DAM

      20      550.   1.000     0.0      0.0     0   1.000    0. CENTERVILLE

      11       25.   1.000     1.1      0.5     0   1.000    0. DONNER DAM

      10      870.   1.000     0.0      0.0     0   1.000    0. UNIONVILLE

       5      950.   1.000     0.0      0.0     0   1.000    0. DRY TOWN
```

***Routing Data** - the linkage between control point locations along with the Routing Methods input for each reach (from **RT** Records). Also shown is the internal program identification number (Index) for each location based on the order that the location was input. Table F.2 is an excerpt from an example output file showing the routing data information.

Table F.2 Example Output Showing **Routing Data*

*Routing Data

Index #	Location	Route To:	Method:	X	K	Lag
1	33	22	2.20	0.25	3.20	0
2	44	40	1.20	0.30	3.00	0
5	40	20	1.90	0.00	0.00	0
3	22	20	2.20	0.45	3.10	0
6	20	10	1.20	0.35	3.00	0
4	11	10	3.20	0.20	3.00	0
7	10	5	1.40	0.20	0.00	0
8	5	0	0.00	0.00	0.00	0

***Rule Curve Summary** - reservoir Storage values (**RL** Records) for each Level. If storage values vary by season (**CS** Record), then the corresponding seasons are also shown Table F.3 is an excerpt from an example output file showing a rule curve summary.

Table F.3 Example Output Showing **Rule Curve Summary*

```
*Rule Curve Summary

   Initial   Cum     Start              Storage for Level:
   Storage   Days    Date        1         2         3         4         5


           -----------------------------------------
           Reservoir Number =   33     AVON DAM
           -----------------------------------------

   151400.     1    01 JAN    31100.    34050.   151400.   350550.   375000.

Season = 2   105    15 APR    31100.    34050.   151400.   350550.   375000.

         3   135    15 MAY    31100.    34050.   197000.   350550.   375000.

         4   151    31 MAY    31100.    34050.   310330.   350550.   375000.

         5   250    07 SEP    31100.    34050.   310330.   350550.   375000.

         6   274    01 OCT    31100.    34050.   254050.   350550.   375000.

         7   305    01 NOV    31100.    34050.   210500.   350550.   375000.

         8   331    27 NOV    31100.    34050.   151400.   350550.   375000.

         9   365    31 DEC    31100.    34050.   151400.   350550.   375000.


           -----------------------------------------
           Reservoir Number =   44     BISHOP DAM
           -----------------------------------------

   146480.     1    01 Jan   131438.   134000.   146480.   562248.   630063.


           -----------------------------------------
           Reservoir Number =   22     CARY DAM
           -----------------------------------------

   255480.     1    01 JAN    21438.   134000.   255480.   389248.   435563.

Season = 2   105    15 APR    21438.   134000.   255480.   389248.   435563.

         3   151    31 MAY    21438.   134000.   362008.   389248.   435563.

         4   250    07 SEP    21438.   134000.   362008.   389248.   435563.

         5   305    01 NOV    21438.   134000.   255480.   389248.   435563.

         6   365    31 DEC    21438.   134000.   255480.   389248.   435563.


           -----------------------------------------
           Reservoir Number =   11     DONNER DAM
           -----------------------------------------

    56480.     1    01 Jan     1638.     4000.    56480.   150200.   215000.
```

***Operation Summary** - a summary of which location each reservoir operates for (**RO** Record). Table F.4 is an excerpt from an example output file showing an operation summary.

Table F.4 Example Output Showing **Operation Summary*

```
*Operation Summary

 Res. No.  Operates for the Following Locations:


      33     33.     22.

      44     44.     40.     20.     10.      5.

      22     22.     20.     10.      5.

      11     11.     10.      5.
```

***Map 1** - a schematic showing the reservoirs that operate for each location (interpretation of the **RO** Records). Table F.5 is an excerpt from an example output file showing the first schematic (*Map 1) information.

Table F.5 Example Output Showing **Map 1*

```
 *Map 1

         HEC-5 Test for Output Displays for User's Manual  (July 1998)

                                Upstream Reservoirs Operating for Each
Location

    33R              AVON DAM
    22R              CARY DAM         33
     |     .----44R  BISHOP DAM
     .----40         ZELMA            44
    20               CENTERVILL       44      22
     .----11R        DONNER DAM
    10               UNIONVILLE       44      22      11
     5               DRY TOWN         44      22      11
```

***Map 2** - a schematic with the following pertinent input data: “Incremental” Flood Control and Conservation storage values for reservoirs, Channel Capacities, Minimum flow requirements (Desired and Required), and Diversion locations. Table F.6 is an excerpt from an example output file showing the second schematic (*Map 2) summary information.

Table F.6 Example Output Showing **Map 2*

```
*Map 2

          HEC-5 Test for Output Displays for User's Manual  (July 1998)

                                   Channel   Flood     Conserv.  Min Des.  Min Req.  Divert     Map  Location
                                   Capacity  Storage   Storage     Flow      Flow      to    Number   Name

    33R              AVON DAM          150.   199150.   120300.        3.        2.       0       33 AVON DAM
    22R              CARY DAM          100.   133768.   234042.        2.        1.       0       22 CARY DAM
     |      .----44R BISHOP DAM        425.   415768.    15042.       20.        2.       0       44 BISHOP DAM
     .----40         ZELMA             450.        0.        0.        0.        0.       0       40 ZELMA
    20               CENTERVILL        550.        0.        0.        0.        0.       5       20 CENTERVILLE
     .----11R        DONNER DAM         25.    93720.    54842.        1.        1.       0       11 DONNER DAM
    10               UNIONVILLE        870.        0.        0.        0.        0.       0       10 UNIONVILLE
     5               DRY TOWN          950.        0.        0.        0.        0.      -1        5 DRY TOWN
```

***Reservoir Data** - summary of the following reservoir input data: Storage values (**RS** Record), along with corresponding Outlet Capacities (**RQ** Record), Areas (**RA** Record), and Elevations (**RE** Record). Table F.7 is an excerpt from an example output file showing the reservoir data summary information.

Table F.7 Example Output Showing **Reservoir Data*

```
*Reservoir Data

                             -----------------------------------------
                             Reservoir Number =   33     AVON DAM
                             -----------------------------------------

RS   Storages (1000's m3) =        0.    31100.    34050.    53000.   100240.
                             151400.   201100.   256350.   297100.   350550.
                             375000.

RQ   Q Capacities (m3/sec)=      0.00     11.00    145.00    178.00    212.00
                               240.00    452.00    664.00   1457.00   1646.00
                              1829.00

RA   Areas not input      :  Only needed for Evaporation

RE   Elevations (Meters)  =    309.00    349.60    351.00    362.10    370.00
                               374.30    377.40    382.00    383.00    384.70
                               386.80


                             -----------------------------------------
                             Reservoir Number =   44     BISHOP DAM
                             -----------------------------------------

RS   Storages (1000's m3) =        0.   124113.   131438.   134000.   146480.
                             253628.   362008.   417740.   465211.   546342.
                             562248.   589251.   630063.

RQ   Q Capacities (m3/sec)=      0.00    333.00    665.00    668.00    681.00
                               796.00    872.00    912.00   2322.00   5664.00
                              6457.00   7646.00   9629.00

RA   Areas not input      :  Only needed for Evaporation

RE   Elevations (Meters)  =    209.70    249.60    250.20    250.40    251.50
                               262.10    270.50    274.30    277.40    282.20
                               283.20    284.70    286.80


                             -----------------------------------------
                             Reservoir Number =   11     DONNER DAM
                             -----------------------------------------

RS   Storages (1000's m3) =        0.     1638.     4000.    56480.    93008.
                             112740.   150200.   215000.

RQ   Q Capacities (m3/sec)=      0.00    657.00    681.00    796.00    872.00
                               912.00   2322.00   5664.00

RA   Areas not input      :  Only needed for Evaporation

RE   Elevations (Meters)  =     59.70     99.60    101.50    112.10    120.50
                               124.30    127.40    132.20
```

***Diversion Data** - summary showing the "from" and "to" locations where diversions are input. Also shown is the diversion type and input diversion data (**DR** Record).Table F.8 is an excerpt from an example output file showing the diversion data summary information.

Table F.8 Example Output Showing **Diversion Data*

```
*Diversion Data

 Div No   From    To   Type   Div Q  %Return   Method     X       K    Div Ratio

    1       20     5     0    88.00     25       1.10    1.00    0.00    1.00
    2        5     0     1     0.00    100       1.10    1.00    0.00    1.00
```

***Routing / Operation Summary** - routing coefficients developed from the routing criteria (**RT** Record) are shown for those downstream locations that a reservoir operates for (**RO** Record). This information is useful in reviewing the reservoir releases for filling the downstream channel in conjunction with the forecast (**J2** Record, field 1). Table F.9 is an excerpt from an example output file showing the routing and operation summary information.

Table F.9 Example Output Showing **Routing / Operation Summary*

```
*Routing/Operation Summary  (Coefficients Based on 3 Hours)


ROUTING COEFFICIENTS  from Reservoir   33   to Downstream Location(s):
Loc=   22 0.0323 0.2269 0.4512 0.1962 0.0665 0.0203 0.0057 0.0010

ROUTING COEFFICIENTS  from Reservoir   44   to Downstream Location(s):
Loc=   40 0.1668 0.6949 0.1158 0.0193 0.0032
Loc=   20 0.0167 0.1780 0.5054 0.2511 0.0419 0.0069
Loc=   10 0.0022 0.0358 0.2021 0.4325 0.2474 0.0641 0.0135 0.0023
Loc=    5 0.0016 0.0262 0.1547 0.3669 0.3005 0.1166 0.0280 0.0055

ROUTING COEFFICIENTS  from Reservoir   22   to Downstream Location(s):
Loc=   20 0.0011 0.0594 0.8243 0.1052 0.0101
Loc=   10 0.0000 0.0086 0.1526 0.6433 0.1630 0.0287 0.0037
Loc=    5 0.0000 0.0062 0.1114 0.5030 0.3002 0.0671 0.0109 0.0013

ROUTING COEFFICIENTS  from Reservoir   11   to Downstream Location(s):
Loc=   10 0.0123 0.0948 0.2648 0.3248 0.1837 0.0786 0.0290 0.0095 0.0026
Loc=    5 0.0088 0.0712 0.2164 0.3079 0.2242 0.1087 0.0432 0.0151 0.0045
```

***FLOWS** - If requested (by including a 128 in the sum of the value in field 1 of the **J3** Record), a formatted listing (in 10-field record images) of input flow data is displayed in flood sets (if subdivision is required). Normally, this option is not requested since the input flow data values are included (by default) in the "echo display" of the input data records.

F.2 Computation of Incremental Local Flows (*LOCFL)

If incremental local flows are being computed from natural or observed data (see **J3** Record, field 6), the observed and routed flows can be shown in the output file for all control points by including a 64 in the sum specified in field 1 of the **J3** Record. For example, Table F.10 shows a HEC-5 input file where Incremental Local Flows are to be computed based on Natural flows (**J3** Record, field 6 = 20).

Table F.10 Example HEC-5 Input for Computing Incremental Local Flows

```
T1      Example for COMPUTING LOCAL FLOWS FROM NATURAL FLOWS
T2      THREE RESERVOIR OPERATION FOR FLOOD CONTROL
T3      2 PARALLEL, 2 TANDEM
J1     0       1       3       2       3       1
J2    24       1    .167
J3   511                                      20
J8 20.02   30.02   20.00   20.24   20.02   50.02    2.99   10.02   10.24
J8 30.02   30.24   30.10   20.02   20.24   20.10   50.10   50.02   10.24   10.02
RL    30                                   50000
RO     1      20
RS     2       0   50000
RQ     2    6000  100000
R2 99999   99999
CP    30    6000
ID RES30
RT    30      20       0       0
RL    20                                  275000
RO     1      10
RS     2       0  275000
RQ     2   21000   21000
R2 99999   99999
CP    20   21000
ID RES20
RT    20      10     1.1     3.1
C     20      10
RL    50                                  200000
RO     1      10
RS     2       0  200000
RQ     2   12000   12000
R2 99999   99999
CP    50   12000
ID RES50
RT    50      10     1.1     3.2
C     50      10
CP    10   25000
ID CPT10
RT    10       0
ED
BF     0      17       0       045062112       0       6                    1900
IN    30               0       0    3000   18000   37000   42000   50000   27000
IN 20000   13000    5000       0       0       0       0       0       0
IN    20               0       0    3000   24000   57000   99000  150000  117000
IN 90000   63000   42000   24000   24000   15000    9000    3000       0
IN    50               0    6000   27000   60000  105000   78000   60000   45000
IN 33000   24000   18000   12000   12000    9000    6000    3000       0
IN    10               0    8000   42000   73000  149000  181000  217000  194000
IN181000  140000  109000   93000   61000   42000   31000   19000   10000
NQ    30               0       0    3000   18000   37000   42000   50000   27000
NQ 20000   13000    5000       0       0       0       0       0       0
NQ    20               0       0    3000   24000   57000   99000  150000  117000
NQ 90000   63000   42000   24000   24000   15000    9000    3000       0
NQ    50               0    6000   27000   60000  105000   78000   60000   45000
NQ 33000   24000   18000   12000   12000    9000    6000    3000       0
NQ    10               0    8000   42000   73000  149000  181000  217000  194000
NQ181000  140000  109000   93000   61000   42000   31000   19000   10000
EJ
```

In this example, the time series data represent “total flows” at all of the model locations. Table F.11 shows a schematic map of the example model locations.

Table F.11 Example Schematic of Input for Computing Incremental Locals

```
*Map 1

 Example for COMPUTING LOCAL FLOWS FROM NATURAL FLOWS


              Upstream Reservoirs Operating for Each Location

    30R         RES30
    20R         RES20           30
     .----50R   RES50
    10          CPT10           20      50
```

The process for computing incremental locals includes routing the upstream total flow hydrograph to the next downstream location and then subtracting these routed flows from the total flow at the downstream location. Included in the output file is a section labeled "Incremental LOCAL FLOW Information" as illustrated in Table F.12 where the observed (or natural) flows are shown twice for each control point. The first group shows the computed value obtained by subtracting the sum of the upstream routed hydrograph from the observed (or natural) hydrograph and the second group shows the adjusted values. The adjustment is made to eliminate any resulting negative local flows and to preserve the correct volume. By default, all negative local flows are set to zero and the negative volume is proportioned to the positive values. However, the user can specify a **negative** value in field 6 of the **J3** Record and the program will allow the computation and use of negative incremental local flows, as illustrated in Table F.13.

Table F.12 Printout of Computation of *"Positive"* Incremental Local Flows

```
          "Incremental"  LOCAL FLOW  Information:
           -------------------------------------

*LOCFL


OBS Q AT   30

M=    30                 0.      0.   3000.  18000.  37000.  42000.  50000.
                     27000.  20000.  13000.   5000.      0.      0.      0.
                         0.      0.      0.
SUM=   215000.

ROUTED Q FROM MX=  30 TO   20
RTMD=      1.10 RTCOF=      1.00 K=      0.00

              COEF=   1.00000

M=    20                 0.      0.   3000.  18000.  37000.  42000.  50000.
                     27000.  20000.  13000.   5000.      0.      0.      0.
                         0.      0.      0.
SUM=   215000.

OBS Q AT   20

M=    20                 0.      0.   3000.  24000.  57000.  99000. 150000.
                    117000.  90000.  63000.  42000.  24000.  24000.  15000.
                      9000.   3000.      0.
SUM=   720000.

ROUTED Q FROM MX=  20 TO   10
RTMD=      1.10 RTCOF=      3.10 K=      0.00

              COEF=   0.33333   0.33333   0.33333

M=    10                 0.      0.   1000.   9000.  28000.  60000. 102000.
                    122000. 119000.  90000.  65000.  43000.  30000.  21000.
                     16000.   9000.   4000.
SUM=   719000.

OBS Q AT   50

M=    50                 0.   6000.  27000.  60000. 105000.  78000.  60000.
                     45000.  33000.  24000.  18000.  12000.  12000.   9000.
                      6000.   3000.      0.
SUM=   498000.

ROUTED Q FROM MX=  50 TO   10
RTMD=      1.10 RTCOF=      3.20 K=      0.00

              COEF=   0.00000   0.33333   0.33333   0.33333

M=    10                 0.      0.   2000.  11000.  31000.  64000.  81000.
                     81000.  61000.  46000.  34000.  25000.  18000.  14000.
                     11000.   9000.   6000.
SUM=   494000.
SUM OF ROUTED FLOWS TO C.P.    10

M=    10                 0.      0.   3000.  20000.  59000. 124000. 183000.
                    203000. 180000. 136000.  99000.  68000.  48000.  35000.
                     27000.  18000.  10000.


INC LOCAL FLOWS COMPUTED
```

... Continued ...

Table F.12 Printout of Computation of *"Positive"* Incremental Local Flows *(Continued)*

```
RES INFLOW,OUTFLOW=   215000.        0. ALL RES I-0=        0.

M=    30                 0.       0.   3000.  18000.  37000.  42000.  50000.
                     27000.  20000.  13000.   5000.      0.      0.      0.
                         0.       0.      0.

M=    30                 0.       0.   3000.  18000.  37000.  42000.  50000.
                     27000.  20000.  13000.   5000.      0.      0.      0.
                         0.       0.      0.
SUM=   215000. -SUM=        0. -MAX=        0.


RES INFLOW,OUTFLOW=   720000.        0. ALL RES I-0=        0.

M=    20                 0.       0.      0.   6000.  20000.  57000. 100000.
                     90000.  70000.  50000.  37000.  24000.  24000.  15000.
                      9000.   3000.       0.

M=    20                 0.       0.      0.   6000.  20000.  57000. 100000.
                     90000.  70000.  50000.  37000.  24000.  24000.  15000.
                      9000.   3000.       0.
SUM=   505000. -SUM=        0. -MAX=        0.


RES INFLOW,OUTFLOW=   498000.        0. ALL RES I-0=        0.

M=    50                 0.    6000.  27000.  60000. 105000.  78000.  60000.
                     45000.  33000.  24000.  18000.  12000.  12000.   9000.
                      6000.   3000.       0.

M=    50                 0.    6000.  27000.  60000. 105000.  78000.  60000.
                     45000.  33000.  24000.  18000.  12000.  12000.   9000.
                      6000.   3000.       0.
SUM=   498000. -SUM=        0. -MAX=        0.


RES INFLOW,OUTFLOW=  1550000.        0. ALL RES I-0=        0.

M=    10                 0.    8000.  39000.  53000.  90000.  57000.  34000.
                     -9000.   1000.   4000.  10000.  25000.  13000.   7000.
                      4000.   1000.       0.


M=    10                 0.    7792.  37986.  51621.  87659.  55517.  33116.
                         0.     974.   3896.   9740.  24350.  12662.   6818.
                      3896.     974.      0.

SUM=   337000. -SUM=    -9000. -MAX=    -9000.
SUM ALL INC FLOWS(CFS-PER)=            1555000. AVE=    91471.

SUM LAST MX=            1550000. D.S.VOL(RES.I-0,+MX)=  1550000.


********
* NOTE *   INCREMENTAL LOCAL FLOWS HAVE BEEN "COMPUTED"
********
```

Table F.13 Printout of Computation of *"Negative"* Incremental Local Flows

```
          "Incremental"  LOCAL FLOW  Information:
           ------------------------------------

*LOCFL


OBS Q AT   30

M=    30                 0.      0.   3000.  18000.  37000.  42000.  50000.
                     27000.  20000.  13000.   5000.      0.      0.      0.
                         0.      0.      0.
SUM=   215000.

ROUTED Q FROM MX=  30 TO   20
RTMD=      1.10 RTCOF=      1.00 K=      0.00

              COEF=   1.00000

M=    20                 0.      0.   3000.  18000.  37000.  42000.  50000.
                     27000.  20000.  13000.   5000.      0.      0.      0.
                         0.      0.      0.
SUM=   215000.

OBS Q AT   20

M=    20                 0.      0.   3000.  24000.  57000.  99000. 150000.
                    117000.  90000.  63000.  42000.  24000.  24000.  15000.
                      9000.   3000.      0.
SUM=   720000.

ROUTED Q FROM MX=  20 TO   10
RTMD=      1.10 RTCOF=      3.10 K=      0.00

              COEF=   0.33333   0.33333   0.33333

M=    10                 0.      0.   1000.   9000.  28000.  60000. 102000.
                    122000. 119000.  90000.  65000.  43000.  30000.  21000.
                     16000.   9000.   4000.
SUM=   719000.

OBS Q AT   50

M=    50                 0.   6000.  27000.  60000. 105000.  78000.  60000.
                     45000.  33000.  24000.  18000.  12000.  12000.   9000.
                      6000.   3000.      0.
SUM=   498000.

ROUTED Q FROM MX=  50 TO   10
RTMD=      1.10 RTCOF=      3.20 K=      0.00

              COEF=   0.00000   0.33333   0.33333   0.33333

M=    10                 0.      0.   2000.  11000.  31000.  64000.  81000.
                     81000.  61000.  46000.  34000.  25000.  18000.  14000.
                     11000.   9000.   6000.
SUM=   494000.
SUM OF ROUTED FLOWS TO C.P.    10

M=    10                 0.      0.   3000.  20000.  59000. 124000. 183000.
                    203000. 180000. 136000.  99000.  68000.  48000.  35000.
                     27000.  18000.  10000.


INC LOCAL FLOWS COMPUTED
```

... Continued ...

Table F.13 Printout of Computation of *"Negative"* Incremental Local Flows *(Continued)*

```
RES INFLOW,OUTFLOW=   215000.         0. ALL RES I-0=         0.

M=     30                  0.       0.   3000.  18000.  37000.  42000.  50000.
                       27000.  20000.  13000.   5000.      0.      0.      0.
                           0.       0.      0.

M=     30                  0.       0.   3000.  18000.  37000.  42000.  50000.
                       27000.  20000.  13000.   5000.      0.      0.      0.
                           0.       0.      0.
SUM=   215000. -SUM=         0. -MAX=         0.


RES INFLOW,OUTFLOW=   720000.         0. ALL RES I-0=         0.

M=     20                  0.       0.      0.   6000.  20000.  57000. 100000.
                       90000.  70000.  50000.  37000.  24000.  24000.  15000.
                        9000.   3000.      0.

M=     20                  0.       0.      0.   6000.  20000.  57000. 100000.
                       90000.  70000.  50000.  37000.  24000.  24000.  15000.
                        9000.   3000.      0.
SUM=   505000. -SUM=         0. -MAX=         0.


RES INFLOW,OUTFLOW=   498000.         0. ALL RES I-0=         0.

M=     50                  0.   6000.  27000.  60000. 105000.  78000.  60000.
                       45000.  33000.  24000.  18000.  12000.  12000.   9000.
                        6000.   3000.      0.

M=     50                  0.   6000.  27000.  60000. 105000.  78000.  60000.
                       45000.  33000.  24000.  18000.  12000.  12000.   9000.
                        6000.   3000.      0.
SUM=   498000. -SUM=         0. -MAX=         0.


RES INFLOW,OUTFLOW=  1550000.         0. ALL RES I-0=         0.

M=     10                  0.   8000.  39000.  53000.  90000.  57000.  34000.
                       -9000.   1000.   4000.  10000.  25000.  13000.   7000.
                        4000.   1000.      0.

M=     10                  0.   8000.  39000.  53000.  90000.  57000.  34000.
                       -9000.   1000.   4000.  10000.  25000.  13000.   7000.
                        4000.   1000.      0.

SUM=   337000. -SUM=    -9000. -MAX=    -9000.
SUM ALL INC FLOWS(CFS-PER)=            1555000. AVE=    91471.

SUM LAST MX=            1550000. D.S.VOL(RES.I-0,+MX)=  1550000.


********
* NOTE *   INCREMENTAL LOCAL FLOWS HAVE BEEN "COMPUTED"
********
```

F.3 Printout of Optimization Trials and Summary

F.3.1 Printout From Each Optimization Trial (*OPTRY)

Table F.14 shows an example input file for optimization of monthly power requirements and installed capacity for Reservoir 1 (**J7** Record, field 1 = 1.1)

Table F.14 Example Input for Hydropower Optimization

```
T1               BOSWELL  RES. POWER OPT. - PHONEY TW CURVE
T2  NATIONAL HYDROPOWER STUDY TEST
T3  MUDDY BOGGY CREEK
J1       0      10       4       3       4       2
J2                               3
J3       4                                       1
J6    2.31    1.23    -.14    -.14    -.14    1.23    1.23    2.31    5.34    7.64
J6    7.64    5.34
J7     1.1                                                       2       6    0.05
J8   1.090   1.100   1.120   1.130   1.150   1.160   1.110   1.220   1.210   1.250
J8   1.161   1.162   1.163   1.164
C        1       1                                                              20
C        2      83     199
RL       1  483242  158238  158238  483242 1130000
RO       1       1
RS       9      0.   1184.   9468.  31955.  84559. 197454. 393897. 697031.1130000.
RQ       91000000.1000000.1000000.1000000.1000000.1000000.1000000.1000000.1000000.
RA       9      0.   299.0  1196.0  2691.0  6638.7 12699.9 20710.0 30669.0 42576.8
RE       9      0.   11.88   23.75   35.63   47.50   59.38   71.25   83.13   95.00
P1       1     1.0
PR-.0506   -.0645  -.0551  -.0467  -.1066  -.1201  -.1828  -.1699  -.1006  -.0381
PR-.0187   -.0463
PQ       0  100000
PT       1       2
CP       1 9999999
IDBOSWELL RESERVOIR
RT       1       2
CP       2 9999999
IDMUDDY BOGGY CREEK
RT       2
ED
BF       0     360                38100000                 720
IN       1  101938      63     230    1506    2760   16708    3827    3638    3701
IN     903    1121     450      17       0       7       9      26     703     498
IN    2321     186      94     247      46       1       0       0       0       1
IN     150      43    4642    4705    2154    1874     454     128      14    1135
IN    1966    1943    4078     389    6775    2697     813     193     156      50
IN    5416    3555    1309     690    1746    1278   20137    2990    7068    1558
IN     135     577     154    1261    2217     190     211    1221    2321    8532
IN    1046      70       1       5     247      13     364     836    4789    4747
IN     918    4391    1089      48      14      55     767     224     732     429
IN    8469   15432   11355    4538   15725    3074    5228    3764    3220     447
IN     173    2802    8615    2072    2656    2488    1815     234     274      86
IN       9    6566    8866     368      97     920    7089    7612    2865     257
IN      44      70       5      72     824    1324    3534    2467      83    3283
IN    2760    1723      20      24       3       7      17    1286    4140    2865
IN     811    6169    2530     105      92     447     650      36     324    3680
.
.  (flows for periods 149 thru 360 not shown)
.
EJ
ER
```

The corresponding HEC-5 printout for the Hydropower Optimization example is shown in Table F.15 and is discussed in detail in the following paragraphs:

a. The first group of output ① shows the allowable error criteria for the optimization process (**J7** Record, field 10). The heading "ALL. PERC NEGATIVE ERROR = .05, POSITIVE ERROR = .05, IND FOR ONE MORE TRY = 0" means that the allowable error for too much drawdown (negative error) and too little drawdown (positive error) are both 5%, and that an additional routing to straighten out HEC-5B output (extra 500,000 units of storage, etc.) will not be made.

b. The second group of output ② shows the periods of the critical drawdown (e.g., from periods 12 to 30) and the average values of several items during the critical drawdown period. The items, described below, are used to calculate estimates of firm energy.

Col	Item	Description
1	INFLOW	Average reservoir inflow in m^3/s (ft^3/s)
2	POW-REL	Average power release in m^3/s (ft^3/s)
3	EL-BTW	Tailwater block-loading elevation in meters (ft)
4	DRAW-RAT	Ratio of drawdown depth to maximum drawdown of conservation pool
5	DIV-Q	Average diversion in m^3/s (ft^3/s)
6	EVAP-P	Average evaporation in m^3/s (ft^3/s)
7	RELEASE	Average reservoir release (for any purpose) in m^3/s (ft^3/s)
8	STORAGE	Average reservoir storage (500,000 has been added) in 1000 m^3 (acre-ft)
9	ELEV	Average elevation in meters (ft)
10	EN-REQ	Average energy requirement in 1000 kWh

c. The third output group ③ shows the periods used in the routing for the current trial and the average values of several items, including four of those previously described. The new items are described below:

Col	Item	Description
3	HEAD	Average pool elevation minus tailwater elevation and hydraulic losses
5	QSPILL	Average quantity of water spilled without generating hydropower
6	TAILWATER	Average tailwater used during the routing
8	H-TOP-C	Head from top of conservation pool to the tailwater (Col 6)
9	H-BOT-C	Head from bottom of conservation pool to the tailwater (Col 6)

Table F.15 Printout of Hydropower Optimization Example *(*OPTRY)*

```
*************************************************************************************************************************
*
 *OPTRY

 ROUTING CYCLE=       1   OPT TRIAL=       1

 ①      ALL. PERC NEGATIVE ERROR=     0.050  POSITIVE ERROR=    0.0500  IND FOR ONE MORE TRY=       0


 ②      AVG. CRITICAL DRAW DOWN RESULTS FROM PER      12  TO      30


      INFLOW      POW-REL      EL-BTW     DRAW-RAT      DIV-Q      EVAP-P     RELEASE     STORAGE       ELEV
EN-REQ
       228.89      450.92       66.54        0.37        0.00       60.80      450.92   830519.75       67.62
1688.88

 ③       AVG. ROUTING PERIOD RESULTS FROM PER       1  TO      34

      INFLOW      POW-REL      HEAD      DRAW-RAT     QSPILL    TAILWATER    RELEASE      H.TOP-C     H-BOT-C
      1547.97     1166.54      69.23        0.23      304.76        1.07     1471.29       73.67       54.17

 MIN HEAD=       55.04 CORR EL=       56.13 TW=        1.09 Q=     8503.92 PF=    0.2949    QMXPOW=       6351.

 GENERATION     1595.88  SHOULD EXCEED DEMAND     1688.88 RATIO=      0.9449

 SX=   354012.75  PSX=   343943.75
 GEN LESS DEMAND,NEW ERRORS ARE-,ERROR= 0.058275 ERR=     -18940.     325004.     343944.      18940.


 ④  OP TRIAL  ERROR-RAT  ERR-STG   TAR-MIN-STG  MIN-STG   PER-MIN-STG  TOP-STG     LOC.TYP
          1    0.058275   -18940.   658238.     658238.        30       983242.      1.10
************
```

... Continued ...

d. A summary of the trial's results is shown in the fourth summary ④ . This output represents the following:

Col	Item	Description
1	OP TRIAL	Trial number
2	ERROR-RAT	Ratio showing error in storage drawdown from top of conservation pool (Col 7) to minimum storage in routing (Col 5)
3	ERR-STG	Error in storage drawdown in 1000 m^3 (acre-ft)
4	TAR-MIN-STG	Target for minimum storage (drawdown) in 1000 m^3 (acre-ft)
5	MIN-STG	Minimum storage reached in current routing in 1000 m^3 (acre-ft)
6	PER-MIN-STG	Time period number of maximum drawdown
7	TOP-STG	Storage at top of conservation and power pool in 1000 m^3 (acre-ft)
8	LOC.TYP	Location number and type of optimization (e.g., 1.1=location 1, firm energy optimization)

e. The fifth group of output ⑤ shows the average annual plant factors. The first annual plant factor shown represents the ratio of the total annual energy generated in the routing (firm and secondary) to the maximum annual energy possible with the assumed installed capacity (INS CAP). The second annual plant factor shown represents the ratio of the annual firm energy generated in the routing to the maximum annual energy possible with the assumed installed capacity.

f. The sixth set of output ⑥ shows the variable being optimized (ITYOPT) and the multiplier which is used to adjust energy and capacity values for the next trial. In addition, the current installed capacity estimate and the projected value of that capacity based on the multiplier are shown. The other items are used in calculating the next estimate of the variable and are described as follows:

Col	Item	Description
1	ASSUMED	Assumed value for the first month of current trial
2	NEXT ASSUM	Value to be assumed for first month of next trial
3	PTWO	Value to be assumed if the two-point projection is used for the next trial
4	EST3	Value to be assumed if accounting estimate (projection using average values in routing) is used for the next trial
5	ER-IMPROVE	Error in storage
6	EST-BOUND	Value of estimate if maximum and minimum boundaries are used for the next trial

Table F.15 Printout of Hydropower Optimization Example *(*OPTRY)* - Continued

```
⑤  AVE ANNUAL PLANT FACTOR(FOR AAE)=     0.204  AVE MONTHLY PLANT FACTOR(FOR FIRM-EN)=     0.083


ANN DES Q ANN REQ Q ANN DIV Q     INS CAP  ANN FIRM E   AVG ANN E
      0.0      0.00      0.00      29614.      21525.      52859.


        ALL. PERC NEGATIVE ERROR=     0.010  POSITIVE ERROR=    0.0500  IND FOR ONE MORE TRY=       0


⑥   ITYOPT=   1  MULTIPLIER=       0.969155

 CHANGE CAPACITY FROM    29614.  TO    28700.

  ASSUMED   NEXT-ASSUM         PTWO          EST3   ER-IMPROVE   EST-BOUND      BNDMAX     BNDMIN   ERR-BN-MAX
ERR-BN-MIN
  1114.85      1080.47         0.00      1080.47         1.00        0.00     1114.85       0.00    -18939.75
0.00

 *Routing/Operation Summary  (Coefficients Based on 744 Hours)



          "Incremental"  LOCAL FLOW  Information:
           -------------------------------------

 ********
 * NOTE *   INCREMENTAL LOCAL Flows were Read from "IN" Records
 ********                       OR  were Read from DSS

           ELAPSED TIME:   0:00:01
```

Col	Item	Description (continued)
7	BNDMAX	Maximum value of variable being optimized from all previous trials
8	BNDMIN	Minimum value of variable being optimized from all previous trials
9	ERR-BN-MAX	Error in storage corresponding to maximum boundary
10	ERR-BN-MIN	Error in storage corresponding to minimum boundary

g. The seventh set of output ⑦ shows the optimization results for the second trial for the critical period.

h. In this example output, since the error ratio (ERROR-RAT) of 0.026531 is within the allowable error of 5% (**J7** Record, field 10), then the eighth output ⑧ section shows the optimized results being applied for the entire period (periods 1 to 360). Note that an allowable error of .95 is printed out when the period of record is routed, regardless of the value in field 10 of the **J7** Record.

i. Finally, the ninth output ⑨ section shows the Firm Yield Optimization Results of Optimized Monthly Energy. These values could subsequently be input as monthly power requirements on the **PR** Record.

Table F.15 Printout of Hydropower Optimization Example *(*OPTRY)* - Continued

```
******************************************************************************************************************************

⑦

ROUTING CYCLE=       1   OPT TRIAL=       2

        AVG. CRITICAL DRAW DOWN RESULTS FROM PER      12  TO      30


     INFLOW      POW-REL      EL-BTW     DRAW-RAT      DIV-Q      EVAP-P     RELEASE     STORAGE        ELEV       EN-REQ
      228.89      449.38       67.04         0.34       0.00       61.90      449.38   838668.06       68.13      1636.79

        AVG. ROUTING PERIOD RESULTS FROM PER       1  TO      34

     INFLOW      POW-REL      HEAD       DRAW-RAT     QSPILL    TAILWATER    RELEASE      H.TOP-C     H-BOT-C
     1547.97     1159.85       69.52         0.21     310.53        1.07     1470.38       73.67       54.17


MIN HEAD=       55.98 CORR EL=       57.06 TW=       1.08 Q=     8104.39 PF=    0.3043    QMXPOW=       6155.

