January 1971

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Recommended Citation
Clyde, Calvin G. and Blood, Wesley H., "Further Studies of the Optimum Operation of Desalting Plants as a Supplemental Source of Firm Yield" (1971). *Reports.* Paper 540.
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FURTHER STUDIES OF THE OPTIMUM OPERATION OF DESALTING PLANTS AS A SUPPLEMENTAL SOURCE OF FIRM YIELD

By Calvin G. Clyde and Wesley H. Blood

Final Report to

The Office of Saline Water
United States Department of the Interior

Under Contract No. 14-30-2534

Utah Water Research Laboratory
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Utah State University
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May 1971

PRWG82-1

ABSTRACT

The Operating Rule Program was developed in an earlier study to furnish a means to determine optimum desalting plant size, optimal operating rule, and costs of operating in conjunction with existing water supply systems. Under the present study, five further objectives were accomplished: (1) The program was applied to a New York City water supply system feasibility study in connection with a dual purpose nuclear power plant to develop costs for adding firm yield to the New York City water supply system in conjunctive operation with the desalting plant. (2) The program was modified to enable assessment of stage construction of desalting units when used in conjunction with a natural water supply system on the basis of both constant costs over the period of analysis and inflationary costs. Techniques were developed for applying the program to determine the optimal plant module size, timing of units, and cost of the water. (3) A separate, smaller program was developed to enable analysis of desalting plant operation in conjunction with a natural water supply system having no storage capacity. (4) A training program provided instruction to a selected group designated by OSW on the detailed use and application of the Modified Operating Rule Program. (5) A feasibility study of the Norfolk, Virginia, water supply system was also carried out by applying the modified program.

ACKNOWLEDGMENTS

The following professional staff members and agencies worked directly on various phases of the project, contributed information or data, or cooperated in parts of the study:

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New York City Board of Water Supply

New York State Conservation Department

Consolidated Edison Company of New York, Inc.

City of Norfolk, Virginia

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INTRODUCTION

As population growth places greater demands on existing water systems, new sources of supplemental water supply must be developed. Desalting of seawater or brackish water is one promising source of additional firm water yield. If the deslating alternative is to be evaluated fairly in any given system, a comparison should be made with other alternatives such as reservoirs, imports, groundwater, or recycled wastewater. In an earlier study by Clyde and Blood (1969) a computer program was developed as a planning tool to assist in evaluating supplemental water sources. Frequent reference will be made to the earlier report instead of repeating material that is adequately covered therein. It is strongly recommended that the reader have a copy of the report for reference, since this current report is viewed as a continuation of and supplement to the earlier report.

The Operating Rule Program of Clyde and Blood (1969) embodied two important considerations. First, the natural supplies in existing water systems are highly variable over time. Thus, a desalting plant utilized as a supplemental source should operate intermittently to supply water only when the natural supplies are insufficient. Second, what is added to the system by the desalting plant is an additional quantity of firm and reliable yield. Thus the relevant parameter to compare is the unit annual cost of additional firm yield.

The Operating Rule Program utilizes modern operational hydrology coupled with digital simulation of the water system to determine the firm yield that will be added by a desalting plant and the associated cost of the firm yield. Optimal size of the desalting plant, optimal reservoir size, and other alternatives can also be investigated utilizing the OPRUL program.

The principal problem solved by the program is when to turn the desalting plant on and off. An operating rule is expressed as a percent of the reservoir contents. Thus a 60 percent turn-on rule implies a decision to turn the plant on when the reservoir storage contents decrease to 60 percent of the total. Delay in turning the plant on as a dry period occurs may result in water shortages. Delay in turning the plant off may result in wasting precious water over the spillway. Thus, the program searches for and finds the optimal operating rule for the desalting plant operated in conjunction with the existing system. The optimal rule is the basis for cost computations and comparisons.

In this study the usefulness, efficiency, and flexibility of the Operating Rule Program have been extended; additional applications of the program have been made in analyzing the desalting alternative in water systems; and a training program in the use of the computer program has been conducted.

The specific objectives of the research are stated briefly as follows:

1. To modify the Operating Rule Program so as to add the capability of analyzing stage construction of the desalting plant, improve the program efficiency and thereby decrease computer costs, add optional ways of defining the firm yield of the system, and test the effects of cost escalation on desalting costs.

2. To apply the Modified Operating Rule Program to analyze the desalting alternative in two systems: New York City (dual purpose nuclear power MSF/VTE plant) and Norfolk City (single purpose MSF plant).

3. To prepare a separate version of the Operating Rule Program suitable for analyzing the desalting alternative for water systems in which there is no reservoir storage.

4. To conduct a Training Seminar to assist interested individuals and agencies in learning to utilize the Modified Operating Rule Program.

The parts of the investigation were separately authorized by the Office of Saline Water (OSW) by means of Work Orders and the presentation of the report sections follows the same sequence.

SUMMARY

The Operating Rule Program as reported by Clyde and Blood (1969) was improved and modified and the program was applied to analyses of desalting feasibility in both New York City and Norfolk, Virginia.

Improvements included a change in the procedure for iterating on a value of firm yield so as to reduce the required computer time. An optional cost analysis for a plant built in stages or modules was added to the program. A procedure was also added to allow a constraint, by month, on the desalting plant operation. The constraint overrides any decision for plant turn-on that would be made by the operating rule and forces the plant to remain off for the month or months specified. This last modification was incorporated to take advantage of low cost process steam that might be furnished by a nearby power plant in all but the months of peak power demand.

Work done on the project was divided into five work orders as follows:

Work Order No. 1, Application of the Operating Rule Program to the New York City Water Supply System. Until 1990 the anticipated 500 MGD growth in water requirements of New York City can be met by conventional projects. During the planning period from 1990 to 2020 an additional 450 MGD of firm yield will be needed according to estimates by the New York Board of Water Supply. The Modified Operating Rule Program was used to perform a cost analysis of supplying the 450 MGD added firm yield by means of a desalting plant operating conjunctively with the existing water supply system. The desalting plant considered was a multistage flash vertical tube evaporator (MSF/VTE) plant with energy supplied by a dual purpose nuclear power plant. Five different policies were studied each producing the required firm yield or more at any point in the planning period. The results showed the trade-off between the capital cost of the increased plant capacity and the lower energy cost to be in favor of building the larger plant and using the surplus interruptible low cost energy. The best policy, staged construction of a 750 MGD plant using interruptible energy, produced the required yield at a total cost of $36,800/yr/MGD. The effect of escalating cost on the results of the stage construction analysis was also studied. The cost increased to 47,300 and 54,300 $/yr/MGD for annual cost escalations of 3 percent and 5 percent.

Work Order No. 2, Stage Construction Analysis. The Operating Rule Program as developed previously was modified to enable assessment of the stage construction of desalting units when used in conjunction with a natural water supply system on the basis of a stable economy (constant costs over the period of analysis). The program was modified and logic extended in order to function in a variety of analytic situations including annual escalation or inflation of costs at a constant rate. Once the planner has ascertained that the given supplemental source is adaptable to stage construction, a staging policy must be determined. The staging policy indicates the point in time at which the next stage of the supplemental source is to be added to the system. The optimal staging policy is not given directly by the computer program. However, by repeating the analysis in the light of practical and physical limitations of the system, a best (least cost) staging policy for the assumed conditions can be approximated.

Work Order No. 3, Operating Rule Program Modification for No Storage Capacity Systems. For the efficient use of the computer, a separate, smaller computer program was developed to enable analysis of the planning situation where the water system has no appreciable reservoir storage capacity. The operating rule is simple, i.e., turn on the desalting plant or a module when the demand becomes greater than the available natural supply. An example application of the no storage capacity analysis was made for a modified Norfolk, Virginia, water supply system.

Work Order No. 4, Training Seminar. To furnish more information and to encourage and facilitate the use of the Modified Operating Rule Program, a training seminar was held May 26-28, 1970, at Utah State University. Necessary instruction and training to a selected technical group as designated by OSW on the detailed use and application of the Modified Operating Rule Program were given.

Computer services utilizing a Univac 1108 computer were provided. All participants were able to analyze the conjunctive operation of a desalting plant, and also to make a stage construction analysis of a desalting plant. Suggestions received from participants were incorporated in the program, especially changes in the format and information of the computer printout.

Work Order No. 5, Application of the Operating Rule Program to the Norfolk, Virginia, Water Supply System. To examine the use of a desalting plant operated in conjunction with the existing Norfolk, Virginia, water supply system to meet future demands, the Modified Operating Rule Program was applied. The desalting plant costs were based on a single purpose multistage flash distillation process. Computer analysis showed that, to fill the requirement of increasing the firm yield by 45 MGD from 80 to 125 MGD and thus meet continuously the needs of the year 2000 A.D., a 60 MGD plant would be required. Average cost to meet such a demand would be 175,000 \$/yr/MGD of added firm yield. This cost is much higher than the cost reported in Work Order No. 1 for the New York City system due to the different type of plant, the much smaller scale of development and the higher cost of firm energy that would be used.

Since demand is actually growing continuously a staged or incremental construction of the facilities may be economically more efficient. Stage construction analyses were carried out for the system with three alternative demand growth curves. For the linear demand growth expressed as $\overline{D}_j = 30 + 1.5j$ in which $\overline{D}_j$ is the average demand rate in year j, "average annual cost/ultimate firm yield increase" is 91,296 \$/yr/MGD. When the demand rate is higher in the earlier stages, and the demand growth curve expressed as $\overline{D}_j = 130 - 50e^{-0.77j}$, "average annual cost/ultimate firm yield increase" becomes 120,659 \$/yr/MGD. When the demand rate is lower in the earlier stages, and the demand growth curve expressed as $\overline{D}_j = 60 + 20e^{0.40j}$, "average annual cost/ultimate firm yield increase" becomes 77,155 \$/yr/MGD.

Another strategy was to build the entire plant the first year with capacity greater than enough to meet the ultimate demand at the end of the period when operated according to the optimal operating rule. Then the operating rule was modified frequently to optimally meet the growing demand. The same three demand growth curves mentioned previously were used in the study, and the desalting costs were found to be higher than stage construction costs. However, this strategy has the additional advantage of providing some extra "drought insurance" and growth capacity in its early years.

Work Order No. 1

APPLICATION OF THE OPERATING RULE PROGRAM TO THE NEW YORK CITY WATER SUPPLY SYSTEM

Introduction

A technical team representing Federal, State, City, and power company interests was organized to study the feasibility of a dual purpose nuclear-power and desalting plant to meet the long range (1985 and beyond) projected water requirements for New York City Metropolitan region. The team consisted of representatives from Consolidated Edison Company, New York City Board of Water Supply, New York State Department of Environmental Conservation, Atomic Energy Commission, and the Office of Saline Water (OSW). The Utah Water Research Laboratory through its contract with OSW was asked to develop costs for adding firm yield to the New York City water supply system in conjunctive operation with the desalting plant.

This report outlines the procedure by which the costs were determined utilizing the Operating Rule Program developed previously for OSW. Results of this work are summarized herein and were utilized in the team study.

General Approach

The Operating Rule Program as reported by Clyde and Blood (1969) was improved and modified slightly to handle the unique features of this application. The procedure for iterating on a value of firm yield was modified in such a manner as to reduce the computational time. A cost analysis for a plant built in modules was added to the program. Further, a procedure was added to put a constraint, by month, on the desalting plant operation. The constraint overrides any decision for plant turn-on that would be made by the operating rule and forces the plant to remain off for the month or months specified.

This last modification was incorporated to take advantage of low cost process steam that can be furnished by the power plant in all but the months of peak power demand.

Data for Simulation Model

Streamflow, storage, and draft data for the study were furnished by the New York City Board of Water Supply. Desalting plant cost data for the MSF/VTE plant were furnished by OSW through the Oak Ridge National Laboratory. The Consolidated Edison Company furnished the energy supply cost details.

The total inflow to the New York City system for the period 1928 to 1967 is shown in Table 1. This includes the runoff into the seven reservoirs. Available storage for the system was determined to be 489.6 BG (billion gallons).

The area-capacity curve, as shown in Figure 1, was used for computing evaporation losses. Monthly evaporation potential for the equivalent reservoir is listed in Table 2.

New York City is required to make releases in excess of its own requirements. The excess release is for pollution control and to fulfill certain court decrees. The required annual mandatory releases were

Table 5. Capital cost of VTE/MSF desalting plant in million dollars.

D.L.F.* (%)	Plant Size (MGD)													
	100	125	150	175	200	225	250	275	300	325	350	375	400	425
30	39.0	47.2	55.6	64.7	72.8	81.2	89.4	97.5	105.3	113.2	120.8	128.8	136.4	144.1
40	40.5	48.6	57.3	66.3	75.1	83.2	92.1	100.0	108.2	116.4	124.4	132.2	140.0	147.9
50	41.4	49.5	59.0	68.0	77.0	85.6	94.4	102.8	111.0	119.5	127.7	135.7	143.6	151.8
60	43.6	53.1	62.5	72.0	81.6	91.5	100.8	109.7	118.4	127.5	136.3	144.8	153.1	161.2
70	46.5	56.2	66.8	76.8	87.0	97.4	108.0	117.3	126.5	135.8	145.3	153.5	162.2	171.3
80	49.9	60.3	71.4	82.6	93.5	104.6	115.4	125.2	134.7	144.5	154.2	163.4	172.7	181.5

Table 5. Continued.

D.L.F.* (%)	Plant Size (MGD)												
	450	475	500	525	550	575	600	625	650	675	700	725	750
30	151.5	159.4	167.1	174.9	182.5	190.5	198.0	205.8	213.5	221.0	228.3	236.0	244.0
40	155.5	163.4	171.2	179.2	187.0	195.5	203.0	210.6	218.4	225.8	233.5	241.5	248.6
50	159.7	167.8	175.6	183.6	191.8	200.2	208.0	215.5	223.3	231.3	238.8	246.5	254.4
60	169.5	177.7	185.9	194.4	202.5	211.0	219.3	227.3	230.5	243.5	251.5	259.4	267.5
70	180.5	189.2	198.2	207.2	216.2	225.5	234.0	241.7	249.8	256.6	265.5	272.0	282.0
80	190.8	199.6	208.8	217.8	228.0	236.0	244.3	252.4	260.5	268.7	276.6	285.0	293.0

*Design Load Factor.

Table 6. **Summary of cost computations for dual purpose plant for New York City.**

Description of Plant	Best Operating Rule		$/yr/MGD	Relative cost of desalted water
	ON	OFF		
Staged construction of a 750 MGD plant using interruptible energy (no production in June, July, and August) to meet growing demand. Add 125 MGD modules in years 1, 6, 11, 16, 21, and 26	79	65	36,800	1.00
Stage construction of 700 MGD plant using firm energy (no constraint on summer operation)	38	70	39,300	1.07
Unstaged construction of 750 MGD plant, but operating with a changing demand	20 to 79	30 to 65	51,000	1.39
A 750 MGD plant to meet constant 450 MGD firm yield increase (no production in summer)	79	65	75,800	--
A 700 MGD plant to meet constant 450 MGD firm yield increase (no constaint on summer operation)	38	70	80,800	--
Same conditions as line 1 except 3 percent per year cost escalation	79	65	47,300	1.29
Same conditions as line 1 except 5 percent per year cost escalation	79	65	54,300	1.48

Work Order No. 2

STAGE CONSTRUCTION ANALYSIS

Introduction

The stage construction analysis is a study to investigate the economic advantage associated with incremental construction of desalting plants. A plant designed and installed with capacity to meet future demand will be economically inefficient in the early years of operation. A plant built in stages, in accordance with projected growth in demand, would defer some capital investment until it is needed. Under many conditions the staging of construction would be a more efficient scheme than an initial full size plant.

The Operating Rule Program originally was developed to determine the least cost operating rule for a fixed size desalting plant in conjunctive operation with an existing water system. The program has been modified and the logic extended in order to function in a variety of analytic situations. In each situation the option specification and input requirements are somewhat different. Table 7 summarizes the utilization of the program and the input requirements by categories. (See Appendix A, input data.)

The Operating Rule Program was substantially modified to decrease the computer execution time and thus decrease the cost of its application in practical problems. Work orders 1 and 5 are applications of the Modified Operating Rule Program and the stage construction analysis. Before presenting the detailed description of the stage construction analysis, the general description and explanation of the Modified Operating Rule Program will be introduced in the following section.

Table 7. Summary of operating rule program* utilization.

Case No.	Description of Utilization	Input Data Categories	Key Option Specification
1	YIELD OF EXISTING SYSTEM. Firm yield determination without supplemental supply system. Set NOF in category I equal to zero.	A thru L, and X	KREAD=2 KVAR=1 STAGE=1
2	CONJUNCTIVE OPERATION YIELD. Firm yield analysis with supplemental supply. Finds feasible rule set, performs cost analysis, and selects minimum cost rule.	A thru P,T,U,W,X	KREAD=3 KVAR=1 STAGE=1
3	COMBINED USAGE. Combines cases 1 and 2.	A thru O,T,X	KREAD=2 KVAR=1 STAGE=1
4	COST ANALYSIS. Finds feasible rule set, performs cost analysis, and selects minimum cost rule (all firm yield data is input).	A thru P,T,V,W,X	KREAD=1 KVAR=1 STAGE=1
5	VARYING OPERATING RULE. The operating rule is varied in such a manner that the yield follows the expected demand function (input category I defines the varying operating rule).	A thru Q,T,U(a),W,X	KREAD=3 KVAR=2 STAGE=1
6	STAGE CONSTRUCTION COST ANALYSIS. The costs for a given stage construction policy are computed.	A thru P,R,S,T,U(a),W,X	KREAD=3 KVAR=1 STAGE=2
7	MODIFIED CASE 2. Analysis is based on selected hydrographs as specified by the arguments of the random number generator.	Same as No. 1 and include P	KREAD=4 KVAR=1 STAGE=1

*The complete deck of IBM cards or magnetic tape of the Operating Rule Program is available for $25 per copy from the Utah Water Research Laboratory, Utah State University, Logan, Utah 84321.

General Procedure for the Application of the Modified Operating Rule Program

The following are suggested steps to follow in a simple application of the Modified Operating Rule Program:

1. Determine the firm yield of the existing reservoir water supply system. Prepare the input data as specified in case no. 1 of Table 7.

2. Estimate the approximate optimal size of the desalting plant from

$$S_1 = 1.3\ (\bar{D}_d - Y_o) \quad \ldots\ldots\ldots\ldots \quad (4)$$

in which

S_1 is the estimate of the optimum size desalting plant
$\bar{D}_d$ is the design demand rate
Y_o is the firm yield w/o desalting (from 1)

The constant 1.3 is based on past applications of the program.

3. Determine the least cost feasible operating rule for the given design demand rate and plant size. Prepare the data deck as specified in case no. 2 of Table 7. The key to this step of the analysis is to input the turn-on and turn-off fractions that will give a fairly broad range of yields. The output of yields from this computer run can serve as the basis for formulating subsequent runs. A typical set would include four turn-on and four turn-off fractions within the range of 0.40 - 0.80.

The first trial may or may not locate an approximate least cost feasible rule. If the operating rule set has a broad enough range of yields, then an approximate least cost rule will probably be located. If not, by analyzing the results of the first trial run, a different and smaller set of operating rules can be specified and another computer run should then locate the optimal rule. The plant size, cost, and operating rule should be recorded.

4. Increase the plant size, S, as determined in step 2, by about 25 percent. Use the same data deck setup as in step 3 but change the plant size and the turn-on and turn-off fractions. Since the size of plant has been increased, the turn-on and turn-off fractions should be somewhat smaller than those used to locate the optimal rule in step 3. If the approximate least cost rule is not obtained on the next trial, adjust the operating rules and run again. A third run is rarely needed.

5. Decrease the plant size, S, from step 2 by approximately 25 percent. Change the plant size and the turn-on and turn-off fractions in the data deck. In this trial the turn-on and turn-off fractions should be somewhat larger than those used in step 3.

6. Compare the costs obtained from steps 3, 4, and 5. The desired condition is that the cost obtained in step 3 be smaller than that obtained in step 4 and step 5. If this condition is not achieved then the plant size and operating rule set must be adjusted accordingly and another trial run made. This fourth run should establish the basis for selecting the approximate optimal size plant.

The additional steps to follow in a stage construction analysis are found starting on page 32.

General Description of the Simulation Model

As the demands on our limited water resources continue to increase, the need for efficient water resource utilization must become the focal point in planning and design. Projected demands for water in most areas show the present supply to be inadequate for the future. Therefore, planners are looking for ways to firm up their present supply and obtain additional water. The conjunctive operation of a supplemental source with the existing surface water facilities warrants consideration in such planning situations.

Conjunctive operation

Conjunctive operation is not a new concept; however, its application by digital simulation, as described herein, is a new approach. The usefulness of operating a supplemental source in conjunction with an existing system can be easily demonstrated. A plot of the accumulation of inflow minus demand as a function of time is shown in Figure 2. The curve ABCD is the mass curve of inflow minus demand. The straight line AJEFG represents a balance between inflow and demand. It is assumed that the storage of the existing system is full at time, t_1. If there are not at least BE units of storage in the system, a shortage will be incurred at time, t_3.

Consider a situation where the existing storage is less than BE and greater than or equal to BK. Under the given inflow-demand pattern, a shortage would be realized at t_3. Therefore, the demand is too great for the given supply. Now consider a supplemental source of a given capacity as represented by line JKLM to be activated at time t_2. The difference, at any point in time, between JKLM and the mass curve ABCD is the amount of natural supply needed to satisfy the demand. Therefore, with the storage as stipulated and the supplemental source operating,a shortage is averted at time t_3.

Once the supplemental source is operating, the problem is to turn it off at the best time. Ideally, before an extended drawdown of storage occurs, the storage should be full. If, referring to Figure 2, the supplemental source is turned off at any time between t_2 and t_4, the storage will not be full when drawdown starts at t_6. If the turn-off is delayed beyond t_4, then the storage will spill supplemental water that has been added. This is inefficient utilization of the supplemental source if the supplemental water is more costly than the natural water of the existing system. The ideal turn-off point in time is t_4. In this case, the storage would just fill at time t_6 prior to the subsequent drawdown. Since it is not possible to have a perfect knowledge of future hydrologic events, only by extreme good luck would the ideal time to turn-off the supplemental source be selected. t_2 is not the time when the supplemental source can be turned on to prevent the shortage from occurring at t_3. Therefore, the basic conjunctive operation problem is to determine, based on a given hydrologic inflow, a method (rule) for operating the supplemental source in such a manner as to prevent a drought (shortage) from occurring and at the same time minimize the amount of supplemental water wasted by spills over an extended period of time.

If the supplemental source were operated independently as a base load source, the system would obviously be using the more costly supplemental water during those periods when the natural or conventional water was adequate. Mawer and Burley (1968) and Clyde and Blood (1969) have demonstrated the efficiency achieved by operating desalting plants in a conjunction with water systems.

Optional criteria for determining firm yield

The firm yield of a water supply system, as presented in this study, involves a rate and a specified tolerance of shortages. The rate is the maximum average demand that can be satisfied on a sustained basis. It is a function of the inflow and demand pattern as well as the specified tolerance of shortages. Factors such as frequency, magnitude, and/or duration of shortages can be used to specify the tolerance in a given planning situation.

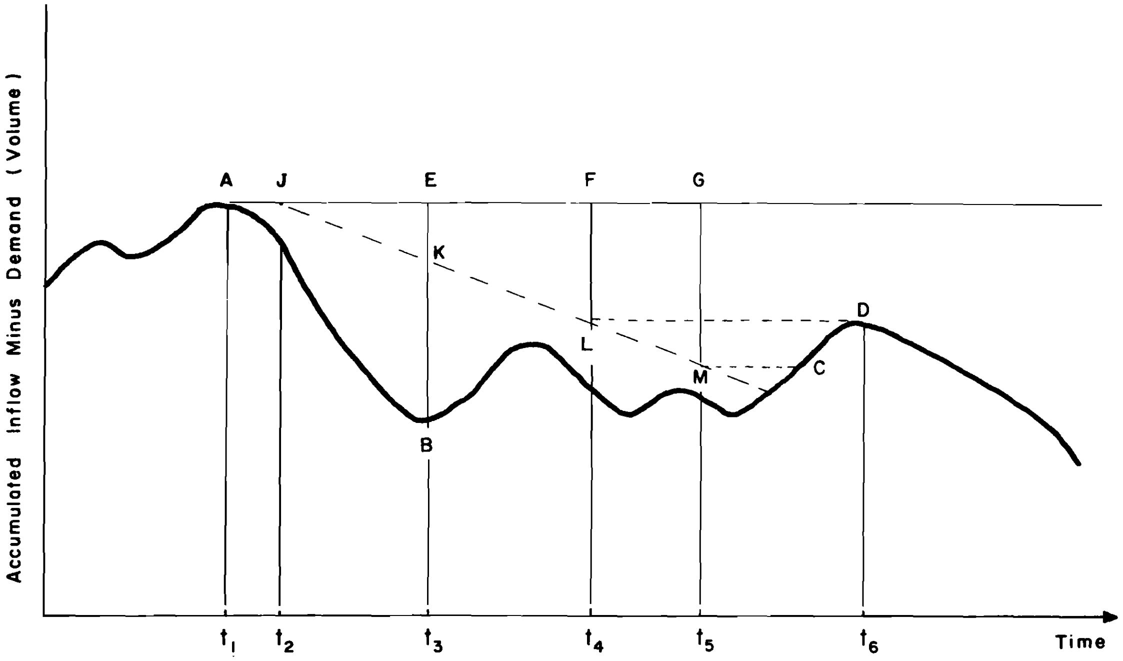

Figure 2. Illustration of conjunctive operation.

The simulation model described herein permits any one of three different tolerance specifications for determining the firm yield as follows:

1. A firm yield that is based on satisfying the expected demand schedule 100 percent of the years; i.e., no shortages tolerated.
2. A firm yield that is based on satisfying the expected demand schedule something less than 100 percent of the years; i.e., a certain number of years with shortages occurring would be tolerated. For example, a firm yield determined on a 95 percent frequency basis would register 5 years out of 100 in which shortages occurred. The magnitude and duration of the shortages are not considered in this type of firm yield determination. However, the average amount and the average duration of shortages for the given period of hydrology are computed and made available to the planner.
3. A firm yield based on the maximum monthly deficit that can be tolerated during the most severe expected drought. This is accommodated in the model by specifying the maximum tolerable deficit as a decimal fraction of the expected demand.

