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14. ABSTRACT

A generalized computer program for evaluating the conservation accomplishments of an extremely complex water resources system developed in the Hydrologic engineering Center of the Corps of Engineers, US Army was described. The program, "Reservoir Systems Analysis-Conservation", has been used in preliminary studies to evaluate the functional (hydrologic) accomplishments of large water resource systems in the Susquehanna and Willamette River Basins and of several smaller systems. This elaborate computer program insulated the operation of a water resources system for many conservation functions such as water supply, power generation and low-flood regulation, recognizing the important constraints imposed by flood control requirements. It simulated the operation usually on a month-by-month basis with provision for operation by regular or irregular intervals. The manner in which the water resources system was described to the computer was illustrated by use of an example for the Willamette River Basin study which considered twenty-seven control points, thirteen diversion, and fourteen reservoirs with five power plants. The program was designed for simplicity of use and costs per operation study with a high-speed computer are nominal.

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FUNCTIONAL EVALUATION OF A WATER RESOURCES SYSTEM(1)

Leo R. Beard(2)

INTRODUCTION

The high degree of development of intra-basin and inter-basin water resources systems that is occurring in many locations throughout the world requires complicated and detailed analyses for evaluation of system performance. The manner of analysis and types of detail that are important differ in different cases, depending on the nature of runoff, water requirements, and other factors.

There are virtually no water resource systems that have been developed on a completely coordinated basis. There are usually many projects that must be operated independently or in independent subsystems. Accordingly, any analysis must recognize the effects of these components on system accomplishments without changing their operation to suit system requirements, when beneficial changes are not technically or legally feasible.

While the amount of runoff during a critical drought period is of primary importance in determining the capability of any water resources system, the annual sequence of runoff and seasonal timing in relation to requirements can be of critical importance. This is especially true

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where hydroelectric power generation, recreation use or evaporation is important or in systems where critical periods for the various purposes may be interdependent but not coincident. For this reason, a detailed simulation of system operation, requiring large amounts of computation, is usually the only sure method of evaluating system accomplishments. Runoff values used for such a simulation study ordinarily consist of past runoff modified for future non-project effects, but can also consist of synthetic runoff values representing a broader sampling of potential runoff.

Heretofore, capability has not existed for analyzing a large water resources system operation in detail, except for highly specialized computer programs for specific systems limited to a few reservoirs. A generalized computer program for evaluating the conservation accomplishments of extremely complex water resources system has been developed in the Hydrologic Engineering Center of the Corps of Engineers, U.S. Army. This program, "Reservoir System Analysis - Conservation", has been used in preliminary studies to evaluate the functional (hydrologic) accomplishments of large water resource systems in the Susquehanna and Willamette River Basins and of several smaller systems. The Susquehanna River Basin study will eventually involve consideration of as many as 100 reservoirs. The many features of this program and examples of some study results are described in this paper.

PURPOSE AND SCOPE

This paper is essentially a description of an elaborate computer program which simulates the operation of a water resources system for the many conservation functions such as water supply, power generation and low-flow regulation, recognizing the important constraints imposed by flood control requirements. A computer program to evaluate the flood control operation is in preparation, but will not be described in this paper. The functional evaluation includes the determination of actual water and power deliveries and shortages, but does not include any economic or social evaluation thereof. The seasonal and annual variation of the various system requirements and controlling factors, sometimes conflicting and sometimes complementary, are accounted for in detail.

Items such as evaporation and hydroelectric power generation are evaluated on the basis of reservoir areas and hydraulic heads that exist at any specific time, thus minimizing the amount of detail required for input by the program user. Recognizing the importance of evaporation in some areas and not in others, and the changing relative importance of many other factors for different regions, the program has been designed to accept input data in great detail when this is important to system evaluation, but as simple generalized values when the associated functions are trivial.

GENERAL PROCEDURE

The computer program described herein essentially simulates the operation of a complex water resources system, usually on a month-by-month basis, but with provision for operation by any regular or irregular intervals. The intervals selected should be long enough that time translations are of negligible effect, because it is assumed that all water released at one location is available at the next during the same period.

In addition to specifying the system configuration and details relative to component capacities, etc., it is necessary to prescribe certain operational rules and priorities and to provide inflow and evaporation data. The computer program will then search through the system in the upstream to downstream direction, determining each system requirement in turn and the amount of that requirement to be satisfied by each reservoir. Inasmuch as evaporation and power generation cannot be estimated satisfactorily until all project releases for each period are known, and since project releases are not known even approximately until the entire system is searched, it is necessary to make at least two searches of the system for each period. In the event that there is a system power requirement in excess of the total individual requirements at all power plants, the distribution of system power among the plants is determined from the first system search and computed approximately in the second system search. It is necessary to make a third search of the system in order to get an accurate computation of the system power generation, using the changed reservoir stages. When it is realized that an enormous amount of computation is required for evaluating release requirements for all purposes, determining availability and location of water, balancing reservoir storages, computing power heads and reservoir areas for evaporation, etc., etc., and that all of these computations must be repeated once or twice during each period of operation, it should be obvious that use of the program on any water resources system of appreciable complexity would require large computer memory and very high computer speeds.

SYSTEM SPECIFICATION

The manner in which the water resources system is described to the computer will be illustrated by use of an example for the Willamette River Basin study, which considers 27 control points, including 13 diversions and 14 reservoirs with 5 power plants. A schematic diagram of this system is shown in Figure 1. The control point is a point where any structure or water requirement exists. It is not necessary that the control points be numbered in any particular sequence, but the control point numbers are used as subscripts, and must therefore be integers equal to or smaller than the maximum number specified in the computer program (presently 51). System specification data are illustrated in Table 1.