GENERATION     1594.48  SHOULD EXCEED DEMAND     1636.79 RATIO=      0.9742


SX=   338572.63  PSX=   333626.63
GEN LESS DEMAND,NEW ERRORS ARE-,ERROR= 0.026531 ERR=      -8623.     325004.     333627.       8623.



 OP TRIAL    ERROR-RAT   ERR-STG   TAR-MIN-STG   MIN-STG   PER-MIN-STG  TOP-STG     LOC.TYP
         2  0.026531     -8623.      658238.    658238.        30      983242.       1.10
************


AVE ANNUAL PLANT FACTOR(FOR AAE)=     0.209  AVE MONTHLY PLANT FACTOR(FOR FIRM-EN)=     0.083


ANN DES Q ANN REQ Q ANN DIV Q     INS CAP  ANN FIRM E   AVG ANN E
      0.0      0.00      0.00      28700.      20861.      52612.
```

... Continued ...

Table F.15 Printout of Hydropower Optimization Example *(*OPTRY)* - Continued

```
 ITYOPT=   1  MULTIPLIER=       0.985936

CHANGE CAPACITY FROM    28700.  TO    28297.

ASSUMED   NEXT-ASSUM      PTWO        EST3   ER-IMPROVE   EST-BOUND       BNDMAX       BNDMIN   ERR-BN-MAX   ERR-BN-MIN
1080.47      1065.27   1051.73     1065.27     10318.13        0.00      1080.47         0.00     -8622.63         0.00

==================== Firm Yield Optimization Results =====================
Location:   1     Optimized Monthly Energy in mW Hours
                   1080.     1333.     1177.     997.     2056.     2565.
                   3777.     3628.     2079.     814.      399.      957.

          DUR       VOL-DUR        PER-START        PER-END        Q-RIVER        Q+QSTOR        EST-STG        DEP CAP
         18.          4306.              12.            29.           239.        538.                0.        36134.

    START-PER        END-PER           DATE
            1            360       38100100

      CON-STG          QMEAN      RAT-STG/Q       DRAW-DUR   APPROX. DEP CAP.
      325004.          1782.          0.252            18.         36134.


*Routing/Operation Summary  (Coefficients Based on 744 Hours)

          "Incremental"  LOCAL FLOW  Information:
           -------------------------------------

********
* NOTE *   INCREMENTAL LOCAL Flows were Read from "IN" Records
********                     OR  were Read from DSS

           ELAPSED TIME:   0:00:01

           ****************************
           TOTAL ELAPSED CLOCK TIME FOR:   360 PERIODS:  0:00:03
           ****************************
```

... Continued ...

Table F.15 Printout of Hydropower Optimization Example *(*OPTRY)* - Continued

⑧

```
*****************************************************************************************************************************

*OPTRY

ROUTING CYCLE=       2   OPT TRIAL=       1

        ALL. PERC NEGATIVE ERROR=     0.950  POSITIVE ERROR=    0.9500  IND FOR ONE MORE TRY=       0


        AVG. CRITICAL DRAW DOWN RESULTS FROM PER      12  TO      30


     INFLOW      POW-REL      EL-BTW     DRAW-RAT      DIV-Q      EVAP-P     RELEASE     STORAGE       ELEV       EN-REQ
      228.89      449.38       67.04        0.34        0.00       61.90      449.38   838668.06       68.13     1636.79

        AVG. ROUTING PERIOD RESULTS FROM PER       1  TO     360


     INFLOW      POW-REL      HEAD      DRAW-RAT     QSPILL    TAILWATER    RELEASE     H.TOP-C     H-BOT-C
     1781.56     1433.51       71.80        0.10      259.80        1.07     1693.31       73.67       54.17


MIN HEAD=       55.98 CORR EL=       57.06 TW=        1.08 Q=     8104.39 PF=    0.7085    QMXPOW=       6155.

GENERATION     1594.48  SHOULD EXCEED DEMAND     1636.79 RATIO=      0.9742


SX=   338134.94  PSX=   333626.63
GEN LESS DEMAND,NEW ERRORS ARE-,ERROR= 0.026531 ERR=      -8623.     325004.     333627.      8623.
```

... Continued ...

Table F.15 Printout of Hydropower Optimization Example *(*OPTRY)* - Continued

```
  OP TRIAL   ERROR-RAT  ERR-STG   TAR-MIN-STG   MIN-STG   PER-MIN-STG   TOP-STG    LOC.TYP
          1  0.026531    -8623.     658238.    658238.        30       983242.      1.10
************

 AVE ANNUAL PLANT FACTOR(FOR AAE)=     0.264  AVE MONTHLY PLANT FACTOR(FOR FIRM-EN)=     0.083

 ANN DES Q ANN REQ Q ANN DIV Q     INS CAP  ANN FIRM E   AVG ANN E
       0.0      0.00      0.00      28700.      20861.      66470.

   ITYOPT=   1  MULTIPLIER=       0.985387

  CHANGE CAPACITY FROM    28700.  TO    28281.

  ASSUMED   NEXT-ASSUM      PTWO         EST3   ER-IMPROVE   EST-BOUND        BNDMAX        BNDMIN   ERR-BN-MAX   ERR-BN-MIN
  1080.47      1064.68      0.00      1064.68         1.00        0.00      1080.47          0.00     -8622.63         0.00

  ⑨
  ==================== Firm Yield Optimization Results =====================
  Location:   1     Optimized Monthly Energy in mW Hours
                      1080.     1333.     1177.      997.     2056.     2565.
                      3777.     3628.     2079.      814.      399.      957.

  New Critical Period=   -11.036     0.050     0.027
```

F.3.2 Output Summary of Conservation Optimization Results (*OPSUM)

A summary of the results of a conservation optimization is printed in the output file anytime a **J7** Record is used in the input data. Table F.16 shows this summary where one line of output for each optimization trial is shown (i.e., optimization results for estimated critical period, check of results with period of record routing, etc.). On each line is shown the following:

Column 1	LOCATION - Identification of Project (from **T1** Record, columns 17 to 26).
Column 2	INS CAP (KW) - Derived installed capacity based on **PR** Record ratios of the firm energy that was dependable for the routing period (length = Col 8, starting date = Col 13) within the allowable storage drawdown error.
Column 3	FIRM ENERGY (MWH) - Annual firm energy which was dependable for the routing period within the allowable storage drawdown error.
Column 4	AVG ANN ENERGY (MWH) - Average annual energy (AAE) for the routing period analyzed. Where the AAE is for the critical period only (plus a few months), a value of -1 is used since this Column has no meaning under these conditions.
Column 5	ERROR RATIO - Drawdown storage error expressed as a ratio. Difference between minimum storage reached in routing and target storage at bottom of conservation pool, expressed as a ratio of total conservation storage. A storage penalty is added when power shortages occur due to the assumed energy being too high.
Column 6	NO. TRIES - Number of iterations (routings) required to determine the firm energy for the routing period selected within the allowable error in drawdown storage.
Column 7	SPILL - The average volume of water in m^3/s (ft^3/s) for the routing period (Col 8) that is passed through the dam without generating energy.
Column 8	NPER - Number of periods of routing for each of the trials.

Column 9	ENERGY RATIO - Factor to adjust monthly power requirements (PR Records) to generate the average annual energy (column 4) with installed capacity shown in column 2. This factor can be entered in the third field of the second PR record (PR.13) to adjust the monthly energy requirements or plant factors.
Column 10	RATIO STG/Q - Ratio of conservation storage to mean annual flow. A value of 1.0 would indicate that there is sufficient power storage to withdraw the reservoir volume over a 12-month period at the same rate as the average annual inflow (ignoring evaporation losses).
Column 11	FIRM ENERGY / PLNT FAC - The ratio of the annual firm energy (Col 3) to the annual energy possible using the installed capacity (Col 2).
Column 12	ASSUMED DEP CAP (kW) - Estimated starting value of Dependable Capacity using power storage and minimum flows available during estimated critical drawdown period.
Column 13	ROUTING/ST PER - Starting year and month of routing (1966.10 indicates October 1966).
Column 14	HEAD - Average head during the routing period (Col 8).
Column 15	DRAW ST PER - Year and month of start of critical drawdown period.
Column 16	DRAW. LENGTH - Length (months) of the critical drawdown period which started at date shown in Col 15.

Table F.16 Summary Printout of Hydropower Optimization Example *(*OPSUM)*

```
*OPSUM
                     T1               BOSWELL  RES. POWER OPT. - PHONEY TW CURVE
                     T2  NATIONAL HYDROPOWER STUDY TEST
                     T3  MUDDY BOGGY CREEK

                     J7  1.10    0.00    0.00    0.00    0.00    0.00    0.00    2.00    6.00    0.05
```

(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*	*(14)*	*(15)*	*(16)*
LOCATION	INS CAP (KW)	FIRM ENERGY (MWH)	AVG ANN ENERGY (MWH)	ERROR RATIO	NO. TRIES	SPILL	NPER	ENERGY RATIO	RATIO STG/Q	FIRM ENERGY PLNT FAC	ASSUMED DEP CAP (KW)	ROUTING ST PER	HEAD	DRAW. ST PER	DRAW. LENGTH
BOSWELL	29613.	21525.	-1.	0.0583	1	305.	34	0.9449	0.2518	0.0830	29613.	1938.10	69.23	1939.09	19.
BOSWELL	28700.	20861.	-1.	0.0265	2	311.	34	0.9742	0.2518	0.0830	28700.	1938.10	69.52	1939.09	19.
BOSWELL	28700.	20861.	66470.	0.0265	1	260.	360	0.9742	0.2518	0.0830	28700.	1938.10	71.80	1939.09	19.

F.4 Output Arranged by Sequence of Control Points (*NORML)

The output from program HEC-5B is preceded by general information that is pertinent to the output results. An example of this information is provided in Table F.17 and described by the following:

FLOOD NUMBER - The basic flood event identifier based on the sequence of events input (**BF**-**EJ** Records), or automatically generated by the program.

NFLRD - The number of flood events read in the input file. This would be the number of **EJ** Records in the input file since each set of time series records requires an **EJ** Record.

IFLRD - The sequence number of the flow series read (NFLRD) which is currently being printed out.

NFLCON - The number of flood ratios to be used (**FC** Record) for the current flood event.

IFLCON - The sequence number of the ratio used (of NFLCON) for the current printout.

Flows Multiplied by - The ratio which is multiplied times all flows on IN Records for current output (**BF** Record, field 4).

Computation Interval in Hours - The simulation time interval (**BF** Record, field 7).

Included alongside the above information is a section showing UNITS OF OUTPUT. All flow and evaporation values are in m^3/s (ft^3/s) and represent the average during each period. Reservoir storage values are in 1000 m^3 (acre-ft). Elevations are in meters (ft). Energy is in 1000 kWh, except when the computation interval is less than 24 hours; then, the energy output is in kWh.

Table F.17   Example Printout of Information for UNITS OF OUTPUT

```
*FLOOD 1
                  UNITS OF OUTPUT:                                                       ***** FLOOD NUMBER  1 *****
          All Flows and Evaporation in m3/s or CFS                                    NFLRD=        1  NFLCON=       0
          Reservoir Storages in 1000 m3 or Acre Feet                                  IFLRD =       1  IFLCON=       1
          Elevations in Meters or Feet
          Energy in 1000 kWh for DAILY-MONTHLY Computations                           Flows Multiplied by    1.000
          Energy in kWh for HOURLY Computations                                       Computation Interval in Hours= 24.00

***************************************************************************************************************
```

Following the general information, the normal sequential program output is listed (if requested by **J3** Record, field 1 containing a code 8) in the sequence the control points were read (downstream order). An example of the *NORML output is shown in Table F.18 for Reservoir locations and Table F.19 for Non-reservoir locations. Each of the items is shown for all periods using 10 or 12 periods per line of output (depending on the simulation time interval). When the time interval is monthly (e.g., 720 hours), as in conservation analysis, the output is 12 periods per line instead of 10. The average, maximum, and minimum values are also provided for all of the output variables.

All possible output items are shown in the following list along with the order number that they would appear in the *NORML sequential output section. The "**R**" represents output for reservoirs only; the "**C**" represents output for non-reservoir control points only; and "**R, C**" represents output for both reservoirs and non-reservoir control points. An asterisk (*) appears for those items that will be omitted if not given or requested in the input:

R, C (1) `LOC 555  RESERVOIR A`
Location Identification Number (from **CP** Record) and Location Identification Name (from **ID** Record)

R, C `SERVED BY   111, -222, 555`
Shows which upstream reservoirs operate for this location. In this example, there are three reservoirs upstream from Reservoir A (location 555). Reservoir 111 operates for Reservoir A; however, Reservoir 222 does not operate for it (indicated by the negative location number). Since all reservoirs operate for themselves, then 555 is also shown.

R `SERVING   15, 16, 18`
Shows which downstream locations that the reservoir operates for. In this example, Reservoir A (555) operates for locations 15, 16 and 18..

R, C (2) `Local Cumulative` - The cumulative local flow for each period is the flow above the current control point and below all upstream reservoirs that have at least one 1000 m^3 (acre-foot) of flood control storage.

R, C* (3) `Natural Q` - The flow that would occur without any reservoirs in the basin. The calculation and printout of natural flows is an optional program feature (**J3** Record, field 4).

R* (4) `Energy Required` - The firm energy requirements at the reservoir as defined by input. Units of output are 1000 kWh unless the time interval is less than 24 hours.

R* (5) `Energy Generated` - The total energy generated by the reservoir, in 1000 kWh unless time periods are less than 24 hours.

R* (6) `Energy Shortage` - The difference between firm energy required and energy generated. Units of output would be the same as (4) and (5).

R* (7) `Q-Spill-Power` - The flow that could not be used to generate energy.

R* (8) `Peak Capability` - Power plant peaking capability in 1000 kWh.

R, C* (9) `Min Desired Q` - The minimum desired flow at the current control point; i.e., demand to be met as long as reservoirs are above top of buffer pool.

R, C* (10) `Deq-Shortage` - The amount by which regulated flow at the current control point falls short of the minimum desired flow.

R, C* (11) `Min Required Q` - The minimum required flow at the current control point; i.e., demand to be met as long as reservoirs are above level 1.

R, C* (12) `Req-Shortage` - The amount by which regulated flow at the current control point falls short of the minimum required flow.

R, C* (13) `Div Requirement` - The flow demand for diversion from this control point.

R, C* (14) `Diversion Q` - The algebraic sum of all diversions from the control point (positive) or to the control point (negative). The regulated flow at the control point or inflow into the reservoir includes the effects of the diversions both from and to the control point.

R, C* (15) `Div Shortage Q` - The amount by which the diversion falls short of the diversion requirement.

R (16) `Inflow` - The inflow hydrograph to a reservoir. The inflow values are equal to the cumulative local flows plus the routed upstream reservoir releases minus any diversions at the reservoir or upstream points.

C (17) `Qmax-Target Flow` - When channel capacity varies at a control point (**CC** Record is used) the channel capacity is shown for each time period.

C (18) `Flow Regulated` - The calculated regulated flow at a control point based on local inflow, upstream reservoir releases, and diversions from and to the control point.

R (19) `Outflow` - The average reservoir outflow.

R* (20) `Case =Loc.Typ` - The reason for making the reservoir release is shown for each time period as a two-part code such as: `0.03` or `18.03`.

The number to the left of the decimal indicates the downstream controlling location. If the controlling location is the reservoir itself, a zero will be printed to the left of the decimal. <u>When operating for a downstream location</u>, the number to the right of the decimal is the number of future time periods controlling the release. For example, `18.03` indicates that the flow at location `18`, `3` time periods in the future was used to determine the final reservoir release. <u>When operating for itself</u>, there is a zero to the left of the decimal, and the number on the right indicates the following:

`00` Release was for minimum desired flow requirements.

`01` Release was constrained by channel capacity at the reservoir.

`02` The release was governed by the maximum permitted rate-of-change from the preceding release.

`03` The release was calculated to exactly empty flood control storage (e.g., to reach Top-of-Conservation).

`04` The release was made to eliminate or minimize storage of water above the top of the flood control pool.

`05` The release was made to bring the reservoir into balance with a downstream tandem reservoir.

`06` The release was constrained by the outlet capacity.

`07` The release was based on LEVEL 1 limitation (top-of-inactive storage).

`08` Release was governed by minimum required flow.

`09` Release was based on buffer level constraint.

`10` Release was based on firm energy hydropower demand.

`11` Flood control releases cannot be made until highest priority reservoir is releasing (ISCHED = 1 on J2.6). Release only for minimum flow requirements.

`12` Release was based on allocated system energy requirement.

`13` Release was based on hydropower LEAKAGE (**P2** Record, field 1)

`14` Release was limited by hydropower PENSTOCK (**P2** Record, field 2)

`15` Release was limited by hydropower GENERATOR CAPACITY (**P1** Record, field 2 or **PP**/**PS** Records)

`20` Release based on Gate Regulation Curve (**RG** Record), Rising Pool

`21` Release based on Emergency operation: Partial Gate Opening

`22` Release based on Emergency operation: Transition

`23` Release based on Emergency operation: Outflow = Inflow

`24` Release based on Emergency operation: All gates fully open

`29` Release based on Emergency operation: Pre-release option (**J2** Record, field 5)

`99` Release was specified by the user on **QA** Records

R (21) `Level` - The index level for each time period is shown. The index level specified on **J1** Record, field 4 (LEVCON) indicates the top of the conservation pool and the index level from the **J1** Record, field 5 (LEVTFC) indicates the top of the flood control pool. Therefore, a level of 3.750, when

LEVCON and LEVTFC are 3 and 4, respectively, would show that 75% of the flood control storage is being used.

R (22) `Level Equivalent` - The equivalent system level, including all upstream tandem reservoirs, of the current reservoir (omitted when no reservoirs are in tandem).

R* (23) `Evaporation` - The volume of water lost to evaporation in 1000 m^3 (acre-ft) is shown for each time period for routing intervals greater than or equal to 24 hours.

R (24) `EOP Storage` - The end-of-period storage in the reservoir is shown for each time period.

R,C* (25) `EOP Elev/Stage` - When elevation (**RE** Record) is provided at a reservoir or stage data (**EL** Record) is provided at a non-reservoir control point, the end-of-period elevation or stage for each time period is shown. Channel stage is based on the regulated flow while the reservoir elevation is based on the reservoir storage.

C (26) `Q Space Avail.` - The channel capacity minus the regulated flow gives the space available in the channel for additional reservoir releases. Negative values indicate the amount of flooding (in excess of channel capacity). This output is omitted when monthly routings are used.

C (27) `Q by US Res,Divs` - This hydrograph is the result of all upstream reservoir releases and diversion return flows routed to the current control point. It is the difference between regulated flow and cumulative local flow.

C (28) `Fl GT Local Q` - The amount of flooding which could have been prevented, if it had been possible to make no releases from all upstream reservoirs and diversion return flows, for each time period. The total flooding shown in this item does not reflect flooding from the cumulative uncontrolled local flow (Item 2). This output is omitted when a monthly routing is used.

R, C* (29) `Local Incremental` - The intervening flow between a location and its upstream adjacent locations.

R* (30) `Sys En Required` - The system energy requirements, in 1000 KWh unless time periods are less than 24 hours. (System output is only shown at the first reservoir in the system.)

R* (31) `Sys En Useable` - The total system energy generated that can be credited to the system. This value could be less than total generated due to maximum plant factor for system use (PFMAX on **P2** Record, field 4).

R* (32) `Sys En Generated` - The total system energy generated by projects in this system, in 1000 KWh unless time periods are less than 24 hours.

R* (33) `Sys En Shortage` - The difference between system energy required and system energy generated. Units of output are the same as 33, 34, and 35. (Negative shortages or surpluses are ignored.)

R* (34) `Power Head` - The head available for producing hydropower.

R* (35) `Mills / kWh` - The benefit rate in MILLS per kWh for power rule curve operation (**PC**, **PF**, **PB** Records).

R* (36) `Plant Factor` - Ratio of energy generated to maximum generation possible for each time period.

R* (37) `Q-Gate Regulation` - The release from the reservoir based on gate regulation operation (**RG** Record).

R (38) `Pct Storage Norm` - Percentage showing how full the conservation pool is for each time period. 100 indicates the conservation pool is full, 50 indicates the conservation pool is half full, etc.

R (39) `Top Con. Storage` - Storage at the Top of Conservation pool for each time period.

Table F.18 "Normal Sequential" Output for Reservoir Locations *(*NORML)*

```
*****************************************************************************************************************************
 *NORML 111

 **** LOC   111 RES 111                          SERVED BY    111
                                                                                                   Starting Time=       1
                                                                                                   Hour= 0,Day= 1,Mon= 1,Year=1999
                                SERVING     111   600   800   999
 PER         Local Cumulative

     1   4200.   4300.   5160.   5860.   5980.   6580.  11300.  46500.  63800.  83000.
    11  90200. 112000.  91900.  50300.  48000.  37100.  51300.  55700.  45500.  30600.
    21  19200.  17100.  16800.  32800.  29000.  25400.  22400.  21000.  18300.  16700.

                                                                                                   Avg=   35599.332  Max=  112000.000
                                                                                                                     Min=    4200.000
 PER         Natural Q

     1   4200.   4300.   5160.   5860.   5980.   6580.  11300.  46500.  63800.  83000.
    11  90200. 112000.  91900.  50300.  48000.  37100.  51300.  55700.  45500.  30600.
    21  19200.  17100.  16800.  32800.  29000.  25400.  22400.  21000.  18300.  16700.

                                                                                                   Avg=   35599.332  Max=  112000.000
                                                                                                                     Min=    4200.000
 PER         Inflow

     1   4200.   4300.   5160.   5860.   5980.   6580.  11300.  46500.  63800.  83000.
    11  90200. 112000.  91900.  50300.  48000.  37100.  51300.  55700.  45500.  30600.
    21  19200.  17100.  16800.  32800.  29000.  25400.  22400.  21000.  18300.  16700.

                                                                                                   Avg=   35599.332  Max=   12000.000
                                                                                                                     Min=    4200.000
```

... Continued ...

Table F.18 "Normal Sequential" Output for Reservoir Locations *(*NORML)* - Continued

```
PER       QMax-Target Flow

   1  12000.  12000.  12000.  12000.  12000.  12000.  12000.  12000.  12000.  26000.
  11  40000.  40000.  61805.  66412.  64023.  61581.  60309.  65483.  73367.  79332.
  21  83269.  85722.  87858.  87153.  90000.  89963.  89661.  90000.  90000.  90000.
                                                                                      Avg=   54331.289  Max=   90000.047
                                                                                                         Min=   12000.040
PER       Outflow

   1   4200.   4300.   5160.   5860.   5980.   6580.   8992.   7602.  12000.  26000.
  11  33303.  40000.  61215.  66412.  64023.  45270.  17305.      0.      0.      0.
  21      0.      0.  22480.      0.  38877.  27890.  15603.  15302.  14028.  14093.
                                                                                      Avg=   18749.121  Max=   66411.906
                                                                                                         Min=       0.000
PER       Case    =Loc.Typ

   1    0.03    0.03    0.03    0.03    0.03    0.03  999.00  999.00  999.00    0.00
  11    0.00    0.00    0.00    0.00    0.00    0.00    0.00  600.00  600.00  600.00
  21  600.00  600.00    0.00  600.00    0.00    0.00    0.00    0.00    0.00    0.00
                                                                                      Avg=     219.906  Max=     999.000
                                                                                                         Min=       0.000
PER       Level

   1   3.000   3.000   3.000   3.000   3.000   3.000   3.004   3.069   3.156   3.252
  11   3.348   3.469   3.521   3.493   3.467   3.453   3.510   3.604   3.680   3.732
  21   3.764   3.793   3.783   3.838   3.822   3.817   3.829   3.838   3.846   3.850
                                                                                      Avg=       3.465  Max=       3.850
                                                                                                         Min=       3.000
PER       Pct Storage Norm

   1    0.00    0.00    0.00    0.00    0.00    0.00    0.39    6.93   15.64   25.22
  11   34.79   46.90   52.06   49.35   46.65   45.28   51.00   60.36   68.01   73.16
  21   76.39   79.26   78.31   83.82   82.16   81.74   82.89   83.84   84.56   85.00
                                                                                      Avg=      46.457  Max=      85.000
                                                                                                         Min=       0.000
```

... Continued ...

Table F.18 "Normal Sequential" Output for Reservoir Locations *(*NORML)* - Continued

```
PER        Top Con. Storage

    1 558000. 558000. 558000. 558000. 558000. 558000. 558000. 558000. 558000. 558000.
   11 558000. 558000. 558000. 558000. 558000. 558000. 558000. 558000. 558000. 558000.
   21 558000. 558000. 558000. 558000. 558000. 558000. 558000. 558000. 558000. 558000.

                                                                                     Avg=  558000.000  Max=  558000.000
                                                                                                       Min=  558000.000
PER        EOP Storage

    1 558000. 558000. 558000. 558000. 558000. 558000. 562578. 639732. 742478. 855538.
   11 968393.1111205.1172069.1140111.1108330.1092125.1159554.1270035.1360285.1420980.
   211459063.1492981.1481715.1546773.1527182.1522244.1535725.1547027.1555501.1560672.

                                                                                     Avg= 1106009.880  Max= 1560672.000
                                                                                                       Min=  558000.000
PER        EOP Elev/Stage

    1  723.02  723.02  723.02  723.02  723.02  723.02  723.19  726.16  729.78  733.43
   11  736.65  740.54  741.97  741.22  740.47  740.09  741.67  744.27  746.38  747.69
   21  748.45  749.12  748.90  750.19  749.80  749.71  749.97  750.20  750.37  750.47

                                                                                     Avg=     738.960  Max=     750.470
                                                                                                       Min=     723.020
PER        Q-Gate Regulatio

    1      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   11      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   21      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.

                                                                                     Avg=       0.000  Max=       0.000
                                                                                                       Min=       0.000
*******************************************************************************************************************************
```

Table F.19 "Normal Sequential" Output for Non-reservoir Locations *(*NORML)*

```
*****************************************************************************************************************************
*
 *NORML 999

 **** LOC   999 CP999                            SERVED BY    111    222    333

 PER        Local Cumulative

     1   1260.   1290.   1548.   1758.   1794.   1974.   3390.  13950.  19140.  24900.
    11  27060.  33600.  27570.  15090.  14400.  11130.  15390.  16710.  13650.   9180.
    21   5760.   5130.   5040.   9840.   8700.   7620.   6720.   6300.   5490.   5010.
                                                                                        Avg=   10679.800  Max=   33600.000
                                                                                                          Min=    1260.000
 PER        Natural Q

     1  13976.  14206.  14564.  14678.  17374.  18784.  26370.  76930. 112200. 143680.
    11 152190. 189600. 177270. 141290. 145500. 135730. 254390. 235510. 173650. 125460.
    21 102810.  95530. 101340. 116040.  96300.  93320.  97020.  93800.  89500.  84720.
                                                                                        Avg=  105124.398  Max=  254390.000
                                                                                                          Min=   13976.000
 PER        QMax-Target Flow

     1  20000.  20000.  20000.  20000.  20000.  20000.  20000.  21552.  36818. 150000.
    11 150000. 150000. 150000. 150000. 150000. 250000. 250000. 250000. 250000. 250000.
    21 250000. 250000. 250000. 250000. 250000. 250000. 250000. 250000. 250000. 250000.
                                                                                        Avg=  161612.359  Max=  250000.063
                                                                                                          Min=   20000.039
 PER        Flow Regulated

     1  13976.  14206.  14564.  14678.  17374.  18784.  20000.  21552.  36818.  56134.
    11  60363.  91800.  88785.  82545.  82200.  80565.  82695.  83355.  77718.  69182.
    21  62904.  57839.  80587.  56478.  79350.  78810.  78360.  78150.  77745.  77505.
                                                                                        Avg=   58500.707  Max=   91799.828
                                                                                                          Min=   13976.000
```

... Continued ...

Table F.19 “Normal Sequential” Output for Non-reservoir Locations *(*NORML)* - Continued

```
PER        Q Space Avail.

    1   6024.   5794.   5436.   5322.   2626.   1216.      0.      0.      0.  93866.
   11  89637.  58200.  61215.  67455.  67800. 169435. 167305. 166645. 172282. 180818.
   21 187096. 192161. 169413. 193522. 170650. 171190. 171640. 171850. 172255. 172495.

                                                                                            Avg=  103111.664  Max=  193521.719
                                                                                                              Min=       0.050
PER        Q by US Res,Divs

    1  12716.  12916.  13016.  12920.  15580.  16810.  16610.   7602.  17678.  31234.
   11  33303.  58200.  61215.  67455.  67800.  69435.  67305.  66645.  64068.  60002.
   21  57144.  52709.  75547.  46638.  70650.  71190.  71640.  71850.  72255.  72495.

                                                                                            Avg=   47820.914  Max=   75546.672
                                                                                                              Min=    7601.880
PER        Fl GT Local Q

    1      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   11      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   21      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.

                                                                                            Avg=       0.000  Max=       0.000
                                                                                                              Min=       0.000
*************************************************************************************************************************
```

F.5 Reservoir Operation Summary and Control Point Summary by Sequence of Time Period (*ROPER).

When requested (**J3** Record, field 1 contains 16), the following items are shown for all reservoirs for each time period:

(1) `Res No` - The identification number of the reservoir.

(2) `TITLE` - The alphanumeric name for the **ID** Record.

(3) `Inflow` - The reservoir inflow.

(4) `Outflow` - The reservoir outflow.

(5) `EOP Stor` - The end of period reservoir storage in 1000 m^3 (acre-ft).

(6) `Elev` - The elevation corresponding to the average reservoir storage.

(7) `Case` - The controlling criteria (LOC.TYP) for determining the reservoir release.

(8) `Level` - The reservoir index level.

(9) `Pct FC` - The percent of Flood Control storage

(10) `EQ Level` - Equivalent level of tandem reservoirs.

Table F.20 shows an example of the *ROPER output.

Table F.20 Example of Reservoir Operation by Period *(*ROPER)*

```
*******************************************

Reservoir Operation by Period

            Cum Time=      1
*ROPER 1

 Res No=       111     222     333
 TITLE=     RES 11  RES 22  RES 33
 Inflow      4200.    356.   8160.
 Outflow     4200.    356.   8160.
 EOP Stor  558000. 553000.1087000.
 Elev         723.    638.    730.
 Case=       0.030   0.030   0.030
 Level       3.000   3.000   3.000
 Pct FC       0.00    0.00    0.00
 Eq Level    3.000   3.000   3.000
```

... Periods 2 through 29 not shown ...

```
            Cum Time=     30
 *ROPER 30

 Res No=       111     222     333
 TITLE=     RES 11  RES 22  RES 33
 Inflow     16700.  20810.  42200.
 Outflow    14093.  18656.  39747.
 EOP Stor 1560672.1381160.2030512.
 Elev         750.    658.    752.
 Case=       0.000   0.000   0.000
 Level       3.850   3.850   3.850
 Pct FC      85.00   85.00   85.00
 Eq Level    3.850   3.850   3.850
```

F.6 Results by Time Period

F.6.1 Reservoir Releases by Period (*RRPER) and Regulated Flows at Control Points (*RQPER)

When requested (**J3** Record, field 1 contains 32), the following items are shown for all reservoirs (see Table F.21, *RRPER output) and for all non-reservoirs (see Table F.22, *RQPER output) for each time period:

`Res No / C.P. No.` - The identification number of reservoir or control point.

`Location` - Alphanumeric name from the **ID** Record.

`Chan Cap` - The non-damaging channel capacity in m^3/s (ft^3/s) at the reservoir or control point. A "`-1`" indicates that the channel capacity varies each time period.

`Min Des Q` - Minimum desired flow at the specified location (-1 if not input).

`Min Req Q` - Minimum required flow at the specified location (-1 if not input).

Reservoir releases or regulated flows for each time period, at all reservoirs and control points, are in m^3/s (ft^3/s).

The Sum, Maximum value, Minimum value, Period number (PMax) of the maximum value, the Average value (Avg), and the Period number (PMin) of the minimum value for each reservoir and control point are also shown.

Table F.21 Example of Reservoir Release by Period *(*RRPER)*

```
*RRPER     Reservoir Release by Period

Res No         111     222     333
Location   RES 111 RES 222 RES 333
Chan Cap       -1.     -1.     -1.
Min Des Q      -1.     -1.     -1.
Min Req Q      -1.     -1.     -1.
 Period
    1        4200.    356.   8160.
    2        4300.    356.   8260.
    3        5160.    636.   7220.
    4        5860.   1240.   5820.
    5        5980.   1800.   7800.
    6        6580.   2260.   7970.
    7        8992.   1670.   5948.
    8        7602.      0.      0.
    9       12000.   3438.   2241.
   10       26000.   3532.   1703.

...  Periods 11 through 28 not shown ...

   29       14028.  17647.  40580.
   30       14093.  18656.  39747.

     Sum = 562474. 109294. 762860.
     Max =  66412.  19732.  66645.
     Min =      0.      0.      0.
     PMax=     14.     27.     18.
     Avg =  18749.   3643.  25429.
     PMin=     18.      8.      8.
```

Table F.22 Example of Regulated Flows by Period *(*RQPER)*

```
*RQPER   Regulated Flows at Control Points by Period
         (Non-Reservoir Locations)

 C.P. No.        600     800     999
 Location    CP 600  CP 800  CP 999
 Chan Cap        -1.     -1.     -1.
 Min Des Q       -1.     -1.     -1.
 Min Req Q       -1.     -1.     -1.
 Period
     1       13346.  13766.  13976.
     2       13561.  13991.  14206.
     3       13790.  14306.  14564.
     4       13799.  14385.  14678.
     5       16477.  17075.  17374.
     6       17797.  18455.  18784.
     7       18305.  19435.  20000.
     8       14577.  19227.  21552.
     9       27248.  33628.  36818.
    10       43684.  51984.  56134.

 ...  Periods 11 through 28 not shown ...

    29       75000.  76830.  77745.
    30       75000.  76670.  77505.