Choosing the manner in which the firm yield is to be determined is the responsibility of the planner. A design based on a firm yield that tolerates a small frequency of shortages or a small amount of deficits may be acceptable in some planning situations, especially if the consequences were to be only minor austerity measures. On the other hand, the responsible planner may not wish to become subject to the social and/or political consequence of any shortages. Thus, to minimize the probability of shortages occurring the planner may only accept a design based on a firm yield determined with no shortages.

These different ways in which the firm yield can be defined permit a degree of flexibility in the use of the model and, consequently, to the planning tasks to which it may be applied. A firm yield value obtained on the basis of no shortages will obviously be smaller than a firm yield value obtained when shortages are tolerated. Thus, different designs to meet a specified requirement would be required and the associated costs would be different. Thus, there is a cost attributable to the definition of firm yield. Analysis of the costs of designs based on different tolerances of shortages may be made to aid in the decision making process.

Storage considerations

Storage is handled in the model by means of a simulated reservoir with a conservation pool. The pool is augmented by monthly flows greater than the demand. On the other hand, the pool is diminished during those months where the demand is greater than the inflow. Limits are set on the size of the pool. Provisions are incorporated for specifying inactive (dead) storage.

For any complete analysis (i.e., determination of the optimum supplemental capacity to meet the specified demand rate), the storage capacity of the system is fixed. This is a reasonable assumption since the methodology is intended to be applied to planning situations dealing with existing water supply systems.

Storage is utilized in the model to meet a primary demand that is described by an average demand rate and a set of monthly coefficients. The primary demand may be for municipal and industrial needs, irrigation, or other uses as long as the monthly coefficients define the total demand schedule. An extension of the model would be required if the reservoir storage is to fulfill multiple purposes that follow different demand patterns.

The parameters required to define the storage in the model are: (1) maximum available capacity of the reservoir; (2) inactive storage; and (3) surface area as a function of reservoir contents (tabular form).

Generation of streamflow values by operational hydrology

Much of the usefulness of simulation as used in this study depends on the capability of approximating the expected performance of the water supply system that is being modeled. The response of the system over a given period is uniquely determined by the particular sequence of streamflow that is input to the model. In most planning situations, the planner is confronted with short historical records of streamflow on which to base the design. Also, future streamflow events will not duplicate those of the past. Consequently, no qualified statement can be made about the expected performance of a system based on only one sequence of streamflow.

To provide more reliability to the design, operational hydrology is used to furnish many different streamflow sequences. Thus, it is possible to analyze the response of the system to as many different, but "equally likely," streamflow sequences as desired or as can be economically justified. From the spectrum of responses, the planner can approximate the expected performance of the system with cognizance of the possible extremes.

Monthly streamflow sequences are generated by means of a mathematical model such as reported by Fiering (1967). A first-order auto-regression process is utilized that reflects the nonrandomness inherent in a monthly streamflow sequence. The basic one station model utilized involves the solution of the following recurrence equation

$$K_{i+1} = \beta_j K_i + Z_i \sqrt{1 - r_j^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

in which

K_{i+1} is the generated monthly flow logarithm expressed as a normal standard deviate for month i + 1
K_i is the generated normal standard deviate for month i
β_j is the least squares regression coefficient for estimating flow in month j + 1 from flow in month j
Z_i is a random number from the standard normal distribution, N(0,1)
r_j is the correlation coefficient between flows in month j + 1 and month j
$j =$ 1,2,3 12
$i =$ 1,2,3 . . . . 12N
N is the number of years to be generated

Equation (5) can be extended to generate flows at more than one gaging station as reported by the Hydrologic Engineering Center (1967) of the Corps of Engineers. The computer subprogram used to generate the monthly streamflow values is a modified version of the computer program developed by the Hydrologic Engineering Center. As presently constituted, the subprogram (GNFLO) can generate monthly flows for as many as five gaging stations for a period of up to 100 years in length.

Operational hydrology should not be considered as the "cure-all" to planning problems encumbered by meager hydrologic data. In fact, the indiscriminate use of generated streamflow in any planning situation can be very dangerous. Fiering (1967) indicates two potential problems that can produce serious discrepancies in generated flow values. First, the stream must have a stable regime. Secondly, the characteristics of the watershed must remain unaltered either by the forces of man or nature. Furthermore, it is obvious that reliable streamflow generation is impossible without a minimal amount of accurate records.

In order to function properly in its intended role, operational hydrology should synthesize the critical patterns of low (and high) flows that are probably not found in a short historical record. Such flow patterns might by chance occur in a short record, but could be expected only in very long records. Thus, the use and adequacy of a streamflow generation model should be based on this consideration as well as those mentioned previously.

Draft on storage

The draft is the rate of outflow from the reservoir conservation pool as a consequence of any or all of the following:

(a) Releases to satisfy the Municipal and Industrial (M & I) water needs serviced by the water supply system.
(b) Mandatory releases for other than M & I requirements.
(c) Evaporation losses.

The overall response of the simulation model is assumed insensitive to any other form of loss (outflow) from storage.

Releases to meet the M & I requirements are specified in the form of a demand schedule. Included is the planner's best estimate of the average demand rate projected to the end of the planning horizon and a schedule of monthly demand coefficients. The projected demand rate is referred to as the design demand rate. The monthly coefficients reflect the variation in demand from one month to the next. By utilizing information on per capita consumption of water, seasonal consumption patterns, and population projections the planner can project water requirements into the future. The response of the water supply system during simulation and, consequently, the optimum design selected depends directly on the demand schedule used in the analysis.

During simulation of the system, a demand rate for M & I requirements is computed each month by the program as follows:

$$d_i = \bar{D}_j C_{Di} \quad \text{for } i = 1,2,\ldots,12$$
$$j = 1,2,\ldots,N \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

in which

d_i is the M & I demand rate for month i
$\bar{D}_j$ is the average demand rate in year j
C_{Di} is the seasonal demand coefficient for month i
N is the number of years in the period of simulation

The seasonal demand coefficient must satisfy the following condition:

$$\frac{1}{12} \sum_{i=1}^{12} C_{Di} = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots (6a)$$

Monthly demand rates must be formulated in the model in two different phases of simulation: (1) Firm yield analysis; and (2) cost analysis. Equation (6) is used in either case, but $\bar{D}$ can have varied functional forms in the cost analysis simulation. The average demand rate, $\bar{D}$, can be represented in one of the following forms:

(a) Constant relationship

$$\bar{D}_j = K \quad \text{for } j = 1,2,\ldots,N \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

in which

K is the design demand rate if doing a cost simulation or a first estimate of firm yield if simulation is to determine the firm yield

(b) Linear relationship (used only in cost analysis)

$$\bar{D}_j = A + j \cdot B \quad \text{for } j = 1,2,\ldots,N \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

in which

A is the demand rate for j = 1 (intercept)
B is the rate of change of demand (slope)

(c) Exponential relationships (used only in cost analysis)

$$\bar{D}_j = U - We^{-aj} \quad \text{for } j = 1,2,\ldots,N \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

in which

U	is the final demand rate in the year $j = N$
W	is the difference between the demand rates in the year $j = N$ and the year $j = 1$
a	is the fraction that defines the curvature of the exponential relationship

Figure 3 illustrates the possible representation of the demand rate functions.

Mandatory releases from storage generally have priority over all other uses. Usually, the mandatory release must satisfy the terms of some decree or compact. An example would be a decree to maintain a certain gage height at some point on a stream for the purpose of water quality and/or fish and wildlife conservation.

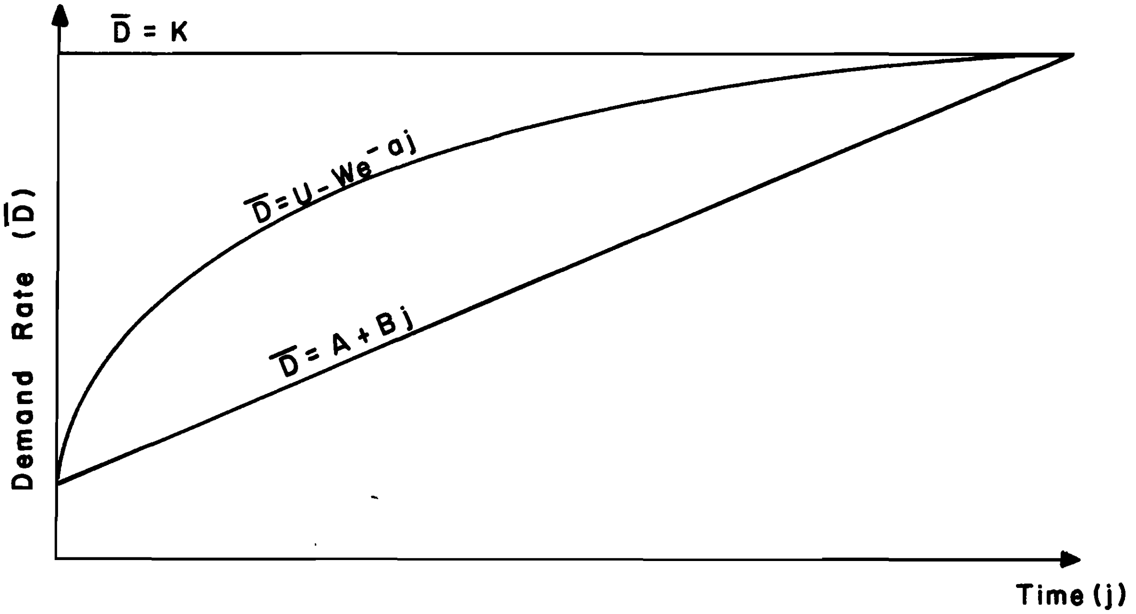

Figure 3. Optional representations of demand rate.

The manner of formulating the mandatory releases will probably vary in each case studied. As a consequence, a modification of the model may be required. The extent of the modification will depend on the complexity of the required releases.

Mandatory releases are formulated in the present model in the same manner as the demand for consumption. A monthly release rate is computed from an average release rate (MGD) over the period of a year and a set of 12 monthly coefficients as follows:

$$m_i = \bar{M} C_{Mi} \qquad \text{for } i = 1,2,\ldots,12 \qquad (10)$$

in which

m_i	is the mandatory release rate for month, i
$\bar{M}$	is the average mandatory release rate over the period of a year
C_{Mi}	is the release coefficient for month, i

The coefficients must satisfy the condition.

$$\frac{1}{12} \sum_{i=1}^{12} C_{Mi} = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10a)$$

The set of monthly release coefficients can, in some cases, be determined from past release information.

Evaporation losses are calculated by means of monthly evaporation coefficients. The coefficients are estimates of the average monthly evaporation from lakes and reservoirs in the area, expressed in inches per month. The water lost by evaporation is calculated from

$$E_i = 2.7152 \times 10^{-5} \bar{A}_i e_i \qquad \text{for } i = 1,2,\ldots,12 \quad \ldots\ldots (11)$$

in which

E_i is the volume of water evaporated in month i in billion gallons (BG)
$\bar{A}_i$ is the average water surface area (acres) in month i
e_i is the evaporation rate for month i in inches

The water surface area is obtained each month by interpolation in the storage content-surface area table.

Operation of the supplemental source of water

The supplemental source is operated in conjunction with an existing water supply system in such a manner as to increase the firm yield of the system. Operating in this way the supplemental source is called on to supply water during the periods of drought which deplete the natural supply. In order to function in its intended role, the supplemental source must satisfy the following requirements:

(1) The supplemental source must be independent from the causative factors producing the natural droughts.
(2) The supplemental source must add water to the system at a constant rate (specified by its capacity or size of development) when it is operating.
(3) The supplemental source must have the capability of being activated (turned on) or deactivated (turned off) with comparative ease.
(4) The capital, operating and maintenance, replacement, turn-on, and turn-off costs must be identifiable.

Any departure from the above would require modifications of some form in the model as presently developed.

During simulation of the system when the supplemental source is activated, it supplies water for a minimum of one full month. There are no provisions in the computer program for operating for any shorter period of time. If extended continuous operation is called for; i.e., for periods of 11 months or greater, provision is made to deactivate the supplemental source for the period of one month for maintenance and/or replacements as required.

Desalination of sea and/or brackish water, pumping from large rivers, pumping from groundwater, importation, and recycling are some of the possible sources of supplemental water.

Operation of the Simulation Model

Simulation is performed in three phases. In phase one the expected firm yield of the reservoir without the supplemental supply is determined. In phase two an expected firm yield is determined for every operating rule specified for the conjunctive operation with the supplemental supply. The time period for which the simulation is conducted is a selected input to the program. Some judgment is required on the part of the user to select an appropriate time horizon. One that appears adequate and is used in subsequent demonstrations is the life expectancy of the reservoir or reservoirs in the system. In phase three costs are determined for a selected set of feasible operating rules.

The basic storage equation involved in the simulation model is

$$I - O = \Delta S \qquad \text{(12)}$$

in which

I is the inflow to the system
O is the outflow from the system
ΔS is the change in storage

Substituting for each term of Equation (12) its components treated as rates and introducing subscripts give the following equation:

$$(\Delta S)_{i,j} = q_{i,j} + w \cdot J - e_i - d_i - r_i \qquad \text{for } i = 1,2,\ldots,12$$
$$j = 1,2,\ldots,N \qquad \text{(13)}$$

in which

$q_{i,j}$ is the average streamflow rate in month i, year j
w is the rate of the supplemental source
J is 1 if the supplemental source is operating and 0 if the supplemental source is not operating
e_i is the average evaporation rate for month i
d_i is the average demand rate for month i as obtained from Equation (6)
r_i is the average mandatory release rate for month i
N is the number of years in the period being simulated

Prior to the start of each month, the state of the storage in the system is examined by converting each term of Equation (13) to a volume (BG) on the basis of the number of days in the given month, and solving

$$S_{i+1,j} = S_{i,j} + Q_{i,j} + W_i \cdot J - E_i - D_i - R_i \qquad \text{(14)}$$

in which

$S_{i+1,j}$ is the contents of storage at the start of month i + 1 (or end of month i), year j
$S_{i,j}$ is the contents of storage at the start of month i year j
All other terms correspond to their counterparts in Equation (13)

The value of $S_{i+1,j}$ is compared to the specified limits of storage. If $S_{i+1,j}$ is greater than the maximum, an average (spill) is recorded and $S_{i+1,j}$ is set equal to the maximum value. On the other hand, if $S_{i+1,j}$ is less than the minimum, a deficit is recorded and $S_{i+1,j}$ is set equal to the minimum value.

Phase One--Reservoir Without the Supplemental Supply

The objectives of the simulation in phase one are as follows:

(1) Obtain the firm yield of the existing water supply system, Y_o.
(2) Identify the critical range of the generated streamflow hydrograph.
(3) Select, at random, a set of reservoir starting contents from a sample of the distribution of year-end contents.

Firm yield of the reservoir without the supplemental supply

As previously mentioned, the firm yield of the system is the average demand rate, with its associated seasonal variation, that can be satisfied subject to some specified constraints on shortages. Thus, the value of the firm yield for any given generated hydrograph cannot be solved for directly. The unknown quantity in the simulation is $\overline{D}$ from Equation (6). Consequently, d_i, in the basic storage equation, Equation (13), is dependent on the value of unknown $\overline{D}$. An iteration procedure is proposed as the method to determine the value of $\overline{D}$ that satisfies the constraints on shortages. Once determined, the value of $\overline{D}$ is identified as the firm yield of the system, Y_o. The following sections outline the iteration procedure used to determine Y_o.

Iteration procedure for determining the firm yield, Y_o

The procedure outlined identifies the critical range of the period of generated monthly streamflow. Iteration is subsequently carried out over the critical range and not over the entire period. The iteration technique is described in the following steps.

Step 1. Make an initial guess for the yield (demand that can be satisfied), Y. This first guess is made as a function of the mean inflow to the system and the estimated scale of development as follows:

$$Y_1 = \overline{Q} \cdot f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

in which

Y_1 is the firm yield estimate and is used as the value of $\overline{D}$ in Equation (6)
$\overline{Q}$ is the mean inflow rate calculated from the historic record in MGD
f is an estimated fraction, $0 < f < 1$

Step 2. Using the demand rate (yield estimation) obtained in step 1, simulate operation of the reservoir without the supplemental supply for the entire period of N years. This involves the repetitive solution of Equation (14). The system is operated under the policy that the full demand is satisfied every month as long as water is available.

During simulation, the response of the system to the particular pattern of inflow and outflow is recorded. Of particular interest are the following:

(a) The relative minimum drawdowns (where the reservoir content stops decreasing and begins to increase).
(b) The month and year of each drawdown in (a).
(c) The month and year of the reservoir full condition prior to each minimum in (a).

(d) The amount of each monthly deficit that occurred, and the amount of the shortages.*
(e) The month and year of each deficit.
(f) Duration, in months, of each shortage.
(g) The month and year of the reservoir full condition prior to each deficit and each shortage in (d).

Step 3. After simulation is completed for the period of N years, the response is compared to the specified definition of firm yield. Logic is provided for the following cases.

Case A. Firm yield defined at the 100 percent level; i.e., no shortages tolerated. The iteration technique in this case works equally well whether shortages did or did not occur during the simulation. The iteration procedure can move directly to step 4.

Case B. Firm yield defined at less than 100 percent; i.e., some number of years with shortages will be tolerated. For example, let the firm yield be defined at the 98 percent level. The iteration scheme then requires, as a minimum, three years in 100 years in which shortages were recorded. In the event that the required number of years with shortages are not obtained, the demand rate, Y, is increased by an appropriate amount. Step 2 and step 3 (case B) are repeated until the requirement on the years with shortages is satisfied. If the initial estimate of the demand rate is large enough, the required number of years with shortages will be obtained on the first trial.

Case C. A specified maximum monthly deficit will be tolerated. In this case monthly deficits become the focal point of the iteration. As in case B some deficits must be recorded before the iteration procedure can continue. Thus, if no monthly deficits were recorded, Y must be incremented and step 2 repeated.

Step 4. Determine the critical range of the period. The logic employed in defining the critical range depends upon the manner in which the firm yield is defined. Thus, either the shortages, the monthly deficits, or the relative minimum drawdown could be the controlling factor. The logic is somewhat different in each of the three cases so each case is treated separately.

1. Shortages are the controlling factor. The critical shortage is a function of the amount of the shortage, the number of months since the prior reservoir full condition, and the tolerance of shortages specified in the definition of firm yield. To illustrate, Figure 4, a graph of reservoir storage versus time, shows shortages A, B, C, and D of amounts 20, 33, 40, and 11 BG respectively. An index of the severity of each shortage is calculated as follows:

$$\text{Severity Index} = \frac{\begin{array}{c}\text{Amount of shortage plus sum of prior}\\ \text{shortages having the same prior}\\ \text{reservoir full condition}\end{array}}{\text{Months since reservoir full}} \quad \ldots .(16)$$

The index calculated in the above illustration produces values of 1.00, 1.77, 1.86, and 1.73 respectively. If firm yield is defined as 100 percent, then shortage C with the largest value of the index (1.86) is the critical shortage. The critical range over which subsequent iteration is conducted is obtained by moving back in time five years from point F. The range is, therefore, 110 months. Moving back five years assures that the reservoir full condition is always achieved when iterating over the critical range.

If the firm yield definition tolerates two occurrences of shortages, then shortage D (Severity Index = 1.73) is the critical shortage and the critical range is 120 months.

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*A shortage is defined as the sum of any consecutive monthly deficits which occur. A single isolated deficit is also termed a shortage.

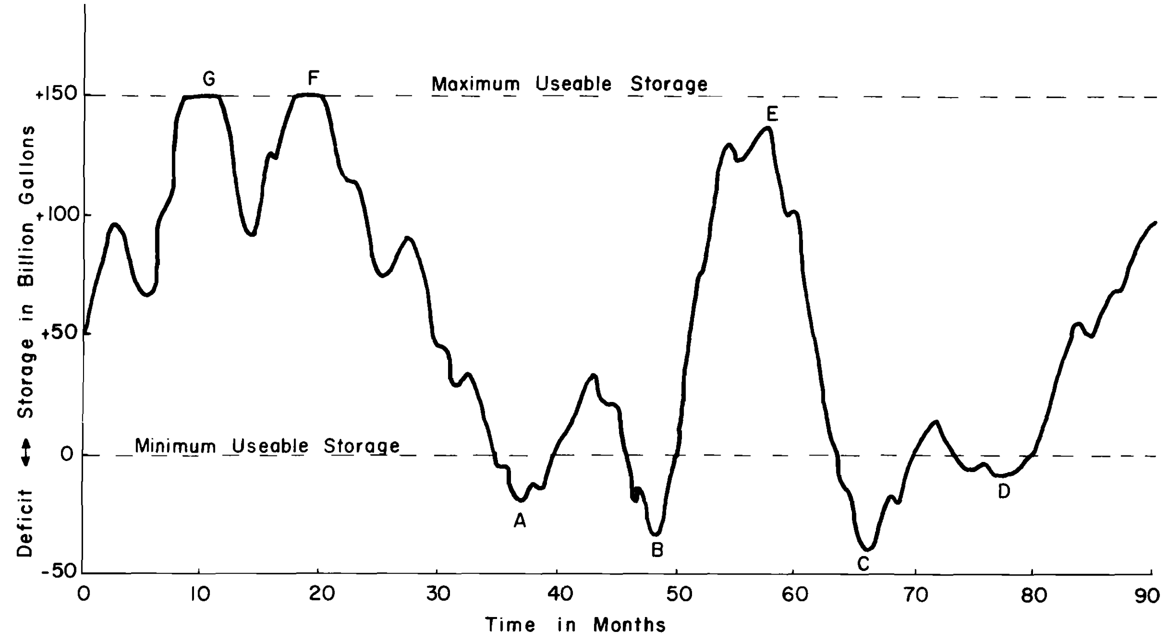

Figure 4. Reservoir storage vs. time showing shortages.

2. Monthly deficits are the controlling factor. The logic in this case is similar to the shortage case. A severity index is determined for each shortage occurring over the simulation period. The critical monthly deficit occurs in some time during the shortage with the largest value of the severity index. The critical range begins five years preceding the reservoir full condition prior to critical deficit and ends at the end of the shortage in which the critical deficit occurs.

3. Relative minimum drawdowns are the controlling factor. The only condition under which this logic is employed is when the firm yield is defined at 100 percent and no shortages were recorded from step 2. Figure 5, a graph of reservoir versus time, shows eight (A-H) relative minimums. The procedure must identify the critical drawdown, that is, the drawdown that approaches the minimum usable storage the fastest as the demand rate, $\overline{D}$, is increased. Minimums at A, B, E, and H can obviously be removed from consideration. Minimums, C, D, F, G, have values of 5, 9, 5, and 10 BG, respectively. The critical drawdown is a function of the difference between the drawdown and the minimum usable storage and the number of months since the prior reservoir full condition. Let the number of months between C and D and full condition at I be 20 and 30 months. Likewise, let the number of months between F and G and full condition J be 18 and 25 months. A critical index is calculated as

$$\text{Critical Index} = \frac{d_m - U_{min}}{\text{Months since reservoir full}} \quad \ldots\ldots\ldots(17)$$

in which

d_m is the drawdown (relative minimum)
U_{min} is the minimum usable storage

The differences in this illustrative example for a minimum usable storage of 2 billion gallons are 3, 7, 3, and 8 respectively. The corresponding values of the critical index are .15, .23, .17, and .32. In this case, the smallest value of the index identifies the critical drawdown. In the example, drawdown C (index of .15) is the critical drawdown and the critical range is I minus five years to the occurrence of drawdown C plus an arbitrary two months.

Step 5. Record the critical range as obtained in either (1), (2), or (3) from step 4 for the given period of generated streamflow.

Step 6. Iterate to obtain the firm yield based on the critical range as recorded in step 5. The logic of the iteration procedure is dependent upon the controlling factor as was the determination of the critical range in step 4. Each case is outlined separately.

1. Shortages are the controlling factor. The objective is to iterate to remove the critical shortage that occurs at the end of the critical range. The iteration formula is:

$$Y_{i+1} = Y_i - \frac{(A_s)_i}{.0305\ M} \qquad \text{for } i = 1,2,\ldots,\leq,15^* \ldots\ldots (18)$$

in which

Y is the estimate of the firm yield
$(A_s)_i$ is the amount of the critical shortage in the i^{th} iteration
M is the number of months since the previous reservoir full condition.

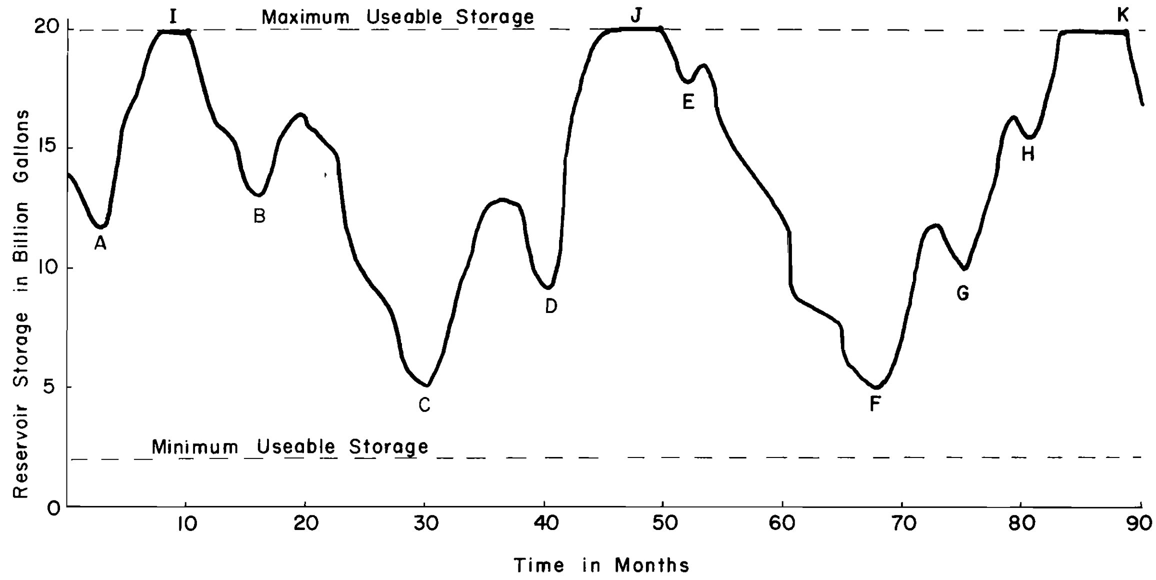

Figure 5. Reservoir storage vs. time showing relative minimum drawdowns.