At any control point, a reservoir or diversion or both can exist, and minimum required and maximum permissible flows can be specified. If desirable, a primary flow requirement at any control point less than the total flow requirement at that control point can be specified so that this flow will be maintained in preference to other flows after upstream reservoirs have reached a certain low storage level. At any control point where a reservoir is specified, a power plant can also exist, along with minimum power requirements. It is possible to specify the afterbay elevation of one reservoir as the forebay elevation of another reservoir downstream.

For each control point, it is necessary to specify the number and identity of all reservoirs at or above (upstream of) that control point, attaching a minus sign to numbers of those reservoirs not operated specifically for the control point. It is also necessary to specify the number and identity of diversions at or above that control point but not above upstream reservoirs, and the number and identity of all reservoirs immediately upstream of that control point (not above other reservoirs upstream of that control point). Control point specification is illustrated in Table 2.

The program performs an operation study for a year at a time, and consequently all inflows and requirements must be specified for a full year. However, only those requirements that would vary from year to year need be re-specified for each year of the operation study. Both inflows and requirements can be given in any desired units of flow or volume, and these will be converted to equivalent flows in cfs for computation and print-out purposes. Desired diversion quantities are specified as positive values if they are diversions out of the stream and negative quantities if they are return flows or imports. A return flow may be specified as a ratio of a diversion that has been previously computed for that period. Diversions receive top priority at each control point unless a minor change in the program is made.

Reservoirs must be numbered the same as the control points at which they are located. For each reservoir, tables of elevation, area, storage capacity, and outlet capacity are required. If hydroelectric power efficiency is to be considered as a function of reservoir head, then a table of efficiency must also be included. While the same basic evaporation pattern for any year is used for all reservoirs, any ratio of the pattern amounts may be specified for each reservoir.

In order to determine the relative priority with which the various reservoirs are called upon to serve common downstream requirements, a system of balancing zones in all reservoirs must be specified. Such a system is illustrated in Figure 2. The top zone (between the top 2 levels) is the flood control space, and water within this space will be evacuated as rapidly as possible without exceeding downstream capacities. No water will be stored above the top reservoir level. The bottom level is that level below which no water will be released, and consequently only evaporation can draw the reservoir below that level. The second level is the level below which only priority services will be satisfied. The zone between the bottom 2 levels will be called the buffer zone. All levels intermediate between the buffer zone and the flood control space are used to determine the relative priority of releases from the various reservoirs. To the extent that required releases permit, all water will be released from each zone at all reservoirs before water from the next lower zone at any reservoir is released.

Examination of Figure 2 will demonstrate the use of reservoir levels to determine reservoir release selection for purposes that can be served by more than one reservoir. In this example, 7 reservoir levels are used, 3 of which are solely for the purpose of establishing priorities among reservoirs for conservation releases. Reservoir 1 has no flood control storage (between level 6 and 7), but is drawn down first (levels 6 to 5) for conservation purposes. Reservoir 2 has a flood control space equivalent to 20% of the reservoir capacity and is drawn down (levels 5 to 4) for conservation after reservoir 1 and before all other reservoirs, except that 20% of the storage space is reserved for priority releases only. Further examination of Figure 2 will reveal the complete picture of reservoir priorities for serving downstream requirements. It should be emphasized that some purposes can be served only by certain reservoirs, and that this can cause the reservoir system to be out of balance at times.

Power plants must be numbered the same as the control points at which they are located. In addition to specifying the power requirement for each period in thousand kilowatt hours or as a plant factor, the plant capacity and the sum of tailwater elevation and hydraulic head losses must be specified. Plant efficiency can be specified as uniform for all plants and all heads, or as a function of head at each plant. Also, it is necessary to indicate whether releases from the buffer storage will be made to satisfy power requirements.

Table 3 illustrates the specification of project features and reservoir balancing levels.

SYSTEM INPUTS

Streamflows to be supplied as input for operation study purposes may be in any units of flow or volume for each period of each year, and streamgage locations need not correspond to control point locations. For each control point, it is necessary to identify the streamflow stations and corresponding ratios used for computing inflow from the local area above the control point and below all upstream reservoirs, unless such local inflow equals the inflows provided for a station that is numbered identically to the control point number. Inflows provided can be observed historical flows modified as necessary for future conditions, or synthetic streamflows that might prevail under future conditions. In addition to providing inflows and system operation requirement data, it is necessary to specify the initial storage at each reservoir in the system. All of these quantities are provided in accordance with a special simplified format for which detailed instructions are available.

COMPUTATION SEQUENCE

After the system specification and requirements that are common to all years of the study are read into the computer, the inflows and requirements that vary from year to year are read, one year at a time. The computer then computes system status, one period (usually a month) at a time. Units of runoff and requirements are first converted to cfs, accounting for differences in length of periods, and then local inflows for each control point are computed and stored. If certain requirements are to be reduced at times of low storage at specified reservoirs, these shortage declarations are next computed. Then the operation of the system is computed in an upstream to downstream sequence.

Wherever diversions exist without reservoir regulation at that point or upstream, all available water is supplied to the diversion up to diversion requirements, and the remaining water is available for downstream use.

For all control points with reservoirs at or above their location, the contribution that each reservoir would provide from local inflow (above the reservoir and below all upstream reservoirs) minus diversions in the local area and evaporation, is computed for end-of-period storage at each balancing level. Some of these quantities may be negative if the reservoir is low at the start of the period. Then the total contribution from all reservoirs at or above the control point corresponding to simultaneous ending storages at each level is computed.