      Sum =1594824.1701622.1755021.
      Max =  78067.  86200.  91800.
      Min =  13346.  13766.  13976.
      PMax=     23.     12.     12.
      Avg =  53161.  56721.  58501.
      PMin=      1.      1.      1.
```

F.6.2 Diversion Flows and Shortages by Time Period (*DVPER, *DVSHORT)

When diversions are input, a summary of diversion flows and shortages for each time period, for all locations, can be requested by including a 32 in the value specified in field 1 of the **J3** Record. Table F.23 shows an example of the diversion flows (*DVPER) output and Table F.24 shows an example of the diversion shortages (*DVSHORT) output.

Table F.23 Example of Diversion Flows by Period *(*DVPER)*

*DVPER   Diversion Flows at Control Points by Period (All Locations)

C.P. No.	55	40	39	30	20	10
Location	ADAM R	BAKERV	RETURN	CONWAY	DAVISV	WILLEY
Period						
1	80.	75.	-53.	5.	-2.	0.
2	80.	75.	-53.	5.	-2.	0.
3	80.	75.	-53.	5.	-2.	0.
4	80.	75.	-53.	5.	-2.	0.
5	80.	75.	-53.	5.	-2.	0.
6	80.	75.	-53.	5.	-2.	0.
7	80.	75.	-53.	5.	-2.	0.
8	80.	75.	-53.	5.	-2.	0.
9	80.	75.	-53.	5.	-2.	0.
10	80.	75.	-53.	5.	-2.	0.
Sum =	800.	750.	-525.	53.	-21.	0.
Max =	80.	75.	-53.	5.	-2.	0.
Min =	80.	75.	-53.	5.	-2.	0.
PMax=	1.	1.	1.	1.	1.	1.
Avg =	80.	75.	-53.	5.	-2.	0.
PMin=	1.	1.	1.	1.	1.	1.

Table F.24 Example of Diversion Shortages by Period *(*DVSHORT)*

*DVSHORT   Diversion Shortages at Control Points by Period (All Locations)

C.P. No.	55	40	39	30	20	10
Location	ADAM R	BAKERV	RETURN	CONWAY	DAVISV	WILLEY
Period						
1	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.	0.
Sum =	0.	0.	0.	0.	0.	0.
Max =	0.	0.	0.	0.	0.	0.
Min =	0.	0.	0.	0.	0.	0.
PMax=	1.	1.	1.	1.	1.	1.
Avg =	0.	0.	0.	0.	0.	0.
PMin=	1.	1.	1.	1.	1.	1.

F.6.3 Percent Flood Control Storage by Time Period (*FCPCT)

To assist in the analysis of a flood control system, a summary of percent flood control storage used by each reservoir can be requested by including a 32 in the value specified in field 1 of the **J3** Record. By reviewing this output, you can see how much flood storage was used by each reservoir throughout the system. Table F.25 shows an example of the *FCPCT output summary.

Table F.25 Example of Percent Flood Control Storage by Period *(*FCPCT)*

```
*FCPCT     Percent Flood Control Storage Used by Reservoir and by Period


Res No            3       2       5
Location      RES C   RES B   RES A
 Period
    1            0.      0.      0.
    2            0.      0.      0.
    3            0.      0.      4.
    4           12.      0.     16.
    5           43.      5.     39.
    6           78.     15.     55.
    7          100.     34.     67.
    8          100.     54.     75.
    9          100.     69.     83.
   10          100.     80.     89.
   11           99.     88.     94.
   12           93.     93.     94.
   13           93.     94.     94.
   14           93.     95.     94.
   15           93.     97.     92.
   16           93.     93.     90.
   17           93.     90.     90.

      Sum =   1190.    907.   1075.
      Max =    100.     97.     94.
      Min =      0.      0.      0.
      PMax=      7.     15.     11.
      Avg =     70.     53.     63.
      PMin=      1.      1.      1.
```

F.7 User Designed Output (*USERS)

Tables of output can be designed by using up to 80 different **J8** Records (see Appendix G, Input Description). Output can be time distributed variables or summary data at any control point or reservoir. Table F.26 shows an example of a User Designed Output table requested by a **J8** Record.

Useful items to include in a *USER table for a reservoir location include the following (shown with with the **J8** Record "code" that would be input with the "X" value being the location identification number):

Inflow	(X.09)	-	Net Inflow at the reservoir (values shown account for Evaporation and Diversions).
Outflow	(X.10)	-	Releases from the reservoir.
Case	(X.12)	-	The "reason" for the reservoir's release. A description of Cases are shown at the end of the output file (*CASES).
Level	(X.13)	-	The level number at the end of the time period (see the **J1** Record for user definition of the level numbers).
EOP Stor	(X.11)	-	End-of-period Storage values.
EOP Elev	(X.22)	-	End-of-period Elevation values (if **RE** Records are input).
Flow Reg	(X.04)	-	Regulated Flow at the Downstream location that the reservoir operates for (**RO** Record).

For non-reservoir locations, there are several items available to analyze the performance of a system. In addition to the Regulated Flow (X.04), the following items might be requested for a location where there is a Water Supply demand:

Min Des	(X.05)	Minimum Desired flow.
Min Req	(X.07)	Minimum Required flow.
Min Des Sh	(X.06)	Minimum Desired Shortage.
Min Req Sh	(X.08)	Minimum Required Shortage.
Div	(X.03)	Diversion.
Div Req	(X.30)	Diversion Requirement.
Div Sh	(X.31)	Diversion Shortage

The following items might be useful for a location where there is a limiting Channel Capacity (e.g., Flood Control Operation):

Qmax-Tar	(X.17)	Channel Capacity
Q Space	(X.18)	Space Available (e.g., Channel Capacity - Regulated Flow)
Local Cu	(X.01)	Cumulative Local Flow (e.g., sum of all upstream routed uncontrolled local flows)
Q By Res	(X.19)	Flows from reservoirs & diversions

Table F.26 Example of a User Designed Output Table *(*USERS)*

*USERS. 1 User Designed Output (Dates shown are for END-of-Period)
Summary by Period Flood= 1

Per	Date:	Hr	Day	BISHOP DA Inflow	BISHOP DA Outflow	BISHOP DA Case	BISHOP DA Level	BISHOP DA EOP Stor	BISHOP DA EOP Elev	ZELMA Flow Reg	ZELMA QMax-Tar	ZELMA Q Space	ZELMA Local Cu
Location No=				44.	44.	44.	44.	44.	44.	40.	40.	40.	40.
J8/JZ Codes=				44.090	44.100	44.120	44.130	44.110	44.220	40.040	40.170	40.180	40.010
1	9Nov73	9	Fri	67.00	80.00	0.00	2.99	146340.00	251.49	132.00	450.00	318.00	52.00
2	9Nov73	12	Fri	78.00	29.00	0.02	3.00	146869.00	251.54	133.50	450.00	316.50	62.00
3	9Nov73	15	Fri	159.00	0.00	40.04	3.01	148586.00	251.71	109.25	450.00	340.75	78.00
4	9Nov73	18	Fri	215.00	0.00	40.03	3.01	150908.00	251.94	202.21	450.00	247.79	197.00
5	9Nov73	21	Fri	309.00	0.00	40.04	3.02	154245.00	252.27	231.87	450.00	218.13	231.00
6	9Nov73	24	Fri	473.00	0.00	40.04	3.03	159354.00	252.77	289.15	450.00	160.85	289.00
7	10Nov73	3	Sat	605.00	0.00	40.04	3.05	165888.00	253.42	473.03	450.00	-23.03	473.00
8	10Nov73	6	Sat	704.00	0.00	40.04	3.06	173491.00	254.17	460.01	450.00	-10.01	460.00
9	10Nov73	9	Sat	960.00	0.00	40.04	3.09	183859.00	255.20	509.00	450.00	-59.00	509.00
10	10Nov73	12	Sat	1022.00	0.00	40.03	3.12	194896.00	256.29	608.00	450.00	-158.00	608.00
11	10Nov73	15	Sat	1133.00	0.00	40.02	3.15	207133.00	257.50	756.00	450.00	-306.00	756.00
12	10Nov73	18	Sat	1378.00	0.00	40.01	3.18	222015.00	258.97	934.00	450.00	-484.00	934.00
13	10Nov73	21	Sat	1696.00	0.00	40.00	3.23	240332.00	260.78	1036.00	450.00	-586.00	1036.00
14	10Nov73	24	Sat	1787.00	0.00	40.00	3.27	259631.00	262.57	882.00	450.00	-432.00	882.00
15	11Nov73	3	Sun	2405.00	0.00	40.00	3.33	285605.00	264.58	715.00	450.00	-265.00	715.00
16	11Nov73	6	Sun	2616.00	0.00	40.00	3.40	313858.00	266.77	529.00	450.00	-79.00	529.00
17	11Nov73	9	Sun	2150.00	0.00	40.00	3.46	337078.00	268.57	374.00	450.00	76.00	374.00
18	11Nov73	12	Sun	1974.00	51.00	0.02	3.51	357847.00	270.18	334.50	450.00	115.50	326.00
... Periods 19 through 31 not shown ...													
32	13Nov73	6	Tue	197.00	346.89	40.00	3.67	424140.00	274.72	438.60	450.00	11.40	57.00
			Sum =	30179.00	4469.73	880.53	108.10	9721559.00	8482.33	13873.92	14400.00	526.08	9678.00
			Max =	2616.00	395.73	40.04	3.69	433131.00	275.31	1036.00	450.00	340.75	1036.00
			Min =	67.00	0.00	0.00	2.99	146340.00	251.49	109.25	450.00	-586.00	52.00
			PMax=	16.00	31.00	3.00	27.00	27.00	27.00	13.00	1.00	3.00	13.00
			Avg =	943.09	139.68	27.52	3.38	303798.72	265.07	433.56	450.00	16.44	302.44
			PMin=	1.00	3.00	1.00	1.00	1.00	1.00	3.00	1.00	13.00	1.00

F.8 Single Flood Summary

A single flood summary of maximums for reservoirs and non-reservoirs for each flood event (where the time interval is Daily or less) can be requested by including a 1 in the value input in field 1 of the **J3** Record. If requested, the following information will be displayed for Reservoir locations and for Control Point locations:

Reservoirs: For each reservoir, the following is displayed as shown in Table F.27:

(1) STOR1 - The starting reservoir storage.
(2) MAX LEVEL - The maximum reservoir level during the flood.
(3) MAX INFLOW - The maximum reservoir inflow.
(4) MAX REL. - The maximum reservoir release.
(5) CHAN CAP. - The channel capacity at the reservoir.

The maximum system storage is printed at the end of the summary table.

Table F.27. Summary of Maximums for Reservoirs (for Daily or Less Time Interval)

```
                                          --------------
                 Summary of Maximums for    RESERVOIRS
                            --------      --------------

      HEC-5 Example 1, Basic Flood Regulation   (EXAMPLE1.DAT)
      SI Units, 24 Hrs Foresight with 20% Contingency
      Rocky River, Bishop Dam Site to Zelma, 9-13 Nov 1973 Flood

           -------------------------------------------------------

           Period of Analysis:  STARTING :  09NOV73 - 0600 Hrs
                                ENDING   :  13NOV73 - 0600 Hrs
                                DURATION :  4 Days,  0 Hrs,  0 Min

                Time Interval:    3 Hours,  0 Minutes

           -------------------------------------------------------

******************************************************************************
*    Reservoir    *     Max     *     Max     *    Max            *     Max    *
*                 *   Inflow    *   Outflow   *  Storage    Elev  *    HEC-5   *
*  ID    Name     *   (m3/s)    *   (m3/s)    * (1000m3)  (Meters)*    Levels  *
*                 *             *             *                   *            *
******************************************************************************
*                 *             *             *                   *            *
*  44 BISHOP DAM  *        2616 *         425 *   351464   269.68 *      3.493 *
*                 * 11NOV-0600  * 10NOV-0300  *    12NOV-1200     * 12NOV-1200 *
*                 *             *             *                   *            *
******************************************************************************


           Maximum System Storage Used =   351464.  (12NOV-1200)
```

Control Points: For each control point location, the following is displayed (as shown in Table F.28):

(1) Max Reg Flow - Maximum regulated flow at control point..
(2) Max Nat - Maximum unregulated (natural) discharge.
(3) MAX UNC - Maximum discharge from the uncontrolled drainage area below all reservoirs which have flood control storage.
(4) Q BY RES - The difference between the MAX REG Q and MAX UNC which shows the remaining possible reduction in peak discharge if all reservoirs had unlimited flood control storage.
(5) CH CAP - Channel capacity.

Table F.28. Summary of Maximums for Control Points (for Daily or Less Time Interval)

```
                                   -----------------------------------
         Summary of Maximums for    CHANNEL CONTROL POINT LOCATIONS
                    --------       -----------------------------------


      HEC-5 Example 1, Basic Flood Regulation   (EXAMPLE1.DAT)
      SI Units, 24 Hrs Foresight with 20% Contingency
      Rocky River, Bishop Dam Site to Zelma, 9-13 Nov 1973 Flood

           -------------------------------------------------------

           Period of Analysis:  STARTING :  09NOV73 - 0600 Hrs
                                ENDING   :  13NOV73 - 0600 Hrs
                                DURATION :  4 Days,  0 Hrs,  0 Min

                Time Interval:    3 Hours,  0 Minutes

           -------------------------------------------------------

******************************************************************************
*  Channel Location  *  Channel     Max     Q from *  Max Cum.  *    Max     *
*                    * Capacity  Reg. Flow    Res. *  Local Q   * Natural Q  *
*  ID    Name        *  (m3/s)    (m3/s)    (m3/s) *  (m3/s)    *  (m3/s)    *
******************************************************************************
*                    *                             *            *            *
*  44 BISHOP DAM     *     425        425        0 *     2616   *      2616  *
*                    *          10NOV-0300         * 11NOV-0600 * 11NOV-0600 *
*                    *                             *            *            *
*  40 ZELMA          *     650        529      425 *      104   *      2532  *
*                    *          10NOV-2100         * 10NOV-2100 * 11NOV-0900 *
*                    *                             *            *            *
******************************************************************************
```

F.9 Multi-flood Summaries: Flood Control (*SUMFS) and Conservation (*SUMPO)

The *SUMFS summary shown in Table F.29 and described below is done for each flood event in turn (FLOOD SUMMARY - EACH FLOOD) and then the maximums and minimums for all flood events are shown (MAX VALUES FOR MULTI-FLOODS). The Multi-flood summary is a summary of the significant features of each event. For each control point, the maximum regulated flow (MAX REG Q), the maximum natural flow (MAX NAT Q) and the maximum cumulative local flow (MAX LOCAL Q) are presented. Also, listed for each control point is the total contribution of upstream reservoirs to the maximum regulated flow at the control point (Q BY RES). For each reservoir, the minimum storage (MIN STG), minimum level (MIN LEVEL), maximum storage (MAX STG), maximum level (MAX LEVEL) and the maximum release (MAX REL) are listed. Finally, the minimum combined storage (MIN SYSTEM STG) and the maximum combined storage (MAX SYSTEM STG) that were reached by the system reservoirs during the flood event are listed.

The flood summary for all floods (MAX VALUES FOR MULTY FLOODS) is presented with the same format as the individual flood summaries.

Table F.29. Summary of Multiple Flood Events *(*SUMFS)*

```
FLOOD SUMMARY-EACH FLOOD  COPY=   1

       HYDROPOWER RESERVOIR WITH MIN FLOW, AND DIVERSION        TEST 5
       MIXED MONTHLY AND 6 HOUR TIME INTERVALS             1982 INPUT FORMAT
       BROKEN BOW DAM
*SUMFS 1
                                           ***** FLOOD NUMBER  1 *****

                               MAX REG Q   MAX NAT Q   MAX LOC Q  Q BY RES
LOC    44 EAGLETOWN                 3612.       3579.          0.       3612.


        RESERVOIRS            MIN STG   MIN LEVEL  MAX STG   MAX LEVEL  MAX REL
LOC    25 BROKEN BOW DAM         530185.    1.173   918800.   2.000     3556.

                          MIN SYSTEM STG=    530185.   MAX SYSTEM STG=    918800.

*SUMFS 2
                                           ***** FLOOD NUMBER  2 *****

                               MAX REG Q   MAX NAT Q   MAX LOC Q  Q BY RES
LOC    44 EAGLETOWN                 8068.     152000.          0.       8068.


        RESERVOIRS            MIN STG   MIN LEVEL  MAX STG   MAX LEVEL  MAX REL
LOC    25 BROKEN BOW DAM         659135.    1.448  1042448.   2.275     8000.

                          MIN SYSTEM STG=    659135.   MAX SYSTEM STG=   1042448.

                                                               COPY=       1

                                      ***** MAX VALUES FOR MULTY FLOODS *****

                               MAX REG Q   MAX NAT Q   MAX LOC Q  Q BY RES
LOC    44 EAGLETOWN                 8068.     152000.          0.       8068.

        RESERVOIRS            MIN STG   MIN LEVEL  MAX STG   MAX LEVEL  MAX REL
LOC    25 BROKEN BOW DAM         530185.    1.173  1042448.   2.275     8000.
```

For events with a monthly time interval, the MINIMUM VALUES AND SHORTAGES FOR CONSERVATION OPERATION - ALL FLOODS table (as shown in Table F.30) provides conservation based results (*SUMPO). For control points including reservoirs, the shortage periods, shortage volume (in month-discharge units), and shortage index are provided for both desired flow and required flow. In the event no minimum flow requirement is defined at a location, the shortage volume value -1 is printed. The shortage index is defined as the sum of the squares of annual shortages prorated to a 100-year period where annual shortages are expressed as a decimal fraction of the demand. For each reservoir, the time period 1 (FLD. PER), the minimum storage (MIN STG), and the minimum level (MIN LEVEL) are printed.

Table F.30. Example Summary Output for Monthly Conservation *(*SUMPO)*

```
*SUMPO
 MINIMUM VALUES AND SHORTAGES FOR CONSERVATION OPERATION-ALL FLOODS
                            ***** DESIRED FLOW ****    **** REQUIRED FLOW ****
                            SHORTAGE SHORTAGE SHORTAGE SHORTAGE SHORTAGE
SHORTAGE
    LOC                     PERIODS  VOLUME   INDEX    PERIODS  VOLUME   INDEX
     20 ALLEN RES               2.       11.     0.01       0.       0.     0.00
     15 BRENDA                  0.       -1.     0.00       0.      -1.     0.00
     10 CHARLES LAKE            0.        0.     0.00       0.       0.     0.00
      5 JAMESTOWN               0.       -1.     0.00       0.       0.     0.00
      NOTE@  -1. INDICATES THAT DESIRED AND/OR REQUIRED FLOWS WERE NOT SPECIFIED
                   FOR GIVEN CONTROL POINT

           RESERVOIRS              FLD.PER    MIN STG   MIN LEVEL
 LOC    20 ALLEN RES               1.04000      8883.     1.692
 LOC    10 CHARLES LAKE            1.04000     24878.     2.352
```

d. If there are power reservoirs in the system, the SUMMARY OF AT SITE ENERGY PRODUCTION (see Table F.31) and the SUMMARY OF AT SITE POWER BENEFITS (see Table F.32) are printed for each event and for the sum for all events. These summaries represent totals for all power reservoirs regardless of whether the projects are operated as one or more power systems (see **SM** Record). The energy production table provides the total primary, secondary, and total energy for each power reservoir based on at-site energy requirements. Also printed are the total shortage, the minimum peaking capability and the installed capacity. Totals of system energy production and shortages are provided for each flood, and a grand total table is provided under the heading ALL FLOODS. The power benefits table shows the energy benefit data (input on **J4** Record) and the total benefits for primary and secondary energy, the cost of purchase energy (based on shortage) and the net total energy value. The capacity value is based on the minimum capability. The benefits table is printed for each flood and the grand total is shown for ALL FLOODS.

Table F.31. Summary of At-Site Energy Production

```
    SUMMARY OF AT-SITE ENERGY PRODUCTIONS ** 1000 KWH **  CAPACITIES ** KW **

                      ***** FLOOD NUMBER  1 *****

LOC=   PROJECT   PRIMARY SECONDARY  SHORTAGE   TOTAL  MIN PEAK CAP  INSTALLED CAP

   1   HARTWELL     4435.    35417.        0.  39853.     299007.       264000.

  99  PUMP-BACK  -102231.        0.        0. -102231.    300000.      -300000.

   2  R RUSSELL    10080.    99894.        0.  109974.    622341.       600000.

   3  CLRK HILL     4704.    76109.        0.   80813.    312742.       280000.

                      TOTALS OF AT-SITE ENERGY PRODUCTIONS

                         -83012.   211421.        0.   128409.

                      ***** ALL FLOODS *****


   1   HARTWELL     4435.    35417.        0.   39853.    299007.       264000.

  99  PUMP-BACK  -102231.        0.        0. -102231.    300000.      -300000.

   2  R RUSSELL    10080.    99894.        0.  109974.    622341.       600000.

   3  CLRK HILL     4704.    76109.        0.   80813.    312742.       280000.

                      TOTALS OF AT-SITE ENERGY PRODUCTIONS

                         -83012.   211421.        0.   128409.
```

Table F.32. Summary of At-Site Energy Benefits

SUMMARY OF AT-SITE POWER BENEFITS ** DOLLARS **

***** FLOOD NUMBER 1 *****

LOC=	PROJECT	BENEFIT RATES PRI	SEC	PUR	CAP	ENERGY VALUE PRIMARY	SECONDARY	PURCHASE	TOTAL ENERGY VALUE	CAPACITY VALUE
1	HARTWELL	1.20	0.80	2.40	20.00	5322.	28334.	0.	33656.	5280000.
99	PUMP-BACK	1.20	0.80	2.40	20.00	0.	0.	0.	0.	0.
2	R RUSSELL	1.20	0.80	2.40	20.00	12096.	79915.	0.	92011.	12000000.
3	CLRK HILL	1.20	0.80	2.40	20.00	5645.	60888.	0.	66532.	5600000.
	TOTALS OF AT-SITE POWER BENEFITS					23063.	169137.	0.	192200.	22880000.

***** ALL FLOODS *****

LOC=	PROJECT	PRIMARY	SECONDARY	PURCHASE	TOTAL ENERGY VALUE	CAPACITY VALUE
1	HARTWELL	5322.	28334.	0.	33656.	
99	PUMP-BACK	0.	0.	0.	0.	
2	R RUSSELL	12096.	79915.	0.	92011.	
3	CLRK HILL	5645.	60888.	0.	66532.	
	TOTALS OF AT-SITE POWER BENEFITS	23063.	169137.	0.	192200.	22880000.

F.10 Damage Computation Data (*ECDAM)

An example of input records and corresponding output for flood frequency and damage data are shown in Table F.33. This is a compilation of flood flow-frequency-damage data for the system and consists of the following:

a. Data Printout. The exceedence frequency, peak flow, and damage data for base conditions, provided as input to the program, is listed in order of increasing flood peaks:

Column 1	Probabilities of exceedence corresponding to each input flood peak in Column 2.
Column 2	Input peak flows corresponding to exceedence probabilities in Column 1.
Column 3	The sum of the damages for all types corresponding to flood peaks in Column 2. Damages are listed in the same units as input to the program (e.g., dollars, thousands of dollars, etc.) and multiplied by escalation factor ECFCT (J4.2).
Columns 4 - 12	Damages for up to 9 types (**DA** Record, field 1); e.g., urban, rural transportation, times ECFCT. Damage types are in the same order as the **DC** Records from which the data are read.

b. Expected Annual Damages. If expected annual damages are computed (**J4** Record, field 1 is positive), they are based on the input discharge-frequency damage data and the results are printed on the line labeled BASE COND-COMPUTED. If expected annual damages for base conditions have been input (**DA** Record), these values are listed as BASE COND-INPUT. If expected annual damages for the existing system have been input (**DB** Record), these values are listed as EXISTING SYSTEM-INPUT.

c. Base Condition Flood Damages. This output includes the flood event number with the unregulated peak flow and the exceedence frequency, probability interval and damage values associated with that event. The unregulated peak flows have been arranged from smallest to largest. The exceedence frequency for the event is determined by logarithmic interpolation of the input flow-frequency data. The probability interval for the event represents the probability between the midpoints of adjacent events. If expected annual damages are computed (**J4** Record, field 1 is positive), the damage values represent the incremental portion between adjacent events. If damages only are computed (**J4** Record, field 1 is negative), the values are the damages for the event interpolated from the input discharge-damage relation and the probability interval is set to 1.0.

d. Modified Conditions Flow-Damage Data. If a design discharge, DESQ (**C$** Record, field1), is provided for a local project or second set of **DC** Records is input, the modified flow-frequency-damage data are listed.

e. Modified Conditions Flood Damages. Modified conditions refer to the system with all reservoirs and local projects in operation. This output has the same format as for the base conditions output except that there is an additional line of output showing damage reduction (the amount by which damages are reduced from the existing system damages).

f. Uncontrolled Local Flow Flood Damages. Uncontrolled local flows refer to those flows which reach the control point without passing through a reservoir; that is, flows for which there are no available controls. Damages with total control at projects refer to the damages that would occur if all upstream reservoirs had sufficient capacity to prevent releases contributing to peak flows downstream. Thus, damages with total control are equivalent to damages from uncontrolled local flow. RESIDUAL DAMAGES is the amount by which damages could be further reduced in the existing system if all reservoirs had sufficient capacity.

Table F.33. Printout of Flood Frequency and Damage Data *(*ECDAM)*

Example Input Records:

```
'
.
.
J4     1     999            .03       .1
.
.
.
CP     4   40000
ID CP 4
C2 0.025     2.5
RT     4
QS     9   10000   20000   30000   40000  100000  300000  500000  700000  900000
EL     9     300     350     450     500     550     600     625     650     700
C$ 40000    2000    4000    5000    6000
DA     2
DB     2     500    1000
DF    17    .999    .900    .800    .700    .600    .500    .400    .300    .250
DF  .200    .150    .100    .050    .020    .010    .005    .002
DQ    17   28800   35000   42000   50500   60500   73000   90000  114000  130000
DQ150000  180000  230000  323000  490000  640000  840000 1000000
DC     1     .05     .08     .10     .11     .14     .19     .29     .38     .48
DC   .60     .80    1.21    2.20    4.20    5.38    6.12    6.50
DC     2     .10     .17     .22     .30     .40     .52     .75    1.10    1.45
DC  1.90    2.80    4.90    9.80   12.20   13.32   14.17   14.66
ED
BF     0      18       0       057060610       0       6
FC    .3       1     1.5       2       3       4
.
.
.
EJ
ER
```

Example Output:

```
*ECDAM 4
                  BASE CONDITION FREQUENCY-FLOW-DAMAGE DATA
    FREQ       PEAK           SUM     TYPE 1    TYPE 2
  0.9990     28800.        149.85      49.95     99.90
  0.9000     35000.        249.75      79.92    169.83
  0.8000     42000.        319.68      99.90    219.78
  0.7000     50500.        409.59     109.89    299.70
  0.6000     60500.        539.46     139.86    399.60
  0.5000     73000.        709.29     189.81    519.48
  0.4000     90000.       1038.96     289.71    749.25
  0.3000    114000.       1478.52     379.62   1098.90
  0.2500    130000.       1928.07     479.52   1448.55
  0.2000    150000.       2497.50     599.40   1898.10
  0.1500    180000.       3596.40     799.20   2797.20
  0.1000    230000.       6103.89    1208.79   4895.10
  0.0500    323000.      11988.00    2197.80   9790.20
  0.0200    490000.      16383.60    4195.80  12187.80
  0.0100    640000.      18681.30    5374.62  13306.68
  0.0050    840000.      20269.71    6113.88  14155.83
  0.0020   1000000.      21138.84    6493.50  14645.34

EXPECTED ANNUAL DAMAGES
   BASE COND-COMPUTED   2206.91     523.61   1683.30
   BASE COND-   INPUT      0.00       0.00      0.00
   EXIST SYSTEM-INPUT   1500.00     500.00   1000.00
```

... Continued ...

Table F.33. Printout of Flood Frequency and Damage Data *(*ECDAM)* - Continued

```
                               BASE CONDITION FLOOD DAMAGES
           EXCD  PROB
NO.  FLOW  FREQ   INT        SUM     TYPE 1    TYPE 2
 1  61200.0.594 0.642     326.82      91.11    235.71
 2 204000.0.123 0.269     728.27     165.94    562.33
 3 306000.0.056 0.046     443.59      83.55    360.04
 4 408000.0.031 0.022     316.22      70.92    245.30
 5 612000.0.011 0.013     219.25      59.74    159.50
 6 816000.0.006 0.008     172.76      52.33    120.43

    BASE COND DAMAGES    2206.91     523.61   1683.30
    EXST SYST DAMAGES    1500.00     500.00   1000.00


                         MODIFIED CONDITIONS FLOW-DAMAGE DATA
    FREQ      PEAK           SUM     TYPE 1    TYPE 2
  0.9990    28800.          0.00       0.00      0.00
  0.8268    40000.        299.70      94.19    205.51
  0.8000    42000.        319.68      99.90    219.78
  0.7000    50500.        409.59     109.89    299.70
  0.6000    60500.        539.46     139.86    399.60
  0.5000    73000.        709.29     189.81    519.48
  0.4000    90000.       1038.96     289.71    749.25
  0.3000   114000.       1478.52     379.62   1098.90
  0.2500   130000.       1928.07     479.52   1448.55
  0.2000   150000.       2497.50     599.40   1898.10
  0.1500   180000.       3596.40     799.20   2797.20
  0.1000   230000.       6103.89    1208.79   4895.10
  0.0500   323000.      11988.00    2197.80   9790.20
  0.0200   490000.      16383.60    4195.80  12187.80
  0.0100   640000.      18681.30    5374.62  13306.68
  0.0050   840000.      20269.71    6113.88  14155.83
  0.0020  1000000.      21138.84    6493.50  14645.34


                          MODIFIED CONDITIONS FLOOD DAMAGES
           EXCD  PROB
NO.  FLOW  FREQ   INT        SUM     TYPE 1    TYPE 2
 1  40000.0.594 0.642      86.68      24.91     61.77
 2  85000.0.123 0.269     184.29      49.29    135.00
 3 127500.0.056 0.046      76.39      19.35     57.04
 4 170000.0.031 0.022      75.70      16.88     58.81
 5 312760.0.011 0.013     111.97      21.61     90.36
 6 463262.0.006 0.008     148.35      40.64    107.71

     MODIFIED DAMAGES     683.37     172.69    510.68
     DAMAGE REDUCTION     816.63     327.31    489.32


                         UNCONTROLLED LOCAL FLOW FLOOD DAMAGES
           EXCD  PROB
NO.  FLOW  FREQ   INT        SUM     TYPE 1    TYPE 2
 1  25500.0.594 0.642       5.06       1.59      3.47
 2  85000.0.123 0.269     157.62      42.96    114.66
 3 127500.0.056 0.046      76.39      19.35     57.04
 4 170000.0.031 0.022      71.92      16.26     55.66
 5 255000.0.011 0.013      81.93      16.09     65.85
 6 340000.0.006 0.008     111.08      23.80     87.29
     DAMAGES W/ TOTAL
  CONTROL AT PROJECTS     504.00     120.04    383.96

   REDUCTION POSSIBLE
   W/ TOTAL CONTROL       996.00     379.96    616.04

     RESIDUAL DAMAGES     179.37      52.65    126.72
```

F.11 Flood Frequency Plots (*EPLOT)

The input exceedence frequency-discharge data, the peak flows for input flood events under base conditions, and the reduced flows resulting from modified conditions are plotted on the exceedence frequency curve (see Figure F.1). An expected annual damages summary is also printed out on the plot. If a single flood event is input to the program the damage values for the modified system are for the single event.

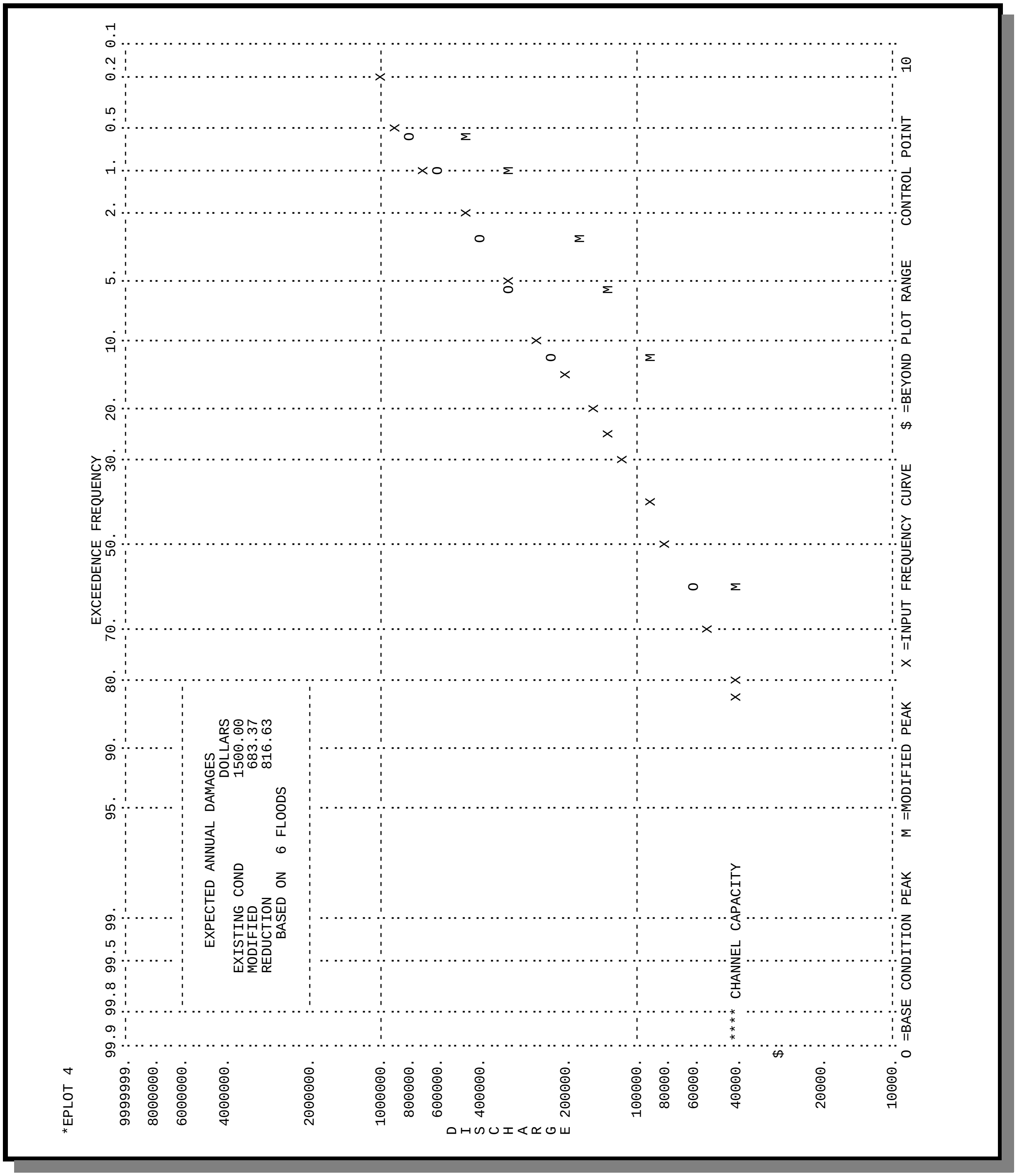

Figure F.1. Example of Flood Frequency Plot *(*EPLOT)*

F.12 Summary of Damages or Average Annual Damages, System Costs and Net Benefits

F.12.1 Summary of Damages and Damage Reductions (*ESUMD)

For each damage control point, the total damages for base conditions, modified conditions and uncontrolled local flows, the damage reductions expected from modified conditions and from total control at projects, and residual damages are summarized. If multiple floods are input to the program, the printout values are either damages for those specific floods (**DA** Record, field 1 is negative) or are expected annual damages (**DA** Record, field 1 is positive). If a single flood event is input, the values are damages for the single event. An example printout of this summary information is shown in Table F.34.

Table F.34. Expected Annual Flood Damage Summary *(*ESUMD)*

```
*ESUMD
                     SUMMARY OF SYSTEM"S EXPECTED ANNUAL FLOOD DAMAGES

                         DAMAGES                          DAMAGE REDUCTION
    CP        BASE COND    MOD COND    LOC COND    MOD COND    LOC COND    RESIDUAL
         4      1500.00      683.37      504.00      816.63      996.00      179.37