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*If the program fails to converge to after 15 iterations, the lack of convergence is flagged, the program then uses the last available iteration result and checks to see if it meets the appropriate firm yield criteria.

The iteration is terminated when

$$(A_s)_i \leq e \cdot Y_i(.0305) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (19)$$

in which

e is the error tolerance expressed as a decimal fraction

2. The monthly deficit is the controlling factor. The iteration is conducted, in this case, in such a manner as to remove all monthly deficits greater than a specified amount. The amount of deficit tolerated is expressed as a fraction of the demand rate (yield). It is specified by the program user as input variable FDT.

The iteration formula is

$$Y_{i+1} = Y_i - \frac{(A_d)_i}{.0305\ M} \qquad \text{for } i = 1,2,\ldots,\leq,15 \quad \ldots\ldots \quad (20)$$

in which

$(A_d)_i$ is the summation of monthly deficits in the critical shortage up to and including the critical deficit, in the i^{th} iteration
M is the number of months between the critical deficit and the prior reservoir full condition
Y is the same as in Equation (18)

The iteration is terminated when

$$\left| (M_c)_i - (.0305)Y_i \cdot f \right| \leq e \quad \ldots\ldots\ldots\ldots \quad (21)$$

in which

$(M_c)_i$ is the critical monthly deficit in the i^{th} iteration
f is the allowable deficit expressed as a fraction
Y_i is the yield (demand rate) in the i^{th} iteration

3. Relative minimum drawdown controls. The objective in this case is to draw the reservoir down to the minimum usable contents without incurring any deficits. The iteration formula is

$$Y_{i+1} = Y_i + \frac{(d_m)_i - U_{min}}{.0305\ M} \qquad \text{for } i = 1,2,\ldots,\leq,15 \quad \ldots\ldots\ldots \quad (22)$$

in which

Y_i is the estimate of the yield
$(d_m)_i$ is the drawdown in the i^{th} iteration
U_{min} is the minimum usable contents
M is the number of months since the reservoir was full

The iteration is terminated when

$$\left| (d_m)_i - U_{min} \right| \leq e \cdot Y_i(.0305) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

The value of the yield determined from any iteration formula (17), (18), or (19) is the corresponding value of firm yield of the reservoir without any supplemental supply and is designated as Y_o.

Critical range of the hydrograph

The identification of the critical range is actually a by-product of the iteration performed above to get Y_0. This range is uniquely determined for each generated streamflow hydrograph by the definition of firm yield (constraints on shortages). It is identified and recorded in this phase of simulation so that the computational effort will be greatly reduced when entering phase two.

Selection of reservoir starting contents

The reservoir contents at the beginning of a simulation period can exert some influence upon the overall results. This is more likely the case if the simulation period is short. A suitable selection of a starting storage content, or a set of replicate starts, requires that the stationary state probabilities of the reservoir contents be known in advance (Fiering, 1967). Since this is not practical to attain, a next best procedure is advocated.

Treating the first period of simulation as a "typical" period, a 50-year sample of year-end storage contents is generated. The assumption was made at the beginning of the computation that initial storage contents were one-half the storage capacity. The first period value of firm yield, Y_0, was determined on this assumption. In the procedure it has been observed that the value of Y_0 determined over a long simulation period is not sensitive to this starting assumption. With the value of $\bar{D}$ in Equation (6) set equal to Y_0, simulation is next conducted for a period of 75 years. The contents of storage are recorded at the end of each year. The first 25 years are discarded and the remaining 50 years are used as a sample from the distribution of year-end reservoir contents. A set of year-end (or start of year) contents are selected in a random fashion from this sample. All the subsequent yield and cost determinations utilize this random selection of starting contents.

Phase Two--Conjunctive Operation

In phase two simulation, the supplemental source is operated in conjunction with the existing water supply system. The increase in yield of the conjunctive system is a function of the capacity of the supplemental source and its mode of operation. In any particular analysis, the capacity is fixed so the mode of operation becomes the focal point of the analysis.

The objective associated with this phase of simulation is to determine the manner in which the supplemental source should be operated to produce a firm yield equal to the design demand rate. This involves the search of a decision space defined by a set of operating rules. The operating rules are furnished by the planner. Judgment must be used in defining the decision space so as to keep the problem tractable.

The following sections will deal with the nature of the operating rule, the formulation of the decision space, determination of the yield of the rules in the decision space, and obtaining a set of feasible rules.

Formulation of operating rules

See pp. 10-11 in Clyde and Blood (1969).

Determination of the firm yield associated with each operating rule

Each operating rule in the decision set will produce a certain firm yield which for a given supplemental capacity is a function of the hydrology and the constraints on the definition of firm yield. As in phase one of the simulation, an iterative scheme is used to determine the various values of firm yield associated with each rule.

An initial estimate of the firm yield is made on the basis of the following:

$$Y_1 = f \cdot (\bar{Q} + C_s) \quad \ldots\ldots (24)$$

in which

Y_1 is the initial estimate of the firm yield (becomes $\bar{D}$ in Equation (6))
f is estimated scale of development
$\bar{Q}$ is the overall average inflow rate
C_s is the capacity of the supplemental source expressed as a rate

Iteration is conducted in much the same manner as in phase one. The variable quantity to be determined is $\bar{D}$ of Equation (14). This quantity is adjusted by iteration until the firm yield constraint is satisfied within a certain error tolerance. Once the constraint is satisfied, this quantity then becomes the firm yield. In this phase of simulation, the term ($W_i \cdot J$) in Equation (14) becomes active in the yield determination. While in phase one, J was set at 0 for all computation, in the conjunctive operation mode, J is set to either 0 or 1 depending on whether the supplemental source is to be shut down or to be operated during the month.

The iteration is conducted over the critical range of the generated streamflow period as was predetermined in the phase one simulation. Equations (18), (19), or (20), (21), or (22), (23), are applicable in the iteration depending on the constraint defining the firm yield and the factor that subsequently controls; i.e., shortages, deficits, or drawdowns.

Upon the completion of the iteration, simulation is conducted over the entire period as specified by the input parameter NYFY. The purpose of this is two-fold. First, to verify the critical range and ascertain that the addition of the supplemental source and its subsequent operation has not changed the critical range of the period. During the check, if some event is encountered that violates the constraining definition of firm yield, the critical portion of the period is relocated and the iteration procedure is repeated. Second, for the verified simulation, two load factors pertaining to the operation of the supplemental source are computed.

(a) The average operational load factor is computed by

$$L_A = \frac{100}{N_o(12)} \sum_{j=1}^{N} O_j \quad \ldots\ldots (25)$$

in which

L_A is the average operational load factor (i.e., the percent of a year the source remains active once it is turned on) for a given operating rule and a given period of hydrology
O_j is the number of months in year j that the source was active
N is the number of years in the simulation period (NYFY)
N_o is the number of times the plant was turned on during the simulation period

(b) A gross load factor is computed as

$$L_G = \frac{100}{N(12)} \sum_{j=1}^{N} O_j \quad \ldots\ldots (26)$$

in which

L_G is the gross load factor or the percent of time the source was active during the entire period
N and O_j are the same as in Equation (25)

After the firm yield and load factors are determined for each rule in the decision set, the whole procedure is repeated for a new period of hydrology; i.e., generated streamflow sequence. The number of period repetitions is specified by the program user as input parameter NPFY.

The expected value for the firm yield of each operating rule is obtained as follows:

$$\overline{Y}_i = \frac{1}{N_p} \sum_{j=1}^{N_p} Y_{i,j} \qquad \text{for } 1 = 1,2,\ldots,N_p \text{ . . . . (27)}$$

in which

$\overline{Y}_i$ is the expected firm yield for rule, i
$Y_{i,j}$ is the firm yield for rule i in period j
N_p is the number of periods (NPFY)

The expected load factors $\overline{L}_A$ and $\overline{L}_G$ are determined for each rule in the same manner as the firm yield.

Generally, the confidence in $\overline{Y}$ as a point estimator of the population mean varies directly as the number of periods used. There is, however, a practical upper limit set by the amount of computational effort involved compared to the amount of new information generated. Here again there is no substitute for judgment on the part of the program user.

Determination of feasible operating rules

See pp. 14-15 in Clyde and Blood (1969).

Stage Construction Analysis

Earlier applications of the Operating Rule Program have been made on the basis that the full capacity of the supplemental source is installed at the beginning of the planning period. Full capacity implies the size of the supplemental source required to meet the project end-of-period demand rate. Furthermore, the end-of-period demand rate is used throughout the entire simulation period. For the purpose of determining the optimum final size of a given supplemental source the procedure is suitable. However, in situations where the planner needs an estimate of the actual expected costs over the plant lifetime or wishes to compare alternate supplemental sources, an additional cost analysis is necessary.

In a situation showing a growth of the demand for water, a supplemental source installed with full capacity in the first year of the planning period is grossly over designed throughout the early portions of the period. There will be an associated loss of efficiency with this type of policy. The ideal condition would be an expansion of the supply system such that the firm yield available just keeps pace with the demand. Practically, the firm yield can only be added to the system in increments. However, by adding small increments as the demand grows, increased operating efficiency and probably increased economic efficiency can be achieved.

The obvious policy, if the nature of the supplemental source permits, is to add the source to the system in stages or modules. Some advantages of the staging policy over the policy of building the full capacity initially are:

1. Deferred investment of capital resulting in savings of interest payments.
2. Reduced operation and maintenance costs in the earlier portions of the operating period.
3. Inadvertent excess capacity can be avoided.
4. Deferred commitments on construction may benefit by advances in technology (especially true in the case of desalting technology).

The following sections will outline a procedure for formulating a stage construction policy and performing a cost analysis.

Formulating a stage construction policy

Once the planner has ascertained that the given supplemental source is adaptable to stage construction, a staging policy must be determined. A staging policy is a step function indicating installed capacity of added firm yield as a function of time. It dictates the point in time at which the next stage of the supplemental source is to be added to the system.

The optimal staging policy is not given directly by the analysis described herein. However, by repeating the analysis in the light of practical and physical limitations of the system, a best (least cost) staging policy can be approximated. Figure 6a, b, and c shows three different policies imposed on a hypothetical demand curve. Staging policy No. 3 consisting of four modules shows the minimum deviation of firm yield from demand and is the best of the three policies. A further reduction in module size would result in a decrease of the deviations of firm yield from demand and, hence, would become the preferred staging policy from that standpoint. Even before the physical limitation of module size is reached, there may be a point of diminishing returns associated with the reduction in size of increments added to the system. The smaller modules have less economies of scale and may not have an economic advantage over larger modules.

The following steps outline a procedure for formulating a staging policy.

1. Obtain the increase in firm yield added to the system as a function of the optimal supplemental capacity as shown in Figure 7.

To obtain the curve in Figure 7, an analysis as outlined in the earlier section must be conducted for the various values of the design demand rate. The number of times to repeat the analysis is somewhat arbitrary but a suggested procedure follows:

(a) Solve for $\Delta\overline{Y}$ in

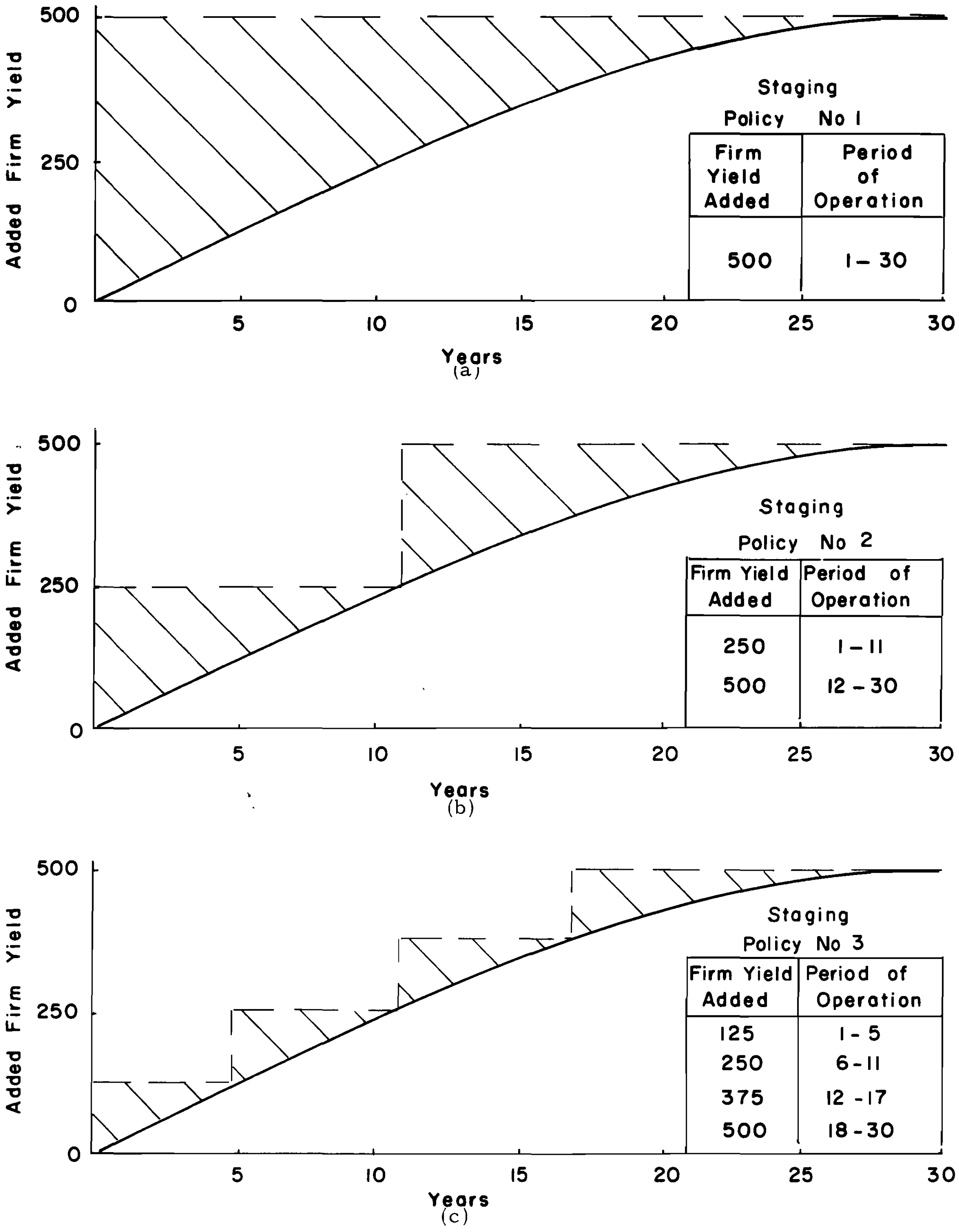
$$\Delta\overline{Y} = \overline{D}_t - \overline{Y}_o \quad \ldots\ldots (28)$$

in which

$\Delta\overline{Y}$ is total increment of yield to be added
$\overline{D}_t$ is the design demand rate (end-of-period)
$\overline{Y}_o$ is the expected firm yield of the system without any supplemental source

(b) Calculate an increment of firm yield by

$$IY = \frac{\Delta\overline{Y}}{n} \quad \ldots\ldots (29)$$



Staging Policy No 1

Firm Yield Added	Period of Operation
500	1 – 30

Staging Policy No 2

Firm Yield Added	Period of Operation
250	1 – 11
500	12 – 30

Staging Policy No 3

Firm Yield Added	Period of Operation
125	1 - 5
250	6 - 11
375	12 - 17
500	18 - 30

Figure 6. Examples of stage construction policies.

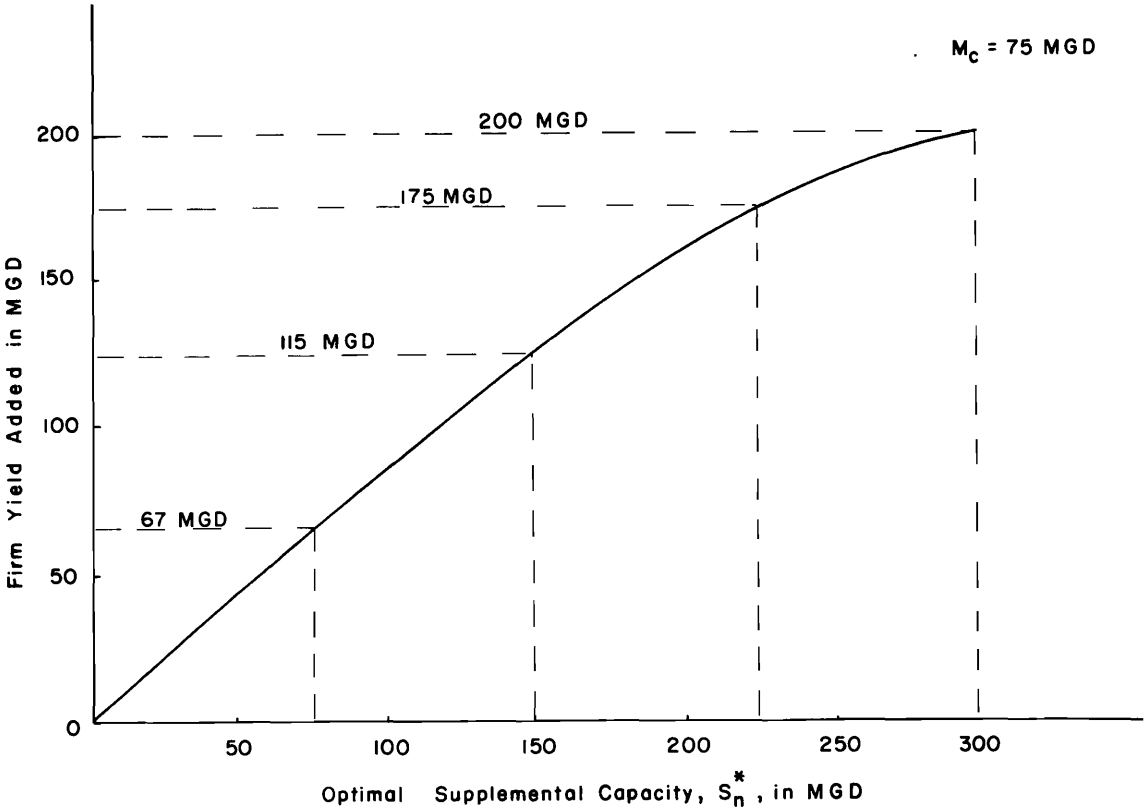


Figure 8. Determination of firm yield as modules are added.

(2) Input categories R through U a. The data for computing costs, category T, must be input in equation form.

(3) Input categories W, X.

An annualized cost is determined in a manner similar to that outlined in pp. 16-17 of Clyde and Blood (1969). However, the equation which is used to compute the uniform fixed cost must be modified for use with a stage construction policy. The capital investments in staged construction produce unequal cost streams which are annualized as follows:

$$V_p = \sum_{j=1}^{N} \frac{1}{(1+I)^j} \cdot [f \cdot k(C_m)] \qquad \text{for } k = 1,2,\ldots,n \; \ldots\ldots\ldots (32)$$

in which

V is the present value of the annual fixed charges
I is the interest rate
f is the fixed charge rate which if multiplied by the capital cost of a module gives the total annual charge for interest on initial capital, amortization of initial capital, interim replacements, taxes, and insurance

C_m is the capital cost of a module of capacity, M_c
k is the multiplier that increases the supplemental capacity in accordance with the staging policy. Thus, k is incremented each year that j equals a year in which a module is scheduled to be built
n is the number of modules

The annualized fixed cost is calculated by

$$U_f = (c.r.f.)\ V_p + I \cdot C_N \qquad (33)$$

in which

U_f is the annualized fixed cost
c.r.f. is the capital recovery factor $I(1+I)^N/(1+I)^N - 1.0$
C_N is the capital costs of nondepreciable items such as land and working capital

The stage construction analyses based on the procedure described in this section have been made for the New York City water supply system (see Work Order No. 1) and the Norfolk, Virginia, water supply system (see Work Order No. 5).

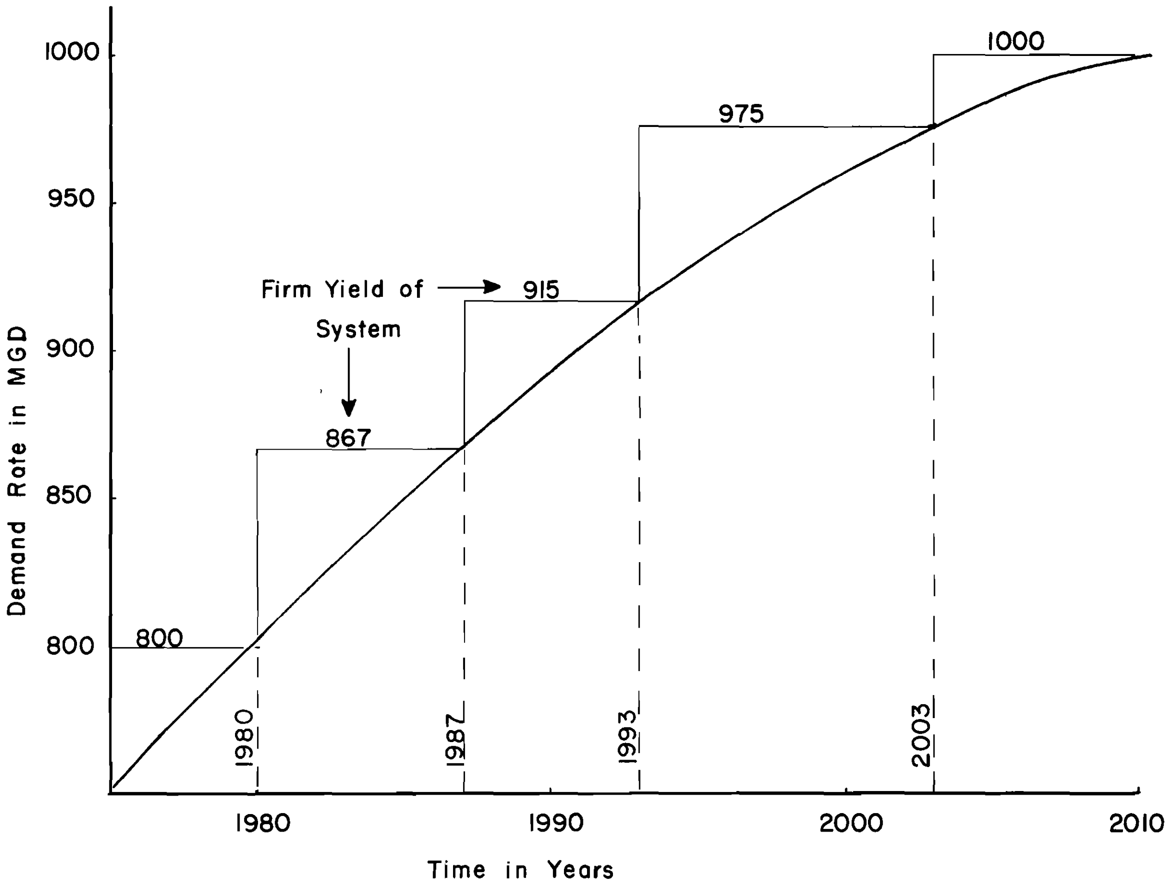


Figure 9. Determination of a staging policy.

Work Order No. 3

OPERATING RULE PROGRAM MODIFICATION FOR NO STORAGE CAPACITY SYSTEM

Introduction

Heretofore, desalting has been considered either as a base load operation or in conjunction with an existing surface water supply with some appreciable carry-over storage. In the conjunctive scheme the desalting plant is operated intermittently. The crux of the conjunctive operation problem is to find the most efficient size plant to furnish the specified requirements on firm yield. This in turn requires looking at many different operating rules and selecting the rule that will meet the requirements at the least cost.

Another application of desalting is found in the planning situation where the municipality has no appreciable storage capacity. In this case the operating rule is simple: turn on the desalting plant or a module thereof when the demand becomes greater than the available natural supply. This too is an intermittent type of operation and a modular type plant would work effectively in this situation.