The required flows at the control point for all purposes are then computed along with reservoir evaporation. Then the level to which all reservoirs must be drawn in order to meet the largest requirement is established and consequent releases from each reservoir are computed. For each upstream reservoir, the portion of this release that does not conflict with outlet and channel capacities is tentatively adopted, and the level to which each reservoir would thus be drawn is established as a maximum constraint. The minimum level to which each reservoir can be drawn without exceeding channel capacities is also established as a minimum constraint, overriding the maximum constraint where there is a conflict. These constrains are re-established as necessary at all upstream reservoirs as each control point in the system is considered.

In determining releases to satisfy requirements at control points where reservoirs do not exist, some contingency allowances can be made to allow for the fact that local unregulated runoff cannot always be utilized effectively. A contingency allowance can also be made for flood control releases to allow for the fact that unregulated runoff cannot be forecasted accurately.

During the first search of the system in each period, average area and head for the period at all reservoirs are assumed to equal the values at the start of the period. If evaporation is an important item or if power generation is involved, a second search of the system is made, and average area and head used in the second search is the average of the beginning and ending values obtained in the first search. It has been demonstrated that two searches are adequate unless system power is included, in which case a third search is necessary.

At the end of each year of the study, sums and averages of pertinent quantities are computed for each year and for all the years to date, and these are printed along with operation values for each period. All pertinent information is also written on binary tape for future use. Most of the print-out can be suppressed, if desired.

SYSTEM POWER OPERATION

Where a variety of requirements is imposed upon a system of reservoirs, it is almost impossible to predict the consequences of various combinations of these requirements as they might develop throughout the long period of operation. Accordingly, the more latitude permitted for providing services from different reservoirs, the more opportunity there is to satisfy needs during critical periods. Where many power plants are included in one system, it is often desirable to specify requirements for the system as a whole as well as minimum requirements for each plant. When system requirements are specified, it is also necessary to specify, for each plant, the maximum generation usable in meeting system requirements. The maximum is usually specified as a plant factor.

During the first search of the system, the minimum power requirement at each plant will be established, and the total generation during the period at each plant will be computed. This total can exceed the minimum required generation if other services call for additional releases from the particular reservoir.

At the end of the first search, a summary is made of the total power generated and required and of the total power generated and usable to satisfy system requirements. If the system requirement has not been satisfied, water levels at those reservoirs where additional generated power could be usable for meeting system requirements would then be drawn toward a common level such that the full system requirement is generated. The allocated system requirements are then used in making a second search of the entire system for all purposes.

Since satisfying these additional requirements will usually change releases at many reservoirs, the average head during the second search will be different from the average obtained from the first search and used in the second search. Accordingly, accurate system power computations require a third complete search of the entire water resources system for each operation period.

EVALUATION OF SYSTEM PERFORMANCE

After the computations for each year of operation, the entire system status for each period is printed out, along with pertinent input and requirement data. This is illustrated in Tables 4 and 5. Wherever a requirement is not fully satisfied, the amount of shortage is tabulated. These shortages are averaged for each and all years, as are other pertinent results. In addition, the total annual shortages expressed as a ratio to the annual requirements for each purpose at each control point are used to compute a shortage index. This is the sum of the squares of the annual shortage ratios converted to a 100-year base period. Inasmuch as the economic cost of a shortage has been observed to be approximately proportional to the square of the annual shortage, this index can be used readily as an economic cost factor. Complete appraisal of the system performance from a functional standpoint would include examination of minimum storages at all reservoirs, as well as shortage values and indices and other pertinent results.

At the present stage of development, the computer program simply analyzes the result of operation under specified conditions during a specified time. The results would ordinarily be used to change certain system components in an effort to improve performance or reduce costs. Hence, a large number of computations would ordinarily be made for the same reservoir system study. It is hoped that an iteration routine can eventually be incorporated in the program to modify certain system components automatically in order to improve system performance.

EXAMPLE OF SYSTEM EVALUATION

One of the studies for which the generalized computer program has been used is in conjunction with a basin planning study of Willamette River and tributaries, Oregon. The basic system considered consists of 8 existing reservoirs, 3 reservoirs under construction, and 3 authorized reservoirs. Initial operation criteria are those developed in earlier hand-computation studies. A complete print-out of system status for each month of 30 years was obtained on the basis of these operating criteria. In addition, certain summary information was obtained, notably 30-year averages and shortage indexes for services at each location. Certain very general averages of these shortage indexes are shown under Plan 1 in Table 6.

Although the official study of basin development will be conducted in the next few years, certain preliminary indications of what might be considered are illustrated under Plans 2 to 4 in Table 6. These are not actual plans being considered officially. Plan 2 was run simply to determine the effect of shortage declaration, and Plans 3 and 4 contain modified shortage declaration criteria based on the results of the Plan 2 study. Plans 1 to 3 incorporate power requirements for each individual plant, whereas Plan 4 has zero power requirement for each plant but a system requirement equal to the total plant requirement for each of the other three plans. All plans are identical in other respects.