   TOTALS       1500.00      683.37      504.00      816.63      996.00      179.37
```

F.12.2 Summary of System Costs (*ESUMC)

For each control point for which a project is being considered, the project type and project costs are listed. The project type will be indicated as either a reservoir or a local protection work. Costs include initial (capital) costs and annual (operation, maintenance and replacement) costs. An example of this summary information is shown in Table F.35.

Table F.35. System Costs Summary *(*ESUMC)*

```
*ESUMC

                           SUMMARY OF SYSTEM COSTS
                           -----------------------
         *************************************************************
         *         *           *           *    ANNUAL    *   TOTAL     *
         * CONTROL *  PROJECT  *  CAPITAL  *    O,M, R    *   ANNUAL    *
         *  POINT  *   TYPE    *   COST    *    COST      *    COST     *
         *************************************************************
         *         *           *           *              *             *
         *     1.  * RESERVOR  *   7600.00 *      152.00  *     380.00  *
         *     4.  * LOCAL     *    600.00 *       15.00  *      30.00  *
         *************************************************************
```

F.12.3 System Economic Cost and Performance Summary (*ESUMB)

Total capital and annual costs include the combined costs of all proposed projects. EXPECTED ANNUAL DAMAGES - EXISTING SYSTEM are the expected annual damages of the system in the base condition, computed from the discharge-frequency curve. Alternatively, the EXPECTED ANNUAL DAMAGES for the existing system may be the sum of the input values by means of base damage records (**DB** Records). EXPECTED ANNUAL DAMAGE - PROPOSED SYSTEM is based on a modified discharge-frequency curve which is derived from flows computed for multiple input flood events. The total system annual costs and expected annual damage reduction is summarized and the net damage reduction benefits computed. If a single flood event is input to the program this portion of the output is deleted. An example of this summary information is shown in Table F.36.

Table F.36. System Economic Summary *(*ESUMB)*

```
*ESUMB
              SYSTEM ECONOMIC COST AND PERFORMANCE SUMMARY
                  (EXCLUSIVE OF EXISTING SYSTEM COSTS)

       TOTAL SYSTEM CAPITAL COST * * * * * * *        8200.00

       TOTAL SYSTEM ANNUAL OPERATING
          MAINTENANCE, AND REPAIR COST * * * *         167.00

       TOTAL SYSTEM ANNUAL COST  * * * * * * *                     410.00


       EXPECTED ANNUAL DAMAGES - EXISTING SYSTEM      1500.00

       EXPECTED ANNUAL DAMAGES - PROPOSED SYSTEM       683.37
```

F.13 Hydrologic Efficiencies (*HYEFF)

The reduction in discharge and stage at each control point as a result of reservoir operation is tabulated in the output as shown in Table F.37. Differences are taken between natural and regulated values.

Table F.37. Example Output of Hydrologic Efficiencies *(*HYEFF)*

```
*HYEFF

HYDROLOGIC EFFICIENCIES

  LOCATION         PEAK DISCHARGE REDUCTION      MAX STAGE REDUCTION
                   NAT Q     REG Q    DIFF Q   NAT STG  REG STG  DIF STG

************************************************************************

 SAVANNAH R. BEL    22936.    18146.    4789.      0.00     0.00     0.00

************************************************************************
```

F.14 Computer Check for Possible Errors (*ERROR)

Results of program operation are scanned for possible reservoir operation errors. If no operation errors are detected, then the output will look like that shown in Table F.38. If a constraint is violated, an error message is printed out (as shown in Table F.39). The basic message has the form "POSSIBLE ERROR: Loc No=, Per=, Act Q=, Min Q=, Res No=, Level=, (Above Level=)". The message states that a possible error was found at a control point (Loc No) for a particular time period (Per). The actual flow (Act Q) and minimum desired or required flow (Min Q) are listed for that control point at that time period. The remaining items identify the reservoir (Res No=) that was the source of the possible erroneous release, the level (Level=) of the reservoir at the end of the period and the next lower integer level (Above Level=). Additional messages are also printed:

a. "MINIMUM FLOW NOT SUPPLIED." The desired or required flow at the current control point was not satisfied and one or more reservoirs had storage that could have eliminated or reduced the shortage.

b. "FLOODING CAUSED BY RESERVOIR." Flooding at the current control point was caused at least in part by nonessential releases from an upstream reservoir.

c. "RESERVOIR RELEASE INCORRECTLY BASED ON D.S. FLOW." Reservoir release (Rel=) was made to provide a target flow at the downstream control point as indicated by the "Case=" and "D.S.Loc=". The downstream flow is either larger than or less than the target flow considering the contingency factor and a 5% allowable departure. When the reservoir is in flood control operation, the downstream flow "D.S. Flow=" should be at channel capacity "CCap=" (allowing for a contingency factor). If the reservoir is in conservation operation, the downstream flows should satisfy minimum desired or required flows.

Table F.38. Example where "No Operation Errors" Detected *(*ERROR)*

```
*****************************************************************************
 *ERROR

              Computer Check for POSSIBLE ERRORS

                            ***** Flood Number  1 *****


     Possible ERRORS Found=       0 Allowable ERROR CHECK=      50



*****************************************************************************
```

Table F.39. Example where "Operation Errors" are Detected *(*ERROR)*

```
 *************************************************************************************************************************

 *ERROR

                   Computer Check for POSSIBLE ERRORS

                       ***** Flood Number  1 *****

         RESERVOIR RELEASE INCORRECTLY BASED ON D.S. FLOW

POSSIBLE ERROR:  Res=  20, Per=  2, Rel=  106.3, Case=  50.00, Level= 2.62, D.S.Loc=  50, D.S.Flow=  106.3, CCap= 4000.0


        MINIMUM FLOW NOT SUPPLIED

 POSSIBLE ERROR:  Loc No=   50, Per=   2, Act Q=   106.3, Min Q=   555.0, Res No=   20, Level= 2.62 (Above Level= 2.00)


 Possible ERRORS Found=     2   Allowable ERROR CHECK=      50

 *************************************************************************************************************************
```

F.15 Case Definitions (*CASES)

A brief table is presented at the end of the output file defining the Case designations used by the program. Table F-40 provides a description of the different case values that show "why" the reservoir made the release it did.

Table F.40. Case Designations for Reservoir Releases *(*CASES)*

```
*CASES

     CASES for  PROGRAM DETERMINED Releases
                ---------------------------

** CASE =  X.Y, Where:  X = Controlling LOCATION
                        Y = NUMBER of Future Period Controlling

EXCEPT When X=0
THEN, TYPE of Release is Based on RESERVOIR REQUIREMENTS,  Y =

     Y=00 Minimum DESIRED FLOW at Dam Site
     Y=01 Operational CHANNEL CAPACITY at Dam Site
     Y=02 Based on MAX RATE of CHANGE of Reservoir Release
     Y=03 Release to Reach TOP of CONSERVATION  POOL
     Y=04 Release to Reach TOP of FLOOD CONTROL POOL
     Y=05 Release to BALANCE TANDEM Reservoirs
     Y=06 Based on MAX RELEASE Due to OUTLET CAPACITY
     Y=07 Based on NOT DRAWING BELOW LEVEL 1
     Y=08 Minimum REQUIRED FLOW at Dam Site
     Y=09 Release to Reach TOP of BUFFER LEVEL
     Y=10 Based on POWER: AT-SITE Demand
     Y=11 MIN FLOW Since Highest Res CANNOT Release
     Y=12 Based on SYSTEM POWER Demand
     Y=13 Based on POWER: LEAKAGE
     Y=14 Based on POWER: PENSTOCK Limit
     Y=15 Based on POWER: GENERATOR CAPACITY
     Y=20 Based on GATE REGULATION CURVE - RISING POOL
     Y=21 Based on EMERGENCY Release: PARTIAL GATE OPENING
     Y=22 Based on EMERGENCY Release: TRANSITION
     Y=23 Based on EMERGENCY Release: OUTFLOW=INFLOW
     Y=24 Based on EMERGENCY Release: ALL GATES FULLY OPEN
     Y=29 Based on EMERGENCY Release: PRE-RELEASE


     CASES for  USER SPECIFIED Release Criteria  (QA Records)
                -------------------------------

** CASE = -X.Y, Where:  X = RELEASE (CFS) or  Release CRITERIA (If Any)
                        Y = CODE that was Input on QA Record
                            (or REPEATED from Previous Period)

     Y=00  X RELEASE Specified by USER
     Y=01  Release SAME as Previous Period's RELEASE
     Y=02  INTERPOLATED Release Between Two USER Supplied Release VALUES
     Y=03  PREVIOUS Period Release  +  X PERCENT
     Y=04  PREVIOUS Period Release  -  X PERCENT
     Y=10  PREVIOUS Period Release  +  X CONSTANT
     Y=20  PREVIOUS Period Release  -  X CONSTANT
     Y=22  Release from GATE REGULATION CURVE
     Y=23  Release to Reach TOP of FLOOD CONTROL POOL
     Y=24  Release for DAM SITE Operational CHANNEL CAPACITY
     Y=25  Release for MAXIMUM OUTLET CAPACITY
     Y=26  Release to REACH TOP of CONSERVATION POOL
     Y=27  Based on MAXIMUM RATE of CHANGE of Reservoir RELEASE (RISING)
     Y=28  Based on MAXIMUM RATE of CHANGE of Reservoir RELEASE (FALLING)
     Y=29  Release to REACH TOP of BUFFER POOL
     Y=30  Release to REACH LEVEL 1 POOL
     Y=31  Based on FIRM ENERGY DEMAND
     Y=32  Based on Allocated SYSTEM POWER ENERGY
     Y=33  Release to BALANCE TANDEM RESERVOIRS
     Y=34  Based on Reservoir LOW FLOW REQUIREMENTS (DESIRED Q)
     Y=35  Based on Reservoir LOW FLOW REQUIREMENTS (REQUIRED Q)
     Y=36  Based on D.S. FLOOD CONTROL Limitations
     Y=37  Based on D.S. LOW FLOW Requirements
     Y=41  OUTFLOW Equal INFLOW
     Y=42  Based on PREVIOUS Period GATE SETTING
     Y=43  Release to REACH  X LEVEL     (At End of CURRENT PERIOD)
     Y=44  Release to REACH  X STORAGE   (At End of CURRENT PERIOD)
     Y=45  Release to REACH  X ELEVATION (At End of CURRENT PERIOD)
     Y=50  MINIMUM Release Made IF D.S. TANDEM RES. is RISING  AND
                                   D.S. Release is LESS than Value X
```

Appendix G

HEC-5 INPUT DESCRIPTION

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Required Records for Basic Application	Input Records
General Data	T1-T3, J1, J3
Reservoir Data	RL, RO, RS, RQ
Control Point Data	CP, ID, RT
End of Control Point Data	ED
Time Series (Flow) Data	BF, IN, EJ
End of Run	ER

Input General Purpose Data	Input Records
Time Series Data	
Time Series Inflow Data Type	J3.6, J3.8
Read or Write Incremental Flows Using Binary File	J3.6
Simulation Time Interval	BF.7
Number of Simulation Time Periods	BF.2, BF.6
Starting Date	BF.5
Time Series Data Input Format	BF.1, QA
Time Series Data Multiplier	BF.4, BF.1, C1.2
Time Series Data (Inflows, etc.)	IN - CC
Multiple Floods Read In	BF.3, BF.9, R1, SS
Multiple Floods - Ratios	FC, R1
HEC-DSS (Data Storage System)	JZ, ID, BF.1, ZW, ZR, J4.10
End of Time Series Data Set for Each Flood	EJ
Reservoir Data	
Allocation of Reservoir Capacity to Project Purpose	J1.3 - J1.7, RL, CP.7
Reservoir Level Balancing Data	J1, RL, CP.7, CL, CG
Reservoir Priorities for Power/Flood Control/Water Supply	J2.4
Release Fluctuation Adjustment	J2.6
Locations Reservoirs Operate for	RO
Reservoir Storage, Outlet, Area, Elevation Data	RS, RQ, RA, RE
Starting Storages	R1, RL.2, SS
User Specified Reservoir Releases	R2.4, QA
Control Point Data	
Control Point Identification	CP.1, ID
Channel Routing Criteria	J3.7, RT, CR, DR, QS-SQ
Location to Compute Flows From	C1.1 - C1.3
End of Control Point Data	ED

Data Used for User Overrides for Specific Time Periods (general options particularly useful for real-time flood control operation):	**Input Records**
Specification of Data for Reservoir Releases (QA Records), Bottom of Flood Pool Storages (ST Record), or Channel Capacities (CC Record):	
Data values for specific time periods or repeating values.	QA, ST, CC
Interpolation between specific values.	QA, ST, CC
Computation of value based on previous periods Value plus or minus a percentage or a constant.	QA, ST, CC
Special format for abbreviated flows.	IN, QA, etc.
Additional Options for Reservoir Releases Data (QA record):	
Allow program to determine **releases** for only certain periods.	QA
User specified **controlling criteria** for reservoir release including twenty-two options such as: * Release = Inflow * Release to draw to designated storage or elevation or level * Release to meet downstream requirements for flood control or low flows * Release to meet at-site requirements for low flow, flood control, hydropower, etc. * Release based on previous periods gate setting * Release based on special tandem reservoir criteria	QA
Allow user specified releases for system power to override final releases and system power allocations for certain time periods and reservoir locations. See TP record to obtain printout of system power allocations.	QA
Limit Release Decisions to Specified Clock Times for Various Days of the Week and Reservoir Locations	
	JR

Data Used for Specific Purposes:	Input Records
Data Exclusively Used for Flood Control Operations:	
Miscellaneous	
Maximum foresight for release decisions	J2.1, R2.5
Contingency allowance for forecasting	J2.2, CP.6
Maximum rate of change of reservoir release	J2.3, R2.1, R2.2
Minimum release as function of reservoir storage	RD.1
Hinged pool for navigation locks during floods	R2.6, R2.7
Induced surcharge operational criteria	RG, RD
Flooding priority	J2.4
Pre-release based on a spill forecast	J2.5
Stages corresponding to river flow	EL - QS
Cost and Damages	
Reservoir and control point cost data	J4, R$, C2.1, C2.2, C$
Flood damage data	J4, DA, DB, DF, DQ, DC
Channel Capacities	
Constant flow (or stage)	CP.2
Varies by month only	CC
Varies by season only	CC, CS
Varies for each time period	CC (after BF record)
Varies by flow at specific location	CC, QS
Varies by reservoir level only	CC, CL
Varies with season and reservoir level (or elevation)	CC, CS, CG
Varies with season and percent system flood control storage	CC, CS, GS, CG
Varies with reservoir inflow	CC
Allowable rate of change for channel capacity	CP.8, CP.9
Data Used for Both Water Supply and Hydropower:	
Evaporation	J6, RA, R2.3, R3, EV
Restricting flow data to critical period	J3.5, J7.8
Optimization criteria	J7
Elimination of channel routing	J3.7
Reservoir drawdown target (levels)	J1.6, CP.7
Suppress increasing levels to 40 (for System Power)	J1.8

Data Exclusively Used for Water Supply:	**Input Records**
Miscellaneous	
Low Flow and diversion priorities	J2.4 (4,8)
Low flow operation locations	RO
Tandem reservoir balancing level	J2.4 (16)
Recycle for improved computational accuracy	J2.4 (32)
Minimum Flow Specifications	
Minimum flow multiplier	CP.5
Constant - required flows (below buffer level)	CP.4
Constant - desired flows (above buffer level)	CP.3
Constant - above cutoff level (CP.7)	CP.3, CP.7
Varies by month - desired, required or cutoff levels	QM, CP.7
Varies by period - desired, required or cutoff levels	MR, CP.7
Varies by season and reservoir level (or elevation)	CS, QM, CG
Diversion Flow Specifications	
Diversion priority	J2.4 (4)
Diversion routing	DR
Diversion multiplier	DR.9
Miscellaneous specification including diversion type	DR
Reservoir diversion based on excess conservation storage	RD.1
Diversion flows - constant	DR.8, CP.7
Diversion flows - vary by month	QD, CP.7
Diversion flows - vary with inflows	QD, QS
Diversion flows - vary with reservoir storage	RS, RD
Diversion flows - vary with hydropower plant's pumped storage requirements	DR.7, J1.7
Diversion flows - vary by month (pumpback)	QD, J1.7
Diversion flows - vary by period	QD (after BF record)

Data Exclusively Used for Hydropower:	Input Records
General Data	
Priority of Power Operations	J2.4 (1, 2, 64)
Installed Capacity	P1.2, R1
Overload Ratio	P1.3
Reservoir Elevations	RE
Headwater Elevation from Remote Reservoir	P1.6
Penstock Head Loss	P1.8, PQ-PL
Leakage Around Power Generation	P2.1
Penstock Capacity	P2.2
Tailwater	
Block Loading	P1.5
Rating Curve	PT-PQ
From Downstream Reservoir or Non-Reservoir	P1.6, EL (after BF Record)
Efficiency	P1.7
As Constant	P1.7, PE
Vs. Reservoir Storage	P1.7, PE
Vs. Operating Head	P1.7, PE
KW/ft^3/s vs. Reservoir Storage	
Peaking Capability	P1.4, PP-PS
Vs. Reservoir Storage	P1.4, PP-PS
Vs. Reservoir Release	P1.4, PP-PS
Vs. Operating Head	
Selection of Energy Simulation Type	PR
At Site - Firm Energy	PC, PF, PB, PR
At Site - Plant Factor vs. Reservoir Storage	SM, P2.3, P2.4
System Power - Firm Energy	SC, SF, P2.3, P2.4
System Power - Plant Factor vs. System Storage	
At site Energy Distribution	PR
Monthly	PD
Daily	PH
Hourly	PV (after BF Record)
Varies by Period	
System Energy Dsitribution	SM
Monthly	SD
Daily	SH
Hourly	
Specialized Data	
Energy Benefits	J4.6-J4.9, PB, PF
Pumped Storage Analysis	J1.6, J1.7, P1.2, DR.7
Optimization of Capacity or Energy from Fixed Storage	J7
Energy Reduction Index Level and Factor	J1.9, PR.14

Miscellaneous Data	**Input Records**
English/Metric Unit Selection	J1.1
Starting Month for All Monthly Data	J1.2
Print Options	J3.1, J3.2, J8, JZ, LIST, NOLIST
Display output variables with schematic map	J8 (summary type 2)
Time window for User Designed Output (J8) and Reservoir Releases and Regulated Flows (J3.1=32)	J8
Plot Options	J3.3, C1.4
Site Identification Code	TI (columns 17-26)
End of Run Record	ER
Comment Records in Data Set	C (ahead of BF Record)
Computation of Natural Flows	J3.4, NQ
Deletion of Reservoirs	J5
Release Scheduling Adjustment (Parallel Reservoirs)	J2.6
Subsystem Operation	J2.7
Printout of HEC-5 Calculations (Trace)	TC, TP, TS
Suppress Writing File for HEC-5B to Save Computation Time	J3.9

G.1 Introduction

The preceding Table of Contents for this appendix lists all HEC-5 records. Also included at the end of the table of contents is the Functional Use Index. This index can be used to determine which input variables are required for specific tasks. This document provides a detailed description of each variable in each input record. The Summary of Input Records located on the inside back cover shows the sequential arrangement of records. It also serves as a "table of contents" by showing the page numbers where the records are described throughout this appendix.

G.1.1 Input Format

An input file is a series of input records based on an 80-character card-image. Each record is defined by the identification (ID) placed in the first two columns. The input descriptions that follow have the record ID in the header for easy reference. Blank lines (records) in an input file are acceptable.

Variable locations for each input record are shown by field number. The records are normally divided into ten fields of eight columns each except Field 1. Variables occurring in Field 1 may normally only occupy columns 3-8 since columns 1 and 2 are reserved for the required record identification characters. The different values a variable may assume and the conditions for each are described for each variable. Some variables simply indicate whether a program option is to be used or not by using numbers such as -1, 0, 1. Other variables contain numbers which express the variable magnitude. For these a + or - sign is shown in the description under "value" and the numerical value of the variable is entered as input. Where the variable value is to be zero, the variable may be left blank since a blank field is read as zero.

If decimal points are not provided in the data, all numbers must be right justified in the field. Any number without a sign is considered positive.

Locations of variables on input records are sometimes referred to by an abbreviated designation, such as J1.4 representing the fourth field of the J1 Record.

G.1.2 Related Programs

The use of the Hydrologic Engineering Center's data storage system (HEC-DSS) for the specification of time series data is described in Section 11, "Specifications for Time Series Data Records", following the input description for the ED Record.

Four other programs (CKHEC5, MOD5, INFIVE and COED) are also available to use with HEC-5. The CKHEC5 program is a comprehensive input data checking program that performs essentially all of the checks that are possible given the knowledge of the problem furnished by the input data. The MOD5 program is an interactive program designed to facilitate input modifications to an existing HEC-5 data file.

The INFIVE program is an interactive program designed to generate an HEC-5 input file containing the input records required to perform any job described by the user through a series of questions and answers. The COED (the Corps of Engineers Editor) program provides special help information for HEC-5 input records.

G.2 Documentation Records

G.2.1 T1, T2, T3 Records - Job Title Records (required)

Three records are required. Both alphabetic and numeric information may be placed on these records. Information on these records will normally be printed out as a job title on the first page of the output. Columns 17-26 of the T1 Record will be used as site identification code for the optimization conservation summary (*OPSUM).

G.2.2 C_ Records - Comment Records (optional)

Optional comment records (C in Column 1 and blank in Column 2) can be used to provide documentation of the input data. The comment record is printed along with the input listing.

G.3 Job Control Records

G.3.1 J1 Record - Storage Allocation and Units (required)

Field	Variable	Value	Description
			Units of Input Data and Output
1	METRIC	1	All input and output are in **metric** (SI) units.
		0	All input and output are in **English** units.
			Monthly Data
2	ISTMO	0-1	The first value of **monthly data records**, within T1-ED portion of an HEC-5 data set, represents **January** data. Monthly data records related to this option are: J6, SM, RL, R3, PR, QD, CC, and QM.
		2-12	Not recommended.
			Reservoir Storage Levels
3	NUMLEV	2-40	Number of **reservoir storage levels** for each reservoir of data set. *Typical data sets may specify 5 levels with level 1=inactive storage; level 2=buffer storage; level 3=top of conservation storage; level 4=top of flood control storage; and level 5=top of dam or top of surcharge storage.*
4	LEVCON	2-39	Level number which corresponds to the **top of the conservation** (water supply-hydropower) storage pool on **RL Records.** *Typically=3*.
5	LEVTFC	2-40	Level number which corresponds to the **top of the flood** storage pool on **RL Records**. *Typically=4*.
6	LEVBUF	2-39	Level number which corresponds to the **top of buffer** (drought contingency) storage pool on **RL Records**. When storage is above this level, minimum desired and hydropower releases will be made. Below this level, only minimum required releases will be made. *Typically=2.*

Field	Variable	Value	Description
			Hydropower and Diversion Options
7	LEVPUM	0	Top of conservation storage level (LEVCON) will be used for top of **pump-back pool** when diversion options -3 or -4 are used. See DR.7
		2-39	Level number used for top of pump-back pool. Must conform to the following: LEVBUF $\leq$ LEVPUM $\leq$ LEVCON.
8	NOADLV	0	Reservoir levels will be increased internally in the program from NUMLEV to KLEV (typically 40) for better accuracy for system power and monthly computations. However, no increase will be made if no power systems are used and time interval is less than monthly.
		10	Reservoir levels will not be increased beyond the input value NUMLEV, and no interpolation of seasonal (monthly) levels will be made for daily routings.
		-	**Number of levels** to be added between Level 1 and LEVBUF (when LEVBUF = 2).
9	LEVPRC	0	Power rule curve will be assumed to be the same as top of buffer pool (LEVBUF). Program can add levels for added accuracy (see J1.8).
		+	Reservoir index level for power rule curve operation of power projects. Above this level (based on previous time period), the project will operate for at site energy (based on either PC vs. PF Records or PR Records only) times the PRCRAT factor (PR.14). Below this level the project will operate for at site energy (assuming PRCRAT=1) if at-site power priority (J2.4=2) is requested. In order to add levels for increased accuracy (see J1.8) this value must be equal to **LEVBUF**.
10			Not used.

G.3.2 J2 Record - Operational Parameters (optional)

Field	Variable	Value	Description
1	IFCAST[1]	0	Twenty-four **hours** of foresight will be used by the program to determine reservoir releases in the system operation when IPER is equal or greater than one hour. When IPER(BF.7) is less than one hour, 4 periods will be used. Value used should represent ability to forecast flows with CFLOD (J2.2) accuracy.
		+	**Number of hours** of foresight on inflows and local flows to be used in system operation for all reservoirs unless different values are specified on R2 Records (R2.5). If IPER(BF.7) is less than 1 hour, specify minutes using a decimal (i.e., use .30 for 30 minutes of foresight).
2	CFLOD	0-1	Constant is assumed = 1.0. (CKHEC5 program will give warning message.)
		1+	**Coefficient greater than or equal to one by** which local flows are temporarily multiplied as a contingency allowance in the determination of reservoir releases. If this value is 1.2, a 20% forecasting error is assumed for IFCAST hours. This 20% error will be used for both flood control and conservation releases. A value of 1.2 is typically used for flood control planning. For "Real-time" water control applications, a value of 1.0 is typically used.
3	RATCHG[1]	0	The maximum rate of change during a **one hour** time period for all reservoir releases will be assumed to be .04 times the designated channel capacity (CP.2 or CC Records) unless specified differently on R2 Records for specific reservoirs.
		+	The maximum rate of change of all reservoir releases during a **one hour** time period expressed as a ratio of the channel capacity (CP.2 or CC Records) unless specified differently on R2 Records for specific reservoirs.

[1]These variables are ignored for weekly or longer (BF.7) time intervals.

Field	Variable	Value	Description
4	IPRIO	0-127	The **sum** of the following codes that represent the desired priorities in the operation is used for IPRIO.

Code[2]	
0	Normal priorities will be made as indicated below by criteria in parenthesis.
1	When **flooding** is occurring at a downstream location, primary **power releases** will be made at upstream reservoirs (*instead of curtailing the power releases*).
2	Primary **at site power releases** will be made as long as the reservoir storage level is above Level 1 (*instead of top of buffer level*).
4	All specified **diversions from reservoirs** will be made as long as the reservoir is above Level 1 (*instead of top of buffer pool*) except when diversions are a function of reservoir storage.
8	When **flooding** is occurring at a downstream location, **minimum** (desired Q, required Q) **flow releases** will be made, which contributes to the flooding (*instead of making no releases*).
16	When **balancing** an upstream tandem reservoir with a downstream tandem reservoir, the **equivalent level** of the system is used *(instead of downstream reservoir level*) for monthly simulations.
32	This code causes the program to **recycle through the solution process twice** (*instead of once*). This option can provide better simulation results for complicated water supply models involving shortages in minimum low flow demands. It is suggested that this option be applied only when water supply simulation results are unsatisfactory producing reservoir release error messages.
64	**System power** releases will be made as long as the reservoir storage level is above Level 1 (*instead of top of buffer level*).
128	**Tandem** reservoir operation will be curtailed at top of buffer level *(instead of Level 1)*.

[2] If any of the codes (1-64) are not selected, operational priority for that item will be based on normal priority as shown in parenthesis.

Field	Variable	Value	Description
5	IOPMD[3]	0	Reservoir releases will be made equal to inflow above top of flood control pool up to outlet capacity, at reservoirs without gate regulation curve data (RG Record).
		1	Same as above except that **pre-releases** equal to channel capacity at the dam site will be made as soon as it can be determined that the reservoir will exceed the flood control storage using IFCAST (J2.1 or R2.5).
		2	Same as 1 except **pre-releases** can be larger or smaller than channel capacity. Constant releases are determined for future periods so that the top of the flood control pool will just be reached within the forecast period, IFCAST (J2.1 or R2.5).
6	ISCHED	0	Do not use scheduling ("0" is typically used).
		1[4]	Use scheduling. No releases will be made from a reservoir unless all higher priority reservoirs in parallel are also releasing. The sum of the releases from all upstream reservoirs during any time period is not allowed to exceed damaging channel capacity at any downstream control point.
		10	Reservoir releases are calculated assuming future releases are the same as the current periods release. This option may reduce large fluctuations in reservoir release.
7	NCPTR	0	All control points will be used in the system.
		+	Identification number of last control point to be used in this run of the system. Option is used to operate a sub-system when data is for a large system. The total number of control points can exceed the dimension limits (KNCPT) as long as subsystem specified does not. The first RL Record should be for the upstream starting point. **NCPTR must be a non-reservoir.**
8	NCYCLE	0-1	When recycle option is specified (J2.4 Sum Includes 32), HEC-5 will cycle through the solution process one more time.
		2-10	When recycle option is specified, HEC-5 will cycle through the solution process 2-10 additional times.
9-10			Not used.

[3] If gate regulation curve option is used (RG Records) the pre-release option will not be applied to that reservoir.

[4] This option is used only if there is a problem in emptying an upstream reservoir which is located many times the travel time to the damage center as other reservoirs.

G.3.3 J3 Record - Output and Flow Options (required)

A continuous listing of all input data record images, including flow, will be made for all jobs stacked together (up to 10,000 lines) unless a "NOLIST" in record columns 1-6 is present. A single "NOLIST" record placed in the data file will terminate the remainder of the data record listing. A series of NOLIST and LIST records can be used to suppress printout of data between the two records.

Each type of output has a label on the left side of the page to make it easier to locate with an interactive text editor. The program labels are shown below.

	Output Label	Output Type
(HEC-5A Output)	*Input	Summary of input data
	*FLOWS	Formatted table of flow data
	*Rule	Summary of reservoir storage levels (Rule Curve)
	*Operation	Summary of locations that are operated for
	*Map	Two schematic maps showing reservoir operation locations and summary information
	*Reservoir	Summary of reservoir data
	*Routing	Operating control points
	*LOCFL	Computation of incremental local flows
	*OPTRY	Optimization results for each try
	*OPSUM	Summary of final optimization results
(HEC5B Output)	*FLOOD n	Start of HEC5B output for flood number "n"
	*NORML	Normal sequential output
	*ROPER	Reservoir data by period
	*PLOTS	Plotted hydrograph
	*SUMF1	Single flood summary
	*SUMFS	Summary for all flood events
	*SUMPO	Summary for conservation operation
	*ECDAM	Economic data and damage computation
	*EPLOT	Flood frequency plots
	*ESUMD	Summary of expected annual damages
	*ESUMC	Summary of system costs
	*ESUMB	System economic cost and performance
	*HYEFF	Hydrologic efficiencies
(Output from HEC-5A/ HEC-5B)[1]	*USER5A	User designed output (J8 and JZ Records) from HEC-5A
	*USERS	User designed output (J8 and JZ Records) from HEC-5B
	*RRPER	Reservoir releases by period
	*RQPER	Control point regulated flow by period
	*DVPER	Diversions by period
	*DVSHORT	Diversion shortages by period
	*FCPCT	Percent flood control storage used
	*ERROR	Output error check
	*CASES	Listing of case definitions (“reasons” for reservoir release)

[1] See J3.9 to select output source.

Field	Variable	Value	Description	
1	PRINT	0-511	The **sum** of the following codes that represent the desired output (in addition to J8 Record output) is used for PRINT.	
			Code	**Option**
			0	All output listed below.
			1	Single flood summary of maximums for reservoirs and control points (where time interval (IPER, BF.7) is DAILY or less) for each flood event.
			2	Summary of maximum and minimum values for each event and for all events. Also summary of monthly operations and system energy. (*SUMFS, *SUMPO)
			4	Output error check **(should always be requested)**. (*ERROR)
			8	Normal sequential output by control point, by variable and by time period. Should only be requested for short flood events due to excessive output. (*NORML)
			16	Reservoir data by period (all floods). (*ROPER)
			32	Reservoir releases and control point regulated flows, percent flood control storage used, and diversions and diversion shortages, by time period (all floods). The time window on the J8 Record also applies to this output. (*RRPER, *RQPER, *DVPER, *DVSHORT, *FCPCT)
			64	Computation of incremental local flows from natural or observed conditions. (*LOCFL)
			128	Flow records. (*FLOWS)
			256	Hydrologic efficiencies (*HYEFF)
2	PRCOL			This option is no longer used.

Field	Variable	Value	Description
3	IPLOTJ		This option is no longer used.
4	FLONAT	0	**Natural** or unregulated flows, that is, flows that would have existed if no reservoirs were upstream, will **not** be **computed**. However, they can be read on NQ Records. If ILOCAL = 20(J3.6), natural flows will be calculated and printed from the IN Record data.
		-1	**Natural flows will be calculated** (omit NQ Records). If ILOCAL (J3.6) = 20, natural flows will be based on adjusted computed local flows (no negative locals).
5	CRITPR		This option is no longer used.
6	ILOCAL		**IMPORTANT:** See next page for description.

SPECIFICATION OF INCREMENTAL LOCAL FLOWS:

This is the single most important input item in an HEC-5 data set. ILOCAL, J3.6, defines the type of flow data (natural, observed, or incremental local flow) entered on "IN" data records within the time series data set (BF through EJ Records). HEC-5 requires a consistent flow data set for a specified period of analysis. This means that a mixture of flow data types, for instance, 5 years of natural (unregulated) flows followed by 10 years of observed (regulated) flows is not valid in a single simulation.

"Incremental local flows" are discharge hydrographs which enter a stream system between adjacent control points. The value of ILOCAL indicates whether incremental local flow data are to be computed from **"natural"** or **"observed"** flow data or **read-in directly**.

A **negative value** for ILOCAL will allow the use and computation of negative local flows. A **positive value** for ILOCAL causes negative local flows to be set to zero. Negative flow volumes will be redistributed within the hydrograph (thus maintaining the proper volume) when flow computations are made with positive ILOCAL values.

HEC-5 may be used to develop a consistent database of local incremental flows from observed or natural flow data by indicating ILOCAL=±15 (observed flows and releases) or ILOCAL=±20 (natural flows) and writing the computed incremental local flows to HEC-DSS for subsequent use with ILOCAL=±1.

For **real-time water control** simulations using ILOCAL=±5 the following should be added to the HEC-5A execution line: **QLOCINC=filename**. Where "filename" is the name specified during the first computation of local flows for the particular forecast time.

Field	Variable	Value	Description
6	ILOCAL	±1	Direct input of **incremental local** flow data in time series data (IN Records).
		±20	Compute incremental local flows from **natural** flow (IN Records).
		±15	Compute incremental local flows from **observed regulated flows** (IN Records) and **corresponding observed reservoir releases** (QA Records[1]).
		±5	**Real-time water control** option to compute incremental local flows from IN and QA Records (same as =±15) while writing the computed local flows to a binary file for subsequent access during re-simulations.

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[1] When computing incremental local flows using QA Records, the reservoir release values must be INTEGER values since decimal values would be interpreted as “release codes” and local flows cannot be calculated when reservoir release codes are used (i.e., do not use codes .001, .22, .24, etc.)

Field	Variable	Value	Description
7	NOROUT	0	Indicator is assumed equal to 24 hours. Channel routing and forecasting will not be made if IPER (BF.7) is greater than NOROUT.
		+	Indicator used to differentiate between short interval operation that would use routing and forecasting IFCAST (J2.1 or R2.5) and long interval conservation operation in which routing and forecasting would not be used.
8	INTYPE	0	Input flow data are average for the period.
		1	Input flow data are end-of-period on IN and NQ Records. QA and MR Records are average values. Program will average flow data.
		5	Input flow data are end-of-period on IN, NQ, and QA Records. MR Records are average values. Program will average flow data.
9	NOOPTS[2]	0	Program HEC-5B should be executed.
		1	Data will NOT be written from the simulation program HEC-5A that is required for the output program HEC-5B to execute. Therefore, job control should execute HEC-5A only and NOT HEC-5B. If J8 Records are input, all user designed output will be displayed from program HEC-5A (except for hydropower peaking capability) along with regulated flows, etc. (J3.1=32).
10			Not used.

[2] Using this option will limit certain capabilities of the program (i.e., no normal sequential output; no multiple floods; no damage calculations; no frequency plots; etc.), since program HEC-5B performs these functions. However, this option can save substantial clock time for a large system of reservoirs.

G.3.4 J4 Record - Benefit/Cost Data (optional)

Field	Variable	Value	Description
1	IANDAM	0	No flood damages will be computed.
		-1	Damages for each individual flood operated by the system will be determined using data from the DA-DC Records (expected annual damages will not be estimated).
		1	Expected annual damages will be calculated for natural conditions, for uncontrolled local flows, and for regulated conditions. The probability for each regulated flood will be assumed equal to the probability of the natural event.
		2-100	Expected annual damages will be calculated for the same three conditions as above. Probabilities for regulated conditions will be based on rearranging the flood events at each control point in the order of magnitude and assigning plotting positions based on IANDAM **years of record**. This option should be used when both monthly and short-interval routings are made.
2	ECFCT	0	No damage data will be used (records DA-DC omitted) or factor "ECFCT" will be assumed = 1.
		+	Factor to be multiplied times all damage data on the DC Record.
3	IPRECN	0	**All** types of economic output will be printed including frequency plot.
		-1	All economic output printed **except** frequency plot.
		1	Economic summary table **(only)** will be printed.
		2	Economic summary table and summary by category **(only)** will be printed.
4	BCRFAC	0	Capital recovery factor, if used, will be specified on the CP Record.
		+	Capital recovery factor (used when data is omitted from first field of C1 Record) which is multiplied by the present worth of reservoir or control point costs (R$ or C$ Records) to obtain the annual cost of the capital investment based on desired interest rate.
5	COSFAC	0	Any cost data will be multiplied by 1.0.
		+	Cost data on records R$ and C$ will be multiplied by COSFAC.

Field	Variable	Value	Description
6	PCVAL	0	Peak power capacity benefits are not to be calculated.
		+	Peak power capacity benefit value in dollars per kW.
7	PEPVAL	0	Primary power benefits are not to be calculated.
		+	Benefits for primary energy in dollars per 1000 kWh (=mills/kWh).
8	PESVAL	0	Secondary power benefits are not to be calculated.
		+	Benefits for secondary energy in dollars per 1000 kWh (=mills/kWh).
9	PEBVAL	0	No penalty will be assessed for power shortages.
		+	A penalty for power shortages in dollars/1000 kWh. Cost to purchase power on open market would be good penalty value.
10	J410[1]	0	Flow-exceedance frequency curve is not written to HEC-DSS.
		1	Flow-exceedance frequency curve is written to HEC-DSS for those locations when damage computations are requested. Exceedance frequency is written as a PROBABILITY (a ZW Record must also be used).
		2	Same as 1, except exceedance frequency is written as a PERCENTAGE (probability x 100).

[1] HEC-5B should be executed if J4.10 = 1 or = 2.

G.3.5 J5 Record - Reservoirs Deleted (optional)

Field	Variable	Value	Description
1	NRDEL	+	Number of reservoir identification numbers to be read on J5 Records starting in Field 2. Maximum of 29. Sets of J5 Records (corresponding to the number of values on FC Record) can be used to describe reservoirs to be deleted for each flood ratio used.
2+	RESDEL(I)	+	Reservoir identification number (same as Field 1 of RL Record) of all reservoirs which are to be operated with outflows equal to inflows instead of using the criteria shown on records RL-RQ. The program will automatically change the storages on the RL Record to zero, will eliminate the downstream control points the reservoir was to have operated for on RO Record, and will change the outlet capacities on RQ Record to 1,000,000 m^3/s (ft^3/s). RO Record must be manually changed if an upstream reservoir operates for the deleted reservoir (see RO.2), or records RL-RQ for the upstream reservoir must be removed.

G.3.6 J6 Record - Basin Monthly Evaporation (optional)[1]

Field	Variable	Value	Description
1-12	EVRAT(K)	+,-	Net evaporation (evaporation minus precipitation rate) in millimeters (inches) per month over the reservoir area for 12 periods starting with January (J1.2). Reservoir areas (1000 m^2 or acres) are input on RA Record. These evaporation rates may be multiplied by Field 3 of each R2 Record. Rates for each reservoir can also be read on R3 or EV Records.

[1] If J6 Record is used, two J6 Records are required.

G.3.7 J7 Record - Conservation Optimization (optional)

Field	Variable	Value	Description
1-4	OPTCON	0	No control points will be optimized.
		+	Reservoir locations (up to 4 which are not in tandem with each other) where conservation storage or reservoir yields are to be optimized. A determination can be made of the minimum conservation storage required (between level LEVBUF and level LEVCON on RL Record) to satisfy the input demands (including minimum flows, diversions and installed power capacity) through the flow period shown on IN Records.[1] To optimize one of the yields of this reservoir using the input conservation storage on the RL Records, one of the codes .1-.6 or .9 is added to the control point number (e.g., 15.1 would optimize power requirements for Reservoir 15). All other demands will be used as specified on input records.

Code		
.0	=	**optimize conservation storage** above top of buffer pool (LEVBUF, J1.6).
.1[2]	=	**optimize the monthly power requirements** (expressed as monthly plant factors on the PR Record) **and the installed capacity of the power plant** (assuming average PR Record plant factor) based on top of buffer unless priority is requested for Level 1 (J2.4=2).
.2	=	**optimize the minimum desired flow** (CP.3 or QM or MR) Records based on top of buffer pool.
.3	=	**optimize the minimum required flow** on CP Record based on Level 1.
.4	=	**optimize the diversion schedule** on QD Records based on top of buffer level (Level 1 if priority is requested (J2.4=4).
.5	=	**optimize the monthly plant factors** (PR Record) based on either top of buffer or Level 1 (J2.4=2) but do not change the installed capacity. This option is normally used to determine firm energy for the existing installed capacity.

Continued on next page

[1] See J7.8 to limit flow data. Flow data must be incremental flows (J3.6=±1). Flows can be monthly or weekly. Daily flows are allowed if the time period dimension limits (KPER) are large enough for the critical period. Columns 17-26 of T1 Record is used for site title on optimization results (*OPSUM).

[2] This option (rather than .5) is normally used when no power plant exists or when the installed capacity might be increased.

Field	Variable	Value	Description
			Code - *continued*
			.6 = **optimize diversions based on water rights priority** (WR Record). Intended for use with a year's worth of daily data. Set OPTERR=.99 (J7.10).
			.9 = **optimize yields for codes .1-.4** based on level 1 using fixed ratios between demands as specified on input data.
5	IDSLOC	0	Optimization of yield will be accomplished on reservoir being optimized.
		+	**Downstream control point location** where yield is to be optimized.
6			Not used.
7	IOPTY1	0	The program will determine the initial estimate of the installed capacity.
		1	The first routing will use the installed capacity of the project from the second field of the P1 Record.
8	CRITPR	0	Operation of reservoirs is simulated for all time periods shown on IN Records.
Recommended Selection		1 or 2	CRITPR is assumed to be equal to 70 times "RAPSQ", which is the ratio of conservation storage to mean annual flow (up to 175 months). The critical drawdown for .3 ratio of conservation storage to mean annual flow would be 21 months. Operation of system is then limited to critical period plus few periods on each end of the critical period. A value of 2 (instead of 1) will provide a table of starting and ending periods for durations from 1 to 60 periods.
		3+	Perform routing for CRITPR periods. Define "CRITPR" as length (periods) of critical drawdown by finding beginning and ending periods corresponding to the minimum flow volume for duration = CRITPR.
		-X.Y	Data grouped by time periods on IN Records, etc., are shifted and reduced so that the first data item is for time period X and the last data item is for time period Y. Operation of system is limited to periods X through Y. A value of -32.064 will use periods from 32 to 64.
9	IFLAG	0,1	Optimize for period of record (critical period only if J7.8.GT.0), then stop.

Field	Variable	Value	Description
Recommended Selection		6	a. Optimize for critical period first (J7.8 must not equal zero), and IN Records must be for period of record), then b. Check above results by routing period of record (once) and c. Stop if drawdown error is less than OPTERR (J7.10); otherwise, optimize using new critical period from step b, then d. Check above results using period of record and e. Stop if drawdown error is less than OPTERR (J7.10); otherwise, optimize using new critical period from step b, then f. Check above results using period of record and g. Stop.
10	OPTERR	+X.Y	Allowable errors between target minimum conservation storage (Level 1 or LEVBUF) and minimum storage obtained in routing. Value (X) to left of decimal indicates allowable **negative** error (causes shortages in yield because drawdown is too great) in **1000 m^3** for metric (acre-feet for English). Value to right of decimal indicates the allowable **positive** error expressed as a **ratio**. A 100.01 indicates that a negative error of 100 acre-feet would be allowed and that a 1% positive error would be acceptable.
Recommended Selection = 0.01		+.Y	If value to left of decimal is zero, then the allowable negative error is the same percentage error as the positive error (a 0.01 would represent a 1% allowable error for both positive and negative).
		+.99	Program will **accept any error** in drawdown storage. Therefore the J7 Record can be used to simply provide special power output rather than an optimization (J7.1 must also be used). This option can be used with R1 and FC Records to allow multiple user determined hydropower capacity estimates.
		-	**Same as** any of the **above** options except that one additional routing will be made after optimization has been found in order to get correct reservoir levels (optimization routine adds 500,000 AF storage) and shortages (except for power, no shortages are allowed in optimization runs) for final printout.
		0	Same as +X.Y option except that a 100 acre-ft negative error and a 1% positive error are assumed.

G.3.8 J8 Record - User Designed Output Format (optional)

Optional record used to define output tables. Each **record** used will specify output variables to be printed for up to 10 columns. Three types of user defined output can be specified by J8 Records. A time window to specify time periods to be printed (for output types 1 or 2) for one or more J8 Records can be specified on any J8 Record. The starting and ending time periods are shown in fields 1 and 2 of the J8 Record with the rest of the record blank.

User Defined Output Type[1]

1 **Data by Period (first field is positive) CP.VAR**

Each **field** of the record used should contain the control point **location** (to the left of the decimal) and variable **code** (to the right of the decimal). For example, a 77.10, 88.10, 77.12, 88.12, 77.13, 88.13 in fields of 1-6 would print six vertical columns for each period of the routing showing in order: for reservoirs 77 and 88 the outflows (code 10=outflow), cases (code 12=cases), and levels (code 13=level). Add .009 if output should be converted from ft^3/s to acre-feet (i.e., 88.109 for reservoir 88 outflow, in acre-feet).

2 **Summary Data by Control Point (first field is negative) TYPE.VAR**

Each record field for this output type is printed in a column for all control points along side a schematic map of the system. When regulated flows are requested (code = .04), both reservoir releases and non-reservoir regulated flows are shown. Regulated flows are also shown for non-reservoir locations when reservoir inflows or outflows are requested.

Each **field** of the record (up to 6 can be used for most schematics) should contain the code for the math function of the variable (to the left of the decimal) and the variable code (to the right of the decimal). Codes for the math function are: 1 = sum, 2 = maximum, 3 = minimum, 4 = period number of maximum, 5 = average. A math **code of 6** or greater is used to specify the **time period** for the output variable corresponding to the variable code specified. For example a J8 - 2.02 2.04 2.0 10.04 11.04 12.04 would show the maximum natural, maximum regulated, difference between the two, and the regulated flows for time periods 10-12. If a single variable is requested on a record, then two schematic maps are drawn beside each other. The first map contains the location numbers and the second shows the output variable.

3 **Annual Data - (first field is positive) CP.VAR + CODE**

Each field of the record used should contain the control point location (to the left of the decimal) and the variable code (to the right of the decimal). In addition, a value of .001, .002, .003, or .004 is added to the number to obtain the annual maximum, annual minimum, annual average, or annual sum, respectively. For example, a 2.031 would request annual maximum data for location 2 for variable 3 (which are diversions).

[1] All three output types are available from the second half of the program, HEC-5B, plus output Type 1 is also available from HEC-5A. In order to get this output from HEC-5A, J3.9 must equal one (1) to suppress HEC-5B output. This option greatly enhances execution times for large systems. See J3.9 description for further information.

Variable Code	Description	Variable Code	Description
	Reservoirs ONLY		
.09	Inflow	.12	Case
.10	Outflow	.13	Level
.36	Gate Regulation Release	.14	Equivalent Level[2]
.11	Storage	.21	Evaporation
.37	% of "Normal" Storage[1]	.22	Elevation
.38	Top of Conservation (Storage)	.41	Top of Conservation (Elevation)[3]
	Power Reservoirs ONLY		**Power Systems ONLY**
.15	Required Energy (at site)	.26	System Energy Required[6]
.16	Generated Energy (at site)	.28	System Energy Generated
.23	Energy Shortage (at site)	.29	System Energy Shortage
.25	Power Capability[4]	.27	System Energy Usable
.32	Power Spillage	.40	System Power-% Power Storage[6, 7]
.33	Power Head	.39	System Power-Monthly Plant Factors[6, 7]
.35	Power Plant Factor		
.34	Energy Benefit Rate (mills/kWh)[5]		
	Reservoirs and Non-Reservoir Control Points		
.01	Cumulative Local Flow	.03	Diversion (Flow)
.02	Natural Flow	.30	Diversion Requirement (Flow)
.24	Incremental Local Flow	.31	Diversion Shortage (Flow)
.05	Minimum Desired Flow	.06	Shortage, Min Desired Flow
.07	Minimum Required Flow	.08	Shortage, Min Required Flow
.17	Channel Capacity (Flow)	.18	Q Space (Flow)
	Non-Reservoir Control Points ONLY		
.04	Regulated Flow	.19	U.S. Res/Div Flow
.20	Flooding Greater Than Local Flow		
	MATH FUNCTIONS		
X.00	Compute **difference** between the previous two columns of data (X is control point number)	X.99	Compute **sum** of previous **X** columns of data.
		.009	Add to flow variable to convert units from ft^3/s to acre-feet.

[1] When output for this variable is displayed, if the value is positive then it represents % *above* "Normal" pool; if the value is negative, then it represents % *below* "Normal" pool, where "Normal" = full conservation pool.

[2] For downstream tandem reservoirs only.

[3] This variable is available only from HEC-5A (see J3.9).

[4] This variable is available only from HEC-5B (see J3.9).

[5] Only if PC-PB Records are used.

[6] System energy variables are displayed for the first reservoir in the system.

[7] These variables are available if SC and SF Records are used but only from HEC-5A (see J3.9).

G.3.9 JZ Record - User Defined Output Variables for HEC-DSS (optional)

Optional record, used in conjunction with the ZW Record, to designate output variables to be stored in an HEC-DSS file. These records are used similar to the "Data by Period" type of J8 Records. The data are both written to DSS and printed (like J8 Records) unless the value for the first field of the first JZ Record is made negative, in which case data is only written to DSS.

If a JZ Record is omitted and a ZW Record is used, the default codes for regulated flow (.04) at all non-reservoir control points plus the inflow (.09), outflow (.10) and EOP storage (.11) for all reservoirs will be written to the HEC-DSS file.

		Data Units		
Variable Code	**"C part"**	**English Units**	**Metric Units**	**Data Type**
.01	FLOW-LOC CUM	CFS	m^3/sec	PER-AVER
.02	FLOW-NAT	CFS	m^3/sec	PER-AVER
.03	FLOW-DIV	CFS	m^3/sec	PER-AVER
.04	FLOW-REG	CFS	m^3/sec	PER-AVER
.05	FLOW-DESIRED	CFS	m^3/sec	PER-AVER
.06	FLOW-DES SHRT	CFS	m^3/sec	PER-AVER
.07	FLOW-REQUIRED	CFS	m^3/sec	PER-AVER
.08	FLOW-REQ SHRT	CFS	m^3/sec	PER-AVER
.09	FLOW-RES IN	CFS	m^3/sec	PER-AVER
.10	FLOW-RES OUT	CFS	m^3/sec	PER-AVER
.11	STOR-RES EOP	ACFT	1000s m^3	INST-VAL
.12	CASE-RES			PER-AVER
.13	LEVEL-RES			INST-VAL
.14	LEVEL-RES EQ			INST-VAL
.15	ENERGY-REQ	MWH	MWH	PER-CUM
.16	ENERGY-GEN	MWH	MWH	PER-CUM
.17	FLOW-CHAN CAP	CFS	m^3/sec	PER-AVER
.18	FLOW-Q SPACE	CFS	m^3/sec	PER-AVER
.19	FLOW-US RES	CFS	m^3/sec	PER-AVER
.20	FLOW-FLOOD RES	CFS	m^3/sec	PER-AVER
.21	EVAP-NET	CFS	m^3/sec	PER-CUM
.22	ELEV	FEET	METERS	INST-VAL
.23	ENERGY-SHRT	MWH	MWH	PER-CUM
.24	FLOW-LOC INC	CFS	m^3/sec	PER-AVER
.25	POWER CAPACITY	MW	MW	PER-AVER
.26	ENERGY-SYS REQ	MWH	MWH	PER-CUM
.27	ENERGY-SYS USE	MWH	MWH	PER-CUM
.28	ENERGY-SYS GEN	MWH	MWH	PER-CUM
.29	ENERGY-SYS SHRT	MWH	MWH	PER-CUM
.30	FLOW-DIV REQ	CFS	m^3/sec	PER-AVER
.31	FLOW-DIV SHRT	CFS	m^3/sec	PER-AVER
.32	FLOW-POWER SPILL	CFS	m^3/sec	PER-AVER
.33	HEAD-POWER	FEET	METERS	PER-AVER
.34	BEN RATE-ENERGY	MILL/kWH	MILL/kWH	PER-AVER
.35	PLANT FACT			PER-AVER
.36	FLOW-GATE REG	CFS	m^3/sec	PER-AVER
.37	PCT STORAGE NORM	PERCENT		INST-VAL
.38	TOP CON. STORAGE	ACFT	1000s m^3	INST-VAL
.41	TOP CON. ELEV	FEET	METERS	INST-VAL

G.3.10 JR Records - Clock Times for Reservoir Release Decisions (optional)

These records specify clock times when reservoir release decisions will be made by HEC-5 (all other computational periods, except the 1st computational time period, will repeat the previously calculated release). If these JR Records are omitted, or if they do not cover specific reservoirs or days of the week, or if the time interval is daily or greater, the program will default to compute releases for all time periods for those locations and days of the week. A maximum of 40 JR Records can be used to describe schedules for various locations and days of the week.

Field	Variable	Value	Description
1	LOC	0	All reservoirs will use the schedule specified on this record unless overridden by data on a subsequent JR Record.
		+	Reservoir location number (RL.1) that will use the clock schedule on this record.
2	IDAYST. IDAYED	X.Y	Starting (X) and ending (Y) day of the week for the schedule on this record (Sunday = 1). For example, use 2.6 for Monday through Friday on one record, and 7.1 for Saturday and Sunday on the next record.
3	CTIME	0	Release decisions will be made for all time periods (fields 4-10 are ignored).
		+	Clock time of the first release decision after midnight. For example use 1300 for 1:00 pm. Times must correspond to whole hours.
4-10	CODEJR	X.Y	Clock times (X) and optional code (Y) describing when release decisions will be made (other than the first decision). If Y is used, it represents the number of release decisions that will be made at intervals represented by the last two clock times. (Y can be from 0 to 9).

Example