General Procedure

No storage analysis is accomplished in the following steps:

1. Determine a module size.

   (a) Compute the variable D

$$D_k = \text{Max } [C - f_i(q_{i,j})k] \qquad \text{for } i = 1,2,\ldots,12 \quad j = 1,2,\ldots,NY \quad k = 1,2,\ldots,N \qquad (34)$$

in which

D_k	is the capacity of desalting plant required to prevent a deficit in the month of lowest flow, in the k^{th} generated streamflow sequence
C	is the projected consumption of water at the end of the planning period (MGD)
$q_{i,j}$	is the average monthly rate in month i of year j of the k^{th} generated streamflow sequence (MGD)
f_i	is the fraction of the natural flow rate that can be withdrawn for consumption in month i
NY	is the number of years in the planning period and the number of years of the generated streamflow sequence
N	is the number of periods

   (b) Treating the variable D_k as normally distributed compute the mean $\overline{D}$, and the standard deviation σ_D

$$\bar{D} = \sum_{k=1}^{N} D_k/N \quad \ldots\ldots\ldots\ldots (35)$$

$$\sigma_D = \sqrt{\frac{\sum\limits_{k=1}^{N} (D_k - \bar{D})^2}{N - 1}} \quad \ldots\ldots\ldots\ldots (36)$$

(c) Calculate a size of module as

$$M_s = (\bar{D} + N\delta_D)/M \quad \ldots\ldots\ldots\ldots (37)$$

in which

M_s is the module size rounded to an integer (MGD)
M is the number of modules as specified by the input parameter NMOD
N is the number of standard deviations to be added to the expected value of D as specified by the input parameter NSTD ex., if N = 0 the average value, $\bar{D}$, will be used as the required capacity of the desalting plant

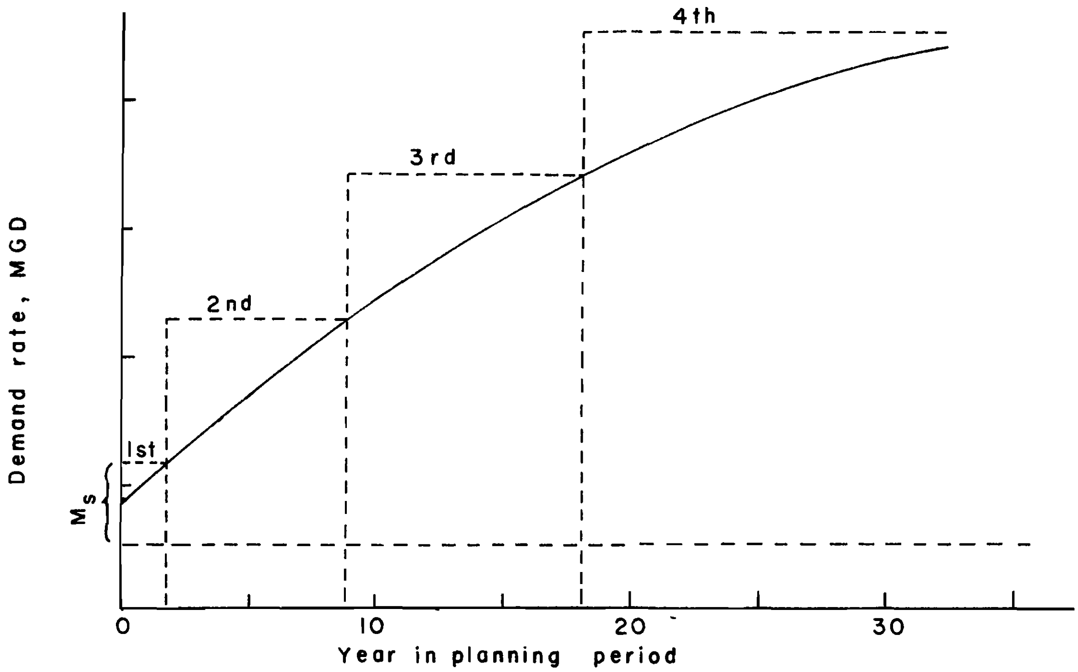


Figure 10. Graphical procedure for determining modular configuration.

2. Determine the modular configuration with respect to time based on the projected demand function. Modules are added to the plant to keep pace with the growth in demand as illustrated in Figure 10. The first module is required at the start of year 1, the second module is required at the start of year 3, the third module is required at the start of year 9, and a fourth module at the start of year 21.

3. Generate a period of streamflow and simulate operation of the desalting plant using the calculated configuration and the demand function. Record, by year, the number of months each module was in operation, and the number of modular turn-on and turn-off events.

4. Perform a cost analysis based on the simulated operation to obtain a uniform annual cost. It is required that all costs are input in equation form as a function of plant or module size. The present value of the costs are obtained as follows:

(a) Capital investments

$$P_c = \sum_{j=1}^{N} \frac{1}{(1 + I)^j} [k \, C_m] \, f \; \ldots\ldots\ldots\ldots\ldots\ldots \quad (38)$$

in which

P_c	is the present value of all capital investments
I	is the interest rate
f	is the fixed charge rate
k	is the number of modules that have been constructed by year j
C_m	is the cost of the module
N	is the number of years in the planning period

$$C_m = a(M_s)^b \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (39)$$

in which

M_s	is the module size calculated in Equation (37)
a,b	are constants specified by the input parameters CCP and EXCP, respectively

(b) Operating and maintenance costs

$$P_o = \sum_{j=1}^{N} \frac{1}{(1 + I)^j} \cdot O_c \left(\sum_{k=1}^{M} c_{k,j} \right) \ldots\ldots\ldots\ldots\ldots\ldots \quad (40)$$

in which

P_o	is the present value of all operating costs for load factors > 0 percent
M	is the number of modules comprising the desalting plant
$c_{k,j}$	is a cost coefficient obtained by linear interpolation in the two dimensional array of load factors, FACT, and coefficients, COEFF. This array is part of the necessary input data for the program.
O_c	is the modular operational cost
N,I	are the same as in Equation (38)

$$O_c = c(M_s)^d \tag{41}$$

in which

M_s is calculated module size
c,d are constants specified by the input parameters COP, and EXOP, respectively

(c) Operating costs at zero load factor

$$P_n = \sum_{j=1}^{N} \frac{1}{(1 + I)^j} (N_n)_j \, O_n \tag{42}$$

in which

P_n is the present value of all modules operating at zero load factor
$(N_n)_j$ is the number of modules, constructed, that did not operate in year j
O_n is the module operating cost at zero load factor
N,I are the same as in Equation (38)

$$O_n = e(M_s)^f \tag{43}$$

in which

M_s is the module size
e,f are constants specified by the input parameters CNO and EXNO, respectively

(d) Plant turn-on and turn-off costs

$$P_t = \sum_{j=1}^{N} \frac{1}{(1 + I)^j} \left(\frac{N_o + N_f}{2}\right)_j O_t \tag{44}$$

in which

P_t is the present value of the turn-on and turn-off costs
N_o is the number of module turn-on events
N_f is the number of module turn-off events
O_t is the cost of a module turn-on, turn-off event
N,I are the same as in Equation (38)

$$O_t = g(M_s)^h \tag{45}$$

in which

M_s is the module size
g,h are constants specified by the input parameters CTN and EXTN, respectively

5. A uniform annual cost for the period is obtained by

$$U = c.r.f.(P_c + P_o + P_n + P_t) \tag{46}$$

in which

U is the uniform annual cost
c.r.f. is the capital recovery factor $I\,(i+I)^N / [(1+I)^N - 1.0]$

6. Repeat steps (3), (4), and (5) for as many periods as specified by the parameter NPSC and obtain an average uniform annual cost

$$\bar{U} = \sum_{i=1}^{N} U_i/N \quad \text{. . . . .}(47)$$

in which

$\bar{U}$ is the average uniform annual cost
N is the number of periods specified by the parameter NPER
U is the uniform cost obtained in Equation (41)

A general logic flow chart for NOSTOR program is shown in Figure 11.

An example application of the no storage capacity analysis was made for a modified Norfolk, Virginia, water supply system. The input data and the simulation results are shown in Figures 12, 13, and 14.

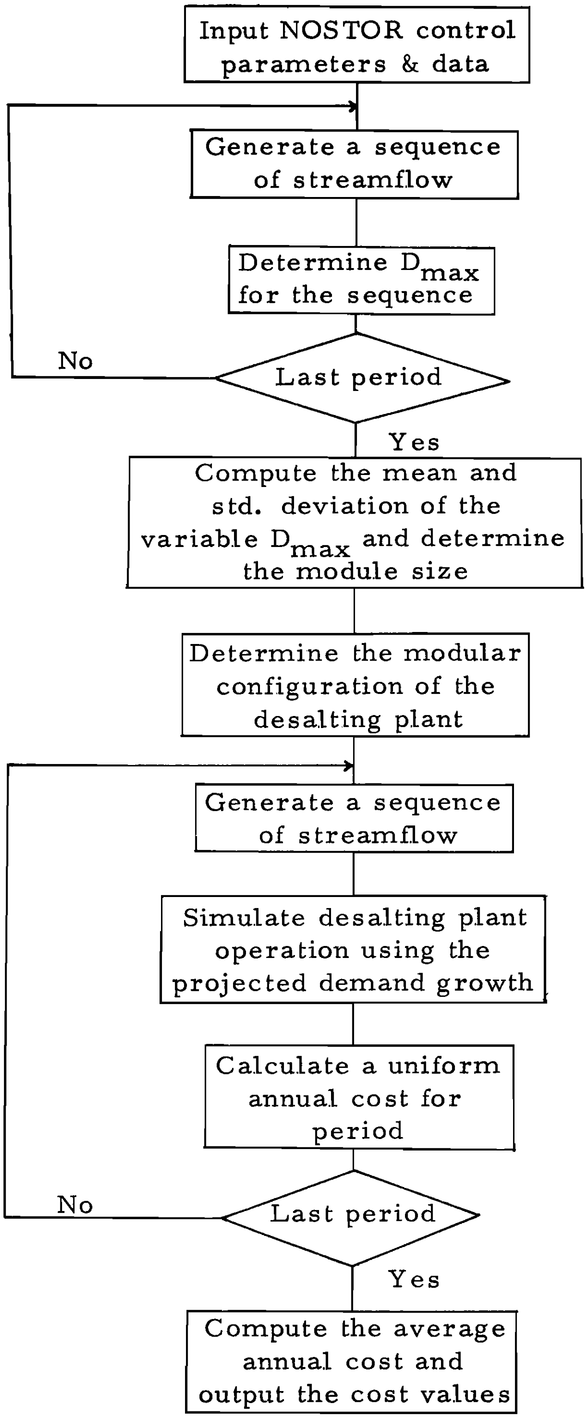


Figure 11. General logic flow for NOSTOR.

```
NO STORAGE RUN USING NORFOLK STREAMFLOW AND DEMAND

NO. OF PERIODS IN ANALYSIS=  10
NO. OF YEARS IN EACH PERIOD= 30
NO. OF PERIODS IN COST SIM=  5
IYEAR= 2
IFLOW= 1
DESIGN DEMAND RATE=    125.
KIO= 1
KIP= 2

                           OCT   NOV   DEC   JAN   FEB   MAR   APR   MAY   JUNE  JULY  AUG   SEPT

DEMAND COEFFICIENTS        1.00   .98   .98   .98   .98   .97   .96   .97  1.03  1.06   .10  1.04

STREAM DIVERSION COEFF.   1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000

DEMAND FUNCTION DATA
CODE= 2     CDEM=  125.     AD=   30.     BD= 1.5     UD=    0.     WD=    0.     AF=  .000
```

Figure 12. NOSTOR input data printout.

```
COST DATA FOR A DESIGN LOAD FACTOR OF 65.

OPERATING LOAD FACTORS ARE          0.        10.        20.        30.        50.        70.        90.       100.
THE COST COEFFICIENTS ARE         .000       .227       .429       .619      1.000      1.370      1.727      1.905


EQUATION USED IN TH COST COMPUTATIONS

OPER. AT ZERO LOAD FACTOR          COST=   4600.*S** .4690

TURN-ON AND TURN-OFF               COST=   1200.*S** .8990

OPERATING AND MAINTENANCE          COST= 105000.*S** .9040*C(I)

CAPITAL COST IN MILL. $            COST=1288000.*S** .8900

WHERE S IS THE MODULE OR THE PLANT SIZE AND C(I) IS THE INTERPOLATED COEF.


FIXED CHARGE RATE=  .08         DISCOUNT RATE=  .05
```

Figure 13. Typical NOSTOR cost printout.

```
OPERATION OF THE MODULAR PLANT FOR PERIOD NO.  5
                                                                                    Modules
    Year   Modules availabe         Months each module operated        Times ON    Times OFF   operated
     1           4                 3     2     0     0     0            3           3           2
     2           4                 3     2     0     0     0            5           3           2
     3           4                 4     3     1     0     0            4           3           3
     4           4                 3     1     0     0     0            3           4           2
     5           4                 5     3     0     0     0            4           4           2
     6           4                 5     3     1     0     0            3           5           3
     7           4                 1     1     0     0     0            2           2           2
     8           4                 4     0     0     0     0            3           2           1
     9           4                 4     2     0     0     0            4           4           2
    10           4                 2     1     1     0     0            4           2           3
    11           4                 6     4     3     0     0            6           5           3
    12           4                 6     4     3     2     0            9           8           4
    13           4                 5     3     3     2     0            1           5           4
    14           4                 1     0     0     0     0            1           1           1
    15           4                 3     1     0     0     0            3           2           2
    16           4                 5     2     1     0     0            4           3           3
    17           4                 2     0     0     0     0            2           2           1
    18           4                 5     1     0     0     0            3           4           2
    19           5                 4     2     2     0     0            6           3           3
    20           5                 6     3     1     0     0            6           5           3
    21           5                 4     3     1     1     0            3           6           4
    22           5                 6     2     0     0     0            6           4           2
    23           5                 5     3     2     0     0            6           5           3
    24           5                 2     1     0     0     0            2           3           2
    25           5                 5     2     0     0     0            3           5           2
    26           5                 6     1     0     0     0            4           3           2
    27           5                 7     3     1     1     0            8           5           4
    28           5                 8     4     2     1     0            5           6           4
    29           5                 5     3     2     0     0            6           6           3
    30           5                 6     4     2     1     0            7           6           4

COL. 1 IS THE YEAR
COL. 2 IS THE NUMBER OF MODULES AVAILABLE
THE NEXT  5 COLUMNS ARE THE NO. OF MONTHS THAT EACH MODULE OPERATED
THE LAST 3 COLUMNS ARE THE MODULE TURN-ON, TURN-OFF, AND NO. OPERATED RESPECTIVELY

   10802020.    10808786.    10902119.    11038559.    10902879.

UNIFORM ANNUAL COST=    10890873.
```

Figure 14. Typical NOSTOR simulation and results printout.

Work Order No. 4

TRAINING SEMINAR

After the publication of Utah Water Research Laboratory report PRWG61-2, "Optimum Operation of Desalting Plants as a Supplemental Source of Save Yield," numerous requests were received asking for more information about the Operating Rule Program and its practical uses. In response to these requests for information and to encourage and facilitate the use of the computer program by others, a training seminar was held May 26-28, 1970, at Utah State University jointly sponsored by the Office of Saline Water, U.S. Dept. of Interior, and Utah State University.

Objectives of the training seminar were as follows:

1. To completely describe for the participants the improved Operating Rule Program including the logic, the various program options, and the various ways of defining the firm yield of a water supply system.
2. To describe in detail the steps to be followed in applying the improved Operating Rule Program to analyze the conjunctive operation of desalting plants.
3. To describe the use of the program in finding the optimal stage construction schedule for a conjunctively operated desalting plant.
4. To give the participants some "hands on" experience in using the improved Operating Rule Program in a practical situation.

A schedule of the training seminar is shown on the following page as Table 9. Costs of instruction, the printed materials and use of the computer were met by Utah State University from funds supplied by the Office of Saline Water. Participants or their employers provided travel and living expenses. The names and addresses of the 21 participants are shown in Table 10.

Computer services for the seminar were provided by a Univac 9200 terminal utilizing a Univac 1108 computer in Salt Lake City, Utah. High priority service was arranged such that very little delay was experienced with most computations. All participants were able to analyze the conjunctive operation of a desalting plant. Teams of participants were organized and each team also carried out a stage construction analysis of a desalting plant.

After the seminar the participants were asked to send in comments and criticisms concerning the seminar and suggestions for improvements in the computer program and the program description. Based on the many thoughtful and constructive suggestions received, several substantial changes were made in the OPRUL program, especially in the format and information of the computer printout.

Copies of the report, "Optimum Operation of Desalting Plants as a Supplemental Source of Safe Yield," (Utah Water Research Laboratory Report No. PRWG61-2 or OSW R & D Progress Report No. 528) were given to the participants.

Complete computer program card decks were made available at a nominal cost to the participants who desired them.

A training manual was prepared for the seminar containing a description of the OPRUL program and its use. The title page and table of contents only are shown on the following two pages. The body of the training manual has been integrated into the appropriate sections of this report. (See Work Order 2 & Appendix A.)

Supplement to PRWG61-2

OPTIMUM OPERATION OF DESALTING PLANTS AS A SUPPLEMENTAL SOURCE OF SAFE YIELD

by

Calvin G. Clyde and Wesley H. Blood

Prepared for a Training Seminar
on the use of the
Operating Rule Program
May 26-28, 1970

at

Utah Water Research Laboratory
College of Engineering
Utah State University
Logan, Utah 84321

May 1970

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Work Order No. 5

APPLICATION OF THE OPERATING RULE PROGRAM TO THE NORFOLK, VIRGINIA, WATER SUPPLY SYSTEM

The Office of Saline Water first suggested that the Operating Rule Program be applied to the Norfolk, Virginia, water supply system. After consultation among OSW, USU, and Norfolk City, it was decided to undertake such a study. The objective of the investigation was to examine the use of a desalting plant operated in conjunction with the existing system to meet future demands. The optimal size plant and the optimal operating rule to meet demands through 2000 A.D. were to be determined. Furthermore, the optimal stage construction policy was to be investigated for the deslating plant. Effects of increased reservoir size and expansion of pumping plants upon the system were also to be studied.

Description of the Norfolk City Water Supply System

Norfolk City furnished most of the basic information describing the water supply system, the available water and the demand. Additional records of streamflow were taken from USGS Water Supply papers. A brief summary of the system is given here. A more detailed description is included as Appendix C.

The Norfolk City water supply system consists of 5 principal storage reservoirs, 2 pumping plants for importing water, several other pumping stations for distribution, several treatment plants, some wells and over 1000 miles of water mains. The system is shown in Figure 15.

The principal storage reservoirs and their capacity, drainage area and estimates of safe yield (reported by Norfolk City) are shown in Table 11. Also shown in the table are the import pumping stations and the wells near Lake Prince.

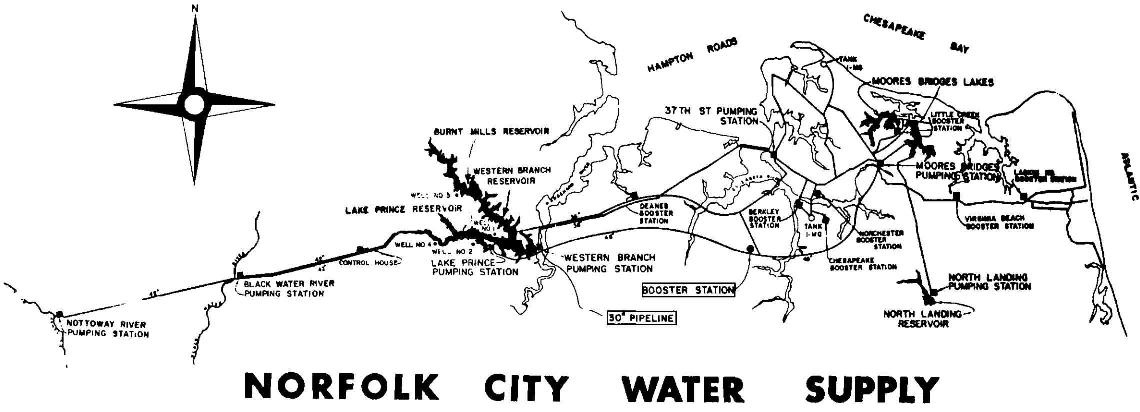


Figure 15. Norfolk City water supply system.

Table 15. **Varying operating rule costs for 60 MGD plant for three demand growth curves.**

$\overline{D}_j = 80 + 1.50j$

Time Period Years	Demand at Start of Period	Operating Rule ON	Operating Rule OFF	Yield MGD
1-6	80	0.10	0.10	9
7-12	89	.20	.10	18
13-15	98	.34	.20	27
16-24	107	.49	.40	36
25-30	116	.59	.60	45

(Average annual cost)/(Ultimate firm yield increase) = 115,935$/yr/MGD.

$\overline{D}_j = 130 - 50e^{-0.077j}$

Time Period Years	Demand at Start of Period	Operating Rule ON	Operating Rule OFF	Yield MGD
1-3	80	0.10	0.10	9
4-7	89	.20	.10	18
8-11	98	.34	.20	27
12-17	107	.49	.40	36
18-30	116	.59	.60	45

(Average annual cost)/(Ultimate firm yield increase) = 129,178$/yr/MGD.

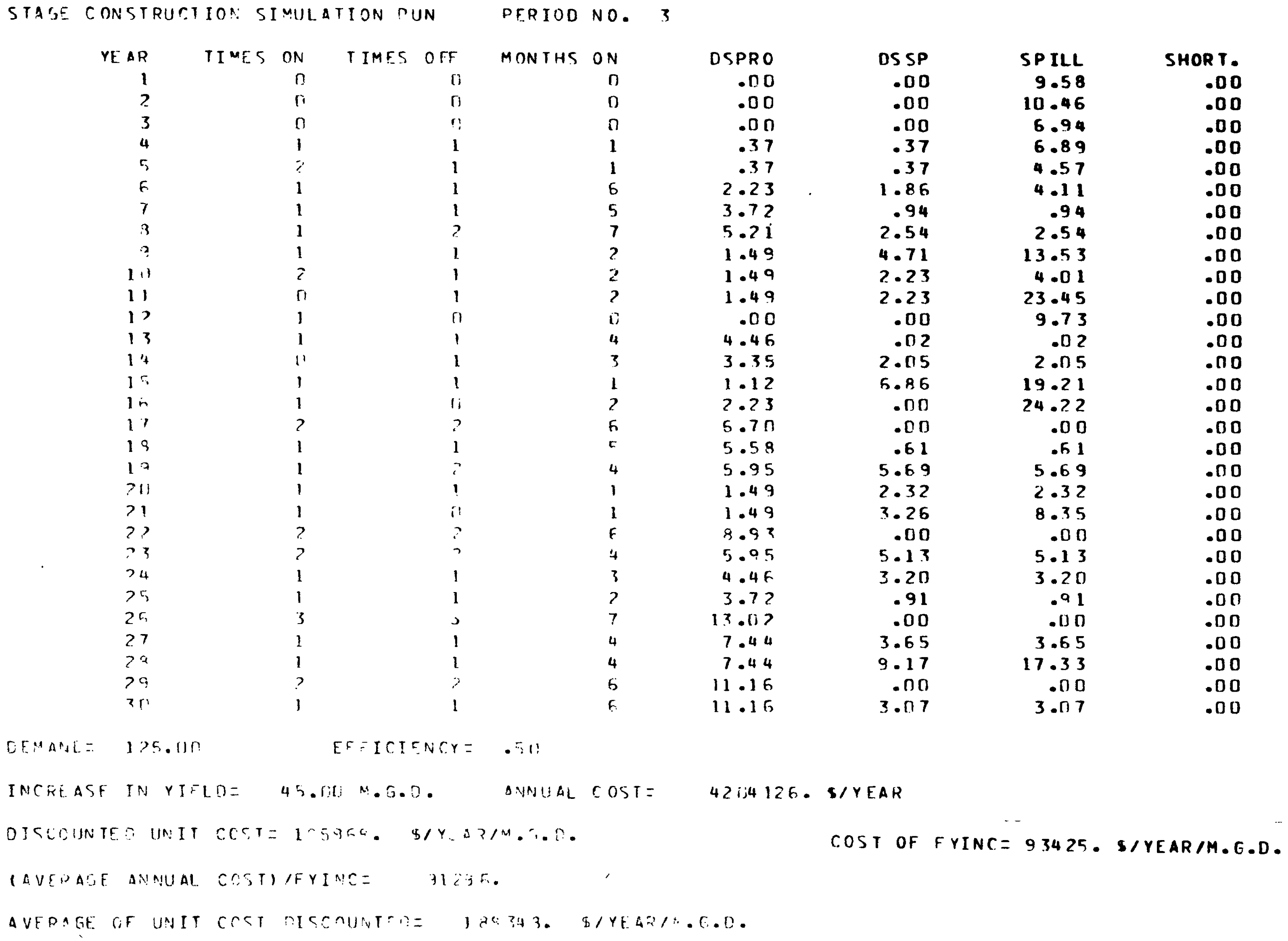
$\overline{D}_j = 60 + 20e^{0.04j}$

Time Period Years	Demand at Start of Period	Operating Rule ON	Operating Rule OFF	Yield MGD
1-9	80	0.10	0.10	9
10-16	89	.20	.10	18
17-22	98	.34	.20	27
23-26	107	.49	.40	36
27-30	116	.59	.60	45

(Average annual cost)/(Ultimate firm yield increase) = 110,550$/yr/MGD.

4. Two 70 MGD pumping plants with 15.75 BG storage. This yields 94 MGD firm yield.
5. Two 70 MGD pumping plants with 21.75 BG storage. This yields 107 MGD firm yield.

If costs of these alternatives were known the unit costs of meeting future demands could be compared with the desalting alternative. The studies mentioned in the previous sections provide only preliminary results and should be used as a basis to justify a more complete and thorough desalting feasibility investigation.



```
STAGE CONSTRUCTION SIMULATION RUN      PERIOD NO.  3

      YEAR    TIMES ON   TIMES OFF   MONTHS ON        DSPRO         DSSP        SPILL       SHORT.
         1           0           0           0          .00          .00         9.58          .00
         2           0           0           0          .00          .00        10.46          .00
         3           0           0           0          .00          .00         6.94          .00
         4           1           1           1          .37          .37         6.89          .00
         5           2           1           1          .37          .37         4.57          .00
         6           1           1           6         2.23         1.86         4.11          .00
         7           1           1           5         3.72          .94          .94          .00
         8           1           2           7         5.21         2.54         2.54          .00
         9           1           1           2         1.49         4.71        13.53          .00
        10           2           1           2         1.49         2.23         4.01          .00
        11           0           1           2         1.49         2.23        23.45          .00
        12           1           0           0          .00          .00         9.73          .00
        13           1           1           4         4.46          .02          .02          .00
        14           0           1           3         3.35         2.05         2.05          .00
        15           1           1           1         1.12         6.86        19.21          .00
        16           1           0           2         2.23          .00        24.22          .00
        17           2           2           6         6.70          .00          .00          .00
        18           1           1           5         5.58          .61          .61          .00
        19           1           2           4         5.95         5.69         5.69          .00
        20           1           1           1         1.49         2.32         2.32          .00
        21           1           0           1         1.49         3.26         8.35          .00
        22           2           2           6         8.93          .00          .00          .00
        23           2           2           4         5.95         5.13         5.13          .00
        24           1           1           3         4.46         3.20         3.20          .00
        25           1           1           2         3.72          .91          .91          .00
        26           3           3           7        13.02          .00          .00          .00
        27           1           1           4         7.44         3.65         3.65          .00
        28           1           1           4         7.44         9.17        17.33          .00
        29           2           2           6        11.16          .00          .00          .00
        30           1           1           6        11.16         3.07         3.07          .00

DEMAND=  125.00              EFFICIENCY=  .50

INCREASE IN YIELD=   45.00 M.G.D.      ANNUAL COST=     4204126. $/YEAR

DISCOUNTED UNIT COST= 105969.  $/YEAR/M.G.D.
                                                         COST OF FYINC= 93425. $/YEAR/M.G.D.
(AVERAGE ANNUAL COST)/FYINC=     91236.

AVERAGE OF UNIT COST DISCOUNTED=   189343.  $/YEAR/M.G.D.
```

Figure 25. Typical stage construction simulation and results printout.