Generalized results shown in Table 6 are not adequate for a reasonable economic evaluation, but are shown to illustrate the principle involved in developing a plan. On the basis of these figures, Plan 2 would gain benefits in irrigation diversions but lose in power generation in comparison with Plan 1. The economic value of these gains and losses would be different functions of shortage index for different services, and it could well be that the apparent small change in power shortage represents more value than the apparent large change in diversion shortage. Plan 3 appears to be a definite improvement over Plan 1, as there is considerable improvement in irrigation diversion and little loss in power generation. Plan 4 represents a definite improvement in power and irrigation over Plan 1 and little change in other services. Although it is difficult to estimate dollar benefits on the basis of values shown in Table 6, the differences shown could well represent benefit differences as large as $1,000,000 per year or more. Of course, a detailed evaluation of each plan studied should be made by computer, using detailed data contained on the magnetic tape, because these generalized figures can be misleading to some extent.

COMPUTER UTILIZATION

As previously indicated, a program of the magnitude described herein should be used on a computer of large memory and high speed. All of the tests to date have been made on the CDC 6600 computer, which has a memory capacity of 130,000 words and an extremely high speed. The computer is capable of performing a system operation study for the Willamette River Basin example as illustrated in Figure 1 at the rate of 15 years of operation per minute of computer time.

FUTURE DEVELOPMENT

In addition to eventually incorporating a routine by which system components can be automatically modified to improve performance, as discussed above, implementation of a flood control operation program in conjunction with this conservation operation program is highly desirable. At the present time, it is anticipated that flood control evaluations will be made by a separate program, using system status at the start of flood months obtained from this conservation operation program.

One of the more urgent needs in relation to this program is the incorporation of water quality requirements in terms of concentrations rather than flows which must be specified as the program now exists. In addition to the fact that permissible concentrations of various water quality factors will provide a more realistic evaluation of system operation for quality control generally, there are some cases where quality factors such as acidity can be controlled simply by mixing flows of different qualities from different reservoirs without greatly increasing flows for dilution purposes. Such problems could only be solved adequately by a water quality operation based on concentrations.

CONCLUSIONS

The high degree of water resources development contemplated in many areas of the world demonstrates a need for a generalized computer program that will satisfactorily analyze the detailed functional operation of a large water resources system. The computer program described in this paper developed in the Hydrologic Engineering Center of the Corps of Engineers, represents a moderately successful attempt at a highly detailed analysis of the sequential operation of a complex water resources system consisting of any number of reservoirs, diversions and power plants. The system need not be confined to a single river basin, and the diversions can represent exports, imports, or ordinary diversions and return flows within a basin. The program provides a means of obtaining releases and power generation each period from reservoirs that are in the best position to make releases. Use of the program in a high-speed computer is practical for large complex systems where a nominal number of trials is satisfactory. The program has been designed for simplicity of use, although there is a minimum degree of complexity associated with any water resources study. Costs per operation study in a high-speed computer are nominal, but optimization routines that might require thousands of iterations of complete studies would probably be impractical at present, except for very small systems.

ACKNOWLEDGMENT

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office of the U. S. Bureau of Reclamation. Valuable suggestions were obtained from these offices and from the North Pacific Division of the Corps of Engineers and the Federal Water Pollution Control Administration. Although many individuals contributed, Mr. Harry E. Schwarz of the North Atlantic Division, Corps of Engineers, was instrumental in initiating the study and contributed many valuable suggestions.

Table 1

SYSTEM SPECIFICATION

```
                          WILLAMETTE RIVER BASIN,OREGON
                        RESERVOIR SYSTEM OPERATION STUDY
                                    OCT 1966

NYRS IYR NPER IPER NRES NCPT NDIV  NL  NPWR NFLOW  NSHR  NSHQ NSHDV NSPER ISPER NCYCL NPWRS  NLYR NDVYR  NQYR
 30 1926  12    1   14   28   13    5    5   27    12     1    10     4     6    -0     1    -0    -0    -0
SHORTAGE RESERVOIRS   13   14   10   11   12   15   16   17   20   21   22   23
SHORTAGE LOCATIONS    48
SHORTAGE DIVERSIONS   41   42   43   44   45   48   39   40   49   50
NRESP=  5 PFMAX= 1.000
RESP 1- 5   10   11   15   21   23

CONTROL POINT SEQUENCE                   NFLW    ALOS    CLOS
     10 HILLS CREEK RES                   -0      -0      -0
     11 LOOKOUT POINT RES                  2      -0      -0
        10  -1.000     11   1.000
      9  BELOW LOOKOUT POINT               1      -0      -0
        11    0.
     12 FALL CREEK RES                    -0      -0      -0
     41 MOUTH MIDDLE FORK                  3      -0      -0
        11  -1.000     12  -1.000     41   1.000
     13 COTTAGE GROVE                     -0      -0      -0
     14 DORENA RES                        -0      -0      -0
     42 MOUTH COAST FORK                   3      -0      -0
        13  -1.000     14  -1.000     42   1.000
     43 EUGENE                             5      -0      -0
        11  -1.000     12  -1.000     13  -1.000     14  -1.000     43   1.000
     15 COUGAR RES                        -0      -0      -0
     16 BLUE RIVER RES                    -0      -0      -0
     17 GATE CREEK RES                    -0      -0      -0
     44 MOUTH MCKENZIE                     4      -0      -0
        15  -1.000     16  -1.000     17  -1.000     44   1.000
     45 HARRISBURG                         8      -0      -0
        11  -1.000     12  -1.000     13  -1.000     14  -1.000     15  -1.000     16  -1.000     17  -1.000
        45   1.000
     18 FERN RIDGE RES                    -0      -0      -0
     46 WEST LONG TOM DIV                  2      -0      -0
        18  -1.000     46   1.000
     19 HOLLEY RES AND DIV                -0      -0      -0
     47 MOUTH CALAPOOIA                    2      -0      -0
        19  -1.000     47   1.000
```