```
JR  0   2.6    800     900.9
JR  0   7.7    700     800.4    1200    1400.4
JR  0   1.1    800      1000    1200      1400    1600
JR 10   2.2      0
```

The 0 in field 1 of the first three JR Records shows the first three schedules apply to all reservoirs in the system. However the fourth record shows an exception for reservoir 10 for Mondays.

The first JR Record shows that for Monday through Friday (2.6) of every week, 9 release decisions will be made per day at each hour of the day from 8:00 am to 4:00 pm. The second JR Record shows that all Saturdays (7.7) will have 4 release decisions at one hour intervals starting at 7:00 am (7:00 am, 8:00 am, 9:00 am, 10:00 am) followed by 4 release decisions at two hour intervals (12:00 noon, 2:00 pm, 4:00 pm and 6:00 pm). The third JR Record shows that all Sundays (1.1) will have release decisions at 8:00 am, 10:00 am, 12:00 noon, 2:00 pm and 4:00 pm. The fourth JR Record shows that on Mondays (2.2), Reservoir 10 will compute releases for all time periods.

G.4 System Power Records

G.4.1 SM Record - System Energy Requirements: Monthly (optional)

These optional records specify the monthly system energy requirements. If used, two SM Records are required. System power analysis may not balance reservoirs adequately where channel routing is used.

System power reservoirs (P2.3=1) within an HEC-5 model can be composed of 3 types of projects. Type 1 is a reservoir with energy drawdown storage located at the headwater of a tributary such that there are no reservoirs above that location. Type 2 is a run-of-river power project which has "no power drawdown storage" and is located downstream of a Type 1 reservoir. Type 3 is a power reservoir "with power drawdown storage" that is located downstream of a Type 1 reservoir. No reservoirs with energy drawdown storage can be incorporated in the HEC-5 power system (P2.3=1) unless they are either Type 1 or Type 3, meaning that they are either at the headwater of a tributary or are downstream of another system power project with drawdown storage. If a system power reservoir with drawdown storage exists which is not a headwater reservoir and does not have a system energy drawdown reservoir above it, but does have a non-system power reservoir above it, then a dummy system power reservoir must be added at the headwaters of the tributary with a 1 or 2 kW plant and no storage.

Field	Variable	Value	Description
1-12	PRWS[1]	+,0	Monthly system energy requirements in 1000 kWh. Specify monthly values in successive order, one value per field. Beginning with the system energy requirement for January (J1.2=1) in the first field.
13	FACT	+,0	If the 13th value (2nd SM Record, 3rd field) is a positive number, the initial 12 values are multiplied by this value (a convenient means of inputting the system requirements in terms of monthly plant factors).

[1] If PC and PF (or SC and SF) Records are used to describe power rule curve, these values are ratios which are multiplied times the plant factors on the PF (or SF) Records.

G.4.2 SD Record - System Energy Requirements: Daily (optional)

This optional record specifies ratios of the weekly system energy requirements for each day of the week (seven values required). The program computes the weekly requirements based on the monthly energy requirement (SM Records). If SH Record is used, the SD Record is required.

Field	Variable	Value	Description
1-7	PWRSD	+	Daily ratios of system energy requirements. Sum of the seven values must equal 1.0. The first value is for Sunday.
8-10			Not used.

G.4.3 SH Record - System Energy Requirements: Multi-hourly (optional)

This optional record specifies ratios of the daily system energy requirements for each time interval IPER (see BF.7) within a day.

Field	Variable	Value	Description
1	N	2-24	Number of ratios to be read starting in Field 2. Minimum number of values = 24/IPER, (e.g., for a six-hour simulation interval, at least four values would be required). The number of ratios used must agree with the PH Record for each reservoir project.[1]
2+	PWRSH	+	Ratios of the daily system energy requirements for each time interval (BF.7) within the day. First value represents the period starting at midnight. Sum of the values must equal 1.0.

[1] Any number of ratios from 1 to 24 can be used in conjunction with any multi-hourly time interval. If, for example, 24 ratios are read on the SH Record and a 4-hour simulation interval (BF.7) is selected, the program will automatically sum up the proper number of ratios in a 4-hour period. If the converse situation exists, where the SH Record is describing the energy requirements in intervals larger than the selected simulation interval, the program assumes the energy requirement is evenly distributed and calculates the proper ratios for the smaller simulation intervals.

G.4.4 SC Record - System Power Rule Curve: Ratios of Storage Capacity (optional)

This record is used in conjunction with the SF Record to define a rule curve for determining the monthly system energy requirements (in a similar manner to the PC Record for at-site energy).

When the SC Record is used, the SM Records are read as usual, but they represent monthly adjustment ratios of the plant factors on the SF Records. The PC and PF Records for at-site requirements would be normally omitted to allow maximum flexibility, but they can be used if desired. This method is an alternative method to firm system energy operation.

Field	Variable	Value	Description
1	NSC	2-9	Number of ratios on SC and SF Records required to define the system energy production rule curve.
2-10	PWRSC	0,+	Ratios of power storage occupied. NSC values, starting with smallest value. The ratios represent the sum of the occupied energy storages for all power system reservoirs divided by the sum of the energy storages available for all power system reservoirs.

G.4.5 SF Record - System Power Rule Curve: Plant Factors (optional)

This record, which must be used if a SC Record is present, is used in conjunction with the SC Record to define the rule curve for determining the system energy requirement based on the amount of power storage (storage between top of conservation pool and buffer level) occupied in the reservoir system.

Field	Variable	Value	Description
1	NSC	2-9	Number of ratios on SC and SF Records required to define the system energy production rule curve.
2-10	PWRSF	0,+	Plant factors (expressed in terms of decimal fractions) corresponding to SC Record values. NSC values must be supplied.

G.5 Trace Records

G.5.1 TC Record - Trace Record - Control Point Selection

The TC, TP and TS Records are normally used only by HEC personnel or by those users who can read FORTRAN and who desire to make program improvements or error corrections; up to 5 sets of TC, TP, and TS Records can be used. If more than 1 set is used, all 3 records must be used for each set. Multiple sets are used so that for a given time period (or periods), trace output for locations and/or subroutines can be different than other time periods in order to reduce the trace output volume.

All control points will be traced if this record is omitted and a TP Record is used. If both TC and TP Records are omitted, trace will not be printed for any time period or control point.

Field	Variable	Value	Description
1	NTRAMX	1-9	Number of location values on TC Record.
2-10	MXTRA(I)	+	Identification numbers of selected control points to be traced for periods and level of trace shown on TP Records (TP.10). The trace consists of additional output for major program loops and variables and are identified by subroutine and program statement numbers in the left hand margin. To read the trace, a listing of the program source code is required, as well as a knowledge of FORTRAN.

G.5.2 TP Record - Trace Record - Time Periods and Trace Level Selection (optional)

The trace level (TRACE, TP.10) is assumed = 15 if this record is omitted.

Field	Variable	Value	Description
1	NTRACE	1-8	Number of time period values on TP Record.
2		0	If NTRACE=1, a general trace before and after operation by period will be generated, but no trace will be generated from system operation.
2-9	ITRAP(I)	+	Selected time period numbers for trace. To trace period 10 of flood 2, as defined by BF-EJ Records, use 10.02. These values can exceed the dimension limit KPER. (Use 11.02 to trace period 1 of second automatic flood).
10	TRACE	0	Trace level is assumed = 15 if TC or TP Record is used.
		1[1]	Very small volume of trace showing how reservoir releases were determined.
		11	Trace of release computation.
		15	Comprehensive trace.
		17	Same as 15 except additional trace for diversions and routing coefficients.
		20	Comprehensive trace including Modified Puls trace.
		32	Trace of subroutine PRHEAD in post-operation (if 83 specified on TS Records).
		20+	NLEVTR (for System Power Routine) TP.10=20+ Reservoir level to be traced (i.e. TP.10 = 35 (20+15) will trace reservoir levels 14 and 15).

Example of System Power Allocation trace for Periods 35 - 37