LIST OF REFERENCES

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APPENDIX A

DETAILED DESCRIPTION OF THE IMPROVED OPERATING RULE PROGRAM AND ITS APPLICATION

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OFI2	medium flow month increment that is subtracted from the turn-off fraction (columns 9-16).
ONI3	high flow month increment that is subtracted from the turn-on fraction (columns 17-24).
OFI3	high flow month increment that is subtracted from the turn-off fraction (columns 25-32).

P. Arguments for random number generator.

IYPER	arguments used in RAN which enable repetitive generation of streamflow sequences must be supplied if KREAD set to 1, 3, or 4 (6 values per card, 6I15, right justified). The number of values entered is the same as the number specified by NPFY.

Q. Variable operating rule schedule.

NVYR	number of times that the operating rule is changed during the period, entered if KVAR=2 (column 1).
KVYR	array of years within the period that signifies a change in the operating rule if KVAR=2 (10I2, starting in column 6).

R. Stage construction schedule.

NMOD	number of modules that comprise the ultimate plant, input if STAGE=2 (column 1).
MODY	schedule of years, within the period, that a new module is added (ex., 1, 6, 11, 16, 21), must be input if STAGE=2 (10I2, starting in column 6).
SIZE	(NMOD) module sizes, input if STAGE=2 (10F8.0).
YLDIN	(NMOD) firm yield increases, input if STAGE=2 (10F8.0).

S. Operating rules for the staged construction.

RFOP	array of operating rules for each period when a module is added to the plant. RFOP(1) is the turn-on fraction for period 1, RFOP(2) is the turn-off fraction for period 1, etc. There must be NMOD pairs entered in RFOP (16F5.0).

T. Desalting plant cost data.

(a) Design (optimized) load factors.

NOLF	number of design load factors for which cost data are to be input (columns 1-2, right justified).
OFACT	array of the design load factors (8F5.0, starting in column 6).

(b) Operational load factors.

NOFF	number of operational load factors for which cost data are to be entered (columns 1-2, right justified).
FACT	array of the operating load factors (8F5.0, starting in column 6).

(c) Operating and maintenance cost.

OPCST	if KCOPT=1, a two-dimensional array (NOFF, NOLF) of operational costs in dollars. NOLF cards are required with NOFF entries per card (8F10.0). if KCOPT=2, a two-dimensional array (NOFF, NOLF) of coefficients used in the equation for computing operational costs (8F10.0).

(d) Interest and fixed charge.

INT	interest rate used in discounting cost streams to the present expressed as a decimal fraction; i.e., 5 percent is 0.05 (columns 1-10).
RATE	fixed charge rate expressed as a decimal fraction; i.e., 12 percent is 0.12 (columns 11-20).
CCND	capital cost of nondepreciable items.

(e) Capital costs, input only if STAGE=2.

CSTM	capital cost of a module, input if STAGE=2 (8F10.0).
CAPC	array of the capital costs of the plants designed at the NOLF different load factors (8F10.0).

(f) Plant turn-on and turn-off costs, if KCOPT=1.

ETONC	estimated cost for turning on the plant in dollars (columns 1-10).
ETOFC	estimated cost for turning off the plant in dollars (columns 11-20).

(g) Constants and exponents of cost equations, if KCOPT=2.

CNO	constant in the equation for computing operating costs at zero load factor (columns 1-10).

EXNO	exponent of plant size in the zero load factor operating equation (columns 11-20).
CTN	constant in the equation for computing on and off costs (columns 21-30).
EXTN	exponent of plant size in the on-off cost equation (columns 31-40).
COP	constant in the equation for computing yearly operating costs for load factors > 0 (columns 41-50).
EXOP	exponent of plant size in the operating cost equation (columns 51-60).

U. Firm yield data if KREAD=3.

FYWO	the expected value of the firm yield of the system without any desalted supplement (columns 1-10).
MSCP	array of starting points for the critical segment of each period of generated flow, input if KVAR≠2 or STAGE≠2 (16I5, right justified).
MECP	array of ending points for the critical segments of each period of generated flow, input if KVAR≠2 or STAGE≠2 (16I5, right justified).
DDCP	array of initial estimates of the yield for each period. Used in the iteration procedure, input if KVAR≠2 or STAGE≠2 (8F10.0).

The above variables are all obtained from some previous computer run when KREAD was set at 2.

V. Firm yield data if KREAD=1.

AVFY	array of expected (average) firm yield values, contain NR values eight per card (8F10.0).
XLF	array of expected average yearly operational load factors, contains NR values eight per card with XLF(1)=0.0; i.e., operation w/o desalting (8F10.0).
GLF	array of expected gross load factors, contains NR values eight per card with GLF(1)=0.0 (8F10.0).

W. Start-of-period reservoir contents.

RS	array of reservoir start-of-period contents as determined in firm yield analysis (8F10.0).

X. Input data to the streamflow generator GNFLO.

(a) Identification card. Contains hollerith information to identify the data being used.

Must have an A in column 1.

(b) Control parameters (all right justified).

IYRA	earliest year of record at any station for which flows are to be generated (columns 2-8).
IMNTH	calendar month number of first month of year being used (columns 9-16).
IMSNG	indicator, any positive number for estimating missing correlation coefficients (columns 17-24).
ITEST	indicator, any positive number calls for consistency test of correlation matrices (columns 25-32).
IRCON	indicator, any positive number calls for reconstitution of missing data (columns 33-40).
NSTA	number of streamflow stations at which flows are to be generated (columns 41-48).
IPCHQ	indicator, any number greater than 0 calls for outputing the generated flows on magnetic tape (columns 49-56).

(c) Historic streamflow data.

ISTAN	station number (columns 1-6, right justified).
IYR	year (columns 11-14).
QM	array of monthly streamflows (12F5.0, starting in column 15).

Repeat (c) for each year of streamflow to be entered.

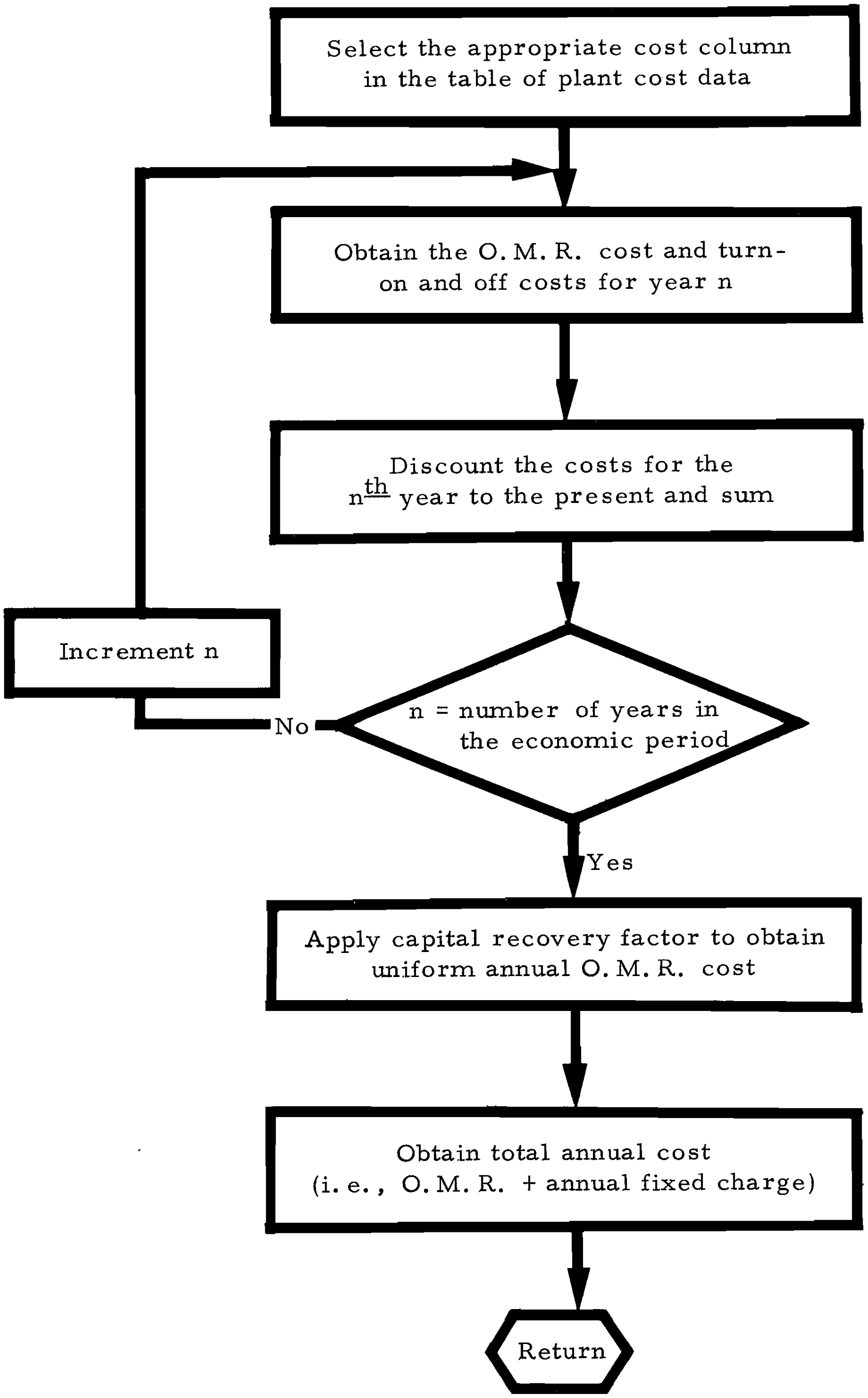
(d) Blank card, terminates the streamflow input.

Y. Factors for escalating prices, if KESC=2 and if STAGE=2.

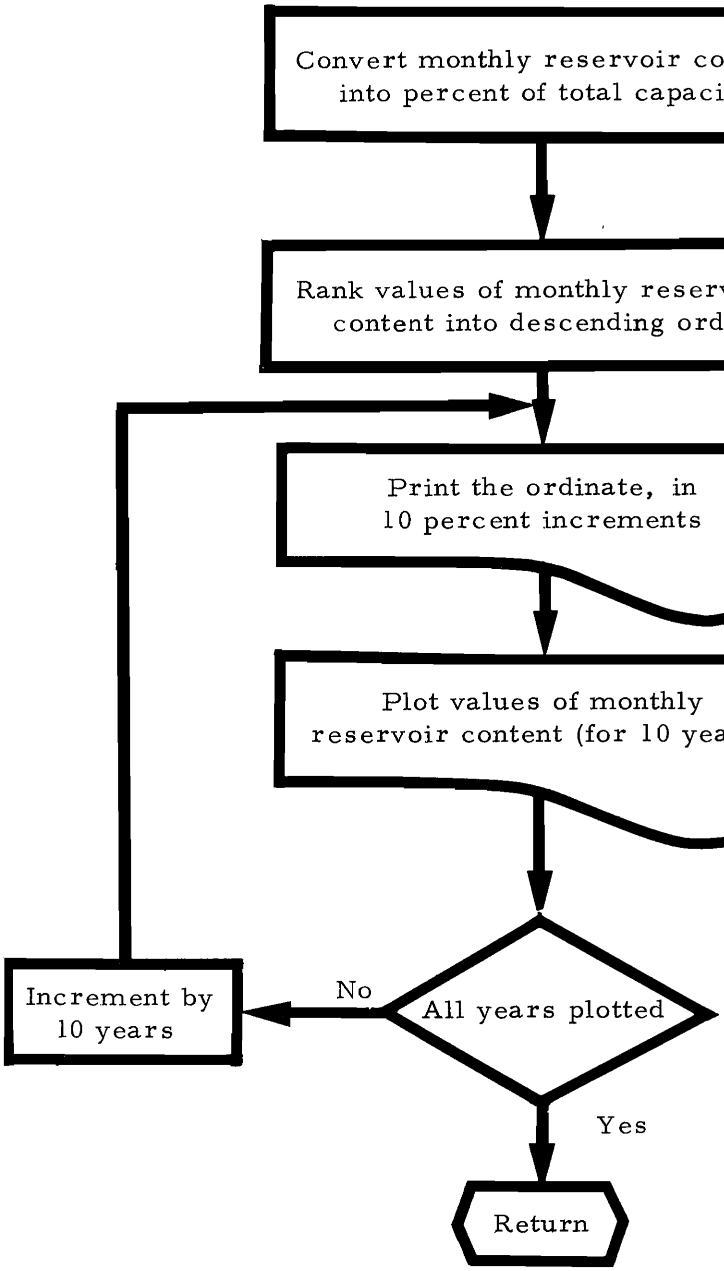
EFO	escalation factor for operating costs (columns 1-10).
EFC	escalation factor for construction costs (columns 11-20).
EFI	escalation factor for the interest rate (columns 21-30).

TERP	entered to perform a linear interpolation in the elevation-capacity-surface area tables. The tables must be arranged with the elevation and corresponding capacity and water surface are in ascending order. The increments should be small enough to adequately describe the curves.
TERP3	interpolates in the three-dimensional array of average firm yield values to determine the set of feasible operating rules. The argument is the projected target demand rate (TRDEM). Each turn-off fraction, in turn, is held constant and the interpolation performed to obtain a turn-on fraction. The number of interpolations attempted is always the same as the number of turn-off fractions specified by NOF. The general logic flow diagram of TERP3 is shown on page 84.
XLOC	for a given period of generated streamflow, XLOC is entered to identify the critical segment of the record. Subsequent iterations are performed using the critical segment and not the entire period.
YIELD	simulates system operation, using a generated streamflow sequence to determine the firm yield of the system for the various operating rules specified in the decision set of rules. An iteration scheme is employed which involves entering subprogram XLOC to identify the critical period of the streamflow sequence and performing an iteration over this period until the defining constraints on firm yield are satisfied. A firm yield of the system w/o desalting is determined unless input paramter KREAD is set to 3. The general logic flow diagram of YIELD is shown on page 85.