Table 2
CONTROL POINT SPECIFICATION

```
CONTROL PT 10  NRES =  1  NDIV = -0  NUPST = -0  QMN =      -1  STDV =     -0  QMAX =    9999  QMN2 =     -0  PR =  -0
  IRESM  10
  QMIN        0    100    100    100    100    100    100    100    100    100    100      0
CONTROL PT 11  NRES =  2  NDIV =  0  NUPST =  1  QMN =      -0  STDV =     -0  QMAX =    9999  QMN2 =     -0  PR =  -0
  IRESM -10  11
  IUPST  10
CONTROL PT  9  NRES =  2  NDIV =  0  NUPST =  1  QMN =      -1  STDV =      0  QMAX =    9999  QMN2 =      0  PR =   0
  IRESM  10  11
  IUPST  11
  QMIN        0   1200   1200   1200   1200   1200   1000   1000   1000   1000   1000      0
CONTROL PT 12  NRES =  1  NDIV = -0  NUPST = -0  QMN =      -1  STDV =     -0  QMAX =    9999  QMN2 =     -1  PR =  -0
  IRESM  12
  QMIN        0     30     30     30     30     30     30     30     30     30     30      0
  QMIN2       0     30     30     30     30     30     30     30     30     30     30      0
CONTROL PT 41  NRES =  3  NDIV =  1  NUPST =  2  QMN =      -1  STDV =     -0  QMAX =    9999  QMN2 =     -1  PR =  -0
  IRESM  10  11  12
  IDIVR  41
  IUPST  11  12
  QMIN        0   1250   1250   1250   1250   1250   1050   1050   1050   1050   1050      0
  QMIN2       0   1250   1250   1250   1250   1250   1050   1050   1050   1050   1050      0
CONTROL PT 13  NRES =  1  NDIV = -0  NUPST = -0  QMN =      -1  STDV =     -0  QMAX =    9999  QMN2 =     -1  PR =  -0
  IRESM  13
  QMIN        0     75     75     75     75     75     50     50     50     50     50      0
  QMIN2       0     75     75     75     75     75     50     50     50     50     50      0
CONTROL PT 14  NRES =  1  NDIV = -0  NUPST = -0  QMN =      -1  STDV =     -0  QMAX =    9999  QMN2 =     -1  PR =  -0
  IRESM  14
  QMIN        0    190    190    190    190    190    100    100    100    100    100      0
  QMIN2       0    190    190    190    190    190    100    100    100    100    100      0
CONTROL PT 42  NRES =  2  NDIV =  1  NUPST =  2  QMN =      -1  STDV =     -0  QMAX =    9999  QMN2 =     -1  PR =  -0
  IRESM  13  14
  IDIVR  42
  IUPST  13  14
  QMIN        0    300    300    300    300    300    175    175    175    175    175      0
  QMIN2       0    300    300    300    300    300    175    175    175    175    175      0
CONTROL PT 43  NRES =  5  NDIV =  3  NUPST =  4  QMN =      -1  STDV =     -0  QMAX =    9999  QMN2 =     -1  PR =  -0
  IRESM  13  14  10  11  12
  IDIVR  42  41  43
  IUPST  13  14  11  12
  QMIN        0   1600   1600   1600   1600   1500   1250   1250   1250   1250   1250      0
  QMIN2       0   1600   1600   1600   1600   1500   1250   1250   1250   1250   1250      0
CONTROL PT 15  NRES =  1  NDIV = -0  NUPST = -0  QMN =      -1  STDV =     -0  QMAX =    9999  QMN2 =     -1  PR =  -0
  IRESM  15
  QMIN        0    300    300    300    300    300    200    200    200    200    200      0
  QMIN2       0    300    300    300    300    300    200    200    200    200    200      0
```