```
TP    3    35    36    37    ...1
TS   95
```

[1] For system power, trace level 1 will give the system power allocation (for time periods specified). In addition, a TS Record requesting trace from subroutine SPREL (95) should also be used for allocation summaries for time periods being traced. Thus QA Records may be used to reduce unacceptable differences between system power energy required and generated where system power is controlling (CASE=.12).

G.5.3 TS Record - Trace Record - Subroutine Selection (optional)

If TS Record is omitted, all subroutines (1-194) that are used, are traced if trace level (TP.10) is high enough. If TS Record is used, subroutines will be traced if a positive (or zero) code number calls that subroutine. Subroutines that should be omitted from the trace are noted by a negative code. Subroutines which are to be traced can be defined using a combination of positive and negative codes on the TS Record.

Field	Variable	Value	Description
1-10	TRASUB (I)	+	Code describing subroutine(s) to be traced.
		-	Code describing subroutine(s) which should not be traced.

Examples

TS	0	-150.1	All subroutines will be traced except 150-157 (see following table).
TS	2	-50.1	All operations subroutines except 50-56 will be traced.
TS	117	112	Only subroutines 117 and 112 will be traced.

Codes for selecting HEC-5 subroutines using the TS Record:

HEC-5 General Subroutines

Code	Subroutine Name
0	All HEC-5A program subroutines (4,6-194)[1]
1	All PRE-operation subroutines (4, 6-35)[1]
2	All OPERATION subroutines (40-127)[1]
3	All POST-operation subroutines (150-194)[1]
4	HEC-5A subroutine/DSSNOB
5	All HEC-5B program subroutines

[1] Code to call or delete a **group** of subroutines.

HEC-5 Pre-Operation Subroutines

Code	Subroutine Name
5.1	**Routines 6-9**[1]
6	PRERD/TS Record
7	JOBRD
8	INCRD (no trace available)
9	DIMLIM
10.1	**Routines 10-33**[1]
10	IN
11	INITLZ
12	RDLBLS (no trace available)
13	RDMODL
14	RDJCDS
15	RDVJCD
16	PRRDSM
17	RDRES
18	PRRDCD
19	RDCP/RELCHG
21	RDROUT
22	RDDAMG
23	BASIN
24	RDBFSS/RELCHG
25	RDTSD
26	CRIPER
27	CRPDEQ
28	WRITQM
29	RDTSD8/RELDEC
31	INTAB/MAPGEN/MAPLIN/RESOPR
32	INTRES
33	INTDIV
34	(not presently used)
35	TSDCOD/LEVRES

HEC-5 Post-Operation Subroutines

Code	Subroutine Name
150.1	**Routines 150-157**[1]
150	OUTPUT/SUMMRY/USER5A/RRPERR
151	CASUSR
152	LEVL
153	CKMINQ
154	CKFLOD
155	CKRES/RELCHG
156	OUTIME
157	MOVARR
160.1	**Routines 160-161**[1]
160	OUTARR
161	PRPRNT
170.1	**Routines 170-174**[1]
170	OUTPER
171	OUTCP
172	OUTPOW
173	OUTDIV
174	OUTRES
180.1	**Routines 180-194**[1]
180	OPT
181	OPTAER
182	OPTERR
183	OPTDRA
184	OPEST3
185	OPPRNT
186	OPASMP
187	OPBNDY
188	OPESTM
189	OPMONV
191	OPDATE
192	OP1MOR
193	OPTP38
194	OPTWR

HEC-5 Utility Routines[2]

Code	Subroutine Name
198	CDATE (needs trace LEVEL = 20)
199	EVAP

[1] Code to call or delete a **group** of subroutines.

[2] No printout unless code appears on TS record.

HEC-5 Operation Subroutines

Code	Subroutine Name
40.1	**Routines 40-49**[1]
40	HMAIN/LEVRES/QMXPUL/TSCARD
41	RTCOEF
42	COMCOF (needs trace level=17)[2]
43	SUBCOF (needs trace level=17)[2]
44	MONPER
45	CHACAP/RELCHG
46	GUIDCV[2]
47	CONQAF
48	RLINT (needs trace level=17 or 18)[2]
49	FLOW
50.1	**Routines 50-56**[1]
50	LOCALQ
51	LOCINC
52	SCALE
53	PROF (no trace)
54	LOCCUM
55	OPTPRE
56	ADDLEV
60.1	**Routines 60-61**[1]
60	ROUT[2]
6l	MUSKRT (trace levels=15,20,25)
70.1	**Routines 70-75**[1]
70	DIVCOR[2]
71	DIVFRM
72	DIVRES
73	DVPUMP
74	DVRSMX
75	DVROUT
80.1	**Routines 80-82**[1]
80	POWER[2]
81	PRREL
82	PREREQ
83	PRHEAD[2, 3]

Code	Subroutine Name
90.1	**Routines 90-97**[1]
90	SYSPOW
91	SPQLEV
92	SPEQMN
93	SPADPT
94	SPFIXT
95	SPREL
96	SPCHCK/SYPRUL
97	PRELEV
98	SYPRUL
100.1	**Routines 100-105**[1]
100	MAINCP/QMXPUL
101	INFLOW
102	VCHCAP/RELCHG
103	BPCTFC
104	REQLEV
105	QTYTAB
110.1	**Routines 110-119**[1]
110	RELMX/DIVADJ/QA4250
111	QMINFC
112	RESROT
113	TANREL/TRELCN
114	PRESNO
115	QTABLV
116	SPACE1/DIVADJ
117	RESREL
118	FUTLEV/LEVRES
119	TQPREP
120.1	**Routines 120-127**[1]
120	FILL
121	TRACIP (no trace)
122	RELQMX
123	QSPACE
124	SCHEDP
125	FILSPA
126	SPATRY
127	MINREL

[1] Code to call or delete a **group** of subroutines.

[2] Subroutine is shown in only one group, but is actually called by other subroutines as well.

[3] No printout is available from subroutine PRHEAD unless code 83 appears on TS Record and time period on TP Record. For trace during post-operation also specify trace level TP.10=32.

G.6 Records for All Reservoirs

Records **RL**, **RO**, **RS**, and **RQ** are **required for all reservoirs**. **Omit for non-reservoirs**. The most upstream control point on each tributary must be a reservoir. Records RL-DC are repeated in turn for each control point (reservoir or information point) in downstream order until all control points have been specified. No downstream locations may be specified until all locations which route to that location are specified. The maximum number of control points KMXCPT (reservoir and non-reservoir) as well as the maximum number of reservoirs KMXRES is shown at the beginning of each HEC-5 output. If a control point is not a reservoir, Records RL-RG and P1-PE are omitted, and only control point Records CP-DC are used. If a reservoir is not a power plant, omit Records P1-PE. All control points above each confluence must be specified before the confluence control point. Last control point cannot be a reservoir. If your system has tandem reservoirs, read the tandem locations in first. Control points with diversions from that location should appear before the return point (diversion to). Model should start with most upstream location of the most complex tributary (after tandem reservoirs).

G.6.1 RL Record - Reservoir Target Levels

Field	Variable	Value	Description
1	MM	+	Reservoir identification number. Must be an integer.
		-	A negative identification number is used to specify a "**flow-through**" reservoir. The specification of a flow-through reservoir permits the summation of cumulative local flows to be continued through this reservoir. This option may be useful when it is necessary to operate an upstream reservoir for water supply goal below a "run-of-river" project.
2	STOR1	+	Starting **storage** of reservoir MM in 1000 m^3 (acre-feet).
		-	Initial **elevation** of reservoir MM in meters (feet).
3-17	STORL(M,L)	+	Cumulative reservoir capacities for reservoir MM in 1000 m^3 or acre-feet for each of NUMLEV levels (J1.3) starting with reservoir storage allocation level 1. If NUMLEV (J1.3) exceeds 8, two RL Records per reservoir are required. Level LEVBUF(J1.6) is the top of buffer pool. Level LEVCON(J1.4) is the top of conservation pool. Level LEVTFC(J1.5) is the top of flood control pool. For routing intervals less than monthly (or less than the length of the season described on the optional CS Record), input capacities represent conditions for cumulative days specified on CS Record or at end of month (if no CS Record). Interpolations between monthly or seasonal storage are made for each time period.

G.6.2 Additional RL Records (optional)

Additional RL Records can be used when reservoir storage allocation levels change during the year. These records will be read after the first RL Record(s) (storage level data will be ignored on the first RL Record(s) if additional RL Records are used). NUMLEV(J1.3) groups (one or two records each) of additional RL Records will be read in increasing order of level.

Field	Variable	Value	Description
1	L	1-40	Reservoir level number.
2	MM	+	Reservoir identification number.
3	IRPT	0	Storage values will be read for all 12 months. Two RL Records are required for this level.
			The first monthly value must correspond to the variable ISTMO(J1.2) (usually January). Seasons for RL Records are monthly. CS Records are not used at this reservoir.
			For daily routings, the monthly storage values represent **beginning** of month values and interpolations are made for each day. For monthly routings the monthly storage values are assumed constant for the entire month and may therefore be thought of as **end** of month values.
		-1	Storage in Field 5 will be used for all seasons. Only one RL Record for this level is required.
		3-36	Number of storage values to be read for Level L. Corresponds to the seasons described by cumulative days (in the calendar year). Seasons are specified on CS Records. **Do not use 12 values since this is reserved for monthly.**
4	FACTR	0	All storage values are read in 1000 m^3 (acre-feet).
		+	Storage in Fields 5-10 will be multiplied by FACTR.
5-10	STORL(M,L,K)	+	Reservoir storage for each season for level L. The first six values of storage appear on the first record in Fields 5-10, the next six values (if used) must be in Fields 5-10 of the second and subsequent records (Fields 1-4 are omitted).
			More than 1000 m^3 (1 acre-foot) of flood control storage should be shown for the first season if downstream CUMULATIVE LOCAL FLOW should not include local flows above this reservoir.
			Interpolation between monthly or seasonal storages are made for each time period.

G.6.3 RO Record - Reservoir Operation Points (required for reservoirs)[1]

1. **RO** Records are used to assign a reservoir to specific downstream control points for flood control and/or water supply release decisions.

2. For **flood control operation**, reservoir releases **for a non-reservoir control point** are based on not exceeding the channel capacities (CP.2) at the **RO** specified locations with consideration for uncontrolled local flows, forecast ability (J2.1), contingency allowance (J2.2), and routing effects. To effectively operate for downstream flood control goals, reservoirs should have both flood storage (J1.5, RL) and operable gates. In general, reservoirs should not be assigned to operate for control points below downstream tandem reservoirs that have flood control storage.

3. For **water supply operation**, reservoir releases **for a non-reservoir control point** are based on providing flow augmenting releases to sustain flow goals (minimum desired CP.3 or minimum required CP.4) at the **RO** specified locations with consideration for diversions, return flows, uncontrolled local flows, and contingency allowance (J2.2). To effectively operate for downstream water supply flow goals, reservoirs should have conservation storage (J1.4, J1.6, RL) and sufficient discharge capability (**RS**/**RQ**). In general, reservoirs should not be assigned to operate for control points below downstream tandem reservoirs that have conservation storage. In the special instance of operating a water supply reservoir for a location downstream of a "run-of-river" reservoir, accuracy in meeting flow goals can be improved by designating the run-of-river reservoir as a "**flow-through**" reservoir (e.g. RL.1= -location **(negative)** number).

4. For **flood control** and **water supply operation** for a downstream **tandem reservoir**, releases are based on balancing reservoir levels in both reservoirs. Multiple reservoirs in tandem may be chained together into the system by assigning each reservoir to operate for the next downstream reservoir in the system. In the special case of operating a **peaking hydropower** (**PD**, **PH**) reservoir for a downstream tandem reservoir, releases to balance levels will be made during power operation periods.

Field	Variable	Value	Description
1	NSERV	+	Number of downstream locations this reservoir will operate to prevent flooding or to provide water supply. If this reservoir operates for flood control, this value should be equal to one or more. All downstream control points may be used.
2+	ISERV(M,K)	+	Control point numbers for which reservoir is operated. NSERV values in any order. If reservoir MM is specified to be operated for the next downstream reservoir, MM will operate to balance levels in both reservoirs. In general, MM should not operate for control points below the next downstream reservoir. If flood routing is used (see RT Record), then all gated upstream reservoirs with flood control storage **which are operated in parallel** must operate for all downstream locations which are subject to flooding.

[1] Downstream locations which are operated for by Reservoir MM, are operated for time periods IFIRST to LOOK. IFIRST is the first time period where the current release would have a one percent or more effect. LOOK is the last time period within the allowable forecast period (J2.1 or R2.5). Where IFIRST for downstream operating locations is greater than LOOK, IFIRST is set equal to LOOK. Thus, reservoir releases will be curtailed if a downstream operation point is flooding at the **maximum forecast** period (LOOK) even though the reservoir release may not reach the downstream location during the forecast period. The controlling location in the program output, under CASE, is for the most downstream location that is flooding.

G.6.4 RS Record - Reservoir Storage (required for reservoirs)

Field	Variable	Value	Description
1	NK	2-60	Number of values of STOR(M,K) on this record and QCAP(M,K) on RQ Record. (Must be at least 2.)
		-	Number (negative) of values of STOR (as described above) to indicate that the values of STOR(M,K) are in 1000's of units on input records and will be multiplied by 1000 by the program.
2+	STOR(M,K)	+	Storage in 1000 m^3 (acre-feet) for reservoir MM corresponding to RQ Record outlet capacities. NK values must be supplied. First or second storage value should be the inactive storage value, and two successive values should not be equal. If more than 9 values are given, start in first field of second RS Record with tenth storage value.

G.6.5 QQ Record - Multiple Reservoir Outlet Capacities (Optional)

Optional data for the specification of multiple reservoir outlet capacities (RQ Records). Backwater effects from a downstream reservoir or non-reservoir which limit reservoir releases may be specified with a QQ Record and up to 10 RQ sets of NK outlet capacities. The QQ Record specifies the downstream location from which backwater conditions limit releases, the number of RQ sets, and the initial elevation for the first period of a simulation.

Field	Variable	Value	Description
1	LOCQQ	+	Location number of downstream reservoir or non-reservoir location from which backwater effects limit reservoir releases.
2	NUNQQ	2-10	The number of sets of reservoir capacity (RQ Record sets which follow this QQ Record)
3	QQDSEL	+	The initial elevation at location LOCQQ for the first period of a simulation.

G.6.6 RQ Record - Reservoir Outlet Capacities (required for reservoirs)

Field	Variable	Value	Description
1	NK	+	Number of values of QCAP(M,K) on this record and STOR (M,K) on RS Record,
	or, for **multiple RQ Record sets** (preceded by an optional QQ Record):		
1	QQDSEL	+	Reference elevation corresponding to downstream location LOCQQ (QQ Record). To simulate the effects of backwater, the first field of the RQ Record specifies the downstream elevation associated with the outlet capacities on this RQ Record. The RQ data sets are input from lowest to highest downstream elevation. (Maximum of 10 sets)
2+	QCAP(M,K)	+	Total outlet capacity in m^3/s (ft^3/s) for reservoir MM corresponding to RS Record storages. NK values must be supplied.
		-1	Unlimited outlet capacity at STOR(M,K). This option sets the outflow equal to the inflow when reservoir storage reaches the value of STOR that corresponds to a negative QCAP. This option should be used for all dummy reservoirs. This option should not be used if a gate regulation curve (RG Record) is used for this location.

G.6.7 RA Record - Reservoir Areas (optional, but required for evaporation)

Reservoir areas are given as a function of reservoir storage as defined on the **RS** records.

Field	Variable	Value	Description
1	NK	+	Number of values of AREA(M,K) on this record and STOR(M,K) on RS Record.
2+	AREA(M,K)	+	Reservoir areas in 1000 m^2 (acres) for reservoir MM corresponding to RS Record storages. NK values must be supplied.

G.6.8 RE Record - Reservoir Elevations (optional, but required for hydropower)

Reservoir elevations are given as a function of reservoir storage as defined on the **RS** records.

Field	Variable	Value	Description
1	NK	+	Number of values of EL(M,K) on this record and STOR(M,K) on RS Record.
2+	EL(M,K)	+	Reservoir elevations in meters (feet) for reservoir MM corresponding to RS Record storages. NK values must be supplied.

G.6.9 RD Record - Reservoir Diversions or Minimum Releases (optional)

Field	Variable	Value	Description
1	DVEXC	0	All diversions are made based on reservoir storage (RS Record).
		-1	**Diversions** are equal to the excess flood waters above the top of conservation up to the outlet capacity of the diversion pipe (FDQ). The second value on this record must be greater than 0.0. Use DR.7 = -2 for this option. Can be used to simulate uncontrolled spillways.
		-10	When the gate regulation curve operation is used (RG Record) the induced surcharge envelope curve values (minimum reservoir releases during emergency conditions) can be shown on RD and RS Records, and maximum reservoir releases vs. reservoir storages on RQ and RS Records. For this option only, **do not use DR Records** since reservoir releases determined from this option will not appear as diversions. (Applies to rising limb of hydrograph only.)
2+	FDQ(M,K)	+	Diversion discharges from reservoir MM corresponding to values of STOR(M,K) on RS Record. If Field 1 is -1, Field 2 must be greater than zero (use .01 or greater). NK values (RS.1) must be supplied.

G.6.10 R$ Record - Reservoir Costs (optional)

Field	Variable	Value	Description
1	NK	+	Number of values of COEF on this record and storages, STOR (M,K), on the RS Record.
2+	COEF	+	Reservoir capital costs (present worth) corresponding to the storages on the RS Record. The storage at the top of flood control pool (RL Record storage corresponding to level LEVTFC from the Field 5 of the J1 Record) will be used as the reference level for storage to determine the cost of the project from the RS and R$ Records. Values should be in the same units as damages (i.e., $, $1,000, etc.).

G.6.11 R1 Record - Multiple Flood Data Starting Storage or Hydropower Capacities (optional)

Field	Variable	Value	Description
1	N	1	Starting storages for reservoir MM (see Record RL.1) for floods 2-9 (either BF through EJ Records or use of flood ratios on FC Record) will appear in Fields 2-9 of this record.
		2	Installed hydropower capacities (see Record P1.2) for reservoir MM for floods 2-9 (either BF through EJ Records or use of flood ratios on FC Record) will appear in Fields 2-9 of this record.
2+	TSTOR1(K)	+	Starting storage (if N = 1) or installed capacities (if N = 2) for flood 2, 3, 4, etc. (K = up to 9).

G.6.12 R2 Record - Additional Reservoir Data (optional)

Field	Variable	Value	Description
1	RTCHGR[1]	0	The rate of change on Field 3 of the J2 Record (or a default value of .04 per hour) will be used for this reservoir (RL.1).
		+	The allowable rate of change of **increasing** reservoir releases, during a one-hour time period, when the release from this reservoir **increases** from the previous period.
			If RTCHGR is **greater than two** (2), expressed as flow in m^3/s (ft^3/s) per hour.
			If RTCHGR is **less than two** (2), expressed as a ratio (per hour) to the channel capacity at this reservoir (CP.2 or CC Record) during a one hour time period.
2	RTCHGF[1]	0	The rate of change on Field 3 of the J2 Record (or a default value of .04 per hour) will be used for this reservoir (RL.1).
		+	The allowable rate of change of **decreasing** reservoir releases, during a one-hour time period, when the release from this reservoir **decreases** from the previous period.
			If RTCHGF is **greater than two** (2), expressed as flow in m^3/s (ft^3/s) per hour.
			If RTCHGF is **less than two** (2), expressed as a ratio (per hour) to the channel capacity at this reservoir (CP.2 or CC Record) during a one-hour time period.
3	EVRTO	0,+	If greater than zero, factor is multiplied times the evaporation rates on EV, J6, and R3 Records.
4	RELSTR	0	Program will determine reservoir release for the first time period.
		+	Reservoir release for the first time period will be RELSTR. program will determine releases for subsequent periods.

[1] Ignored for weekly or longer routing intervals.

Field	Variable	Value	Description
5	IFCST(M)	0	The foresight shown on J2.1 for inflows and local flows will be used for reservoir MM when short interval routings are made, i.e., when IPER (BF.7) is less than or equal to NOROUT (J3.7).
		+	IFCST(M) hours of foresight for inflows and local flows will be used for reservoir MM when IPER is less than or equal to NOROUT.
		-	If a negative number is entered, the number refers to a reservoir location which will be the basis for evaporation calculations at this reservoir. Computed evaporation at the specified reservoir will be distributed between both reservoirs, based on the ratio of storage in this reservoir to the storage in the specified reservoir.
6	HPOINF(M)	0	No hinged pool operation.
		+	Inflow magnitude (m^3/s or ft^3/s) above which the reservoir top of conservation storage will be reduced from RL data to HPOSTG(M). This hinged pool operation is sometimes used on navigation locks.
7	HPOSTG(M)	0	No hinged pool operation.
			Storage (1000 m^3 or acre-feet) at top of conservation pool when inflow is at or above HPOINF(M).
8	IOPMX(M)		Reserved for future use.
9	IPRIMX(M)		Reserved for future use.
10	ITAPER(M)[1]		Flood Control Drawdown Option for **Real-time Water Control Applications**:
		+	Number of **hours** (after forecast time) that the reservoir will "taper" its releases in order to complete its flood control drawdown.
		-1	HEC-5 will **calibrate** the flood control drawdown using the "slope" of the previous releases (prior to time of forecast).
		0	Taper logic **not used**. HEC-5 will evacuate flood storage as soon as possible (i.e., using downstream channel capacities as well as the reservoir rate-of-change and outlet capacity constraints).

[1] For Real-time Water Control Applications (typically using MODCON), the HEC-5 execution line includes Forecast Date and Time which are used in conjunction with ITAPER. An example HEC-5 execution line follows:
H5A I=BASIN.DAT O=BASIN.OUT DSS=BASIN.DSS RT=ON **FD=19FEB86** **FT=1200**

G.6.13 R3 Record - Reservoir Evaporation (optional)

Optional data for varying the monthly net evaporation rates (net=evaporation-precipitation) for reservoir MM, instead of using the monthly basin evaporation on the J6 Records. Non-monthly evaporation rates must be read on EV Records. If used, two R3 Records are required.

Field	Variable	Value	Description
1-12	EVRATM(K,M)	+ or -	Monthly net evaporation rates in millimeters (inches) over the reservoir area for 12 monthly periods. The first month of the evaporation must correspond to ISTMO (J1.2), usually January.

G.6.14 RG Record - Gate Regulation Curve (optional)[1]

Field	Variable	Value	Description
1	ELTSUR(M)	+	Elevation in meters (feet) of top of induced surcharge (usually 1 to 5 feet above top of flood control pool). If this elevation does not exceed Field 2, the program will assume .1 meter (foot) higher than Field 2.
2	ELSURO(M)	+	Elevation in meters (feet) of bottom of induced surcharge (usually equal to top of flood control pool).
3	QSURO(M)	0,+	Discharge in m^3/s (ft^3/s) on induced surcharge envelope curve at elevation "ELSURO" (should be equal to channel capacity or less) used to develop default induced surcharge envelope curve when no RD Record.
4	TSCON(M)	+	Constant representing recession of hydrographs in **hours** (see EM 1110-2-3600).
5	SPWID(M)	+	Width in meters (feet) of spillway excluding piers (used in calculating approximate gate opening).
6	ELSPI(M)	+	Elevation in meters (feet) of spillway crest.
7	QMIN1(M)	0	One hundred percent of flood control storage will be used.
		+	Percent of flood control storage above which emergency transition releases will be made (HEC-5 output case = 23 or 21) if not using RD Record.
8	CQELSP(M)	0,+	Physical conduit discharge in m^3/s (ft^3/s) at spillway crest.

[1] A default induced surcharge envelope curve will be assumed if not given on RD Record (-10 for first field of RD Record).

When an RG Record is used, the RE Records are also required. The pre-release option (J2.5) if used, is not applied for any project that has an RG Record.

The RG Record should not be used for an uncontrolled spillway.

Field	Variable	Value	Description
9	ITYSP(M). TYOPFL(M)	X.Y	A "2-part" value where the "X-part" specifies the time interval to be used in Gate Regulation Curve calculations and the "Y-part" specifies the Recession Operation Code (.0 or .1). The "Y-part" indicates the type of operation to be followed when emergency releases have been made and the pool has fallen to the top of the flood pool.
			X-Part
		X=1	Gate regulation curve calculations will be based on the average inflow during the previous **one** hour.
		X=2	Gate regulation curve calculations will be based on the average inflow during the previous **two** hours.
		X=3	Gate regulation curve calculations will be based on the average inflow during the previous **three** hours.
			Y-Part
		Y=.0	Releases will be based on **average** of previous period's outflow and the current period's inflow (Case=0.22).
		Y=.1	Release will be based on **outflow=inflow** until normal flood control releases can be resumed (Case=0.23).
10	ELOPMN(M)	0	Emergency transition releases are made to the top of flood pool.
		+	Releases defined by this elevation and code Y (RG.9) will be made until normal "downstream based" flood control releases can be resumed. This elevation and code Y will determine releases when Gate Regulation Curve releases have been made and reservoir storage has fallen to or below the top of the flood pool.

G.7 Records for Hydropower Reservoirs

G.7.1 P1 Record - Hydropower Capacity, Efficiency, Overload (required for hydropower reservoirs)

This record specifies physical characteristics of a powerplant located at this reservoir. **Omit** records P1-PE if no powerplant exists; next record would be a CP Record for this reservoir without a powerplant.

Field	Variable	Value	Description
1	LOC	+	**Location** identification number (same as RL.1 and CP.1)
2	PWRMX[1]	+	Rated **capacity** in kilowatts (kW). Station service units are usually excluded. For optimizing **proposed** power projects (using J7 Record), use value of 1.0.
		-	**Pumping capacity** in kW (for pumped storage simulation, DR.7= -3).
3	OVLOD	+	**Overload ratio** for the power installation. Many older plants have been designed with 1.15, but many recent projects are designed for 1.0. If left blank, program assumes 1.0.
4	IPOW	0	Power peaking capability function will not be used. This means that the only limitation of power output will be the powerplant rated capacity.
		1	Peaking **capability** vs. reservoir **storage** relationship will be read on records **PP** and **PS** and used to calculate the turbine-generator capability as a function of reservoir storage. This option is used when head fluctuations are primarily dependent upon headwater fluctuations.
		2	Peaking **capability** vs. reservoir **release** relationship will be read on records **PP** and **PS** and used to calculate the turbine-generator capability as a function of reservoir release. This option is used when head fluctuations are primarily dependent upon changes in tailwater.
		3	Peaking **capability** vs. reservoir operating **head** will be read on records **PP** and **PS** and used to calculate the turbine-generator capability as a function of reservoir head. This option is more accurate than using IPOW=1.

[1] For optimizing **existing** power project (with J7 Record), enter the existing installed capacity (optimization will not optimize to value less than existing).

Field	Variable	Value	Description
5	TLWEL[1,2]	0	**Tailwater elevation** will be based on reservoir release relationship (**PQ** and **PT** Records) or elevation at downstream reservoir (**P1.6**).
		+	Tailwater elevation in meters (or feet). For hydroelectric projects providing "peaking" power, this should be a "block-loading" or average "on-line" tailwater elevation that would be expected normally during periods of power generation.
6	IDPR[2]	0	Indicates that there is no downstream reservoir whose elevation affects tailwater elevation at this powerplant.
		+	Location number of **downstream reservoir** (or control point if EL Records are used after BF Record) whose elevation affects **tailwater** elevation at this powerplant.
		-	Location number of reservoir whose elevation affects **headwater elevation** at this powerplant.
7	EFFCY	0	Standard ratio of .86 for generator-turbine efficiency is used.
		+	**Generator-turbine efficiency** expressed **as a ratio**.
		-1	**Generator-turbine efficiency** vs. **reservoir storage** relationship or vs. operating **head** is specified on **PE** Record. If the values on the PE Records are greater than 1.0 (an impossible efficiency), the integer portion of the value represents the head corresponding to the efficiency in the remainder of the value.
		-2	kW per m^3/s (ft^3/s) coefficient vs. reservoir storage relationship is specified on PE Record.
8	HLPO	+	Fixed **head loss** in meters (or feet).
9-10			Not used.

[2] Tailwater used by the program is the highest of the block-loading tailwater (P1.5), the tailwater based on downstream reservoir (P1.6 if used), and the tailwater rating curve (PQ and PT if used).

[3] If a J7 Record is used and this field is blank, a block-loading tailwater will be calculated using 100% of discharge required to produce installed capacity.

G.7.2 P2 Record - Hydropower Penstock Capacity, Leakage (optional)

Field	Variable	Value	Description
1	QLKG	0,+	**Leakage** through or under dam or powerhouse (or fish ladder or navigation lockage flows) in m^3/s (ft^3/s). Used to specify water which continuously passes the dam but cannot be used for power generation.
2	PENQ	0	Penstock discharge capacity will **not** be considered when making power releases.
		+	Maximum **penstock discharge capacity** for power releases. Program will convert the penstock capacity to an average discharge over the time interval based on the plant factor for that time period. The computed power release will be checked to ensure it does not exceed the penstock capacity.
3	MPSYS	0	This power plant is not a part of a power system but will be operated for at-site energy requirements.
		1	This **reservoir is part of a power system** and will be operated for the system (if there is power storage) while observing minimum requirements for at-site energy as expressed on PR Records. Run-of-river project whose output should be included as part of the system must use a 1 for power system 1. (Only referenced if SM Record is used.)
4	PFMAX	0	No system power is used or PFMAX is assumed to be equal to OVLOD (P1.3).
		+	**Maximum plant factor** for power generation from this project to contribute to meeting **system power load**. Must be equal to or less than OVLOD (P1.3). Generation rates greater than indicated by PFMAX will be permitted when excess water is available, but only the portion of generation up to PFMAX is considered to be usable in meeting the system load.
5-10			Not used.

G.7.3 PC Record - Hydropower Rule Curve (optional)

This record is used in conjunction with the PF (and optionally with the PB Record) to define a rule curve for determining energy production. The energy schedule is based solely on the amount of power storage, expressed in terms of the **percent of power storage** available (from top of conservation pool to top of buffer pool). This method is an alternative method to firm energy operation (see PR Record footnote).

Field	Variable	Value	Description
1	NPC	2-9	Number of ratios required to define the energy production rule curve.
2-10	RSPF	0,+	Ratio of conservation storage which may exceed 1.0. NPC values must be supplied starting with smallest value.

G.7.4 PF Record - Hydropower Rule Curve (optional)

This record, which must be used if the PC Record is present, is used in conjunction with the PC Record to define a rule curve for determining energy production and defines the amount of energy to generate (expressed as a plant factor) based on the amount of **power storage** in the reservoir (PC Record).

Field	Variable	Value	Description
1	NPC	0	All plant factors will be assumed to be 1.0.
		2-9	Number of plant factors required to define the energy production rule curve. (Must be equal to NPC (PC.1).)
2-10	RSPG[1]	0,+	Plant factors (expressed in terms of decimal fractions) corresponding to PC Record values.
			The plant factor for "0%" power storage will be applied below the top of buffer pool if a power drawdown priority (J2.4=2) is specified.

[1] These ratios are multiplied by the ratios shown on the PR, PD and PH Records.

G.7.5 PB Record - Hydropower Benefit Rate (mills/kWh) vs. Plant Factor (optional)

This record can be used in conjunction with the PC/PF Records to define the value of energy generated as a function of the project plant factor.

Field	Variable	Value	Description
1	NPC	0	Hydropower Benefit rate assumed to be zero.
		2-9	Number of values required to define the benefit relationship (must be equal to NPC (PC.1)).
2-10	RSMS	0,+	Energy benefit values (expressed in terms of mills/kWh) corresponding to PF Records.

G.7.6 PR Record - Hydropower Energy Requirements - Monthly (required for hydropower reservoirs)

This record specifies the monthly at-site requirements (1000 kWh or plant factors) for this project. Two records are required.

Field	Variable	Value	Description
1-12	POWRM	+	Monthly at-site **energy requirement** in 1000 kWh. Specify 12 values in successive order, one value per field beginning with January (J1.2=1)
		"or"	
		+	If **PC**, **PF** and **PB** Records are used, these monthly values (PR Records) are simply adjustment ratios of the plant factors (PF Records) and not firm energy requirements.
		-	At-site energy requirement as **plant factor** ratio times -1.0. Specify 12 monthly **negative** values starting with January (J1.2=1).
13	COEF	0	Factor of 1.0 is multiplied times all POWRM values.
		+	Factor COEF is multiplied times all POWRM values.
14	PRCRAT	0	Power guide curve factor not used.
		+	Power guide curve factor. When project for previous time period is above the top of buffer pool or LEVPRC (J1.9), the at-site energy requirements (from PC vs. PF Record or just PR Record data) will be multiplied by PRCRAT. When below this pool, a factor of 1.0 will be used.

G.7.7 PD Record - Hydropower Energy Requirements - Daily (optional)

This optional record specifies **peaking power** generation requirements for daily and hourly simulations. When the PD Record is used in conjunction with PR Records (only), the PD values are **percent** multipliers (e.g. PD 0, .2, .2, .2, .2, .2, 0) which distribute the monthly **energy requirement** over the days of a week. When the PD Record is used in conjunction with PC, PF, and PR Records, the PD values are **ratio** multipliers (e.g. PD 0, 1, 1, 1.5, 2, 1, 0) of PF plant factors.

Zero values indicate days during which power generation is not required. In the instance of a peaking power reservoir which also operates for a **downstream tandem reservoir**, tandem releases (case .05) will not be made during a day with a zero PD value. If it is necessary to make a tandem release in this instance, during a non-power day, a small value (say .0001) should be specified in place of a zero value.

Field	Variable	Value	Description
1-7	POWRD	0,+	Daily/weekly ratios (less than 1.0) of at-site energy requirements. Sum of the seven values must equal 1.0. The first value is for Sunday.
		"or"	
		0,+	If PC, PF and PB Records are used for this reservoir, these daily values are used as ratios to adjust PF plant factors. To turn off power requirements for a particular day, enter a zero.

G.7.8 PH Record - Hydropower Energy Requirements - Multi-hourly (optional)

This optional record specifies ratios of the daily energy requirements for each time interval (IPER, BF.7) within a day.

Field	Variable	Value	Description
1	N[1]	2-24	Number of ratios to be read starting in Field 2 for all power plants. The number of values must be greater than or equal to 24/IPER, e.g., for a 6-hour simulation interval, four or more values would be required. If 24 hourly values are given and the simulation interval is 6 hours, ratios will be summed as appropriate.
2+	POWRH[2]	0,+	Ratios (less than 1.0) of the daily energy requirements for each time period within the day. First value represents the period starting at midnight. Sum of the values must equal 1.0.
		"or"	
		0,+	If PC, PF and PB Records are used for this reservoir, these hourly values are used as ratios to adjust PF plant factors. To turn off power requirements for a particular hourly period, enter a zero.

[1] All power reservoirs must use the same number of values.

[2] Flexibility in pumping (or generating) additional hours on certain days of the week can be obtained by using digits to the left of the decimal point to indicate applicable days. For example, if the fifth hourly value on the PH Record is 17.10, then pumping (or generation) would occur from 4-5 a.m. on Sunday (Day 1) and Saturday (Day 7), with no pumping or generation from 4-5 a.m. on the other 5 days. In this case, the sum of the ratios can exceed 1.0. A zero to the left of the decimal implies every day of the week.

G.7.9 PQ Record - Hydropower Releases (optional)[1]

Field	Variable	Value	Description
1-10	QT	+	Reservoir **outflow** in m^3/s (ft^3/s). Begin with lowest value in Field 1 and specify values in increasing order. Values should cover the range of discharges expected. Program uses linear interpolation between points, so values should be selected so that linear interpolation is reasonably accurate. If less than 10 values are needed, the unneeded fields should be left blank. Used with PT Record to specify tailwater rating curve and optionally with the PL Record to specify hydraulic losses.

G.7.10 PT Record - Hydropower Tailwater (optional)

The number of values on this record must be the same as the number of values on the **PQ** Record.

Field	Variable	Value	Description
1-10	TL[2]	+	Tailwater **elevation** in meters (or feet) corresponding to reservoir outflow in same fields on the PQ Record.

G.7.11 PL Record - Hydropower Losses (optional)

The number of values on this record must be the same as the number of values on the **PQ** Record.

Field	Variable	Value	Description
1-10	HL[2]	+	Hydraulic **losses** in meters (or feet) corresponding to power release outflow in same fields on the PQ Record.

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1 PQ and PT Records are used to specify the tailwater-discharge relationship at this powerplant instead of using TLWEL (P1.5). A maximum of ten values can be used to define the relationship.

2 Normally, this curve is used with **average** reservoir releases to obtain an average tailwater (and or hydraulic losses) for run-of-river projects or to obtain a tailwater (and hydraulic losses) for storage projects where flood control releases cause higher than normal tailwater. When a J7 Record is used to maximize the firm energy for a proposed powerplant (P1.2, LE.1), the tailwater is based on the discharge required to produce 100% of the installed capacity (discharge used for tailwater=average discharge/plant factor).

G.7.12 PP Record - Hydropower Peaking Capability (optional)[1]

Field	Variable	Value	Description
1-10	PKPWR	+	Maximum **peaking capability** in kW. The capability must correspond to the specified values on the PS Record. Program uses linear interpolation in this table; values should be selected so that linear interpolation is reasonably accurate.

G.7.13 PS Record - Hydropower Storages (or Releases, or Head) (optional)

The data on this record can be either reservoir storages, reservoir releases, or reservoir operating heads. Reservoir storages are specified if IPOW (P1.4) is 1; reservoir releases are specified if IPOW is 2; and operating heads are specified if IPOW is 3. The number of values on this record must be the same as the number on the PP Record. The largest value should be larger than the highest storage, release, or head anticipated. The smallest value should be smaller than the lowest storage, release, or head anticipated.

Field	Variable	Value	Description
1-10	CQOEL	+	Reservoir **storage** in 1000 m^3 (acre-feet) if IPOW (P1.4) is 1; reservoir **release** in m^3/s (ft^3/s) if IPOW is 2; or **head** in meters (feet) if IPOW is 3. Begin with smallest value in the first field and specify values in increasing order. Values must correspond to peaking capabilities on the PP Record.

[1] PP and PS Records define the relationship between peaking capability and either reservoir storage, reservoir outflow, or power head. P1 Record, Field 4 must be equal to 1, 2, or 3 to determine type of data being read. A maximum of 10 values can be used to define the relationship.

G.7.14 PE Record - Hydropower Efficiencies vs. Storage (optional)

This record is used to specify the relationship between reservoir storage (**RS** Record) and either plant efficiency ratio or kW per m^3/s (ft^3/s) coefficient, rather than using a fixed efficiency of EFFCY (P1.7). Additionally, this record is used to specify efficiency as a function of operating head. If EFFCY (P1.7) is specified as -1, plant efficiency ratios are specified on this record. If EFFCY is specified as -2, kW per m^3/s (ft^3/s) coefficients are specified. The number of values on this record must be the same as the number of storage values on the **RS** Record(s). Note however, that the first storage on the **RS** Record appears in Field 2 while the corresponding (first) efficiency on the **PE** Record is in Field 1. Thus corresponding values are offset one field.

Field	Variable	Value	Description
1-10	EFCY	+X.Y	Plant efficiency ratio equal to X (Y is ignored) if EFFCY (P1.7) is -1; or, kW per m^3/s (ft^3/s) coefficient, if EFFCY is -2. Values must correspond to storage values given on the RS Records. If EFFCY (P1.7) is -1 and EFCY value is greater than 1.0 (an impossible efficiency), the value to the left of the decimal point (X) represents the head (in meters or feet) corresponding to the efficiency to the right of the decimal point (Y).

G.8 Control Point Records for Operational and Hydrologic Data

Records **CP**, **ID**, and **RT** are **required** for all control points including reservoirs.

G.8.1 CP Record - Control Point Operational Data (required)

Field	Variable	Value	Description
1	MM	+	Location identification (integer) number. Must be equal to MM on the RL Record (RL.1) if this control point is a reservoir.
2	QMX(M)	+	Maximum flow (non-damaging channel capacity) in m^3/s (ft^3/s) at control point MM. Must be greater than 1.0.
		-	Stage, in meters (feet), for location MM at which upstream reservoirs operating for location MM will make minimum releases. Stage hydrographs for location MM may be read on EL Records with other time series data such as inflows (IN Records).
3	QMIND(M)	0	Minimum flow, if any, is specified on QM or MR Records.
		+	Constant minimum **desired** flow at control point MM for all periods. Minimum desired flows will be met as long as upstream reservoirs are above Buffer level LEVBUF (J1.6).
4	QMINR(M)	+	Constant minimum **required** flow at control point MM for all periods. The target flows will be reduced from the desired flows to the required flows when upstream reservoirs are below Buffer level LEVBUF(J1.6) and are above Level 1.
		-	Minimum required flow will be set equal to the minimum desired flow(s) (either from CP.3 or QM or MR Records) and therefore can vary from month to month or period to period. The value of QMIND (CP.3) will be ignored if QM or MR Records are used. A dummy control point is required if it is necessary to specify time varying desired **and** required flows at the same location.
5	QMDRAT	0	Ratio of 1.0 will be used.
		+	Ratio which is multiplied times minimum desired flow(s) (CP.3, QM, or MR Records).
6	CFLD(M)	0	Factor CFLOD(J2.2) will be used for contingency factor.
		+	Contingency factor (equal to one or more) for forecasting cumulative local flows at control point MM.

Field	Variable	Value	Description
7	LEVCPT	0	Cutoff level will be same for all locations (based on buffer level or level 1 (see IPRIO, J2.4)).
		+	Level number below which all conservation demands (minimum flows, diversions, power requirements) for this control point will be ignored by reservoir(s) serving this location.
8	CCRTR(M)[1]	0	An unlimited increase in channel capacity can be made when using CG Record criteria.
		+	Allowable **increase** in channel capacity from the previous period (if CG Record is used) in m^3/s (ft^3/s).
9	CCRTF(M)[1]	0	An unlimited decrease in channel capacity can be made when using CG Record criteria.
		+	Allowable **decrease** in channel capacity from the previous period (if CG Record is used) in m^3/s (ft^3/s).
10			Not Used

[1] If values are less than or equal to 2, they represent ratios of channel capacity.

G.8.2 ID Record - Identification Record for Control Point (required)

Field	Variable	Value	Description
1-4	CPT(M)	any	Title (alphanumeric) of control point in columns 3-32. Columns 3-11 will be printed in J8/JZ summary output.
5-10			Not used.

NOTE: When using **HEC-DSS** (JZ, ZW, ZR Records), the following will apply (see G.11):

1-2	NAMCPO	any	The control point name which is the B part of the pathname to be used with the **ZW** Record to identify any **output data which may be stored** to HEC-DSS.
3-4	NAMCPI	"blank"	If this field is blank, the output name for HEC-DSS (NAMCPO) will be used for the input name (NAMCPI).
		any	The control point name used with the **ZR** Record to identify the **input data which will be read** from HEC-DSS.
5-10			Not used.

G.8.3 C1 Record - Additional Control Point Data (optional)

Field	Variable	Value	Description
1	LQCP(M)	0	Flows for location MM are read from IN Records.
		+	IN Records do not have to be read for control point MM; instead, flows for MM can be based on values on IN Records for the same or another control point LQCP(M) in the system. Flows for MM are equal to factor RTLQ(M) multiplied times the flows on the IN Records for location LQCP(M) and lagged by QLAG(M).
2	RTLQ(M)	0	Flows will be based on factor of 1.0 times flow for location LQCP(M).
		+	Ratio which is multiplied by flows at LQCP(M) to obtain flows at location MM.
3	QLAG(M)	0	No lag.
		+ or -	Number of periods local flows are to be lagged forward (+) or backward (-) in time, expressed in IPER (BF.7) units.
4	IPLOT		This option is no longer used since the DSPLAY program plots hydrographs of data stored in HEC-DSS.
5-10			Not Used.

G.8.4 C2 Record - Additional Control Point Data (optional)

Field	Variable	Value	Description
1	CRFAC	0	Capital recovery factor from J4.4 will be used for this control point.
		+	Capital recovery factor for this control point or reservoir to convert present worth cost (R$ or C$ Records) to an annual figure.
2	OMPER	0	No operation and maintenance costs.
		+	Percentage of capital cost, that will be required for annual operation, maintenance and replacement of the facilities (reservoir or local protection works).
3-10			Not used.

G.8.5 RT Record - Routing Record (required)

Field	Variable	Value	Description
1	RTFR(M)	+	Control point number of upstream end of routing reach. Equal to MM on the CP Record (CP.1).
2	RTTO(M)	+	Control point number of downstream end of routing reach. Equal to MM of the CP Record for the next downstream control point. May be left blank for last control point in system (last point must be a non-reservoir).
3	RTMD(M)	0	No routing. Fields 4 and 5 ignored.
		+X.Y	Number of subreaches (X), maximum of 12, (to the left of decimal) and codes (Y) for method of routing (to the right of the decimal).

Code	
Y = 1	for Straddle-Stagger and Tatum,
Y = 2	for Muskingum,
Y = 3	for Modified Puls,
Y = 4	for Working R&D,
Y = 5	for Modified Puls as a function of inflow,
Y = 6	for SSARR Time of Storage,
Y = 9	for given Routing Coefficients values

A 3.2 indicates three subreaches will be used in the Muskingum method.
NOTE: Methods 3, 4 and 5 require QS and SQ Records. The QS and SQ Records are required for Method 6 if Fields 4 and 5 are 0. Method 9 requires CR Records.

Field	Variable	Value	Description
4	X[1]		Routing coefficient "X" for each subreach of the reach. The value depends on the routing method used, as follows:
		+	**Method 1**, enter the number of ordinates for **straddle-stagger** (such as 3.1 for 3/1 straddle-stagger). For routing by the **Tatum** (successive average-lag) **method**, enter a 2.1 and make the “X part” of RTMD (Field 3) equal to the integer value of 2K/IPER+1 (where K is the travel time in hours and IPER is the simulation time interval (BF.7)).
		0	**Method 2** and **Method 4,** enter the **Muskingum** X coefficient between 0 and .5. Zero value gives a maximum attenuation and a .5 value gives none (direct translation of hydrograph).

Continued on next page

1 Do not use routing criteria that specifies that outflows are a function of future period inflows (e.g., Straddle-Stagger of 3/0). The 3/0 Straddle-Stagger would have outflow for the present period equal to 1/3 the inflow for the previous, present, and future periods.

Field	Variable	Value	Description
		0,+	**Method 6**, zero value indicates Time of Storage (T_s) will be defined in table form on QS and SQ Records. Non-zero value defines variable **n**; the exponent of Q in the equation T_s=KTS/Q**n**.
		0	**Method 3, Method 5** and **Method 9**, enter zero (0).
5	K		Routing coefficient K value depends on the routing method used, as follows:
		0	**Method 1, 3, 4 ,5 or 9**, enter zero (0).
		+	**Method 2**, travel time (K) in **hours** for Muskingum **subreach**. Total travel time will be the product of number of subreaches and value of K. To avoid negative coefficients, value of K should approximately equal the computational time interval (IPER, BF.7). Value of K must be greater than IPER/[2*(1-X)] and less than IPER/2X (where X is the Muskingum X coefficient (RT.4)).
		0,+	**Method 6**, zero value indicates T_s will be defined in table form on QS and SQ Records. A positive value defines variable **KTS** in the routing equation T_s = **KTS**/Qn.
6	LAG	0	No lag in addition to routing.
		+	In addition to routing specified by Methods 1-5, lag outflow by the number of periods shown in this field.
7	RTPER(M,I)	0	First RT Record criteria for this control point (MM) will be used whenever flood routing is done.
		+	Time interval applicable to this RT Record. A second RT Record can be used to describe a second set of RT data (second RT Record is limited to linear routing method; i.e., Modified Puls and R&D are not allowed). The second RT Record criteria will be used only if IPER (BF.7) is equal to RTPER; otherwise the first RT Record criteria will be used.
8	RTMNAT(M)	0	The routing criteria specified on this record will be used for all flow types (natural, regulated, etc.).
		1	The routing criteria specified on this record will be used **only** for **natural flow** calculations. No routing will be performed for other types of flows. This option allows the inflows specified at headwaters of a reservoir (specified as a dummy reservoir) to be routed through the reach, which is now occupied by water in the reservoir.
9-10			Not used.

G.8.6 CR Record - Routing Coefficients (optional)

Field	Variable	Value	Description
1	NUMCOF(M)	+	Number of routing coefficients on this record(s). Maximum number of values = 11.
2+	TRTCOF (M,K)	+	Routing **coefficients** to be used in this reach for routing **Method 9** (see RT.3). Sum of coefficients must equal 1.0.

G.8.7 WR Record - Water Rights Diversion Data

Optional record to specify water rights limits for diversion options. Data includes priority date, start and end dates (Julian days) and water-right volume in acre-feet. Input WR Record directly prior to the DR Record.

Field	Variable	Value	Description
1	IDPRIO	+	Date of water right (for use in determining relative priority among water right divertors). Format of date entry is similar to BF Record FLDAT (2 digits each for year, month and day), for example: a water right approved on 10 June 1937 is entered as 370610.
2	IDSTART	1-364	Starting date for diversion (in Julian days). As an example, a diversion for irrigation which begins on April 15th, would be entered as 105.
3	IDEND	2-365	Ending date for diversion (in Julian days).
4	WRVOL	+	Water right volume in acre-feet.

G.8.8 DR Record - Diversion Data for Control Point (optional)

For diversion requirements to be satisfied by upstream reservoirs, RO Records must specify that one or more reservoirs will operate for the diversion location. The maximum number of diversions is displayed in the program "banner" (see output file just prior to the data file listing).

Field	Variable	Value	Description
1	DRTFR(NDIV)	+	Control point identification number (same as MM on CP Record) where diversion is **made "from"**.
2	DRTTO(NDIV)	0,+	Control point number where diversion **returns "to"** system. Diversion flows will be routed from MM to DRTTO(NDIV). Can be zero if there is no return flow.
3	DRTMD(NDIV)	+	Routing method for diversion. (See RTMD of RT Record, Field 3). Only linear methods are allowed.
4	DRTCOF(NDIV)	+	Routing coefficient "X" for diversion. (See RT Record, Field 4).
5	DMUSK(NDIV)	+	Routing coefficient "K" for diversion. (See RT Record, Field 5).
6	DCON(NDIV)	0	One hundred percent of diversion flow is returned.
		+	Percentage of flow (expressed as a ratio) diverted from MM which returns at DRTTO(NDIV). A .2 indicates 20% of diversion returns.
7	KDTY(NDIV)	0	Diversion flow is **constant** and equal to DFLOW(NDIV) in Field 8.
		1	For **monthly** operations, 12 flow values on the QD Records would provide monthly diversions that would apply to each year's operation.
		-1[1]	Diversion quantity is a function of the **inflows** at control point MM according to the tables of CHQ (QS Records) and FDQ (QD Records).
		-2	Diversion quantity is a function of the reservoir **storage** for MM according to the tables of STOR (RS Records) and FDQ (RD Records).

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[1] Since these diversion types (DR.7, KDTY = -1 or -4) are not based upon fixed schedules, but are functions of flows or levels which are dependent upon upstream reservoir releases, simulations of complex systems which employ these diversions should be carefully reviewed to ascertain if the desired precision of operation is achieved. If increased precision in the operation of complicated water supply models is desired see J2.4 (code 32).

Field	Variable	Value	Description
		-3	Diversion quantity is a function of the **off-peak energy** available on the **PR**, **PD**, and **PH** Records for the dummy reservoir that represents a **pumped storage project**. Diversion (negative) is located at dummy reservoir just upstream of upstream generating plant. **Diversion is made from the dummy reservoir to the tailwater reservoir**. Diversion is limited by top of conservation pool or level LEVPUM(J1.7) at upstream project and by top of buffer pool (level 1 if power drawdown priority is used (J2.4)) of afterbay.
		-4[1]	Diversion quantities on the **QD** Record specify **monthly diversion** expected to arrive at the upstream location from a downstream (later in record sequence) location. This could represent a **pumping condition**.This option is similar to the pumped storage option (see KDTY = -3) in that negative diversions are specified at the upstream location (this control point) which diverts to the downstream location. If the upstream location is a reservoir, the diversions are limited by the top of conservation pool or level LEVPUM (see J1.7). If the downstream location is a reservoir, the diversions are limited by the top of buffer pool (or Level 1 if diversion priority IPRIO = 4 (J2.4)). If the downstream location is not a reservoir, the diversions are limited by the local inflow. For this option, a dummy reservoir is not required above the upstream diversion reservoir as is the case for pumped storage.
		-5	Diversions **vary by period** and are based on the QD Records which appear in the time series data (after the BF Record).
		-6	Diversion is equal to the **flow at the reference location** defined in Field 10 (see DR.10, IREFER). May be used with ratio specified in field 9.
8	DFLOW(NDIV)	0	Diversion flow is not constant.
		+	Diversion flow is **constant** and equal to DFLOW. Field 7 must be = 0.
9	DIVRAT	0	Ratio used is 1.0.
		+,-	**Ratio** which is multiplied times the diversion flows (RD, DR.8, QD Records).
10	IREFER	+	**Reference location** used in determining diversion using diversion type "-6" (see DR.7, KDTY=-6).

[1] Since these diversion types (DR.7, KDTY = -1 or -4) are not based upon fixed schedules, but are functions of flows or levels which are dependent upon upstream reservoir releases, simulations of complex systems which employ these diversions should be carefully reviewed to ascertain if the desired precision of operation is achieved. If increase precision in the operation of complicated water supply models is desired see J2.4 (code 32).

G.8.9 QS Record - River Discharges for Diversions, Variable Channel Capacity or Routing Options (optional)

QS Records are used with DR and QD Records to specify diversions which vary with flow in channel (diversion type -1); with CC Records for specification of variable channel capacities (channel capacity option 3); and with RT and SQ Records for specification of Modified Puls routing data (routing methods .3, .4 and .5).

For Modified Puls routing which varies as a function of inflow (RT.3 = .5) multiple sets of QS and SQ Records may be provided for up to six sets of storage and outflow data which are each a function of a given index inflow. For this method the maximum number of outflow values = 9. Also the storage outflow (QS-SQ) sets must be input in increasing magnitude of inflow and the first index inflow should be zero. The zero inflow set would be equivalent to the basic Modified Puls (RT.3=.3) which does not consider inflow.

Field	Variable	Value	Description
1	NPTSQ	2-18	Number of river discharges on QS Record. For use with diversion and variable channel capacity options (RT.3=.3).
		0,+	**Index inflow** for Modified Puls as a function of inflow (RT.3=.5). Maximum number of outflow values specified in fields 2 through 10 is nine values.
2-19	CHQ(M,N)	+	A table of river **outflows** in m^3/s (ft^3/s) at the downstream end of routing reach. Outflows correspond to the storages given on the SQ Records for use in non-linear flood routing from control point RTFR(M) (RT Record, field 1). NPTSQ values. Successive values should *increase*.

G.8.10 SQ Record - Channel Storages (optional)

Field	Variable	Value	Description
1	NPTSQ	2-18	Number of storage values on SQ Records (Must be same as NPTSQ on QS Record, field 1).
2-19	CHSTG(M,N)	+	A table of channel **storages** in 1000 m^3 (acre-feet). Storages correspond to the outflows given on the QS Records. Storage represents total volume between control point RTFR(M) and control point RTTO(M) (RT Record, fields 1 and 2). NPTSQ values.

G.8.11 QD Record - Diversion Flows for Diversion Types 1, -1, and -4 (optional)

Field	Variable	Value	Description
1	NUMDQ	+	Number of diversion values on QD Records for this control point. Maximum number = 18.
2-19	FDQ(M,N)	+	When KDTY (DR Record, field 7) = 1 or -4, these values represent the **monthly diversion** flows in m^3/s (ft^3/s). Twelve monthly values are given. The first value must correspond to January (ISTMO=1, J1.2).
"or"			
2-19	FDQ(M,N)	+	When KDTY (DR Record, field 7) = -1, Fields 2-10+ (up to 18 values) are the diversion flows corresponding to values of channel flow on the **QS Record**.

G.8.12 EL Record - Elevation or Stage for Non-reservoir Location (optional)

Field	Variable	Value	Description
1	NPTSQ	2-18	Number of elevation values (must be same as NPTSQ on QS Record, field 1).
2-19	EL(M,N)	+	Elevation or stage in meters (feet) corresponding to outflows given on QS Record. NPTSQ values.

G.8.13 C$ Record - Non-Reservoir Control Point (local project) Cost Data (optional)

Field	Variable	Value	Description
1	DESQ	0	Damages for the modified channel are reflected in the **second set of DC Records**.
		+	Design discharge (for the local project) below which there are no damages. Damages described on the DC Records will be eliminated below this discharge if one damage condition is provided. The channel capacity in Field 2 of the CP Record should be modified accordingly, but it can be different if desired.
2-19	COEF(N)	+	Capital (present worth) cost of the local project (channel modification, levee, floodwall, etc.) corresponding to the flows on the QS Record. The design discharge (DESQ) will be used as the reference level for discharge in determining the cost of the project from the QS and C$ Records.

G.8.14 CL Record - Reservoir Levels for Variable Channel Capacities (optional)

Optional record for specifying the reservoir levels corresponding to the channel capacity at location MM (CP.1). These reservoir levels correspond to location ILOCCC on the following CC Record, Field 1.

Field	Variable	Value	Description
1	NLEVS	1-18	Number of reservoir levels on this record. Maximum number of values = 18.
2-19	RLEVCC(M,K)	+	Reservoir levels corresponding to channel capacities on the next CC Record. NLEVS values in increasing order.

G.8.15 CC Record - Channel Capacity for Control Point (optional)

Optional record for varying the operational channel capacity at this location, **CP**.1, (either a reservoir or a control point). The channel capacity can vary monthly or by seasons or with the flow at any location; or it may be based on reservoir levels; or it may be based on seasonal guide curves; or be based on seasonal total system flood control storage. Maximum of two records per location. When this record is omitted, QMX (**CP** Record, field 2) is used for the channel capacity.

Operational Channel Capacity Options

Option	Description	Records Required[1]
1	Channel capacity is based on **month**.	CC
2	Channel capacity is based on **season**.	CC,CS
3	Channel capacity at this location is based on **flow** at another specified location.	CC,QS
4	Channel capacity at this location is based on **reservoir level** at specified reservoir.	CC,CL
5	Channel capacity at this location is a function of both **season** (time of year) and **level** (or **elevation**) at specified reservoir.	CC,CS,CG
6	Channel capacity at this location is a function of both **season** and percent of total **system flood control storage**.	CC,CS,GS,CG
7	Channel capacity at this location is a function of **rising** or **falling inflow** at specified reservoir.	CC

NOTE: CC Records can also be used in time series data (BF-EJ) to input period-by-period varying channel capacities.

Field	Variable	Value	Description
1	ILOCCC(MM) .OPTION	0.1	**OPTION 1**: Channel capacities are based on the **months** of the year. The number of channel capacities read is equal to 12 (two CC Records). The first channel capacity (Field 2) must correspond to January (ISTMO=1, J1.2).
		0.2	**OPTION 2**: Channel capacities are based on **season** of year (up to 18 seasons) using the CS Record to define the ending day of each season. Interpolations will be made for each time period of the simulation.

Continued on next page

[1] These records all appear at the current control point (CP.1) eventhough some locations reference data at another control point.

Field	Variable	Value	Description
		X.3	**OPTION 3**: Identification number (X) of control point used to obtain **inflows** that are compared with flows (read on the QS Records) for this location. Channel capacities corresponding to QS flows, start in Field 2.
		X.4	**OPTION 4**: Identification number (X) of reservoir (RL.1) whose **level** is used to compute the channel capacity based on CL Record data.
		X.41	Same as X.4 except use **previous period level** instead of forecasted level.
		X.5	**OPTION 5**: Identification number (X) of reservoir (RL.1) whose **level** (or **elevation**), from CG Record, and **season** (CS Record) will be used to compute the channel capacity.
		X.6	**OPTION 6**: Channel capacity at this location is a function of both **season** (CS Record) and total **system flood** control storage (CG Record) above location X. Location X can be a non-reservoir location. Also, see GS Record.
		X.7	**OPTION 7**: Identification number (X) of reservoir (RL.1) used to determine channel capacity as a function of **rising** or **falling** reservoir **inflow**.
2-13	CHCAPT(K)	+	**OPTION 1**: Twelve **monthly** channel capacities are specified, starting with January (ISTMO=1, J1.2).
"or"			
2-19	CHCAPT(K)	+	**OPTION 2**: Up to 18 channel capacities are specified, corresponding to the **seasons** shown on the CS Record.
"or"			
2-19	CHCAPT(K)	+	**OPTION 3:** Channel capacities on this record(s) correspond to **inflows** at location ILOCCC(MM) based on the QS Record flow values for this location. Interpolated values of the channel capacity will be used as the flood hydrograph progresses, except that the channel capacity is never decreased until the current inflow is less than the first inflow. Thus, once the maximum regulated discharge is reached, the corresponding channel capacity is maintained. Number of channel capacities read is NPSTQ (QS.1). Maximum number of values = 18.
			OPTION 4: Channel capacities on this record(s) correspond to the reservoir **levels** on the CL Record for location ILOCCC(MM) ("X part" of CC Record, field 1). Interpolations are made for channel capacities between values on these records. NLEVS (CL.1) values. Maximum of number of values = 18.

Field	Variable	Value	Description
"or"			
2-19	CHCAPT(K)	+	**OPTION 5**: Channel capacities on this record (in increasing order) correspond to the reservoir **levels or elevations** on the CG Records for location ILOCCC(MM) and **seasons** on the CS Record. A maximum of 18 channel capacities may be used.
"or"			
2-19	CHCAPT(K)	+	**OPTION 6**: Channel capacities on this record (in increasing order) corresponding to the percent of **reservoir system flood control storage** based on the CG Record for location ILOCCC(MM) and **seasons** on the CS Record. A maximum of 18 channel capacities may be used.
"or"			
2-4	CHCAPT(K)	+	**OPTION 7**: The channel capacity in field 2 of this CC Record is used when **reservoir inflows** at location ILOCCC(MM) are **rising**. The channel capacity in field 3 is used when **reservoir inflows** are **falling**. Optional value in field 4 is required change in reservoir inflow (m^3/s (ft^3/s) per period) necessary to trigger the change from rising to falling (or visa versa) channel capacity.

G.8.16 CS Record - Seasons for Variable Channel Capacities or Reservoir Levels (optional)

Field	Variable	Value	Description
1	NSEA	+	Number of seasons to be read on this record as well as on each CG Record and/or RL Record. A maximum of 36 seasons can be used in conjunction with RL, CG, or QM Records, and a maximum of 18 is permitted for use with the CC Record.
2-19	CGSEA(MM,IS)	+	Cumulative number of days from the beginning of the calendar year for each season (IS) that will correspond to each value specified on CG Records and/or RL Records for location MM. The last value must be = 365.

G.8.17 GS Record - System Flood Control Guide Curve Specification Record (optional)[1]

Optional record used with CC Record channel capacity (Option 6) for location MM (CP.1) to specify certain parameters concerning the guide curve (CG Records) for a flood control system. Only one GS Record can be used in the basin and MM must be at a non-reservoir location that is downstream from flood control projects which are to be used in calculating the percent of flood control storage in the system. Values given on the CG Record are **percent flood control storage** (instead of elevation or reservoir level).

Field	Variable	Value	Description
1	GCFCST	0	IFCAST (J2.1) hours will be used.
		+	Number of hours into the future when the percent of flood control storage will be calculated.
2	GCSYFC	0	The system flood control storage will be based on summing the flood control storage in all reservoirs that are located above MM.
		+	The system flood control storage in 1000's m^3 (acre-feet), which is used to calculate the percent of system flood control storage. Used as a parameter with the CG Record data for location MM (percent is used instead of level or elevation).
3	GCSYSQ	0	Reservoir release for system evacuation for future periods (GCFCST) will be based on the sum of the channel capacities for all reservoirs that release directly (not through other reservoirs) to location MM.
		+	Sum of reservoir releases (in m^3/s or ft^3/s) representing the expected system releases during the forecasted period (GCFCST).
4	GCSYMT	0	Equation 2 will be used.
		1 or 2	Equation number for calculating the percent of system flood control storage above location MM at time GCFCST into the future. Equations are as follows: EQ1 = (100./GCSYFC) * (SUMS+SUMIO) EQ2 = (100./GCSYFC) * (SUMS+SUMIOA) where: SUMS = sum of flood control storage used for current time period (no negatives) in all upstream reservoirs above MM. SUMIO = sum of inflows less sum of reservoir releases expected in next GCFCST hours converted to m^3 (acre-feet). SUMIOA = sum of inflows less GCSYSQ releases in next GCFCST hours converted to m^3 (acre-feet).

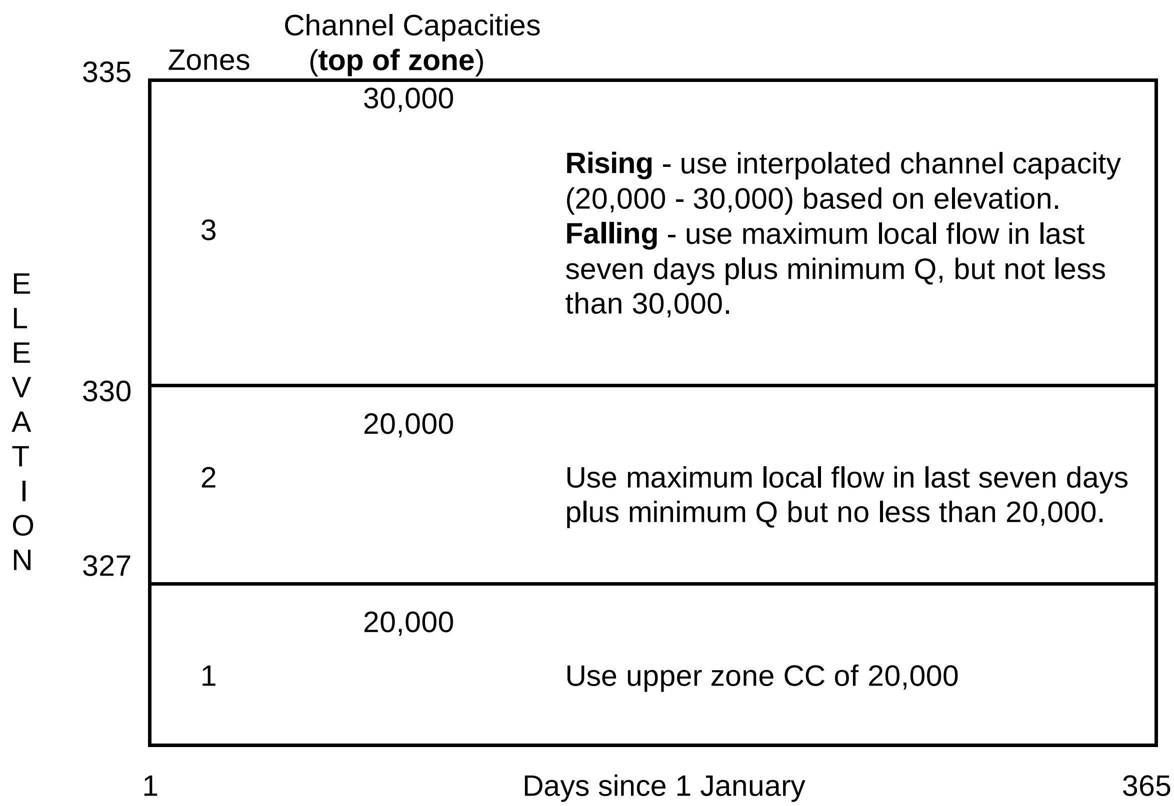
[1] GS Record follows the CS Record and precedes the CG Records. These Records plus CC Record (Option 6) are required if a GS Record is used.

G.8.18 CG Record - Seasonal Guide Curve for Channel Capacities or Minimum Flows Using CC Record (Options 5 and 6) or QM Record (-LOC Option) (optional)

Discussion: The operational channel capacity for flood control that can vary seasonally with reservoir level or elevation represents a rule curve operation. The rule curve describes the operational channel capacity within various seasonally varying elevation (or level) ranges called zones. Within each elevation zone, the criteria for the operational channel capacity can be specified differently for rising and falling reservoir stages. A zone is defined as the area between two adjacent channel capacities. The code X applies to the zone represented by the current channel capacity and the previous channel capacity (if any). A value of -0.2000 for the first **CG** Record would represent using 2000 m^3/s (ft^3/s) for all elevations below the elevations on this **CG** Record corresponding to the season on the **CS** Record.

Example:

Sample Rule Curve of Augusta, Georgia (Location 303)



HEC-5 Channel Capacity Data for Augusta Rule Curve (Location 303)

CC	303.5	20000	20000	30000
CS	1	365		
CG	-404.1	327		
CG	-707.2	330		
CG	-207.3	335		

A **CG** Record is required for each channel capacity specified on the **CC** Record, up to 18 seasonal values, in order to specify the guide curve for that capacity. If more than 9 seasons are specified on the **CS** Records, two **CG** Records are required for each channel capacity. The **CG** Records are arranged in the same order as the channel capacities on the **CC** Record.

Field	Variable	Description
1	CGVAR(IC,MX)	This code describes the method to be used in determining the channel capacity (or minimum flow if QM Record is used instead of CC Record) within the reservoir zones. The X value (to the left of the decimal) represents a code to describe the method. Reservoir levels (see J1 Record) are used as the parameter on this record starting in Field 2 unless Field 1 is **negative**, and then elevations are used. The parameter is percent flood control storage if GS Record is used for this location instead of elevation or level. The Y value (to the right of the decimal) is not used by the program but is available to reference the channel capacity (IC) (or minimum flow) corresponding to the reservoir (MX) data on the current CG Record. A suitable reference number might be the channel capacity expressed as a decimal (e.g., divided by 1,000 or 10,000), or perhaps the CC Record field number in which the channel capacity is specified. The codes for the X values are as follows:

Code[1,2]	Method of Determination
X = 1	Channel capacity for a reservoir level (or elevation) within a zone is the capacity associated with the level (or elevation) specified for the **bottom of the zone**.

Continued on next page

[1] A single digit entry represents criteria for both **rising** and **falling** reservoir levels. If desired, specify different rising and falling criteria for a zone using a compound code as follows: 201 represents code 2 for rising and code 1 for falling.

[2] For the first CG Record, codes of 1, 2, or 3 should not be used since there is no data for the previous zone.

Field	Variable	Description

Code	Method of Determination
X = 2	Channel capacity for a reservoir level (or elevation) within a zone is obtained by **linear interpolation** between the levels (or elevations) specified for the top and bottom of the zones.
X = 3	Channel capacity for a reservoir level (or elevation) within a zone is the **arithmetic average of values specified** for the top and bottom of the zone.
X = 4	Channel capacity for a reservoir level (or elevation) within a zone is the capacity associated with the level (or elevation) specified for the **top of the zone**.
X = 5	Channel capacity is equal to the **maximum regulated** flow that has occurred at this location during the **last seven days**. However, the channel capacity is constrained to **not exceed** the capacity associated with the **top** of the zone, or to be less than the capacity associated with the bottom of the zone.
X = 6	Channel capacity is equal to the **maximum regulated** flow that has occurred at this location during the **last seven days**. However, channel capacity will **not be less** than the channel capacity at the **top** of the zone.
X = 7[3]	Channel capacity is equal to the **maximum local flow** (plus minimum flow) that has occurred at this location during the **last seven days**. However, channel capacity will **not be less** than the channel capacity at the **top** of the zone.
X = 8	Channel capacity (or minimum flow on QM Record varies with CG Record) for the current period will be based on the **minimum elevation** (or level) **experienced** prior to the current period (instead of the current period) if this option is used. For example, a code of 802 or 208 would cause the program to use a linear interpolation (X=2) of the values between the top and bottom of the zones based on the maximum drawdown level experienced prior to the current period.

[3] Minimum flow will be added to **maximum local** flow to determine channel capacity only if IPRIO (J2.4) contains codes 1 or 8.

Field	Variable	Description
2-19[4]	CGUIDE(IS,IC,MM)	If Field 1 is **positive**, specify reservoir **levels** for reservoir location (MM) shown on Field 1 of CC Record corresponding to the channel capacity (IC) on the CC Record for season (IS) on the CS Record. Specify NSEA (CS.1) values. Maximum = 18 values if CC/CS Records are used; maximum = 36 values if CS/QM Records are used. If Field 1 is **negative**, specify reservoir **elevations** for reservoir location (MM) shown on Field 1 of CC Record corresponding to the channel capacity (IC) on the CC Record for season (IS) on the CS Record. Specify NSEA (CS.1) values. Maximum = 18 values if CC/CS Records are used; maximum = 36 values if CS/QM Records are used. If **GS** Record is used, specify **percent** of system flood control storage above location ILOCCC on Field 1 of CC Record corresponding to the channel capacity (IC) on the CC Record for season (IS) on the CS Record. Specify NSEA (CS.1) values. Maximum = 18 values if CC/CS Records are used; maximum = 36 values if CS/QM Records are used.

[4] Even though the description of the CG Record primarily discusses channel capacities, the CS/CG/QM Records can be used for specifying seasonally varying minimum flow goals based on guide curves. If the QM Record is used (instead of the CC Record), then up to 36 values can be specified (fields 2-37).

G.8.19 QM Record - Minimum Desired Flows Which Vary Monthly (optional)[1]

Field	Variable	Value	Description
1-12	COEF(I)	+	Minimum desired **monthly** flow goals for control point MM for 12 periods. The first monthly value must correspond to January (ISTMO=1, J1.2). If semi-monthly flows are used, enter 24 values.
"or"			
1-36	COEF(I)	+	Minimum desired flow goals for control point MM vary by **seasons** (CS Record). Maximum number of values = 36.
"or"			
1	COEF(1)	**-**LOC	Minimum **desired** flow goal for control point MM varies with the Reservoir (LOC) elevation or level (as shown on **CG Record** for location MM) and season (**CS Record** for location MM). If this option is used for location MM, the channel capacity for location MM cannot vary with the CG Record (see CC Record description). A dummy control point can be added if both minimum flows and channel capacities vary with reservoir level.
2-21	COEF(I)	+	Minimum desired flows at this location (in increasing order) corresponding to the reservoir levels or elevations on the CG Record for location, LOC, and seasons on the CS Record. A maximum of 20 values can be used. One QM Record may be used if there are 9 or less minimum flows given.

[1] QM Records are assumed applicable to all events (time series data sets: BF through EJ Records). MR Records (period-by-period varying minimum desired flows input following the BF Record) are not required for short interval simulation periods if flows still vary monthly; but if MR Records are used for any event, they will override the monthly QM Record data for that event only.

G.8.20 WA Record - Water Allocation based on Natural Flows and Reservoir Level (optional)

Optional record to define a **Minimum Desired** flow sequence as a **ratio of natural flows** at a **non-reservoir** location. The ratio selected is a function of both the seasonal volume of natural runoff and the status of a reference reservoir.

The ratio, WARAT1 (input in the second field), is used to derive the minimum desired flow sequence, unless the annual natural runoff volume exceeds the specified test volume WAVOL (input in the fifth field) and either of the following conditions occur at the reference reservoir:

CONDITION 1: On the specified date, the elevation of the reference reservoir is **greater than** test elevation 1 (WAELE1);

"or"

CONDITION 2: On the specified date, the elevation of the reference reservoir is **less than** test elevation 1 (WAELE1) but **greater than** test elevation 2 (WAELE2) "and" since the last occurrence of an elevation equal to or greater than the test elevation 1(WAELE1), the reservoir has not had an elevation less that test elevation 2 (WAELE2) on the specified date.

When either of the two volume-elevation conditions occur, the second ratio (WARAT2) will be used to derive the minimum desired flow sequence.

This record is input following the CP-QM Records. **Calculation of natural flows** (J3.4=-1) **must also be specified** when using this option. When this option is used, the volume of natural flow (1000 m^3 or acre-feet) is output in an user defined table and/or written to HEC-DSS by the specification of code .22 on the **J8**/**JZ** Records.

Field	Variable	Value	Description
1	IWARES	+	The location number of the reference reservoir used in determining which of the two ratios will be selected to compute the minimum desired flow sequence.
2	WARAT1	+	First of two alternative ratios used in deriving the minimum desired flow sequence from natural flow.
3	WARAT2	+	Second ratio used in deriving minimum desired flow sequence.
4	IWAVOL	1-365	Julian date for the summation and testing of natural runoff volume (e.g. June 1 = 152)
5	WAVOL	+	Natural runoff test volume (1000 m^3 or acre-feet) determined on Julian date IWAVOL.
6	IWAELE	1-365	Julian date for testing elevation criteria at reference reservoir.
7	WAELE1	+	Test elevation 1 for reference reservoir.
8	WAELE2	+	Test elevation 2 for reference reservoir.
9	WAELE3	+	Initial value of past minimum IWAELE elevation (for Condition 2 check at the start of a simulation).
10	IWASUM	1-365	Julian date to start summation of annual natural flow volume.

Application Example:

The following records example the application of the **Water Allocation** option to derive a sequence of minimum desired flows based on natural runoff. In this example, the location where minimum desired flow sequence is being derived is location 11; the reference reservoir location is 83; the two ratios are 0.5 and 0.4; the date to determine the volume of runoff is June 1; the test runoff volume is 40,500 ac. ft.; the date to check the reference reservoir elevation is June 1; the test elevations are 1594.8, 1593.8, and 1594.4; and, the date to start the summation of natural flows is January 1.