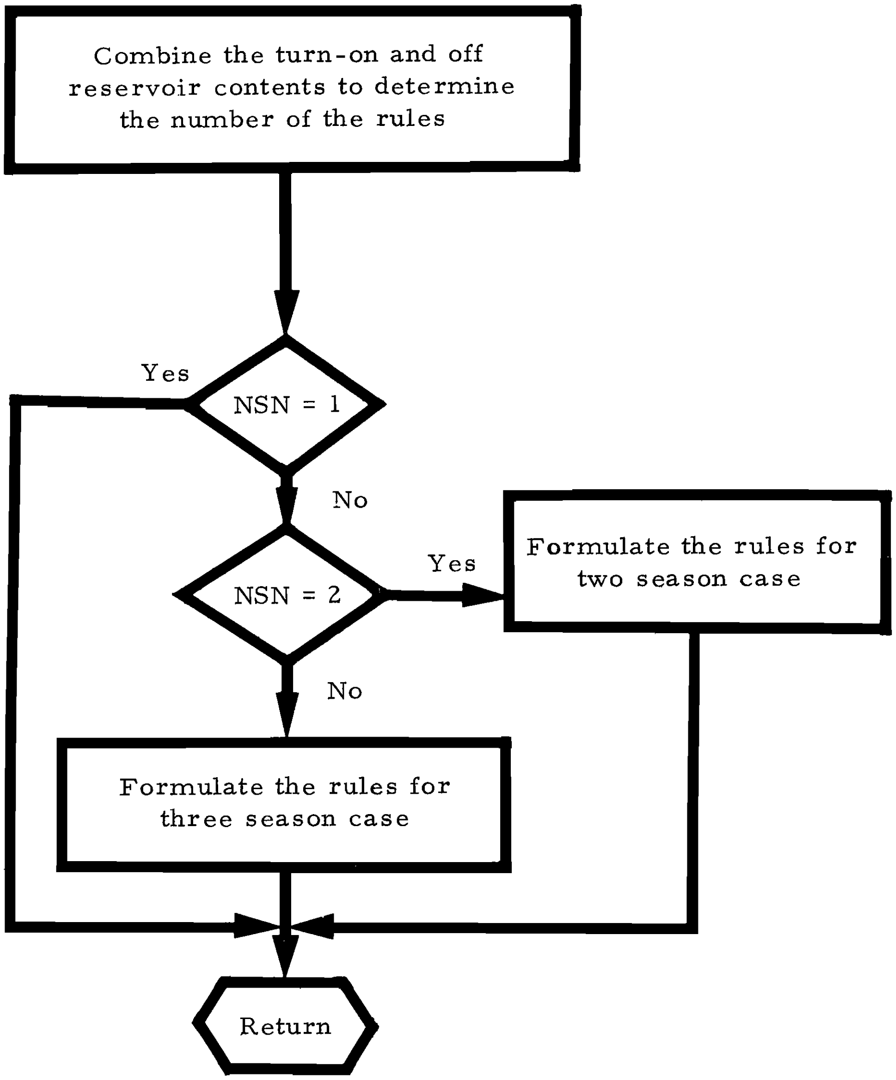
SUBPROGRAM COST FLOW DIAGRAM



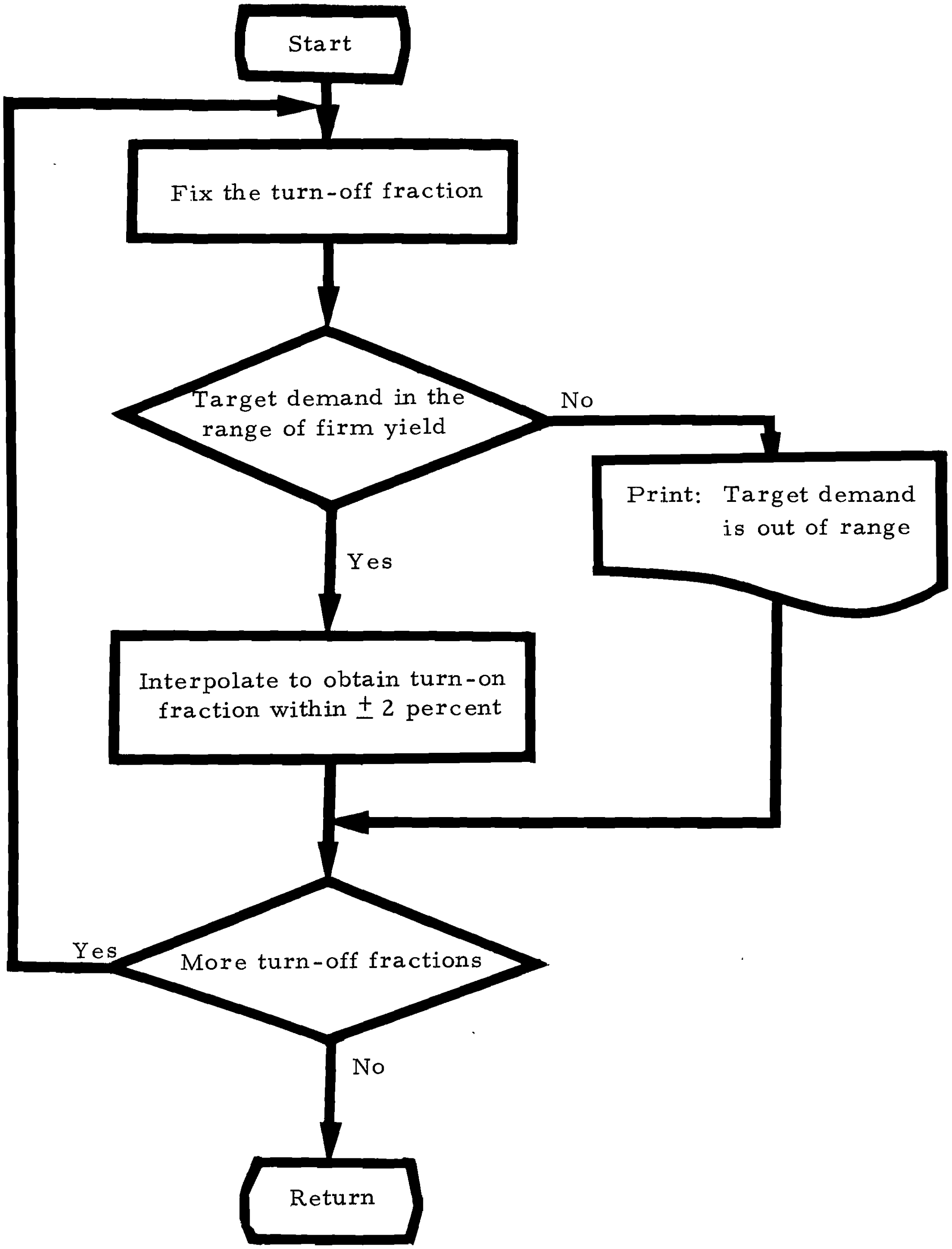
SUBPROGRAM PLOT FLOW DIAGRAM



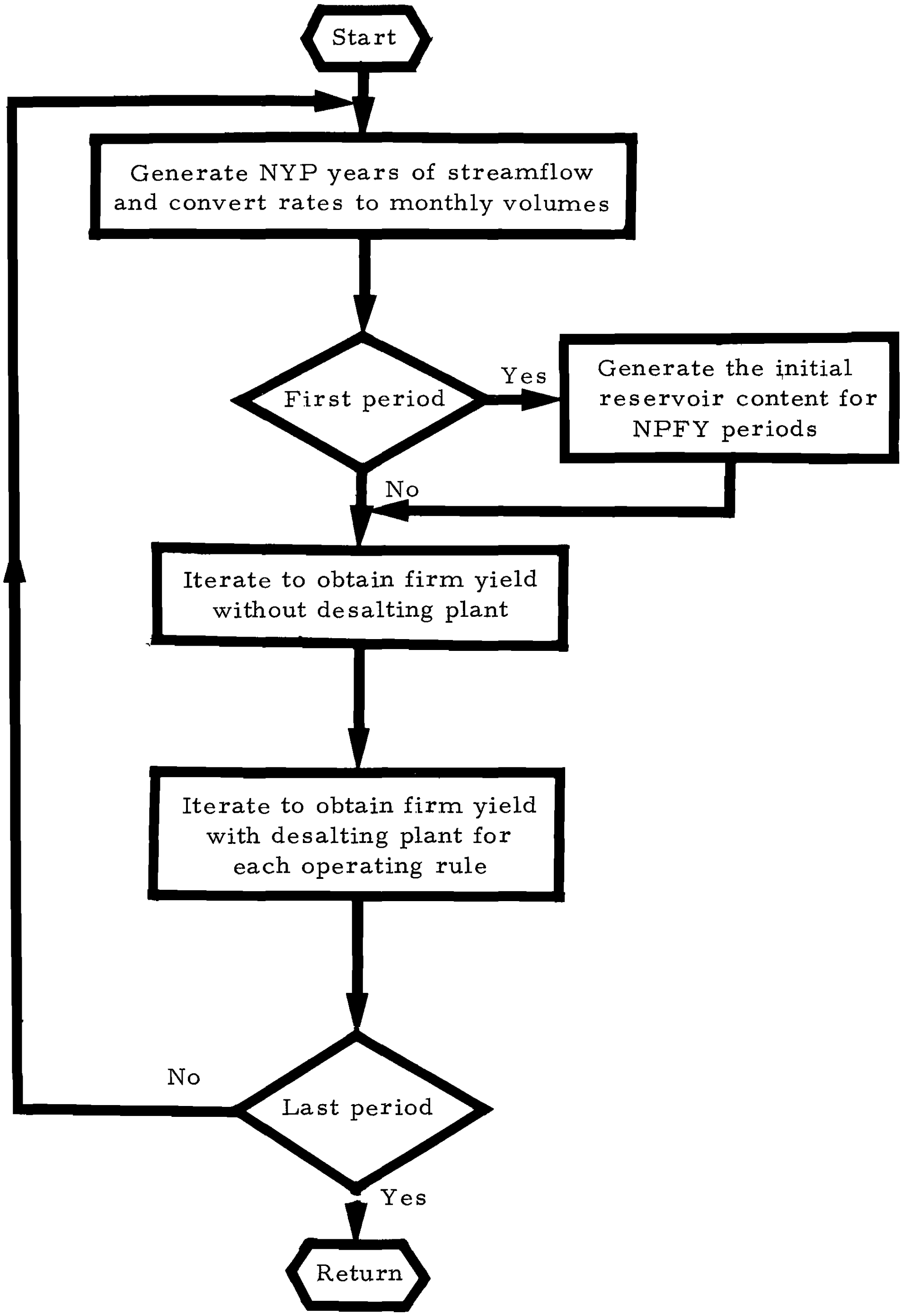
SUBPROGRAM RULE FLOW DIAGRAM



SUBPROGRAM TERP3 FLOW DIAGRAM



SUBPROGRAM YIELD FLOW DIAGRAM



LISTING OF SAMPLE INPUT DATA CARDS

```
A        NEW YORK STUDY WITH A 400 M.G.D. DESALTING PLANT     FY=100

B      5    30     5    75    24     5 489.5     20.0       400.       0.15

C    2 4 2 2 1 2 2 1 1 2 1 1 2 2

D   2350.      .980 .985 .973 .961 .968 1.0331.0561.0491.0361.000.976 .941

E    1         1785.0    1525.0    15.0

F   0.0       2.6       10.3      15.7      17.3      20.4      28.2      38.4      51.8      66.7
    85.6      106.0     128.0     151.4     176.5     204.0     233.9     264.4     297.4     332.7
    370.0     407.9     448.0     491.0

G   0.0       118.      471.      794.      2239.     3967.     6573.     8178.     9212.     11473.
    12812.    13786.    14700.    15906.    17109.    18315.    19307.    20235.    22009.    23390.
    24037.    24878.    25632.    26506.

H       3.60  .50  .40

I       3.70  .60  .50

J   .65       1.0       .05

K   296.5     .07  .09  .15  .15  .18  .30  1.81 3.30 2.63 2.69 .55  .06

L       1    2    2    3    4    5    5    4    3    2    1    1

M       3    2    2    3    3    2    1    1    1    1    1    2    2

N   0.0      1    1    1    1    1    1    1    1    1    1    1    1

O   .05       .05       .10       .10

P            798531     30642311515     304831194     18029102224     17838365287

Q   6      1  712192428

R   6      1  611162126

S   .78  .65  .78  .65  .78  .65  .79  .65  .79  .65  .79  .65

T (a) 5    30.  40.  50.  60.  70.

  (b) 8    0.   10.  20.  30.  50.  70.  90.  100.

           ACTUAL COST
  (c1)135000.   4452000.  8427000.  12398000. 20339000. 28280000. 36018000. 39987000.
      135000.   4280000.  8065000.  11850000. 19418000. 26987000. 34355000. 38081000.
      135000.   4104000.  7703000.  11302000. 18498000. 25693000. 32689000. 36407000.
      135000.   3956000.  7465000.  10973000. 17987000. 24997000. 31809000. 35265000.
      135000.   3910000.  7228000.  10643000. 17474000. 24300000. 30929000. 34304000.

           COEFFICIENTS
  (c2)0.0       0.218     0.649     1.061     1.376     1.753     2.256
      0.00      0.212     0.626     1.032     1.336     1.706     2.204
      0.0       0.206     0.604     1.000     1.296     1.659     2.143
      0.0       0.194     0.567     0.939     1.218     1.564     2.024
      0.0       0.184     0.535     0.887     1.150     1.482     1.923
      0.0       0.175     0.508     0.884     1.093     1.413     1.840
```

```
  (d)0.05      0.08

  (e)17118000. 17895000. 18673000. 19300000. 19923000.

  (f)250000.   250000.

  (g)2985.     0.6504    1791.     .67.      74100.    0.964     0.44      0.995

U (a)1525.30
  (b)  64   48    4   20    1
  (c)  867  663  159  447  101
  (d)1511.24   1550.55   1538.18   1526.37   1500.17

V    1525.30   1853.12   1794.91   1740.91   1779.20   1720.15   1666.95
     .00       57.64     42.30     31.97     58.64     44.30     26.92
     .00       57.16     44.70     34.76     30.93     21.76     13.60

W    486.97    476.19    240.36    159.70    415.90

X    A    NEW YORK STREAM FLOW DATA       10-6-1969
         1928         1         0         1         0         1         0
     480826      1929 66.9 99.8 93.0139.9122.6153.5108.7 95.8 45.1 13.2 13.1 28.5
     480826      1929 54.3 51.2213.2226.3127.0 30.9 14.7  6.3  3.9 51.4 54.9 83.3
     480826      1930 84.5 74.3170.7 83.9 39.3 63.0 15.7  8.1  7.4  4.2 17.3 19.4
     480826      1931 16.3 26.7 96.5271.0140.3 79.6 80.5 18.7 11.2  7.3 11.4 44.4
     480826      1932124.1 85.9 66.4158.0 61.3 44.9 20.7  9.4  3.4117.8162.8 41.4
     480826      1933 56.8 49.7126.3215.9 51.7 14.7  6.7133.5104.0 40.7 40.8 55.9
     480826      1934 91.4 21.5118.6170.6 72.7 26.7 15.6 12.5 72.6 54.7 85.7109.0
     480826      1935 37.0 44.7141.0107.8 74.3 32.8 99.2 11.9  7.8 19.8116.7 56.8
     480826      1936 66.9 30.2399.7151.3 39.0 21.1  6.6 13.5  9.9 29.0 58.4103.4
     480826      1937168.7104.8 67.4154.7127.7 62.5 32.8 49.3 62.6102.7101.9 75.8
     480826      1938 36.3 63.4 93.2 84.7 55.4 56.9119.5 90.9155.8 38.1 61.7155.6
     480826      1939 49.0123.1139.0111.2 33.8 11.4  6.5  7.3  6.4 23.0 57.4 43.0
     480826      1940 27.3 22.7116.5337.9136.7 59.9 25.5  8.8 21.7 11.3 60.1 98.7
     480826      1941 53.6  7.3 53.5142.5 31.2 24.2 16.8 17.9  3.7  5.7 20.7 66.5
     480826      1942 51.5 78.8176.1109.2 85.1 44.0 18.6 24.4 57.4 79.2107.0121.9
     480826      1943 79.5 95.9174.6122.1135.8 67.9 16.5  8.3  4.3 36.7 97.3 29.7
     480826      1944 21.1 13.2125.4147.2 62.7 25.6 11.5  8.7 24.8 17.5 43.5 79.7
     480826      1945 77.3 62.6269.[illegible] 98.0155.2 61.3122.4 43.7 54.3 75.7102.4 81.0
     480826      1946109.0 36.8150.4 41.6127.3 84.7 32.7 18.7 16.5 27.7 18.9 26.6
     480826      1947 96.8 53.4135.1174.4171.9 60.2 49.7 24.3 12.4  7.4 89.6 42.1
     480826      1948 25.5 71.1266.0151.1119.1 72.5 28.8 12.0  2.5  6.1 47.5118.3
     480826      1949175.6100.3 80.6 89.6 92.7 18.3  6.2  6.4 11.6 10.4 26.2 81.2
     480826      1950105.1 58.0139.7171.4 85.3 59.8 34.4 26.4 24.0 14.6122.3161.0
     480826      1951115.7143.0161.2185.9 41.6 31.8 48.2 22.3 18.1 45.5152.4122.2
     480826      1952137.5 79.3139.1204.1107.1 75.0 54.0 23.4 29.5  6.8 53.2144.0
     480826      1953135.1 97.7190.2143.8116.4 21.0 10.7  6.1  7.5 11.6 39.6109.8
     480826      1954 55.8105.4113.2 97.3129.8 27.6  7.5  8.4 27.9 19.6129.7115.0
     480826      1955 54.7 64.5154.9116.0 43.4 33.6  6.9155.2 22.8289.5155.5 41.4
     480826      1956 45.9 56.3131.5288.0 93.1 43.6 20.2  7.9 26.3 26.0 53.7107.9
     480826      1957 70.5 50.3 83.2141.9 75.6 17.9  9.0  3.7  4.0  8.8 31.5171.7
     480826      1958 81.9 46.0 94.6331.5121.7 37.3 18.8  8.7 16.6 53.8 99.6 53.9
     480826      1959 91.3 49.3 99.4153.9 45.2 18.6  9.3  9.2 12.0101.7141.8142.7
     480826      1960 92.4108.5 86.3211.5 66.1 60.0 32.9 25.1123.0 36.4 44.3 37.3
     480826      1961 24.2125.3151.0200.9106.3 57.9 23.1 21.8 10.2  5.2 21.7 29.3
     480826      1962 95.9 30.8127.3197.0 45.8 13.6  4.1  5.3  3.3 18.9 56.6 67.8
     480826      1963 34.7 26.5172.0110.0 49.6 26.5 17.4 16.3  7.1  4.9 56.5 62.7
     480826      1964109.7 46.9204.1130.7 43.1 11.6  7.5  2.3  0.1  1.7  3.9 29.3
     480826      1965 33.4 90.6 55.3117.5 41.4  9.9  3.8 11.7 16.6 37.5 29.5 49.4
     480826      1966 35.1 61.5167.2 69.5 67.0 37.0  3.6  2.4 10.5 17.3 53.2 47.3
     480826      1967 71.1 54.0106.9162.8 98.2 45.1 23.7 23.4 11.6 36.6 68.1 93.0
     Blank Card To Terminate Stream Flow Data
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TYPICAL PRINTOUT

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                ***** OPERATING RULE PROGRAM *****

                      OFFICE OF SALINE WATER

             UNITED STATES DEPARTMENT OF INTERIOR


             PROJECT NAME .
                  OPTIMUM OPERATION OF DESALTING PLANTS AS
                  A SUPPLEMENTAL SOURCE OF SAFE YIELD.

             CONTRACT NUMBER .  14-01-0001-1711

                  A COMPUTER PROGRAM DEVELOPED BY
                  UTAH WATER RESEARCH LABORATORY
                      UTAH STATE UNIVERSITY
                            JULY 1969

             PROJECT STAFF.
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                ROLAND W. JEPPSON     ASSOCIATE PROFESSOR
                JAMES H. MILLIGAN     RESEARCH ENGINEER
                WESLEY H. BLOOD       RESEARCH ENGINEER
                                      AND PROGRAMMER


    CON-ED STUDY VTE DESALTING PLANT

NO.OF PERIODS IN SIMULATION=  5          NO. OF YEARS IN EACH PERIOD=  30
NO.OF PERIODS IN FIRM YIELD=  5          NO.OF YEARS IN EACH PERIOD=  75

NPRC= 24
CMAX=489.600 B.G.
CMIN= 20.000 B.G.
DSCAP=300.00 M.G.D.
FORCE= 1
KIO= 1
KPC= 2
KIP= 2
KREAD= 2
IFLOW= 4
ISTOR= 2
IYEAR= 2
KIK= 1
KESC= 2
NRSC= 10
STAGE= 1
KVAR= 1
KYLD= 1
FDT=  .15
KCOPT= 2

DESIGN DEMAND RATE= 1785.          DEMAND CODE= 1
AD= 1335.     BD= 1.50     UD=     0.     WD=     0.     AF=  .000

DEMB=2350.000 M.G.D.
RBAR= 296.500 M.G.D.


DEMAND COEFFICIENTS          .98   .98   .97   .96   .97  1.03  1.06  1.05  1.04  1.00   .98   .98

RELEASE COEFFICIENTS         .07   .39   .15   .15   .18   .30  1.81  3.30  2.63  2.69   .55   .06

EVAPORATION COEFFICIENTS    1.00  2.00  2.00  3.00  4.00  5.00  5.00  4.00  3.00  2.00  1.00  1.00

MAXY=  0

PERIOD=  1           IY=          7985 31
```

```
SEASON 2 ON=154.75 M.G.          OFF=278.28 M.G.
SEASON 3 ON=160.9  M.G.          OFF=254.30 M.G.
PERIOD NO.= 1      RULE NO.=  3
YIELD= 1723.99       FREQ= 97.       PI=170.0       AVDUR=1.0       ALOAD= 45.3       GLOAD= 22.3       ITERATIONS=  2


  KREAD=1 TEST RUN

NO.OF PERIODS IN SIMULATION=  1            NO. OF YEARS IN EACH PERIOD=  30
NO.OF PERIODS IN FIRM YIELD=  5            NO.OF YEARS IN EACH PERIOD=  75

NPRC= 24
CMAX=489.600 M.G.
CMIN= 20.000 M.G.
DSCAP=400.00 M.G.D.
FORCE= 1
KTO= 1
KPC= 1
KIP= 2
KREAD= 1
IFLOW= 4
ISTOR= 2
IYEAR= 2
KIK= 1
KESC= 2
NRSC=  5
STAGE= 1
KVAR= 1
KYLD= 1
FDT=  .15
KCOPT= 1

DESIGN DEMAND RATE= 1785.          DEMAND CODE= 1
AD= 1525.      RD=15.00      UD=      0.      WD=      0.      AF=  .300

DEMB=2350.000 M.G.D.
RBAR= 296.500 M.G.D.


THIS IS A 3 SEASON RUN
AVE. SEASON ON INC= .050           AVE. SEASON OFF INC= .050
WET SEASON ON INC.= .100           WET SEASON OFF INC.= .100

                                   JAN    FEB    MAR    APR    MAY   JUNE   JULY   AUG   SEPT   OCT    NOV    DEC
MONTHLY SEASON ASSIGNMENT           2      2      3      3      2      1      1      1      1      1      2      2

DEMAND COEFFICIENTS                .98    .98    .97    .96    .97   1.03   1.06   1.05   1.04   1.00    .98    .98

RELEASE COEFFICIENTS               .07    .09    .15    .15    .18    .30   1.81   3.30   2.63   2.69    .55    .06

EVAPORATION COEFFICIENTS         1.00   2.00   2.00   3.00   4.00   5.00   5.00   4.00   3.00   2.00   1.00   1.00

TURN-ON FRACTIONS        .80   .40
TURN-OFF FRACTIONS       .30   .60   .40

START= .65
PCF=1.00


                                        DESALTING PLANT COST DATA

OPER. L. F.        ANNUAL COST IN $/YR. FOR THE PLANT THAT IS OPTIMIZED AT THE GIVEN LOAD FACTOR (IN PERCENT)
(IN PERCENT)

                            30.         40.         50.         60.         70.

     0.                   135000.     135000.     135000.     135000.     135000.

    10.                  4453000.    42[illegible]000.   4104000.    3956000.    3813000.

    20.                  8427000.    [illegible]   7793000.    7466000.    7228000.

    30.                 12722000.  11[illegible].  11307000.  10973000.  10643000.

    50.                 [illegible].  184[illegible].  1[illegible]2000.  17897000.  17474000.
```

```
    70.              28287000. 26987000. 25693000. 24997000. 24300000.

    90.              36019000. 34355000. 32589000. 31809000. 30929000.

   100.              39987000. 38781000. 36407000. 35265000. 34304000.

ANNUAL FIXED CHARGE  17118000. 17846000. 18673000. 19307000. 19923000.

ESTIMATED TURN-ON COST=  250000.
ESTIMATED TURN-OFF COST= 250000.

FIXED CHARGE RATE= .0800
THE INTEREST RATE= .0500

AVERAGE FIRM YIELD
   1525.30    1853.12    1794.91    1740.91    1778.20    1720.15    1666.95

AVERAGE LOAD FACTORS
        .00      57.64      42.35      51.97      58.64      44.30      26.92

GROSS LOAD FACTORS
        .00      57.16      44.36      34.76      30.93      21.76      13.60



MAXIMUM VALUE OF CURVE 3 LESS THAN TRDEM



INTERPOLATED TURN-ON FRACTIONS
       .436         .747          .000

INTERPOLATED AVERAGE LOAD FACTORS
      58.55      42.57         .00



RULE NO.= 2          PERIOD NO.= 1

        YEAR     TIMES ON    TIMES OFF    MONTHS ON       DSPRO        DSSP       SPILL      SHORT.
           1            1            0            3       36.80         .00      190.52         .00
           2            1            1            7       84.80         .00         .00         .00
           3            1            2            6       72.40         .00         .00         .00
           4            1            1            2       24.40      194.00      359.87         .00
           5            1            0            2       24.40       24.40      330.99         .00
           6            1            1            8       97.20         .00         .00         .00
           7            1            1            8       97.20         .00         .00         .00
           8            2            2            5       60.40       74.71       74.71         .00
           9            0            1            2       23.60      134.75      533.78         .00
          10            1            1            3       35.40         .00      455.53         .00
          11            2            1            5       60.00       10.76       10.76         .00
          12            1            2            4       48.80       22.17       22.17         .00
          13            1            1            4       48.80      112.28      197.39         .00
          14            0            0            0         .00       48.80       54.49         .00
          15            1            1            4       48.80         .00      317.76         .00
          16            1            0            4       48.80       48.80      172.81         .00
          17            1            2            6       72.80         .00         .00         .00
          18            1            0            5       61.20      121.60      274.30         .00
          19            1            1            8       97.20         .00         .00         .00
          20            1            2            8       96.80         .00         .00         .00
          21            2            1            4       48.00       78.64       78.64         .00
          22            1            1            6       72.40       20.13       20.13         .00
          23            1            1            7       84.80         .00         .00         .00
          24            1            2            5       60.40      148.82      148.82         .00
          25            1            1            4       48.80       14.43       14.43         .00
          26            1            0            5       61.20       88.28       88.28         .00
          27            1            1            6       72.40       36.24       36.24         .00
          28            1            2            3       35.60      142.57      167.65         .00
          29            1            0            5       61.20       12.00      105.12         .00
          30            1            2            6       72.80       43.26       43.26         .00

DEMAND= 1785.00          EFFICIENCY=  .22

INCREASE IN YIELD=  259.70 M.G.D.      ANNUAL COST=17309766.0 $/YEAR      COST OF FYINC= 66653. $/YEAR/M.G.D.

AVERAGE COSTS FOR FEASIBLE OPERATING RULES
  44748.1943  66652.9307************
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MINIMUM COST OF FYINC= 44745. $/YEAR/M.G.D. ADDED FIRM YIELD

INCREASE IN FIRM YEILD= 259.70 M.G.D.

TURN ON=    .44            TURN OFF=    .80

DESIGN LOAD FACTOR=58.5      GROSS LOAD FACTOR=33.3
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  SINGLE PLANT WITH A VARYING OPERATING RULE

NO.OF PERIODS IN SIMULATION=  5           NO. OF YEARS IN EACH PERIOD=  30
NO.OF PERIODS IN FIRM YIELD=  5           NO.OF YEARS IN EACH PERIOD=  75

NPRC= 24
CMAX=489.600 B.G.
CMIN= 20.000 B.G.
DSCAP=750.00 M.G.D.
FORCE= 1
KIO= 1
KPC= 2
KIP= 2
KREAD= 3
IFLOW= 4
ISTOR= 2
IYEAR= 2
KIK= 1
KESC= 2
NRSC=  5
STAGE= 1
KVAR= 2
KYLD= 1
FDT=  .15
KCOPT= 1

DESIGN DEMAND RATE= 1966.           DEMAND CODE= 2
AD= 1516.     BD=15.00     UD=     0.     WD=     0.     AF=  .000

DEMB=2350.000 M.G.D.
RBAR= 296.500 M.G.D.


THIS IS A 3 SEASON RUN
AVE. SEASON ON INC= .050           AVE. SEASON OFF INC= .050
WET SEASON ON INC.= .100           WET SEASON OFF INC.= .100

                              JAN   FEB   MAR   APR   MAY   JUNE  JULY  AUG   SEPT  OCT   NOV   DEC
MONTHLY SEASON ASSIGNMENT       2     2     3     3     2     1     1     1     1     1     2     2

DEMAND COEFFICIENTS           .93   .98   .97   .96   .97  1.03  1.06  1.05  1.04  1.00   .98   .98

RELEASE COEFFICIENTS          .07   .03   .15   .15   .18   .30  1.81  3.30  2.63  2.69   .55   .06

EVAPORATION COEFFICIENTS  1.00  2.00  2.00  3.00  4.00  5.00  5.00  4.00  3.00  2.00  1.00  1.00

TURN-ON FRACTIONS        .20  .30  .40  .40  .40  .79
TURN-OFF FRACTIONS       .30  .40  .50  .60  .70  .65

START= .65
RCF=1.00
```

```
      DO 90 J=1,NYP
      DO 80 I=1,12
      IF(STAGE.NE.2) GO TO 14
      IF(J.NE.MODY(IN)) GO TO 14
      S=S+PS
      L=2*(IN-1)+1
      ONCON(1)=RFOP(L)*UCAP+CMIN
      OFCON(1)=RFOP(L+1)*UCAP+CMIN
      IF(NSN.EQ.1) GO TO 514
      ONCON(2)=ONCON(1)-UCAP*ONI2
      OFCON(2)=OFCON(1)-UCAP*OFI2
      IF(NSN.EQ.2) GO TO 514
      ONCON(3)=ONCON(1)-UCAP*ONI3
      OFCON(3)=OFCON(1)-UCAP*OFI3
  514 CONTINUE
      DO 515 L=1,12
      CALL CON(S,DS,I,IYEAR)
      DSV(L)=DS
  515 CONTINUE
      IN=IN+1
   14 IF(KVAR.NE.2) GO TO 518
      IF(J.NE.KVYR(IN)) GO TO 518
      ONCON(1)=ONLEV(IN)*UCAP+CMIN
      OFCON(1)=OFLEV(IN)*UCAP+CMIN
      IF(NSN.EQ.1) GO TO 517
      ONCON(2)=ONCON(1)-UCAP*ONI2
      OFCON(2)=OFCON(1)-UCAP*OFI2
      IF(NSN.EQ.2) GO TO 517
      ONCON(3)=ONCON(1)-UCAP*ONI3
      OFCON(3)=OFCON(1)-UCAP*OFI3
  517 IN=IN+1
  518 JJ=NSN*(N-1)+MSN(I)
      IF(I.EQ.12) GO TO 519
      JJ=NSN*(N-1)+MSN(I+1)
  519 RSP=RSTOR
      DELP=DELS
      M=M+1
      MM=MM+1
C   CALL TERP TO OBTAIN THE SURFACE AREA
      CALL TERP(CAP,SA,NPRC,RSTOR,SSA,NSIG)
      IF(NSIG.EQ.1) GO TO 132
      EVAP=SSA*RLOSS(I)*C
      DELS=Q(M,1)-CMD(I,J)-EVAP
      RSTOR=RSTOR+DELS
      GO TO (17,16),KADD
   16 IF(KCON.LT.11) GO TO 118
      IF(NSN.GT.1) GO TO 116
  115 KADD=1
  114 NTOF(J)=NTOF(J)+1
      KF=FORCE
      KCON=0
      GO TO 17
  116 IF(MSN(I).GT.1) GO TO 115
  118 IF(NOPCV(I).EQ.1.OR.RSTOR.LT.OPCON) GO TO 117
      IF(KOFF.EQ.2) GO TO 17
      KOFF=2
      GO TO 114
  117 IF(KOFF.EQ.1) GO TO 119
      KOFF=1
  119 DELS=DELS+DSV(I)
      KEND=1
      KF=KF-1
      KCON=KCON+1
      DSPRO(J)=DSPRO(J)+DSV(I)
      SDSP=SDSP+DSV(I)
      NMON(J)=NMON(J)+1
      KON=1
      RSTOR=RSTOR+DSV(I)
   17 IF(RSTOR.LT.CMAX) GO TO 26
      IF(KADD.EQ.2.AND.DELP.LT.0.0) GO TO 218
      GO TO 19
  218 KGO=2
      GO TO 33
   19 DELS=RSTOR-CMAX
      RSTOR=CMAX
      LEV=1
      SSPL(J) = SSPL(J) + DELS
      IF(KON.EQ.0) GO TO 70
      GO TO(18,22),KEND
   18 IF(DELS.LT.SDSP) GO TO 20
      DSSP(J)=DSSP(J)+SDSP
      SDSP=0.
      KEND=2
      GO TO 22
   20 DSSP(J)=DSSP(J)+DELS
      SDSP=SDSP-DELS
   22 GO TO(70,23),KADD
   23 IF(KF)24,24,70
C     ENTER HERE TO TURN OFF THE DESALTING PLANT
   24 KADD=1
      KOFF=1
      NTOF(J)=NTOF(J)+1
      KF=FORCE
      KCON=0
      GO TO 70
   26 KGO=1
      IF(RSTOR.GT.CMIN) GO TO 30
      IF(CMIN.LT..0005) GO TO 201
      GO TO(201,200), DFLAG
  201 DFLAG=2
      DELS=CMIN-RSTOR
      RSTOR=CMIN
      GO TO 202
  200 LD=LD+1
      IF(CMD(I,J).LT.Q(M,1)) GO TO 1202
      ALOSS=ALOSS+EVAP
      DELS=CMD(I,J)-Q(M,1)
      RSTOR=CMIN-ALOSS
      IF(RSTOR.GT.0.) GO TO 202
      RSTOR=0.
      GO TO 202
 1202 DELS=CMIN-RSTOR
  202 LEV=2
      SSHT(J)=SSHT(J)+DELS
      IF(I.EQ.12.AND.J.EQ.NYP) GO TO 330
   28 GO TO(38,70),KADD
   30 GO TO (331,330), DFLAG
  330 ID=ID+1
      IF(I.EQ.12.AND.J.EQ.NYP) GO TO 80
      LD=1
      DFLAG=1
      ALOSS=0.0
  331 IF(KADD.EQ.1) GO TO 35
   31 IF(DELS) 35,35,32
   32 IF(DELP) 33,33,34
   33 TEM=DSV(I)
      IF(NOPCV(I).EQ.0) TEM=0.
      IF((RSP-CMIN).GT.(SDSP-TEM)) GO TO 134
      SDSP=RSP-CMIN+TEM
  134 GO TO(34,19),KGO
   34 IF((RSTOR-CMIN).GT.SDSP) GO TO 35
      SDSP=RSTOR-CMIN
   35 IF(OFCON(JJ).LT.ONCON(JJ)) GO TO 45
      GO TO(37,41),KADD
   37 IF(RSTOR.GT.ONCON(JJ ))GO TO 70
C     ENTER HERE TO TURN ON THE DESALTING PLANT
   38 IF(NOPCV(I).EQ.0.AND.RSTOR.GT.OPCON) GO TO 70
      KADD=2
   40 NTON(J)=NTON(J)+1
      GO TO 70
   41 IF(RSTOR.GT.OFCON(JJ ))GO TO 23
      GO TO 70
   45 IF(RSTOR.LT.ONCON(JJ ))GO TO 50
      GO TO 22
   50 IF(RSTOR.GT.OFCON(JJ ))GO TO 53
      GO TO 55
   53 IF(DELS.LT.0.0.AND.DELP.LT.0.0) GO TO 54
      GO TO(70,23),KADD
   54 GO TO(38,70),KADD
   55 GO TO (38,70),KADD
   70 IF(KPC.NE.1) GO TO 80
   71 KSTO(MM-1)=RSTOR+0.5
   80 CONTINUE
C    AT THIS POINT HAVE COMPLETED ONE YEAR OF THE PERIOD
   90 CONTINUE
C   AT THIS POINT HAVE JUST COMPLETED A PERIOD OF NYP YEARS *   *   *   *
      GO TO(91,92),KPC
   91 CALL PLOT(KSTO,NYP,KMAX,KMIN)
   92 TEMA=0.
      TEMB=0.
      DO 95 J=1,NYP
      TEMA=TEMA+DSPRO(J)
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      TEMB=TEMB+DSSP(J)
   95 CONTINUE
      DSEFF(NP)=(TEMA-TEMB)/TEMA
      IF(KIK.EQ.2) GO TO 97
      IF(STAGE.NE.2) GO TO 196
      WRITE(6,2090) NP
 2090 FORMAT(1H1,'STAGE CONSTRUCTION SIMULATION RUN      PERIOD NO.'I3)
      GO TO 197
  196 IF(KVAR.NE.2) GO TO 96
      WRITE(6,2091) NP
 2091 FORMAT(1H1,'VARYING OPERATING RULE SIMULATION RUN  PERIOD NO.'I3)
      GO TO 197
   96 WRITE(6,3000) ON(N),OFLEV(N),NP
 3000 FORMAT(1H1,'OPERATING RULE.. - .. .. .ON='F4.2,3X,'OFF='F4.2,5X,'PERI
     1OD NO.'I3)
  197 WRITE(6,3001)
 3001 FORMAT(1H0,'         YEAR     TIMES ON    TIMES OFF    MONTHS ON
     1DSPRO         DSSP         SPILL        SHORT.')
      DO 3002 J=1,NYP
 3002 WRITE(6,3003) J,NTON(J),NTOF(J),NMON(J),DSPRO(J),DSSP(J),SSPL(J),
     1SSHT(J)
 3003 FORMAT(4I12,4F12.2)
      WRITE(6,3004) DD,DSEFF(NP)
 3004 FORMAT(1H0,'DEMAND='F8.2,10X'EFFICIENCY='F5.2)
   97 IF(STAGE.EQ.1) GO TO 98
      CALL SCOST(NYP,ANCST,NMOD,KESC,PWTH,AUNIT,EFI)
      AVEU=AVEU+AUNIT
      SAC=SAC+ANCST
      GO TO 100
   98 AVELF=AL(N)
      CALL COST(NYP,NP,AVELF,ANCST,KCOPT,DSCAP,KVAR)
  100 UCFY(NP,N)=ANCST/FYINC
      GO TO(120,300),KIK
  120 WRITE(6,2000) FYINC,ANCST,UCFY(NP,N)
 2000 FORMAT(1H0,'INCREASE IN YIELD='F8.2,' M.G.D.'5X'ANNUAL COST='F12.0
     1,' $/YEAR'5X'COST OF FYINC='F7.0,' $/YEAR/M.G.D.')
      IF(STAGE.EQ.2) WRITE(6,2092) AUNIT
 2092 FORMAT(1H0,'DISCOUNTED UNIT COST='F8.0,'   $/YEAR/M.G.D.')
  300 CONTINUE
  400 CONTINUE
C   AVERAGE THE UNIT COST OF THE INCREASE IN FIRM YIELD
      DO 410 J=1,NOF
  403 DO 405 I=1,NPER
      AVUC(J)=AVUC(J)+UCFY(I,J)
  405 CONTINUE
      AVUC(J)=AVUC(J)/NPER
  410 CONTINUE
      IF(STAGE.NE.2) GO TO 406
      AVAN=SAC/NPEP
      IF(EFI.LT.0.0005) GO TO 398
      WRITE(6,2096) AVAN
 2096 FORMAT(1H0,'THIS IS AN INTEREST ESCALATION RUN, THE COST NUMBER GI
     1VEN BELOW IS THE AVERAGE OF THE PRESENT VALUE OF THE COSTS OF NPER
     2 PERIODS'/1H0,'AVPV='F12.0,' DOLLARS')
      GO TO 415
  398 AVEU=AVEU/NPER
      WRITE(6,2093) AVUC(1),AVEU
 2093 FORMAT(1H0,'(AVERAGE ANNUAL COST)/FYINC='F10.0,/1H0,'AVERAGE OF UN
     1IT COST DISCOUNTED='F10.0,'  $/YEAR/M.G.D.')
      IF(KESC.EQ.1) GO TO 3530
      EFORT=100.0*FFO
      WRITE(6,3330)EFORT
 3330 FORMAT(1H0,'THIS IS A COST ESCALATION AT'F4.1,' PERCENT/YR.')
 3530 GO TO 415
  406 IF(KVAR.NE.2) GO TO 411
      WRITE(6,2094) AVUC(1)
 2094 FORMAT(1H0,'AVERAGE UNIT COST='F10.0,'  $/YEAR/M.G.D.')
      GO TO 415
  411 WRITE(6,2009)
 2009 FORMAT(1H0,'AVERAGE COSTS FOR FEASIBLE OPERATING RULES')
      WRITE(6,2010) (AVUC(J),J=1,NOF)
 2010 FORMAT(1H ,10F12.4)
C     FIND THE LOWEST AVERAGE UNIT COST OF FYINC
      IX=1
      CALL FIND(AVUC,NOF,IX)
  412 WRITE(6,3005) AVUC(IX)
 3005 FORMAT(1H1,'MINIMUM COST OF FYINC='F7.0,' $/YEAR/M.G.D. ADDED FIRM
     1 YIELD')
      WRITE(6,3006) FYINC
 3006 FORMAT(1H0,'INCREASE IN FIRM YEILD='F7.2,' M.G.D.')
      WRITE(6,3007)  ON(IX),OFLEV(IX)
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 3007 FORMAT(1H0,'TURN ON='F6.2,10X'TURN OFF='F6.2)
      WRITE(6,3008) AL(IX),GL(IX)
 3008 FORMAT(1H0,'DESIGN LOAD FACTOR='F4.1,5X'GROSS LOAD FACTOR='F4.1)
  415 STOP
  132 WRITE(6,4001) RSTOR
 4001 FORMAT(1H0,'RSTOR=' F10.2)
      STOP
      END
@FOR,IS CSTIO,CSTIO
      SUBROUTINE CSTIO(KCOPT,STAGE,NMOD)
C THIS SUBPROGRAM IS ENTERED TO INPUT AND OUTPUT THE COST DATA
      COMMON/BLOCC/ FACT(10),CAPC(10),OPCST(10,10),OFACT(10),NOLF,NOFF,