Table 3
PROJECT SPECIFICATION

```
NCAYS                       31      28      31      30      31      30      31      31      30      31      30      31
DIV41                     -3.0    -2.0      0.      0.    11.0    55.0    81.0    68.0     5.0    -7.0    -5.0    -5.0
DIV42                     -5.0    -2.0      0.      0.    16.0    50.0    80.0    70.0    -3.0   -10.0    -8.0    -7.0
DIV43                       0.      0.      0.      0.     1.0     1.0      0.     7.0     6.0     1.0    -2.0     1.0
DIV44                     -5.0    -4.0      0.    89.0   242.0   656.0  1052.0   924.0   160.0   -11.0   -10.0    -8.0
DIV45                    -21.0   -14.0      0.    -8.0    13.0   118.0   183.0   136.0   -17.0   -45.0   -39.0   -28.0
DIV46                     -6.0    -4.0      0.    29.0    70.0   155.0   246.0   208.0    56.0   -11.0   -10.0    -8.0
DIV47                    -29.0   -29.0   -29.0    16.0   149.0   317.0   508.0   397.0   134.0   -51.0   -35.0   -32.0
DIV48                    -79.0   -56.0      0.     6.0    73.0   383.0   551.0   528.0   -36.0  -159.0  -142.0  -107.0
DIV39                     -5.0    -4.0      0.    59.0   108.0   390.0   574.0   466.0   113.0   -11.0   -10.0    -6.0
DIV40                     -1.0      0.      0.   106.0   123.0   654.0   920.0   750.0   190.0    -3.0    -2.0    -2.0
DIV49                    -17.0   -12.0      0.    -7.0   -15.0   -12.0   -12.0   -23.0    36.0   -33.0   -28.0   -21.0
DIV50                    -74.0   -56.0      0.    40.0   147.0   433.0   838.0   647.0   153.0  -198.0  -124.0   -99.0
DIV51                    -59.0   -43.0      0.    22.0    65.0   200.0   500.0   425.0   116.0  -116.0  -101.0   -78.0
POWER PLANT   10  TLWEL=  1225.8  PWRMX=   30000
POWER PLANT   11  TLWEL=   691.0  PWRMX=  120000
POWER PLANT   15  TLWEL=  1254.2  PWRMX=   25000
POWER PLANT   21  TLWEL=   699.5  PWRMX=   80000
POWER PLANT   23  TLWEL=  1201.0  PWRMX=  100000

RESERVOIR 10   INITIAL STOR =    156000  CEVAP = 1.000  STORAGES
                   1         2         3         4         5         6         7         8         9        10        11        12
LEVEL   5     356000    356000    356000    356000    356000    356000    356000    356000    356000    356000    356000    356000
LEVEL   4     156000    250000    290000    330000    350600    350600    350600    350600    295000    238000    156000    156000
LEVEL   3     156000    250000    290000    330000    350600    350600    350600    350600    295000    238000    156000    156000
LEVEL   2     107000    107000    107000    107000    107000    107000    107000    107000    107000    107000    107000    107000
LEVEL   1     107000    107000    107000    107000    107000    107000    107000    107000    107000    107000    107000    107000
ELEV         1373.00   1414.00   1448.00   1464.00   1474.00   1495.00   1517.00   1535.00   1548.00   1560.00
STOR           50000    107000    156000    181000    200000    241000    293000    338000    372000    417000
AREA          1020.0    1320.0    1570.0    1730.0    1850.0    2110.0    2400.0    2640.0    2800.0    2930.0
QCAP            9000      9000      9000      9000      9000      9000      9000      9000      9000      9000

RESERVOIR 11   INITIAL STOR =    106600  CEVAP = 1.000  STORAGES
                   1         2         3         4         5         6         7         8         9        10        11        12
LEVEL   5     456000    456000    456000    456000    456000    456000    455000    456000    456000    456000    456000    456000
LEVEL   4     118800    265000    340000    420000    443100    443100    443100    443100    345000    245000    118800    118800
LEVEL   3     118800    265000    340000    420000    443100    443100    443100    443100    345000    245000    118800    118800
LEVEL   2     106600    106600    106600    106600    105500    105500    105600    106600    106600    105600    106600    106600
LEVEL   1     106600    106600    106600    106600    106600    106600    105600    106600    106600    105600    106600    106600
ELEV          765.00    819.00    834.00    857.00    878.00    895.00    920.00    934.00    943.00       -0.
STOR           50000    106500    138000    200000    262000    325000    417000    479000    520000        -0
AREA          1450.0    2000.0    2260.0    2860.0    3300.0    3700.0    4140.0    4500.0    4830.0       -0.
QCAP           15000     15000     15000     15000     15000     15000     15000     15000     15000        -0
```

Table 4
OPERATION RESULTS

```
                           ALL FLOWS IN CFS, STORAGES AND EVAP IN AC-FT AND POWER IN THOUSAND KWH

 10   HILLS CREEK RES                    SERVED BY  10
                                       SERVING     10   9  41  43  45  48  50  51

YR 1926       AVG     YEAR        1        2        3        4        5        6        7        8        9       10       11       12
LOC FLW       852      852     1150     2300     1000      745      630      340      235      234      270      365     1440     1635
UNREG         852      852     1150     2300     1000      745      630      340      235      234      270      365     1440     1635
INFLOW        852      852     1150     2300     1000      745      630      340      235      234      270      365     1440     1635

EOP STR (CAP =  356000)      156000   250000   260297   253921   257495   244384   226314   177656   148147   120113   156000   156000
EOP EL                      1448.00  1493.81  1503.16  1500.47  1501.98  1495.43  1487.48  1461.86  1442.55  1423.10  1448.00  1448.00
EVAPO        4624     4624        0        0        0      717      639      906     1099      725      326      211        0        0
REG PWR         0        0       -0       -0       -0       -0       -0       -0       -0       -0       -0       -0       -0       -0
POWER      130136   130136    13838     7421    12414    12158     8375     7811     7370    13678     9032     9165     9200    19675
SHORTGE         0        0        0        0        0        0        0        0        0        0        0        0        0        0
CASE                           1003     1003     1002     1002      901      901     5001     5001     5001     4801     1003     1003
LEVEL                          3.00     3.00     2.84     2.66     2.62     2.56     2.49     2.29     2.22     2.10     3.00     3.00

CSV FLW       510      510        0      100      833      840      561      545      511     1014      760      817      100        0
RIV FLW       846      846     1150      607      833      840      561      545      511     1014      760      817      837     1635
DES FLW        83       83        0      100      100      100      100      100      100      100      100      100      100        0
SHORTGE         0        0        0        0        0        0        0        0        0        0        0        0        0        0


 40   MEHAMA DIV                         SERVED BY  23

YR 1926       AVG     YEAR        1        2        3        4        5        6        7        8        9       10       11       12
LOC FLW      1017     1017     1200     3330     1160      550      430      191      103      113      210      740     2480     1900
UNREG        2769     2769     2960     8300     3060     1860     1750      991      643      678     1130     1830     6010     4520
DIVERSN     191.0    191.0     -1.0       0.       0.    105.0    123.0    534.2    751.5    612.6    155.2     -3.0     -2.0     -2.0
SHORTGE      38.7     38.7       0.       0.       0.       0.       0.    119.8    168.5    137.4     34.8       0.       0.       0.
INFLOW       2762     2762     2960     5977     2520     1891     1430     1734     1700     1668     1265     1490     6303     4520

CSV FLW       870      870        0     1200     1200     1200     1200     1200      900      900      900      900      900        0
RIV FLW      2571     2571     2961     5977     2520     1785     1307     1200      948     1056     1109     1493     6305     4522
DES FLW       870      870        0     1200     1200     1200     1200     1200      900      900      900      900      900        0
SHORTGE         0        0        0        0        0        0        0        0        0        0        0        0        0        0
```