```
CP    11    9999
ID CP11
RT    11      22
WA    83      .5      .4     152   40500     152 1594.8 1593.8 1594.4   1
```

G.9 Control Point Records for Damage Data

Evaluation can be made of the damages that would result from a single flood or a series of floods. In addition, the expected value of annual damages (average annual damages) can be determined. The evaluation is made for base conditions, regulated conditions, and for conditions resulting from uncontrolled local flows below the reservoirs. Damages can be a unique function of peak flow rate or include a maximum of five different durations. Damages can also be defined for a maximum of seven seasons within the year. Damages are computed at each damage center and for the basin as a whole. Total damage for a single flood or a series of floods can be evaluated. However, when the expected value of annual damages is computed, at least six floods representing the full range of expected discharges should be processed. The BF and FC Records control the number of floods[1] to be processed, and the J4 Record, Field 1, provides the damage computation option. The DA, DF, DQ, and DC Records describe the frequency, flow, and damage data required for each control point (either reservoir or non-reservoir).

If damages are not to be evaluated, all DA-DC Records are omitted.

[1] For damage calculations based on season and duration, a maximum of 10 floods may be used.

G.9.1 DA Record - Damages (Expected-Annual) for Base Conditions (optional)[1]

Field	Variable	Value	Description
1	J	1 to 9	Number of damage categories to be read on this record (maximum of 9). DC Records (1 or 2 sets) will be read for each of these categories for each season and for each duration.
		-1 to -9	Same as + except that damages on DC Record are functions of stage or elevation (for reservoir) instead of discharge. Stages are given on DQ Record instead of discharges. QS and EL Records must also be used to describe the stage-discharge relationship at non-reservoir control points. At reservoirs, RE Records are required to describe the elevation in the reservoir. QS and EL Records cannot be used at reservoirs.
2-10	COEF	0	Expected annual damages for base conditions are not given. The damages for base conditions will be computed from the input flow-damage-frequency functions and used in adjusting the integration procedure for the modified conditions as discussed below.
		+	Expected annual damage for base conditions for each of (J) damage categories.

NOTE: Records DA-DC can be omitted if damage data will be calculated by routines available through random access storage (HEC-DSS).

[1] When DA Record is read, all other damage records (except DB) are required.

G.9.2 DB Record - Base Damage Record for Existing System (optional)

The DB Record may be used to input the expected annual damage for each damage category for an existing reservoir system. These expected damages are then substituted for expected damages for the base condition so that the incremental reduction due to additions to the existing system can be displayed.

Field	Variable	Value	Description
1	J	1-9	Number of damage categories on the DA and DB Records.
2-10	COEF	+	Expected annual damage for each damage category in turn for this control point for existing reservoirs and other developments (base conditions). Base condition damage data (see DC.2) are not provided if this option is used.

G.9.3 DF Record - Damage Frequencies (optional)[1]

Field	Variable	Value	Description
1	K	1-19	Number of values of exceedance probabilities on this DF Record which will correspond to discharge values on DQ Record and damages on DC Records. Maximum of 19 values.
2-20	COEF	+	Exceedance probabilities (in order of decreasing magnitude, i.e., .99, .95, etc.) from a frequency curve for each value of discharge on the DQ Record. Values can be annual series or partial duration.

G.9.4 DQ Record - Damage Discharge or Stage/Elevation (optional)[1]

Field	Variable	Value	Description
1	K	1-19	Same as DF Record, Field 1.
2-20	COEF	+	Discharges (K values) corresponding to the exceedance probabilities on the DF Record. These discharges must be in increasing order of magnitude. Discharge values should be average values for the time interval used (IPER, BF.7). Stages or elevation (for reservoirs) if J is negative (DA.1). These data must be in increasing order of magnitude.

[1] When DA Record is read, all other damage records (except DB) are required.

G.9.5 DC Record - Damage for Each Category (optional)[1]

Base condition damages for each damage category (J from DA Record, Field 1). X sets for each damage category, where X = number of seasons used (1-7) times the number of durations used (1-5). "J" sets of additional DC Records may be used if one represents base conditions and the second represents modified conditions from channel improvement or land purchase, etc.

Field	Variable	Record Column	Value	Description
1[2]	ID	1-2	DC	Identification letters.
	CAT	3	1-9	Damage category (maximum of 9).
	SEA[3]	4-6	0-365	End of current season in days for damages on this DC Record. (Jan 1 = 1.) A maximum of 7 seasons may be used.
	DUR	7-8	0-99	Duration in days for current damages on this DC Record. A maximum of 5 durations may be used.
2-10	COEF		-	Factor which is multiplied times all damage values on previous DC Records to obtain damages for this category, season and duration. Fields 3-10 of this record are ignored, and a second DC Record for this category, season and duration will **not** be read.
			+	Damage in dollars or multiples thereof corresponding to the same fields of the DF and DQ Records and for damage category N. All damages on these records will be multiplied by ECFCT (Field 2 of J4 Record) to obtain the damages in dollars. K(DQ.1) values on each set of records. J(DA.1) sets of DC Records are used for base conditions, and J additional sets may be used for modified conditions. Input for the J additional sets would follow the complete input for the base condition.

1 When a DA Record is read, all other damage records (except DB) are required.

2 Field 1 is optional if DC Records for only one season and duration are used.

3 Maximum of ten floods may be used for seasonal damages.

G.10 End of Control Point Data

G.10.1 ED Record - End of Control Point Data (required)

Required record at end of last set of control point data records (CP - DC) and just before BF Record for first event.

Field	Variable	Value	Description
1-10			Not used.

G.11 Specification for Time Series Data Records

Data records after the ED Record represent time series data. Data for each flow data set are bounded by a BF and an EJ Record. For any set of flow data, the set is preceded by a single BF Record. A single FC Record and/or one or more SS and/or ZR or ZW Records may follow the BF Record. These records may be followed by a set of IN Records for each control point in the system where inflows are to be specified. Omitted flow data for control points will be assumed as zero unless computed by a ratio of another location (see C1.1). The order of the time series records (IN, QA, NQ, etc.) is not important.

HEC-DSS

HEC has developed a data storage system (HEC-DSS) and a set of utility programs to interact with HEC-DSS to facilitate analysis of water resource time series data. HEC-DSS stores data in elemental blocks or records representing convenient groups of sequential data or pairs of data defining a relationship. The utility programs that have been developed act as interfaces between HEC's generalized application programs such as HEC-5 and HEC-1 and HEC-DSS.

Data stored in HEC-DSS may be plotted or tabulated using the DSPLAY program, or used by other programs for a subsequent analysis (e.g. STATS). Time series data to be input to HEC-5 (e.g., flows) can be entered into a DSS file using programs such as WAT2DSS (WATSTORE to DSS) and DSSIN or DSSTS. Program DSSUTL performs utility functions (editing data, renaming records, etc.) while program DSSMATH can mathematically manipulate the data stored in HEC-DSS.

HEC-DSS uses "pathnames" to identify data stored in a DSS file. For time series data, information is organized into blocks of data, each block containing data at one location, for one variable over a specific period of time (e.g., 1 month or 1 year). The pathname used to identify the block is divided into six parts, each part separated by a slash "/". The first or the "A part" corresponds to the basin or project name (see example below). The second or "B part" is the location name for the data. The "C part" identifies the data variable (e.g., FLOW, ELEV, etc.). The "D part" gives the beginning date of the time block, the "E part" gives the time interval between data (e.g., 1DAY), and the "F part" is for any additional qualifications needed that the user might want to supply (plan labels are a good example of what the "F part" may contain).

<u>Sample Pathname</u>:

/RED RIVER/DAVIS/FLOW/01JAN1981/1DAY/PLAN 3A/

When specifying pathname parts on ZW and ZR Records, each part is given in free format style, with commas or blanks separating the parts. A pathname part may have embedded blanks, but no leading or trailing blanks.

Writing to DSS

Writing to HEC-DSS by HEC-5 is controlled by **JZ**, **ZW**, **ID**, and **BF** Records. The presence of a ZW Record will cause HEC-5 to write to DSS. When writing data generated by HEC-5 to a DSS file, a ZW Record is required in the input following each BF Record. The A and F parts of the pathname are specified on the ZW Record in a free format style. An example which would write data to DSS is:

ZW A=RED RIVER, F=PLAN 3A

The A and F parts are the only pathname parts that need to be specified on the ZW Record. The B part of the pathname is obtained from the ID Record. The C part is provided by the program based on the variables (default or specified on JZ Record) to be written. The D and E parts are determined by the program from the time parameters on the BF Record. Specific control point locations and data variables to be stored may be specified on the JZ Record.

Reading from DSS

The access of time series data from an HEC-DSS file is controlled by ZR, ID, and BF Records. Field 1 of the BF Record must always be set to 2 when reading from DSS. Data stored in a HEC-DSS file are read by HEC-5 using a ZR Record. The ZR Record, which follows the BF Record for each flood, indicates which data is to be read from DSS. The A, C and F parts of the pathnames for the data to be read are specified on the ZR Records. The type of HEC-5 time series input data (i.e., IN, QA) must also be specified in the ZR Record. Similar to the ZW Record, these pathname parts are given in a free format form. For example:

ZR=IN A=RED RIVER, C=FLOW, F=OBS

This would cause IN time series data to be read from DSS for all control points in lieu of the user supplied IN Records. The A and the F parts, defined on the first ZR Record, remain the same until reset by a later ZR Record.

The B part of the pathname is obtained from Fields 3 and 4 of the ID Record, unless blank, whereby Fields 1 and 2 are used. The D and E parts are generated using the time parameters given on the BF Record. If data is missing from the DSS file at the beginning or end of the requested time period, the first or last data value is repeated and extended to replace the missing data and a warning message is printed. If data is missing in the middle of a data block, the missing data is assigned the value of the last valid period. If no data exists, a warning message is printed and no data is read into HEC-5. Data is attempted to be read for each relevant control point, unless ZR Records restrict the reading to specific control points.

The specific control point form of the ZR Record allows the user to read data for only the specific control point indicated on the record using pathname parts different from the default parts. The B part of the pathname may be given if different than the name given on the ID Record. The A, B, C, and F parts given on the specific control point form of the ZR Record do not become defaults for later ZR Records, they are only used for processing that record. If specific control point ZR Records are used in conjunction with a global ZR Record, global parts are used for any parts not given on the specific record. For example:

```
field = (1)   (2)                        (5)               (7)          (10)
BF      2    365                   59010100                24           1900
ZR=IN     A=RED RIVER        C=FLOW      F=OBSERVED
ZR=IN25        B=DRY CAMP                   F=PLAN3A
ZR=IN42        B=BRIDGE PORT   C=FLOW-NAT
EJ
```

These records will cause one year of daily inflow data (starting on January 1, 1959) to be read at every control point using the parts given on the first ZR Record, except at control point 25, where an F part of "PLAN3A" will be used, and at control point 42 where a B part of "BRIDGE PORT" and C part of "FLOW-NAT" will be used (F part will be OBSERVED as given on the "global" ZR Record).

If data is to be read for only certain control points, specific ZR Records are used. For this method, the A, C, and F parts are set on the ZR Record for the specific control point (the B part is optional if same as the name given on the ID Record). For example:

```
field =(1)         (2)                 (5)              (7)                     (10)
BF      2          24              64010100             720                     1900
ZR=IN32        A=RED RIVER     B=FARMTOWN       C=FLOW       F=OBSERVED
ZR=IN105       A=RED RIVER     B=WHEATLAND      C=FLOW       F=OBSERVED
IN    25
IN  1875       1950    1475      890     510      330         320     285       270      310
IN  1300       1540    1975     2110    1710      980         620     430       310      280
IN   265        360    1120     1550
EJ
```

The above example will cause two years of monthly data (starting on January 1, 1964) to be read from HEC-DSS for only control points 32 and 105. This method should be used when reading from both DSS and user-supplied time series records or when C1 Records are used to specify inflows. Flow data in this example for control point 25 is entered on IN Records.

The names of the HEC-DSS file(s) to be used are specified on the execution line of the program HEC-5A. If data is to be read from and written to the same file, the word "DSSFILE" should be used. If data is to be read from one file and written to another the words "DSSIN" and "DSSOUT" should be used. For example:

HEC5A,INPUT=SCIN.DAT,DSSFILE=SCIDSS.DSS

"or"

HEC5A,INPUT=SCIN.DAT,DSSIN=SCIOBS.DSS,DSSOUT=SCIPLAN.DSS

For flow-frequency data, the "DSSFILE" must be specified on the execution line of HEC-5B as shown in the following example:

HEC5A, INPUT=SCIN.DAT, OUTPUT=SC.OUT,DSSFILE=SC.DSS

HEC5B, OUTPUT=SC.OUT, DSSFILE=SC.DSS

G.11.1 BF Record - Beginning of Flood (time series data set) (required for each flow data set)

Field	Variable	Value	Description
1	FLOFMT	2	All time series data (Records IN-ST) will be read using the standard format of 10 fields per record. For each set of data, the location identification number (LOC) is read on the first record and the data values are read starting with the first field of the second record. If the third field of the first time series data record is greater than zero, it will be used as a multiplier for all time series data on remaining records of the set. Fields 4-10 of the first record of the set are not used.
		0,1	Obsolete data formats.
2	NPER	+	The number of periods of flow data on next set of records (IN-ST). Maximum value = 2000[1].
3	NPSTO	0	Reservoir storages are not transferred to the next event (also referred to as floods or flow data sets or time series data sets). These sets are defined by BF and EJ Records.
		+	Time period of this time series data set for which reservoir storage will be transferred to the next time series data set (next BF-EJ data set). This is normally set equal to NPER less IFCAST(J2.1). When a monthly operation follows a short interval event, NPSTO must equal NPER.
4	CNSTI	0	Flow data will not be multiplied.
		+	Factor which is multiplied times all inflows and local flows on the next IN and NQ Records.
5	FLDAT	+	Date corresponding to the **beginning of the time interval** of the first flow on the next IN Record. The date is an 8 digit number (2 digits each for year, month, day, hour) such as 54120223 for December 2, 1954 at 11 p.m. For monthly simulation intervals the day should be = 01, and the hour = 00. For daily the hour = 00.
6	EPER	0	Last computation period will be NPER (BF.2).
		+	Last computation period of simulation (must be less than NPER, BF.2). Typically, not used but may be useful when debugging. Can be used within the first BF-EJ data set only.

[1] If more than 2000 periods are needed for an HEC-5 model, then multiple events (BF-EJ) can be used and storages transferred (BF.3) between events. Maximum of 80 events (BF-EJ sets).

Field	Variable	Value	Description
7	IPER.MINPER	+	Time interval in hours (IPER) **or** minutes (MINPER) between data in all time series data records (i.e., IN, QA, etc.). For intervals of one hour or longer use integer values of IPER (i.e., 24 for a daily interval, 720 for a monthly interval, 240 for 3 intervals per month, and 360 for 2 intervals per month). For intervals of 60 minutes or less use a **decimal point** followed by the number of minutes (i.e., for a half-hour interval use .30, for a 15 minute interval use .15). Where power reservoirs are used, interval must be equal to 1 hour or more.
8			"No longer used" for specifying day of week since program determines day of week based on field 5 (FLDAT).
9	ONESUM	0	Output summaries will be based on time periods designated by input data (BF-EJ Records) unless NPER(BF.2) exceeds 365, and IPER(BF.7) = 24 hours. In this case, the individual flood events (BF-EJ) will be combined into a continuous string of output so that 50 years of daily data will be summarized as one flood event.
		1	A single flood summary will be used regardless of values of NPER and IPER for the individual floods.
		2	The output summary will correspond to the input flood periods (BF-EJ Records) regardless of the values of NPER and IPER.
10	ICENT	+	Integer number for century of year in FLDAT (eg. 1800).
		0	Integer number for century of year in FLDAT (BF.5) defaults to 1900.

G.11.2 FC Record - Flood Ratios (optional)

Field	Variable	Value	Description
1-10	CNSTI	+	Ratios to multiply next set of flow data (IN Records) by to obtain additional system operations. A maximum of 10 values are read. The program will make a complete operation for each ratio of the given flow data. One of the CNSTI values should be 1.0 if given flow data is to be one of the events.

G.11.3 SS Record - Starting Storages (optional)[1]

Field	Variable	Value	Description
1	MM	+	Identification number (RL.1) of reservoir whose starting storage is in Field 2 of this record.
2	STOR1(M)	+	Starting **storage** for reservoir MM at beginning of event (see FLDAT, BF Record, field 5).[2]
		-	Starting **elevation** for reservoir MM at beginning of event (see FLDAT, BF Record, field 5).

[1] These starting storages will override those on the RL or R1 Record and can be specified for any or all reservoirs by using an SS Record for each reservoir. SS Records may be used for any or all floods by inserting them after the appropriate BF Records.

[2] A ZR Record, (ZR=SS) when used, will read in starting storages from HEC-DSS.

G.11.4 ZR Record - Identification Record for Reading Data from HEC-DSS (optional)

Read time series data from HEC-DSS (see Section G.10, page 90 for additional description).

Record Columns	Variable	Value	Description
1-2	ID	ZR	Record identification characters.
3-5	Data type	Blank	When this field is blank the ZR Record is only used to set the default A and F parts for subsequent ZR Records.
		=Data Type	An equal sign and the HEC-5 time series record 2-letter identification characters indicating what data type is to be read from HEC-DSS (i.e., =IN, =QA, =SS, or =NQ).
6-8	MM	Blank	When no control point number is specified, data will be read for all control points defined in the HEC-5 data input that require the type of data specified in columns 3-5.
		+	Up to 3-digit "left justified" location number (as defined on CP Record, field 1), causes data for only that location to be read from HEC-DSS. Any pathname parts appearing on this record will be used only for this current record and will not reset the default values for subsequent pathname parts.
10-80	Pathname Parts		Free form identification of pathname parts. Each pathname part is separated by a comma or space. Unspecified pathname parts will assume default values specified on previous ZR Records, except as noted for specific locations above. Examples: ZR=IN A=RED RIVER, C=FLOW-LOC INC, F=PLAN A ZR=IN25 B=BOGGY CREEK, C=FLOW-REG, F=PLAN E ZR=QA C=FLOW-RESOUT, F=PLAN C

G.11.5 ZW Record - Identification Record for Writing to HEC-DSS (optional)

Write data to HEC-DSS. See Section 11 (page 96) for additional description. Locations and variables to be written to HEC-DSS are controlled by the **JZ** Record(s).

Record Columns	Variable	Value	Description
1-2	ID	ZW	Record identification characters.
3-4		Blank	Time series data will be written to HEC-DSS. If Field 10 of the J4 Record is set, flow-exceedance frequency data will also be written to HEC-DSS.
		QF	Only flow-exceedance frequency data will be written to HEC-DSS (the tenth field of the J4 Record must be set for this option).
5+	Pathname Part		Free form identification for A and F parts of the pathname. When writing flow-exceedance frequency curves (J4.10 = 1 or 2) specify E part of pathname. Each pathname part is separated from other parts by either a space or a comma. Examples: ZW A=RED RIVER F=PLAN 6C ZWQF A=RED RIVER E=1970 F=PLAN 7

G.12 Time Series Data Records

These time series data represent all data that vary with time according to the specifications given on the preceding BF Record.

Standard Time Series Data Format Example

With the standard time series data format (BF.1=2), the first record (IN-ST) in a sequence specifies the location number for the data. Each subsequent data record of the series contains 10 values except for the last record which may have less than 10 values. In the following example 28 months of flow data (starting in January 1, 1964) are specified for location 25.

```
BF     2      28               64010100            720                 1900
IN    25
IN  1875    1950    1475     890     510     330     320     285     270     310
IN  1300    1540    1975    2110    1710     980     620     430     310     280
IN   265     360    1120    1400    1400    1400    1400    1400
EJ
```

Abbreviated Time Series Record Format

An abbreviated flow format is available that requires one record image to specify up to 5 consecutive flows starting with the input starting time period. Multiple record images can be used to specify other periods. All flows not specified by these records are assumed to be equal to zero. This abbreviated format is:

Field	Variable	Value	Description
1	LOC	+	**Location** identification number of control point
2	IDAT	-	Starting period number (**negative**) for flow or code value in field 6
3	MULT	+	**Multiplier** (default = 1.0) times flow values in fields 6-10
4	CONST	+	**Constant** (default = 0) which is added to flow values in fields 6-10.
5	IREP	0	Last flow value will not be repeated.
		+	Number of periods that last flow or code value will be **repeated**.
		-	Same as +, except product of flows and "MULT" will be truncated and added to "CONST."
		-999	Last flow will not be repeated, but product of flows and "MULT" will be truncated and added to "CONST ".
6-10	QTC	+	Up to 5 consecutive **flow** or **code** values starting at time period IDAT (field 2). The flow values will be multiplied by "MULT" and "CONST " will be added.

Abbreviated Time Series Data Format Example:

With the abbreviated format, each record specifies both the location and the starting time (period number) of the data. In the following example, the 28 flow values for location 25 are entered on 6 records. The flow data for periods 24-28 are entered with a single value (1400 for period 24) and the notation that 1400 will be “repeated” **4 more** periods (25-28).

The single QA Record in the data set directs Reservoir 25 to make releases of 1250, 1000, and 750 during periods 15-17. In all other periods (1-14 and 18-28) the program will determine releases for Reservoir 25.

```
BF     2      28               64010100            720                        1900
C
IN    25      -1       0       0       0    1875    1950    1475       890       510
IN    25      -6       0       0       0     330     320     285       270       310
IN    25     -11       0       0       0    1300    1540    1975      2110      1710
IN    25     -16       0       0       0     980     620     430       310       280
IN    25     -21       0       0       0     265     360    1120
IN    25     -24       0       0       4    1400
C
QA    25     -15       0       0       0    1250    1000     750
EJ
```

Uses of the Abbreviated Format:

1. Can be used to specify fewer than "NPER" (BF.2) time periods (useful for QA Records).

2. Can be used to specify record values that require more than six digits including the decimal point (field 1 of standard format provides only 6 digits of information).

3. Is used by HEC-DSS to preserve accuracy when reading flow data from HEC-DSS into HEC-5.

G.12.1 IN Record - Inflows or Local Flows (required)

Flow data for NPER (BF.2) periods of IPER (BF.7) hours/min. duration starting on the date indicated by FLDAT (BF.5). **Type of flow** (e.g. local incremental, observed, or natural) is denoted by ILOCAL (J3.6) and INFLOW (J3.8). Flow units (m^3/s or ft^3/s) are specified by METRIC (J1.1).

Field	Variable	Value	Description
			First *IN Record in a Time Series Sequence*
1	LOC	+	Location identification number (CP Record, field 1).
2			Not used.
3	CNSTIN	0	Flow values on IN Records will not be adjusted.
		+	Multiplier to adjust flow values for this location (LOC).
4-10			Not used.
			Second *and* ***Subsequent*** *IN Records in a Time Series Sequence*
1-10	QII(I,M)	+ or -	Values are **incremental** local flows if ILOCAL (J3.6) = 1. Values are **cumulative** observed (gaged) flows if ILOCAL=10 or =15. Values are **natural** flows if ILOCAL=20 or =25.

G.12.2 QA Record - User Specified Reservoir Releases (optional)

User specified reservoir **releases** (m^3/s or ft^3/s) and operation **codes** which override rule-based reservoir release decisions determined by HEC-5. Same input format as IN Records. Abbreviated format is particularly useful for QA data input.

Field	Variable	Value	Description
	First *QA Record in a Time Series Sequence*		
1	LOC	+	Location identification number (RL Record, field 1)
2-10			Not used.
	Second *and* ***Subsequent*** *QA Records in a Time Series Sequence*		
1-10	QA(I,M)	0	Program will determine release
		0.001	Release = 0.0 will be made.
		+ Flows[1]	Release = **QA** will be made for **current period only**. (Special code = 0).
		+ Y.Code	Special codes on following page allow user to specify controlling type of release for **current period only** (i.e., .01 repeats previous release, etc.). Codes for QA Records only include inflow (.41) plus codes .22 to Y.5 described on next page.
		- Flows	Release = **-QA** will be made starting with current period and continuing until changed by QA Record criteria for a later time period.
		- Y.Code	Special codes (-QA) allow user to specify controlling type of release starting with current period and continuing until changed by QA Record criteria for a later time period.

Special Codes[2]	Description
.01	Value **repeats** previous period's value
.02	Value is based on **interpolation** between user specified values (not codes)
Y.03	Value equals previous period's value **plus Y percent**
Y.04	Value equals previous period's value **minus Y percent**
Y.10	Value equals previous period's value **plus Y**
Y.20	Value equals previous period's value **minus Y**

[1] When a QA sequence for a given location includes a **non-integer** value with an *invalid code* (**Y.X**, where X is "not" a valid code), then the entire sequence for that **location** will be treated as **flow** values instead of code values.

[2] Special Codes .01 - .20 are items of general use for reservoir releases (QA Records), channel capacities (CC Records), or top of conservation storages (ST Records). For the QA Record only, these codes (except .02) can reference a program determined release in addition to a user specified release on the QA Record.

Flood Control Release[3]

.22	Gate regulation **emergency** release
.24	Dam site operational **channel** capacity
.25	Maximum **outlet** capacity
.27	Rate of change - **rising** release
.28	Rate of change - **falling** release
.36	Release based on **downstream** flood control regulation
.41	Release = **Inflow**
.42	Release based on previous period's **gate** setting

Release to Reach User Specified Levels, etc.

Y.43	Release is based on reaching (at end of current period) **level** (Y) specified (example: 122.43 draws reservoir to level 1.22)
Y.44[4]	Release is based on reaching (at end of current period) **storage** (Y) specified (example: 10000.44 draws reservoir to storage 10,000 AF)
Y.45[4]	Release is based on reaching (at end of current period) **elevation** (Y) specified (example: 12201.45 draws reservoir to elevation 1220.1)

Release to Reach Fixed Storage Zones

.23	Release for top **flood** control pool
.26	Release for top **conservation** pool
.29	Release for top **buffer** pool
.30	Release for **Level 1** pool

Release to Meet Requirements

.35	Release based on reservoir low flow - **required** Q
.34	Release based on reservoir low flow - **desired** Q
.37	Release based on **downstream** low flow requirement
.31	Release based on at-site **firm energy** demand
.32	Release based on allocated **system power** energy

Release For Balancing Tandem Reservoirs

.33	Release based on **balancing** with equivalent level of downstream reservoir
Y.50	Release of this upstream tandem reservoir is set to minimum release if (1) the immediate downstream tandem reservoir (first reservoir for which this reservoir operates) is rising (during previous two periods) and (2) the release from the downstream tandem reservoir (for the previous period) is less than Y, unless emergency releases override.

---

[3] Codes .22 to .50 are applicable to QA Records only. If criteria specified by codes is not applicable or results in negative releases, program determined releases are made. Positive releases specified by criteria will always be made except where those releases exceed outlet capacity or discharge to reach level 1.

[4] Use of Abbreviated Time Series Format provides the ability to store large values using CONST = code and MULT with IREP = -999 (See description for Abbreviated Time Series Format, Section 12 before IN Record description).

G.12.3 NQ Record - Base Condition Flows (optional)

Base condition flows (normally **natural flows** but can be flows for an existing system). Natural flows will be computed and printed when these records are omitted and when FLONAT (J3.4) = -1.

Field	Variable	Value	Description
	First *NQ Record in a Time Series Sequence*		
1	LOC	+	Location identification number (CP Record, field 1).
2			Not used.
3	CNSTIN	0	Flow values on NQ Records will not be adjusted.
		+	Multiplier to adjust flow values for this location (LOC).
4-10			Not used.
	Second *and* ***Subsequent*** *NQ Records in a Time Series Sequence*		
1-10	QPREP(I,M)	+	Base condition flows in m^3/s (ft^3/s) used for printout purposes and for expected annual damage base flows. Provide NPER (BF.2) values.

G.12.4 MR Record - Minimum Desired Flows (optional)

Field	Variable	Value	Description
	First *MR Record in a Time Series Sequence*		
1	LOC	+	Location identification number (CP Record, field 1).
2			Not used.
3	CNSTIN	0	Flow values on MR Records will not be adjusted.
		+	Multiplier to adjust flow values for this location (LOC).
4-10			Not used.
	Second *and* ***Subsequent*** *MR Records in a Time Series Sequence*		
1-10	QMIN(I,M)	+	**Minimum desired flows** ("or" minimum **required** flows if CP.4 is **negative**) in m^3/s (ft^3/s) for control point LOC. Required flows will be operated for when reservoir is "below" Top of Buffer pool, LEVBUF(J1.6). Provide NPER (BF.2) values.

G.12.5 QD Record - Diversion Flows (optional)[1]

Field	Variable	Value	Description
	First *QD Record in a Time Series Sequence*		
1	LOC	+	Location identification number (CP Record, field 1).
2			Not used.
3	CNSTIN	0	Flow values on QD Records will not be adjusted.
		+	Multiplier to adjust flow values for this location (LOC).
4-10			Not used.
	Second *and* ***Subsequent*** *QD Records in a Time Series Sequence*		
1-10	DQ(I,M)	0,+,-	Diversion flows in m^3/s (ft^3/s). Provide NPER (BF.2) values.

[1] DR.7 must = -5 for location LOC in order to read this QD Record.

G.12.6 EL Record - Stages (optional)

Stages for **non-reservoir** location. These data can be used in the operation and displayed only if ILOCAL (J3.6) = 1.

Field	Variable	Value	Description
	First *EL Record in a Time Series Sequence*		
1	LOC	+	Location identification number (CP Record, field 1).
2			Not used.
	Second *and* ***Subsequent*** *EL Records in a Time Series Sequence*		
1-10	ELEV(I,M)	+	Stages in meters (feet). Only positive stages can be used. Provide NPER (BF.2) values.

G.12.7 EV Record - Evaporation Rates (optional)

Evaporation rates for **reservoir** location. Each rate will be multiplied by EVRTO (R2.3), if EVRTO is greater than zero.

Field	Variable	Value	Description
	First *EV Record in a Time Series Sequence*		
1	LOC	+	Reservoir identification number (RL Record, field 1).
2			Not used.
3	CNSTIN	0	Evaporation rates on EV Records will not be adjusted.
		+	Multiplier to adjust EV evaporation rates for this reservoir.
4-10			Not used.
	Second *and* ***Subsequent*** *EV Records in a Time Series Sequence*		
1-10	EVRATM(I,M)	0,+,-	Net evaporation (total evaporation minus precipitation) rate in millimeters (inches) over the reservoir area for each period. Provide NPER (BF.2) values.

G.12.8 PV Record - Hydropower Energy Requirements (optional)

Field	Variable	Value	Description
	First *PV Record in a Time Series Sequence*		
1	LOC	+	Reservoir identification number (RL.1 and P1.1).
2			Not used.
3	CNSTIN	0	Energy values on PV Records will not be adjusted.
		+	Multiplier to adjust PV energy values for this reservoir.
4-10			Not used.
	Second *and* ***Subsequent*** *PV Records in a Time Series Sequence*		
1-10	POWR(I,M)	+	At-site **energy requirements** in thousands kWh. These values will override any values on PR, PD, or PH Records for this reservoir. Provide NPER (BF.2) values.

G.12.9 CC Record - Specified Operational Channel Capacities (or Stages) (optional)

Specified non-damaging operational channel capacities. Non-zero values of channel capacity for any given time period will override the values of channel capacity that are based on the constant channel capacity (CP.2) or the seasonal CC Records (before the ED Record) for the same location. Special codes .01, .02, Y.03, Y.04, Y.10 and Y.20 can be used for the CC Records (as well as the ST and QA Records) as explained in the QA Record description. These codes allow an easy way to repeat, increase, decrease or interpolate values on these records. Provide NPER (BF.2) values.

Field	Variable	Value	Description
	First *CC Record in a Time Series Sequence*		
1	LOC	+	Location identification number (CP Record, field 1).
2-3			Not used.
4	FLAGFT	0	CC values are in flow units (m^3/s or ft^3/s).
		10	CC values are in **stage** units (meters or feet). Stage values will be converted to flows using this control point's QS and EL Records.
5-10			Not used.
	Second *and* ***Subsequent***		*CC Records in a Time Series Sequence*
3+	CHCAP	0	Channel capacity for current time period will be the value previously defined by data records prior to ED Record (unless a negative code (repeat previous value) occurs for a previous time period).
		+	The CHCAP value, m^3/s (ft^3/s), will be used for location LOC for current time period **only**.
		"and/or"	
		+	Special codes (.01, .02, Y.03, Y.04, Y.10, Y.20) for current period **only**.

G.12.10 ST Record - Specified Reservoir Target Storages (optional)

Specified reservoir target storages which override RL Record storage values for Top of Conservation pool (for level LEVCON, J1.4) (bottom of the flood control space). Special codes .01, .02, Y.03, Y.04, Y.10 and Y.20 can be used for the ST Records (as well as CC and QA Records) as explained in the QA Record description. These codes allow an easy way to repeat, increase, decrease or interpolate values on these records. Provide NPER (BF.2) values.

Field	Variable	Value	Description
	First *ST Record in a Time Series Sequence*		
1	LOC	+	Reservoir identification number (RL Record, field 1).
2-10			Not used.
	Second *and* ***Subsequent*** *ST Records in a Time Series Sequence*		
1-10	STCON	+	Storage for reservoir LOC for current time period **only** for level LEVCON, in 1000 m^3 (acre-feet).
		"and/or"	
		+	Special codes (.01, .02, Y.03, Y.04, Y.10, Y.20) for current period **only**.

G.13 End of Time Series Data

G.13.1 EJ Record - End of Time Series Data (required)

Record read after last record for each time series data set (defined as data between BF and **EJ** Records).

Field	Variable	Value	Description
1-10			Not used.

G.13.2 Start New Time Series or Job, or End All Data

Enter next set of flow data (records BF - EJ); **or** begin next job (T1-EJ) with T1 record, **or** use **ER** Record after last job.[1]

G.13.3 ER Record - End of All Data (Run) (required)

Record read to terminate the run after last time series of last job is read. Program will end with an ER Record.

Field	Variable	Value	Description
1-10			Not used.

[1] Up to 80 events (BF - EJ) may be read, and an unlimited number of jobs (T1 - EJ) may be used unless FC or SS Records are used. When FC and SS Records are used, a maximum of 25 jobs may be read.

Sequence of HEC-5 Input Records

OPERATIONAL AND PHYSICAL RECORDS

Record Description	Record	Page G-
Documentation	T1 - T3	3
Job Control	J1 - J8	4-21
	JZ	22
	JR	23
System Power	SM	24
	SD	25
	SH	25
	SC	26
	SF	26
Reservoirs	RL	32-33
	RO	34
	RS	35
	QQ	35
	RQ	36
	RA	37
	RE	37
	RD	38
	R$	39
	R1 - R3	39-42
	RG	43
Power Reservoirs	P1	45
	P2	47
	PC	48
	PF	48
	PB	49
	PR	49
	PD	50
	PH	51
	PQ	52
	PT	52
	PL	52
	PP	53
	PS	53
	PE	54
Control Points	CP	55
	ID	57
	C1	58
	C2	59
	RT	60
	CR	62
	WR	62
	DR	63
	QS	65
	SQ	65
	QD	66
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	CG	73
	QM	77
	WA	78
	DA - DC	80-83
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TIME SERIES RECORDS

Record Description	Record	Page G-
Time Series Specs.	BF	88
	FC	90
Starting Storage (Res.)	SS	90
Read "from" HEC-DSS	ZR	91
Write "to" HEC-DSS	ZW	92
Time Series Data	IN	95
	QA	96
	NQ	98
	MR	98
	QD	99
	EL	100
	EV	100
	PV	101
	CC	102
	ST	103
End of Time Series	EJ	104
End of All Data	ER	104