     1INT,RATE,ETONC,ETOFC,CNO,EXNO,CTN,EXTN,COP,EXOP,CCND
      COMMON/BLOCD/ MODY(10),SIZM(10),YLDIN(10),CSTM(10),EFO
      DATA A/1H*/,E/2H**/
      INTEGER STAGE
      REAL INT
    1 READ(5,1000) NOLF,(OFACT(J),J=1,NOLF)
      READ(5,1000) NOFF,(FACT(J),J=1,NOFF)
 1000 FORMAT(I2,3X,8F5.0)
      DO 5 J=1,NOLF
      READ(5,1001) (OPCST(I,J),I=1,NOFF)
 1001 FORMAT(8F10.0)
    5 CONTINUE
      READ(5,1001) INT,RATE,CCND
      IF(STAGE.NE.2) GO TO 6
      READ(5,1001) (CSTM(L),L=1,NMOD)
      GO TO 7
    6 READ(5,1001) (CAPC(J),J=1,NOLF)
    7 IF(KCOPT.EQ.2) GO TO 8
      READ(5,1001) ETONC,ETOFC
      GO TO 9
    8 READ(5,1001) CNO,EXNO,CTN,EXTN,COP,EXOP
    9 WRITE(6,1022) .
 1022 FORMAT(1H1,40X'DESALTING PLANT COST DATA')
      GO TO(10,12),KCOPT
   10 WRITE(6,1023)
 1023 FORMAT(1H0,'OPER. L. F. '5X,'ANNUAL COST IN $/YR. FOR THE PLANT TH
     1AT IS OPTIMIZED AT THE GIVEN LOAD FACTOR (IN PERCENT)'/1H ,'(IN PE
     2RCENT)')
      GO TO 15
   12 WRITE(6,1024)
 1024 FORMAT(1H0,'OPER. L. F. '5X,'TABLE OF COEFFICIENTS USED FOR COMPUT
     1ING THE OPERATING COSTS'/1H ,'(IN PERCENT)')
   15 WRITE(6,1025) (OFACT(J),J=1,NOLF)
 1025 FORMAT(1H0,15X,10F10.0)
      DO 20 I=1,NOFF
      GO TO(16,18),KCOPT
   16 WRITE(6,1026) FACT(I),(OPCST(I,J),J=1,NOLF)
 1026 FORMAT(1H0,2X,F5.0,13X,10F10.0)
      GO TO 20
   18 WRITE(6,1027) FACT(I),(OPCST(I,J),J=1,NOLF)
 1027 FORMAT(1H0,2X,F5.0,11X,10F10.3)
   20 CONTINUE
      IF(STAGE.NE.2) GO TO 21
      WRITE(6,1028) (CSTM(L),L=1,NMOD)
      GO TO 121
   21 WRITE(6,1028) (CAPC(L),L=1,NOLF)
 1028 FORMAT(1H0,'CAPITAL COSTS'7X,10F10.0//)
  121 GO TO(22,25),KCOPT
   22 WRITE(6,1029) ETONC,ETOFC
 1029 FORMAT(1H0,'ESTIMATED TURN-ON COST= 'F8.0,/1H ,'ESTIMATED TURN-OFF
     1 COST='F8.0)
   25 WRITE(6,1030) RATE,INT
 1030 FORMAT(1H0,'FIXED CHARGE RATE='F6.4,/1H ,'THE INTEREST RATE='F6.4)
      GO TO(40,26),KCOPT
C  OUTPUT THE EQUATIONS USED IN THE COST COMPUTATIONS
   26 WRITE(6,2000)
 2000 FORMAT(1H0,'EQUATIONS USED IN THE COST COMPUTATIONS')
      WRITE(6,2002) CNO,A,E,EXNO
 2002 FORMAT(1H0,'OPER. AT ZERO LOAD FACTOR'10X'COST='F8.0,A1,'S'A2,F6.4
     1)
      WRITE(6,2003) CTN,A,E,EXTN
 2003 FORMAT(1H0,'TUPN-ON AND TURN-OFF'15X'COST='F8.0,A1,'S'A2,F6.4)
      WRITE(6,2004) COP,A,E,EXOP,A
 2004 FORMAT(1H0,'OPERATING AND MAINTENANCE ' 9X'COST='F8.0,A1,'S'A2,F6.
     14,A1,'C(I)')
   40 RETURN
      END
@FOR,IS COST,COST
      SUBROUTINE COST(NYP,NP,AVEL,ANCST,KCOPT,S,K)
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```
      COMMON/BLOCC/ FACT(10),CAPC(10),OPCST(10,10),OFACT(10),NOLF,NOFF,
     1INT,PATE,ETONC,ETOFC,CNO,EXNO,CTN,EXTN,COP,EXOP,CCP,EXCP,CCND
      COMMON/BLOCKD/ NTON(50),NTOF(50),NMON(50)
      REAL INT
      IF(K.EQ.2) GO TO 3
      IF(AVEL.GT.OFACT(1)) GO TO 12
    3 J=1
      GO TO 20
   12 IF(AVEL.LT.OFACT(NOLF)) GO TO 14
      J=NOLF
      GO TO 20
   14 DO 18 I=1,NOLF
      IF(OFACT(I+1).LT.AVEL) GO TO 18
C    ENTER HERE IF AVEL FALLS BETWEEN OFACT(I) AND OFACT(I+1)
      IF(AVEL-OFACT(I).LT.OFACT(I+1)-AVEL) GO TO 17
      J=I+1
      GO TO 20
   17 J=I
      GO TO 20
   18 CONTINUE
   20 PWTH=0.
C     ANNUALIZE THE OPERATING EXPENSES
      DO 40 L=1,NYP
      AA=NMON(L)
      XLF=AA/12.0*100.0
C  DO TABLE LOOK-UP WITH INTERPOLATION(LINEAR TO OBTAIN COST($/YEAR)
      IF(XLF.GT.0.) GO TO 22
      CST=OPCST(1,J)
      IF(KCOPT.EQ.2) CST=CNO*S**EXNO
      TEM=0.
      GO TO 35
   22 IF(XLF.LT.95.0) GO TO 25
      CST=OPCST(NOFF,J)
      GO TO 30
   25 DO 27 I=1,NOFF
      IF(XLF.GT.FACT(I+1)) GO TO 27
C    ENTER HERE IF XLF FALLS BETWEEN FACT(I) AND FACT(I+1)
      FRAC=(XLF-FACT(I))/(FACT(I+1)-FACT(I))
      CST=OPCST(I,J)+FRAC*(OPCST(I+1,J)-OPCST(I,J))
      GO TO 30
   27 CONTINUE
C   DISCOUNT THE COSTS FOR THE L TH YEAR TO THE PRESENT
   30 GO TO(31,33),KCOPT
   31 TEM=ETONC*NTON(L)+ETOFC*NTOF(L)
      GO TO 35
   33 CST=CST*COP*S**EXOP
      TEM=(NTON(L)+NTOF(L))/2.0*CTN*S**EXTN
   35 FAC=(1.0+INT)**L
      PWTH=PWTH+(CST+TEM)/FAC
   40 CONTINUE
C    APPLY CAPITAL RECOVERY FACTOR TO OBTAIN UNIFORM SERIES
      USER=PWTH*INT*FAC/(FAC-1.0)
   41 CAP=CAPC(J)*RATE
   45 ANCST=USER+CAP+INT*CCND
      RETURN
      END
@FOR,IS SCOST,SCOST
      SUBROUTINE SCOST(NYP,ANCST,NMOD,KESC,PWTH,AUNIT,EFI)
      DIMENSION COEFF(10,10),CAPT(50)
      COMMON/BLOCC/ FACT(10),CAPC(10),OPCST(10,10),OFACT(10),NOLF,NOFF,
     1INT,RATE,ETONC,ETOFC,CNO,EXNO,CTN,EXTN,COP,EXOP,CCND
      COMMON/BLOCKD/ NTON(50),NTOF(50),NMON(50)
      COMMON/BLOCD/ MODY(10),SIZM(10),YLDIN(10),CSTM(10),EFO
      EQUIVALENCE (OPCST,COEFF)
      DATA KENT/1/
      REAL INT
      GO TO(5,1),KFSC
    1 GO TO(2,7),KENT
C IF ENTERING COST FOR THE FIRST TIME READ IN THE ESCALATION FACTORS
    2 PEAD(5,1000) EFO,EFC,EFI
 1000 FORMAT(3F10.0)
      KENT=2
      GO TO 7
    5 EFO=0.
      EFC=0.
      EFI=0.
    7 PWTH=0.
      PWUC=0.
      MI=1
      CADD=0.
      DO 9 J=1,NYP
      IF(J.EQ.MODY(MI)) GO TO 8
      CAPT(J)=CAPT(J-1)
      GO TO 9
    8 FIXC=RATE+EFI*(J-1)
      CAPT(J)=(CSTM(MI)*(1.0+EFC*(J-1)))*FIXC+CADD
      CADD=CAPT(J)
      MI=MI+1
    9 CONTINUE
      MI=1
      S=0.
      DO 30 J=1,NYP
      IF(J.NE.MODY(MI)) GO TO 10
      S=S+SIZM(MI)
      YINC=YLDIN(MI)
      MI=MI+1
   10 TEM=1.0+EFO*(J-1)
      AA=NMON(J)
      XLF=AA/12.0*100.0
      IF(XLF.GT.0.) GO TO 12
      CST=TEM*CNO*S**EXNO
      GO TO 20
   12 IF(XLF.LT.95.) GO TO 15
      C=COEFF(NOFF,1)
      GO TO 17
   15 DO 19 I=1,NOFF
      IF(XLF.GT.FACT(I+1)) GO TO 19
      FRAC=(XLF-FACT(I))/(FACT(I+1)-FACT(I))
      C=COEFF(I,1)+FRAC*(COEFF(I+1,1)-COEFF(I,1))
      GO TO 17
   19 CONTINUE
   17 CST=TEM*COP*S**EXOP*C
   20 CTURN=(NTON(J)+NTOF(J))/2.0*TEM*CTN*S**EXTN
      TI=INT+(J-1)*EFI
      FAC=(1.0+TI)**J
      YEARC=CST+CTURN+CAPT(J)
      UNIT=YEARC/YINC
      PWTH=PWTH+YEARC/FAC
      PWUC=PWUC+UNIT/FAC
   30 CONTINUE
      ANCST=PWTH
      IF(KESC.EQ.2.AND.EFI.GT.0.00005) GO TO 35
   31 AFAC=INT*FAC/(FAC-1.0)
      ANCST=AFAC*PWTH+INT*CCND
      AUNIT=AFAC*PWUC+INT*CCND
   35 RETURN
      END
@FOR,IS YIELD,YIELD
      SUBROUTINE YIELD(NOP,NYP,NOR,KIO,ONLEV,OFLEV,NON,NOF)
      COMMON /BLOCKA/Q(1201,5)
      COMMON /BLOCKB/ONCON(100),OFCON(100),UCAP
      COMMON/BLOCKZ/IY
      COMMON /BLOCKG/GLF(50)
      COMMON /BLOCKC/CAP(100),DM(12),RS(50),SA(100),RLOSS(12),
     1REL(12),MSN(12),DSV(12),SSHT(100),        FY(20,50),AVLF(50),
     2CMAX,NPRC,DSCAP,FORCE,START,ERR, PCF,NSN,DEMB,CMIN,KIP,RBAR,
     3KREAD,RSTOR,IFLOW,IYEAR,NPER,NRSC,OPER,OPCON,NOPCV(12)
     4,IYPER(20),KYLD,FDT,MSCP(50),MECP(50),DDCP(50)
      COMMON/BLOCW/STOT(50),MOS(50),MOF(50),MRM(25),MRF(25),SMIN(25)
      DIMENSION KON(75),IDD(75),DD(75),CMD(12) ,KDUR(200),RCON(100)
     1,DFCIT(20,10),MOD(20,10),MPF(20,10),TEMH(12),TEML(12)
      DIMENSION ONLEV(10),OFLEV(10)
      INTEGER FORCE,DFLAG
      FNYP=NYP
      MAXY=(FNYP-PCF*FNYP)+0.51
      WRITE(6,5000) MAXY
 5000 FORMAT(1H0,'MAXY='I3)
      NYPSV=NYP
      PPCF=PCF*100.
      C=.00004356*7.48/12.
      KSTRT=1
      KTHRU=1
      IARG=798531
      ZRAN=RAN(IARG)
      IY=IARG
      DO 6 L=1,50
      AVLF(L)=0.
      GLF(L)=0.
    6 CONTINUE
      DO 170 NP=1,NOP
      IF(KREAD.EQ.2) GO TO 7
      IY=IYPER(NP)
```

```
    7 KIT=1
      DBAR=DEMB
      NV=1
      MS=1
      ME=NYP*12+1
      IF(KREAD.EQ.3) NV=2
C GENERATE NYP YEARS OF STREAMFLOW AND CONVERT TO MONTHLY VOLUMES
   10 NYG=NYP
      IF(NP.EQ.1.AND.NYP.LT.75.AND.KREAD.NE.3) NYG=75
      IF(KREAD.EQ.2) IYPER(NP)=IY
      WRITE(6,1000) NP,IY
 1000 FORMAT(1H0,'PERIOD='I3,10X,'IY='I15)
      CALL GNFLO(NYG,KIP,IFLOW,IYEAR)
   11 NR=NOR+1
   12 DO 160 N=NV,NR
      JJ=NSN*(N-2)+MSN(1)
      ITIME=0
      DD(1)=DBAR*START
      IF(KREAD.NE.3) GO TO 311
      DD(1)=DDCP(NP)+DSCAP
      MS=MSCP(NP)
      ME=MECP(NP)
      KIT=2
      IF(MS.EQ.1) KFULL=2
      GO TO 13
  311 IF(N.EQ.1) GO TO 13
      A=ONCON(JJ)
      B=OFCON(JJ)
      RA=0.5*UCAP+CMIN
      RB=0.75*UCAP+CMIN
      IF(A.GT.RA) GO TO 313
      IF(B.LT.RA) DD(1)=DBAR*(START-0.05)
      GO TO 13
  313 IF(A.GT.RB.AND.B.GT.RB) DD(1)=DBAR*(START+0.05)
   13 DO 14 J=1,20
      KON(J)=0
      IDD(J)=0
   14 CONTINUE
      DX=0.
      DELS=0.
      II=0
   20 II=II+1
      IF(II.NE.1) DD(II)=DD(II-1)+DX
      TEST=DD(II)*.0305
      IF(KYLD.EQ.2) TEST=FDT*TEST
C  CONVERT THE MONTHLY DEMAND RATES TO VOLUMES
  322 DO 21 I=1,12
      DEM=DD(II)*DM(I)+REL(I)*RBAR
      CALL CON(DEM,CD,I,IYEAR)
      CMD(I)=CD
   21 CONTINUE
   22 LEV=1
      DO 323 L=1,75
  323 STOT(L)=0.
      KCON=0
      KSUM=0
      KADD=1
      RSTOR=RS(NP)
      IF(N.EQ.1) GO TO 30
      IF(RSTOR.GT.ONCON(JJ)) GO TO 23
      KADD=2
      KCON=1
      KON(II)=1
   23 IF(RSTOR.LT.OFCON(JJ)) LEV=2
   30 KF=FORCE
      KD=0
      MD=0
      KH=0
      KL=0
      IF(KYLD.NE.2) GO TO 26
      DO 25 I=1,12
      TEM=TEST*DM(I)
      TEMH(I)=TEM+ERR*TEM
      TEML(I)=TEM-ERR*TEM
   25 CONTINUE
   26 ID=0
      ALOAD=0.
      GLOAD=0.
      LD=1
      KFULL=1
      IF(MS.EQ.1) KFULL=2
```

```
      MFULL=1
      MF=1
      DFLAG=1
      ALOSS=0.
      KDUR(1)=0
      RMIN=999999.
      CRITM=999999.
      MCFLG=2
      DO 330 J=1,20
  330 SMIN(J)=99999.
      DO 31 J=1,NYP
      SSHT(J)=0.
   31 CONTINUE
      M=1
       IF(MS.GT.1) M=(MS-1)*12+1
      DO 90 J=MS,NYP
      DO 81 I=1,12
      M=M+1
      IF(M.GT.ME.AND.KTHRU.NE.2) GO TO 93
      DELP=DELS
      IF(N.EQ.1) GO TO 32
      JJ=NSN*(N-2)+MSN(1)
      IF(I.EQ.12) GO TO 32
      JJ=NSN*(N-2)+MSN(I+1)
   32 CALL TERP(CAP,SA,NPRC,RSTOR,SSA,NSIG)
      IF(NSIG.EQ.1) GO TO 902
      EVAP=SSA*RLOSS(I)*C
      DELS=Q(M,1)-CMD(I)-EVAP
      RSTOR=RSTOR+DELS
      GO TO(36,35),KADD
   35 IF(KCON.LT.11) GO TO 338
C  ENTER HERE IF CONTINUOUS OPERATION FOR 11 MONTHS
      IF(NSN.GT.1) GO TO 336
  335 IF(DFLAG.EQ.2.OR.RSTOR.LT.CMIN) GO TO 339
C  TURN OFF DESALTING PLANT IF STORAGE IS NOT EMPTY
      KF=FORCE
      KADD=1
      KSUM=KSUM+KCON
      KCON=0
      GO TO 36
  336 IF(MSN(I).GT.1) GO TO 335
  338 IF(NOPCV(I).EQ.0.AND.RSTOR.GT.OPCON) GO TO 335
  339 DELS=DELS+DSV(I)
      KF=KF-1
      KCON=KCON+1
C  ADD DESALT PRODUCTION FOR THE GIVEN MONTH
      RSTOR=RSTOR+DSV(I)
   36 IF(RSTOR.LT.CMAX) GO TO 50
      MFULL=M
      DELS=RSTOR-CMAX
      RSTOR=CMAX
      KFULL=2
      LEV=1
   42 IF(KADD.EQ.1) GO TO 80
C  ENTER HERE IF STORAGE IS FULL AND DESALTING PLANT IS ON
   44 IF(KF) 46,46,80
   46 KADD=1
      KF=FORCE
      KSUM=KSUM+KCON
      KCON=0
      GO TO 80
   50 IF(RSTOR.GT.CMIN) GO TO 56
      IF(CMIN.LT.0.0005) GO TO 54
      GO TO(54,53),DFLAG
   54 DFLAG=2
      KD=KD+1
      MOF(KD)=MFULL
      DELS=CMIN-RSTOR
      RSTOR=CMIN
      GO TO 55
   53 LD=LD+1
      IF(CMD(I).LT.Q(M,1)) GO TO 155
      ALOSS=ALOSS+EVAP
      DELS=CMD(I)-Q(M,1)
      IF(N.GT.1.AND.NOPCV(I).NE.0) DELS=DELS-DSV(I)
      RSTOR=CMIN-ALOSS
      IF(RSTOR.GT.0.) GO TO 55
      RSTOR=0.
      GO TO 55
  155 DELS=CMIN-RSTOR
   55 LEV=2
```

```
C    SUM THE SHORTAGES
      IF(KYLD.EQ.1.OR.KIT.EQ.1) GO TO 156
C  RECORD TH MONTHLY DEFICITS ***************************************************
      IF(KTHRU.EQ.2.AND.DELS.GT.TEMH(I)) KH=KH+1
      MD=MD+1
      DFCIT(MD,KD)=DELS
      MOD(MD,KD)=M
      MPF(MD,KD)=MFULL
  156 STOT(KD)=STOT(KD)+DELS
      SSHT(J)=SSHT(J)+DELS
      IF(M.EQ.ME.AND.KTHRU.NE.2) GO TO 57
      IF(N.EQ.1) GO TO 80
      GO TO(65,80),KADD
   56 IF(DFLAG.EQ.1) GO TO 59
C ENTER HERE IF COMING OFF A DROUGHT
   57 ID=ID+1
      MD=0
      IDD(II)=ID
      KDUR(ID)=LD
      LD=1
      DFLAG=1
      MOS(KD)=M
      ALOSS=0.0
      IF(M.EQ.ME.AND.KTHRU.NE.2) GO TO 80
   59 IF(KIT.EQ.1.AND.KTHRU.EQ.1) GO TO 60
      IF(RSTOR.GT.RMIN) GO TO 62
      RMIN=RSTOR
      MF=MFULL
      MOM=M
      GO TO 62
   60 IF(RSTOR.GT.UCAP*0.75) GO TO 62
      SMAX=0.
      DO 61 IM=1,20
      IF(SMIN(IM).LT.SMAX) GO TO 61
      SMAX=SMIN(IM)
      IX=IM
   61 CONTINUE
      IF(RSTOR.GT.SMAX) GO TO 62
      SMIN(IX)=RSTOR
      MRF(IX)=MFULL
      MRM(IX)=M
   62 IF(N.EQ.1) GO TO 80
      IF(OFCON(JJ).LT.ONCON(JJ)) GO TO 70
      IF(KADD.EQ.2) GO TO 68
      IF(RSTOR.GT.ONCON(JJ)) GO TO 80
C ENTER HERE TO TURN ON THE DESALTING PLANT
   65 IX=I+1
      IF(IX.EQ.13) IX=1
      IF(NOPCV(IX).EQ.0) GO TO 80
      KADD=2
      KON(II)=KON(II)+1
      GO TO 80
   68 IF(RSTOR.GT.OFCON(JJ)) GO TO 44
      GO TO 80
C ENTER HERE IF TUPN-ON LEVEL HIGHER THAN TURN-OFF
   70 IF(RSTOR.GT.ONCON(JJ)) GO TO 42
      IF(RSTOR.LT.OFCON(JJ)) GO TO 75
      IF(DELS.LT.0.0.AND.DELP.LT.0.0) GO TO 75
      GO TO (80,44),KADD
   75 IF(KADD.EQ.1) GO TO 65
   80 IF(MAXY.EQ.0) GO TO 81
      IF(ABS(M-MCRIT).GT.2.OR.MCFLG.EQ.1) GO TO 81
      IF(RSTOR.GT.CMIN) GO TO 378
      MCFLG=1
      GO TO 81
  378 IF(RSTOR.LT.CRITM) CRITM=RSTOR
      MCF=MFULL
   81 CONTINUE
      IF(KSTRT.NE.2) GO TO 90
      RCON(J)=RSTOR
   90 CONTINUE
C AT THIS POINT A PERIOD OF NYP YEARS HAS BEEN COMPLETED
      IF(KTHRU.EQ.1) GO TO 93
   91 IF(KSTRT.EQ.1) GO TO 100
C IF KTHRU=2 AND KSTRT=2 GENERATE STARTING CONTENTS
      DO 92 L=1,NRSC
      XNUM=RAN(IARG)*50.0+0.5
      NUM=XNUM
      NUM=NUM+25
      RS(L)=RCON(NUM)
      TXST=CMAX-0.001*CMAX
      IF(RS(L).GT.TXST) RS(L)=TXST
   92 CONTINUE
      WRITE(6,3020)(RS(L),L=1,NRSC)
 3020 FORMAT(1H0,'RESERVOIR STARTING CONTENTS'/(1H ,10F12.4))
      KSTRT=1
      NYP=NYPSV
      GO TO 100
C ENTER HERE WHEN IN ITERATION PROCESS
   93 IF(KIT.EQ.2) GO TO 96
      IF(KD.GT.MAXY) GO TO 394
      DX=0.05*DBAR
      IF(II.EQ.5) STOP
      GO TO 20
  394 CALL XLOC(KD,MSTRT,MEND,DX,CMIN,MAXY,MD,TEST,KYLD)
      MCRIT=MEND-2
      MS=1
      IF(MSTRT-60.GT.0) MS=(MSTRT-60)/12+1
      ME=MEND
      TEM=DD(II)+DX
      WRITE(6,3030) MS,TEM
 3030 FORMAT(1H+,60X'MS='I4,5X'ADJUSTED DEMAND='F8.2)
      KIT=2
      MSSV=MS
      MESV=ME
      GO TO 20
   96 IF(KFULL.EQ.1.AND.MS.NE.1) GO TO 501
      IF(II.LE.15) GO TO 97
      WRITE(6,6000) N,NP
 6000 FORMAT(1H0,'RULE NO.'I3,5X'IN PERIOD'I3,2X'DID NOT CONVERGE')
      DD(II)=(DD(II)+DD(II-1))/2.
      GO TO 100
   97 IF(KD.EQ.0) GO TO 98
C SHORTAGE OCCURRED AT LOCM
      IF(KYLD.EQ.2) GO TO 99
      IF(MAXY.EQ.0) GO TO 397
      IF(MCFLG.EQ.1) GO TO 395
C    ENTER IF MAXY.GT.0 AND MCFLG.EQ.2
      RMIN=CRITM
      MOM=MCRIT
      MF=MCF
      GO TO 98
  397 SMAX=0.
      SSUM=0.
      DO 94 L=1,KD
      SSUM=SSUM+STOT(L)
      IF(STOT(L).LT.SMAX) GO TO 94
      SMAX=STOT(L)
      IT=L
   94 CONTINUE
      GO TO 95
  395 SSUM=STOT(KD)
      IT=KD
   95 WRITE(6,7000) MOS(IT),MOF(IT),SSUM
 7000 FORMAT(1H 'MONTH OF SHORTAGE=' I3,10X'MONTH FULL='I3,F15.2)
      IF(SSUM.LT.ERR*TEST) GO TO 100
      DX=-SSUM/((MOS(IT)-MOF(IT))*.0305)
      GO TO 20
C RSTOR GREATER THAN CMIN AT LOCM
   98 WRITE(6,7001) MOM,MF,RMIN
 7001 FORMAT(1H ,'MONTH OF MIN=' I3,10X'MONTH FULL='I3,F15.2)
      IF(RMIN-CMIN.LT.ERR*TEST) GO TO 100
      DX=(RMIN-CMIN)/((MOM-MF)*.0305)
      GO TO 20
   99 IF(KD.EQ.0) GO TO 503
      L=1
      IF(KD.EQ.1) GO TO 250
      TMAX=0.
      DO 240 I=1,KD
      TES=STOT(I)/(MOS(I)-MOF(I))
      IF(TES.LT.TMAX) GO TO 240
      TMAX=TES
      L=I
  240 CONTINUE
  250 LNGTH=KDUR(L)
      ITRUN=(MOD(1,L)-1)/12
      IMULT=ITRUN*12
      ICC=MOD(1,L)-IMULT-1
      IF(ICC.EQ.0) ICC=12
      IC=ICC
      DO 255 I=1,LNGTH
      IF(DFCIT(I,L).GT.TEMH(IC)) KH=KH+1
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      IF(DFCIT(I,L).LT.TEML(IC)) KL=KL+1
      IC=IC+1
      IF(IC.EQ.13)IC=1
  255 CONTINUE
      IF(KH.EQ.0.AND.KL.NE.LNGTH) GO TO 100
      IF(KH.GT.0) GO TO 257
      LL=LNGTH
      ITR=(MOD(LL,L)-1)/12
      IM=ITR*12
      ICC=MOD(LL,L)-IM-1
      IF(ICC.EQ.0) ICC=12
      SUM=TEMH(ICC)-DFCIT(LL,L)
      DX=SUM/((MOD(LL,L)-MPF(LL,L))*.0305)
      GO TO 20
  257 IF(LNGTH.GT.1) GO TO 259
      IX=1
      SUM=DFCIT(1,L)-(TEMH(ICC)+TEML(ICC))/2.0
      GO TO 265
  259 IX=2
      IC=ICC
      SUM=DFCIT(1,L)
      DO 263 I=2,LNGTH
  262 IC=IC+1
      IF(IC.EQ.13) IC=1
      IF(DFCIT(I,L).LT.TEMH(IC)) GO TO 263
      SUM=SUM+DFCIT(I,L)
      IX=I
  263 CONTINUE
      IF(IX.EQ.LNGTH) SUM=SUM-TEST
  265 DX=-SUM/((MOD(IX,L)-MPF(IX,L))*0.0305)
      GO TO 20
C  ENTER HERE IF THE ITERATION IS COMPLETED
  100 IF(KTHRU.EQ.2) GO TO 101
      KTHRU=2
      MS=1
      ME=NYP*12+1
      IF(NP.EQ.1.AND.N.EQ.1.AND.ITIME.EQ.0) KSTRT=2
      KON(II)=0
      KSUM=0.
      GO TO 22
  101 IF(MAXY.EQ.0) GO TO 102
      IF(KYLD.EQ.2) GO TO 406
      IF(KD.GE.MAXY-1.AND.KD.LE.MAXY+1) GO TO 104
      IF(KD.GT.MAXY+1) GO TO 404
      WRITE(6,4050) KD,MAXY
 4050 FORMAT(1H1,'ONLY REGISTERED'I3,' SHORTAGES'5X
     1'LOOKING FOR'I3,' SHORTAGES')
      STOP
  102 IF(ITIME.GT.5) GO TO 502
      IF(KD.EQ.0.OR.II.EQ.16) GO TO 104
      SSUM=0.
      DO 402 L=1,KD
      IF(MAXY.EQ.0) GO TO 103
      IF(MOS(L)-5.LT.ME.OR.MOS(L)+4.GT.ME) GO TO 402
  103 SSUM=SSUM+STOT(L)
  402 CONTINUE
      IF(SSUM.LT.ERR*TEST) GO TO 104
C ENTER HERE IF ITERATION OVER PREDETERMINED CRITICAL
C PERIOD NOT VALID FOR THE ENTIRE PERIOD
      ERR2=5.0*ERR
      IF(SSUM.LT.ERR2*TEST) GO TO 104
      IF(ITIME.GT.2.AND.SSUM.LT.0.10*TEST) GO TO 104
  404 CALL XLOC(KD,MSTRT,MEND,DX,CMIN,MAXY,MD,TEST,KYLD)
      MS=1
      MCRIT=MEND-2
      IF(MSTRT-48.GT.0) MS=(MSTRT-48)/12+1
      ME=MEND
      WRITE(6,4040) MS,ME
 4040 FORMAT(1H ,'ADJUSTED CRITICAL PERIOD, MS='I3,5X'ME='I3)
      KTHRU=1
      DD(1)=DD(II)+DX
      ITIME=ITIME+1
      GO TO 13
  406 IF(KH.EQ.0) GO TO 104
      WRITE(6,4051)
 4051 FORMAT(1H0,'CHECK RUN.....FOUND A DEFICIT LARGER THAN ALLOWABLE')
      IF(ITIME.LT.6) GO TO 404
      STOP
  104 KTHRU=1
      ITIME=0
      KSTRT=1
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      MS=MSSV
      ME=MESV
C COMPUTE THE FREQUENCY,AMOUNT AND AVERAGE DURATION OF SHORTAGES
      KFQ=0
      TOT=0.
      DO 105 J=1,NYP
      TOT=TOT+SSHT(J)
      IF(SSHT(J).NE.0.) KFQ=KFQ+1
  105 CONTINUE
      YDEM=DD(II)*.365
      FNYP=NYP
      FKFQ=KFQ
      FREQ=(1.0-FKFQ/FNYP)*100.
      PI=(1.0-TOT/(FNYP*YDEM))*100.
      KDSUM=0
      DO 110 L=1,ID
      KDSUM=KDSUM+KDUR(L)
  110 CONTINUE
      SUM=KDSUM
      FID=ID
      AVDUR=0.
      IF(FID.GT.0.) AVDUR=SUM/FID
C COMPUTE THE LOAD FACTORS
      IF(N.EQ.1) GO TO 123
      FKSUM=KSUM
      FKON=KON(II)
      ALOAD=FKSUM/(FKON*12.)*100.
      GLOAD=FKSUM/(NYP*12)*100.
      AVLF(N)=AVLF(N)+ALOAD
      GLF(N)=GLF(N)+GLOAD
  123 FY(NP,N)=DD(II)
      GO TO (125,150),KIO
C ENTER HERE IF INTERMEDIATE PRINTOUT IS CALLED FOR
  125 IF(N.GT.1) GO TO 128
      WRITE(6,3000)
 3000 FORMAT(1H0,'OPERATION WITHOUT THE DESALTING PLANT')
      GO TO 132
  128 KP=NSN*(N-2)+1
      WRITE(6,3001)
 3001 FORMAT(1H0,'OPERATING RULE, EXPRESSED AS RESERVOIR CONTENTS')
      DO 130 K=1,NSN
      WRITE(6,3002)K,ONCON(KP),OFCON(KP)
 3002 FORMAT(1H ,'SEASON'I2,' ON='F6.2,' B.G.'10X'OFF='F6.2,' B.G.')
      KP=KP+1
  130 CONTINUE
  132 WRITE(6,3003) NP,N
 3003 FORMAT(1H ,'PERIOD NO.='I2,5X'RULE NO.='I3)
      WRITE(6,3004)DD(II),FREQ,PI,AVDUR,ALOAD,GLOAD,II
 3004 FORMAT(1H ,'YIELD='F8.2,5X'FREQ='F4.0,5X'PI='F5.1,5X'AVDUR='F3.1,
     15X'ALOAD='F5.1,5X'GLOAD='F5.1,5X'ITERATIONS='I3//)
      WRITE(6,3005) KD
 3005 FORMAT(1H0,'SHORTAGE INFORMATION--- THERE WERE'I2,' SHORTAGES I
     1N THIS SIMULATION'/)
      IF(KD.EQ.0) GO TO 150
      DO 149 L=1,KD
      WRITE(6,3021) MOS(L),KDUR(L),STOT(L)
 3021 FORMAT(1H ,'CRITICAL MONTH OF SHORTAGE='I4,10X'DURATION IN MONTHS=
     1'I2,10X'AMOUNT IN B.G.='F7.1)
  149 CONTINUE
  150 IF(N.EQ.1)DBAR=DEMB+DSCAP
  160 CONTINUE
C AT THIS POINT HAVE COMPLETED ALL RULES FOR ONE PERIOD
  170 CONTINUE
C AT THIS POINT HAVE COMPLETED ALL PERIODS
      WRITE(6,3008)
 3008 FORMAT(1H1,'TABULATION OF FIRM YIELD BY RULE AND PERIOD')
      WRITE(6,3009) (FY(L,1),L=1,NOP)
 3009 FORMAT(1H ,'ON= .00',5X'OFF= .00',5X,15F6.0)
      IF(NOF.EQ.0) GO TO 200
      K=1
      DO 181 IA=1,NON
      DO 181 IB=1,NOF
      K=K+1
      WRITE(6,3010) ONLEV(IA),OFLEV(IB),(FY(L,K),L=1,NOP)
 3010 FORMAT(1H ,'ON='F4.2,5X'OFF='F4.2,5X,15F6.0)
  181 CONTINUE
  200 RETURN
  501 WRITE(6,6001)
 6001 FORMAT(1H1,'THE RESERVOIR DID NOT REACH THE FULL CONDITION PRIOR
     1TO LOCM')
      GO TO 999
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  502 WRITE(6,6002)
 6002 FORMAT(1H1,'CRITICAL PERIOD NOT LOCATED IN 5 ITERATIONS')
      GO TO 999
  503 WRITE(6,6003)
 6003 FORMAT(1H1,'NO MONTHLY DEFICITS WERE RECORDED')
      GO TO 999
  902 WRITE(6,4002)
 4002 FORMAT(1H1,'SSA NOT IN RANGE OF TABLE')
  999 STOP
      END
@FOR,IS XLOC,XLOC
      SUBROUTINE XLOC(KD,MSTRT,MEND,DD,CMIN,MAXY,MD,TOL,KYLD)
      COMMON/BLOCW/STOT(50),MOS(50),MOF(50),MRM(25),MRF(25),SMIN(25)
      DIMENSION AMT(50),TEST(50)
      IF(KD.EQ.0) GO TO 10
      KNT=0
    1 AMT(1)=STOT(1)
      IF(KD.EQ.1) GO TO 5
      DO 4 L=2,KD
      IF(MOF(L).NE.MOF(L-1)) GO TO 3
      AMT(L)=AMT(L-1)+STOT(L)
      GO TO 4
    3 AMT(L)=STOT(L)
    4 CONTINUE
    5 SMAX=0.
      DO 8 L=1,KD
      TEST(L)=AMT(L)/(MOS(L)-MOF(L))
      IF(TEST(L).LT.SMAX) GO TO 8
      SMAX=TEST(L)
      IX=L
    8 CONTINUE
      IF(MAXY.EQ.0.OR.KYLD.EQ.2) GO TO 9
      KNT=KNT+1
      IF(KNT.GT.MAXY) GO TO 9
      STOT(IX)=0.
      GO TO 1
    9 WRITE(6,1002)(MOS(I),MOF(I),AMT(I),TEST(I), I=1,KD)
 1002 FORMAT(1H0,'RECORDED SHORTAGES USED TO DETERMINE THE CRITICAL RANG
     1E'/1H ,'   MOS    MOF         SHORTAGES        SEV.INDEX'/1H ,(/1H+,2I6,
     22F15.2))
      MSTRT=MOF(IX)
      MEND=MOS(IX)+2
      DD=-AMT(IX)/((MEND-MSTRT)*.0305)
      IF(KYLD.EQ.2) DD=DD*0.75
      WRITE(6,1000) MSTRT,MEND,AMT(IX)
 1000 FORMAT(1H0,'FULL='I3,10X'SHORT='I3,10X'AMOUNT='F8.2)
      GO TO 15
   10 STEST=99999.
      DO 13 L=1,20
      TEST(L)=SMIN(L)/(MRM(L)-MRF(L))
      IF(TEST(L).GT.STEST) GO TO 13
      STEST=TEST(L)
      IX=L
   13 CONTINUE
      MSTRT=MRF(IX)
      MEND=MRM(IX)+2
      DD=(SMIN(IX)-CMIN)/((MRM(IX)-MRF(IX))*.0305)
      WRITE(6,1001) MSTRT,MEND,SMIN(IX)
 1001 FORMAT(1H0,'FULL='I3,10X'MIN='I3,10X'RMIN='F8.2)
   15 RETURN
      END
@FOR,IS TERP3,TERP3
      SUBROUTINE TERP3(NON,NOF,TRDEM,ONLEV,OFLEV)
      COMMON /BLOCKG/GLF(50)
      COMMON /BLOCKE/ AVFY(50),XLF(50),ON(10),AL(10),GL(10)
      DIMENSION ONLEV(10),OFLEV(10)
      DO 5 J=1,NOF
      ON(J)=0.
    5 CONTINUE
      KNT=NOF
    1 DO 60 L=1,NOF
      DO 50 J=1,NON
      I=NOF*(J-1)+L+1
      IF(AVFY(I).LT.TRDEM) GO TO 48
      IF(J.NE.NON) GO TO 50
   45 DIFF=AVFY(I)-TRDEM
      IF(DIFF.GT.0.0025*TRDEM) GO TO 50
      ON(L)=ONLEV(J)
      AL(L)=XLF(I)
      GL(L)=GLF(I)
      GO TO 60
   48 IF(J.EQ.1) GO TO 52
      GO TO 57
   52 DIFF=TRDEM-AVFY(I)
      IF(DIFF.GT.0.0025*TRDEM) GO TO 55
      ON(L)=ONLEV(J)
      AL(L)=XLF(I)
      GL(L)=GLF(I)
      GO TO 60
   57 ON(L)=ONLEV(J)+(TRDEM-AVFY(I))/(AVFY(I-NOF)-AVFY(I))*(ONLEV(J-1)-
     1ONLEV(J))
      AL(L)=XLF(I)+(ON(L)-ONLEV(J))/(ONLEV(J-1)-ONLEV(J))*(XLF(I-NOF)-
     1XLF(I))
      GL(L)=GLF(I)+(ON(L)-ONLEV(J))/(ONLEV(J-1)-ONLEV(J))*(GLF(I-NOF)-
     1GLF(I))
      GO TO 60
   50 CONTINUE
      WRITE(6,2000) L
 2000 FORMAT(1H0,'MINIMUM VALUE OF CURVE'I2,' GREATER THAN TRDEM')
      KNT=KNT-1
      GO TO 60
   55 WRITE(6,2001) L
 2001 FORMAT(1H0,'MAXIMUM VALUE OF CURVE'I2,' LESS THAN TRDEM')
      KNT=KNT-1
   60 CONTINUE
      WRITE(6,2002) KNT
 2002 FORMAT(1H0,//1H ,'FEASIBLE RULE INFORMATION'/1H ,'NUMBER OF FEASIB
     1LE RULES FOUND='I2/)
      IF(KNT.EQ.0) STOP
      DO 62 L=1,NOF
      IF(ON(L).GT.0.0) WRITE(6,2003) ON(L),OFLEV(L),AL(L),GL(L)
   62 CONTINUE
 2003 FORMAT(1H ,'ON='F4.2,5X'OFF='F4.2,5X'OP. L.F.='F4.0,5X'GROSS L.F.=
     1'F4.0)
      RETURN
      END
@FOR,IS PLOT,PLOT
      SUBROUTINE PLOT(MSTOR,NY,NFULL,NEMPT)
      DIMENSION NARR(120),MA(120),OUT(120),MSTOR(360)
      DATA BK/1H /,X/1H*/
      NKNT=NY*12
      DO 2 I=1,NKNT
      MSTOR(I)=(MSTOR(I)*100)/NFULL
      TEM=MSTOR(I)
      TEM=TEM/2.0
      NTEM=TEM
      ATEM=NTEM
      IF(TEM-ATEM.NE.0.0) MSTOR(I)=MSTOR(I)+1
    2 CONTINUE
      FLTN=NY
      TEM=FLTN/10.+0.5
      NN=TEM
      DO 30 II=1,NN
      KK=120
      LL=(II-1)*10
      IF((NY-LL).LT.10) KK=LL*12
      JA=(II-1)*120
      DO 5 JJ=1,KK
      NARR(JJ)=MSTOR(JJ+JA)
      MA(JJ)=JJ
    5 CONTINUE
C     RANK VALUES IN DESCENDING ORDER
      N=KK
      M=N
    9 M=M/2
      IF(M) 10,20,10
   10 K=N-M
      J=1
   11 I=J
   12 L=I+M
      IF(NARR(L)-NARR(I)) 16,16,15
   15 NB=NARR(L)
      NA=MA(L)
      NARR(L)=NARR(I)
      MA(L)=MA(I)
      NARR(I)=NB
      MA(I)=NA
      I=I-M
      IF(I-1)16,12,12
   16 J=J+1
      IF(J-K)11,11,9
   20 WRITE(6,1000) NFULL,NEMPT,II
```