Table 5
SYSTEM POWER SUMMARY

```
                                   SYSTEM 1 POWER SUMMARY

YR 1926       AVG    YEAR       1       2       3       4       5       6       7       8       9      10      11      12
10   HILLS CREEK RES
REQ PWR     34956   34956       0       0   12414   12158       0       0       0   10385       0       0       0       0
11   LOOKOUT POINT RES
REQ PWR     59316   59316       0       0   19075   18973       0       0       0   21268       0       0       0       0
15   COUGAR RES
REQ PWR     30157   30157       0       0    8917    8550       0       0       0   12690       0       0       0       0
21   GREEN PETER RES
REQ PWR     39455   39455       0       0   13136   12030       0       0       0   14290       0       0       0       0
23   DETROIT RES
REQ PWR     64315   64315       0       0   23358   22591       0       0       0   13257       0       0       0       0
SYSTEM TOTAL
REQ PWR    228200  228200      -0      -0   76900   74400      -0      -0      -0   75900      -0      -0      -0      -0
POWER      228200  228200      -0      -0   76900   74400      -0      -0      -0   76900      -0      -0      -0      -0
SHORTGE         0       0       0       0       0       0       0       0       0       0       0       0       0       0
```

TABLE 6

SUMMARY OF DEFICIENCIES UNDER FOUR SYSTEM DESIGNS

Average Shortage Index

	Plan 1	Plan 2	Plan 3	Plan 4
13 Diversions	2.85	.00	1.13	1.10
5 Power Plants	.19	.38	.22	.10
27 Low Flows	.02	.08	.02	.02
1 Low Flow	.22	.18	.22	.23

Plans:

1. Shortage declaration proportional to 1 June deficiency in total system storage below system capacity (2,402,000 ac-ft).
2. No shortage declaration.
3. Shortage declaration proportional to 1 June deficiency in total system storage below 2,100,000 ac-ft. Special reserves for upstream services.
4. Same as Plan 3 but with system power operation.

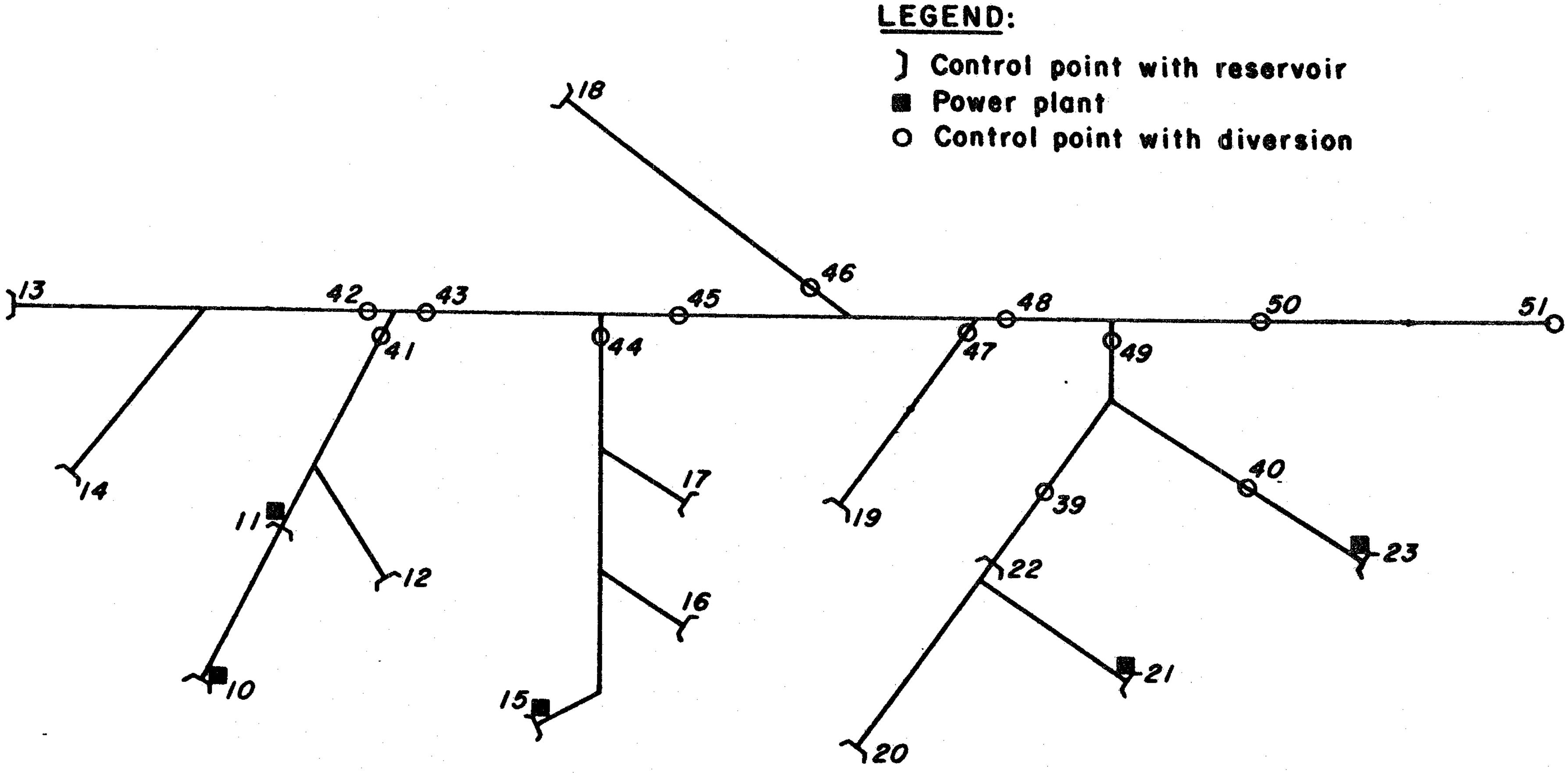

Figure 1
WATER RESOURCES SYSTEM
SCHEMATIC DIAGRAM

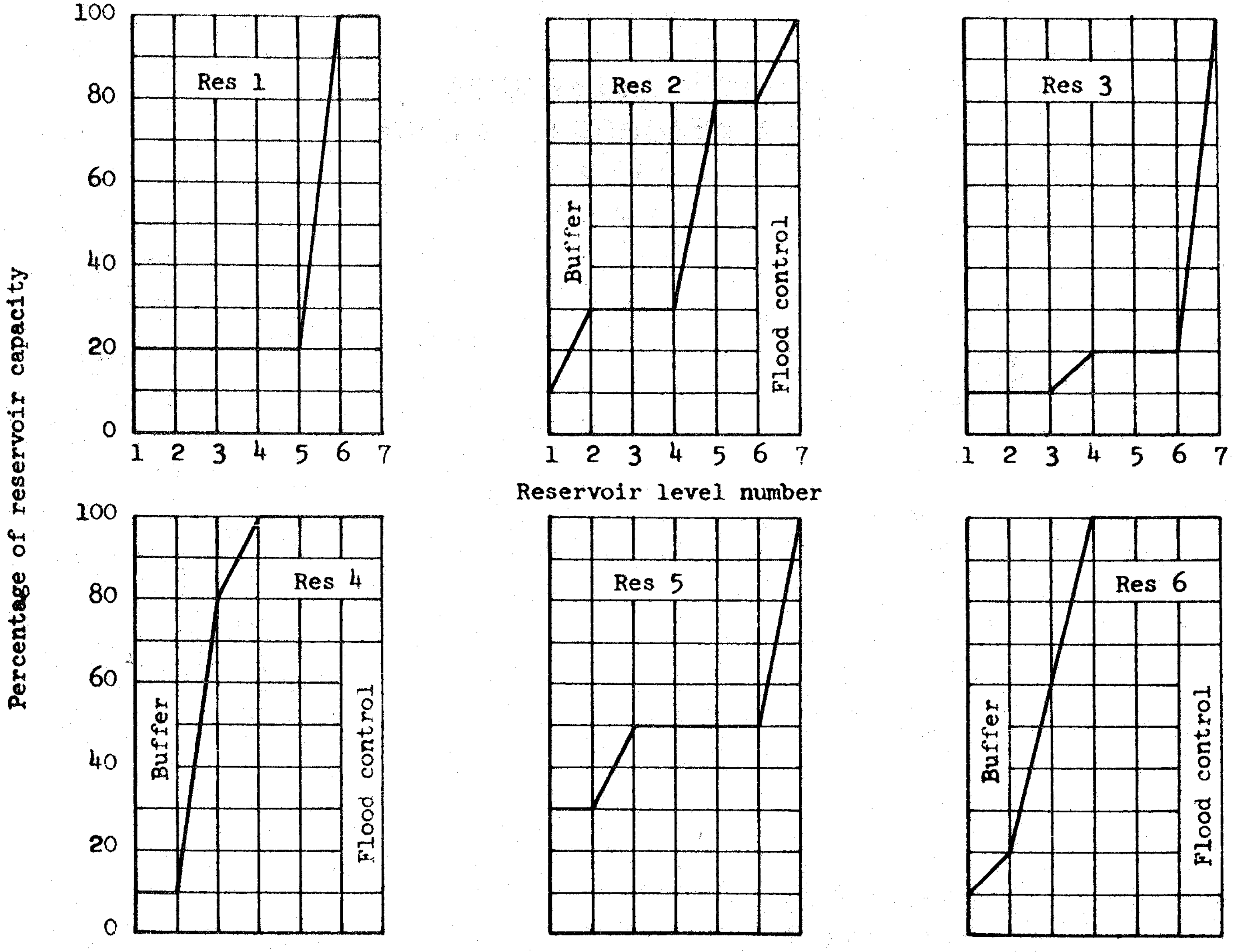

Figure 2

SAMPLE PRIORITY OF RESERVOIR USE

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TP-2 Optimization Techniques for Hydrologic Engineering
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TP-105	Use of a Two-Dimensional Flow Model to Quantify Aquatic Habitat
TP-106	Flood-Runoff Forecasting with HEC-1F
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TP-108	Role of Small Computers in Two-Dimensional Flow Modeling
TP-109	One-Dimensional Model for Mud Flows
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