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 1000 FORMAT(1H1,'CAPACITY WHEN FULL='I6,' B.G.',4X,'CAPACITY AT MIN. US
     1ABLE LEVEL='I4,' B.G.'/1H ,'ORDINATE(RESERVOIR CONTENT) IS IN PERC
     2ENT',20X,'PAGE='I2/)
      KORD=100
      K=1
      IX=1
      DO 28 I=1,51
      IF(I.NE.IX) GO TO 22
      NORD=(51-IX)*2
      IX=IX+5
      WRITE(6,1002) NORD
 1002 FORMAT(1H ,I3,1H-)
      GO TO 122
   22 WRITE(6,1003)
 1003 FORMAT(1H ,3X,1H-)
  122 DO 23 J=1,120
   23 OUT(J)=BK
   24 IF(K.GT.KK) GO TO 26
      IF(NARR(K).NE.KORD) GO TO 25
      L=MA(K)
      OUT(L)=X
      K=K+1
      GO TO 24
   25 KORD=KORD-2
   26 WRITE(6,1001) (OUT(J),J=1,120)
 1001 FORMAT(1H+,6X,120A1)
   28 CONTINUE
   30 CONTINUE
   35 RETURN
      END
@FOR,IS TERP,TERP
      SUBROUTINE TERP(A,B,NPTS,ARG,VAL,NSIG)
C     THIS SUBROUTINE ASSUMES THAT THE B ARRAY IS NONDECREASING AS THE
C     A ARRAY INCREASES.
      DIMENSION A(100),B(100)
      IF(ARG.LT.A(1).OR.ARG.GT.A(NPTS)) GO TO 30
      IF(ARG.NE.A(NPTS)) GO TO 10
      VAL=ARG
      GO TO 50
   10 DO 20 I=1,NPTS
      IF(ARG.GE.A(I)) GO TO 20
      VAL=B(I-1)+(B(I)-B(I-1))*(ARG-A(I-1))/(A(I)-A(I-1))
      GO TO 50
   20 CONTINUE
      GO TO 50
   30 WRITE(6,40)
   40 FORMAT(1H0,'THE ARGUMENT IS OUT OF THE RANGE OF THE RESERVOIR DATA
     1')
      NSIG=1
   50 RETURN
      END
@FOR,IS RULE,RULE
      SUBROUTINE RULE(NON,NOF,NOR,NSN,KIO)
      COMMON /BLOCKB/ONCON(100),OFCON(100),UCAP
      COMMON /BLOCKF/ONI2,OFI2,ONI3,OFI3
      DIMENSION RUL(25,2)
C
C   THIS ROUTINE FORMULATES THE RULES THAT CONSTITUTE THE DECISION SPACE ** ** *
      KM=0
      DO 5 I=1,NON
      DO 5 J=1,NOF
      KM=KM+1
      RUL(KM,1)=ONCON(I)
      RUL(KM,2)=OFCON(J)
    5 CONTINUE
      KP=NSN*KM
      IF(NSN.EQ.1) GO TO 15
      DON2=ONI2*UCAP
      DOF2=OFI2*UCAP
      IF(NSN.EQ.2) GO TO 15
      DON3=ONI3*UCAP
      DOF3=OFI3*UCAP
      IF(NSN.NE.3) GO TO 900
   15 NOR=KM
      L=0
      DO 20 I=1,KP,NSN
      L=L+1
      ONCON(I)=RUL(L,1)
      OFCON(I)=RUL(L,2)
      IF(NSN.EQ.1) GO TO 20
      ONCON(I+1)=ONCON(I)- DON2
      OFCON(I+1)=OFCON(I)- DOF2
      IF(NSN.EQ.2) GO TO 20
      ONCON(I+2)=ONCON(I)-DON3
      OFCON(I+2)=OFCON(I)-DOF3
   20 CONTINUE
      GO TO (21,22),KIO
   21 WRITE(6,1005) (ONCON(J),OFCON(J),J=1,KP)
 1005 FORMAT(1H1,'OPERATING RULES'//(1H ,10F10.2))
   22 RETURN
  900 WRITE(6,2000)
 2000 FORMAT(1H1,'NUMBER OF SEASONS SPECIFIED IS IN ERROR')
      STOP
      END
@FOR,IS CON,CON
      SUBROUTINE CON(VAL,CVAL,K,IYEAR)
      GO TO(10,11),IYEAR
   10 GO TO(1,3,1,1,2,1,3,1,3,1,1,3),K
   11 GO TO(1,2,1,3,1,3,1,1,3,1,3,1),K
    1 CVAL=.031*VAL
      GO TO 5
    2 CVAL=.028*VAL
      GO TO 5
    3 CVAL=.030*VAL
    5 RETURN
      END
@FOR,IS FIND,FIND
      SUBROUTINE FIND(AA,N,IX)
      DIMENSION AA(50)
C THIS SUBROUTINE FINDS THE MINIMUM COST OF THE INCREASE IN FIRM YIELD'
    1 AMIN=9999999.
      DO 20 J=1,N
      IF(AA(J).GT.AMIN) GO TO 20
      AMIN=AA(J)
      IX=J
   20 CONTINUE
      RETURN
      END
@FOR,IS DEMF,DEMF
      FUNCTION DEMF(L,JY,C,A,B,U,W,AF)
      GO TO(1,2,3),L
    1 DEMF=C
      GO TO 5
    2 DEMF=A+B*JY
      GO TO 5
    3 DEMF=U-W*EXP(-AF*JY)
    5 RETURN
      END
@FOR,IS RAN,RAN
      FUNCTION RAN (IARG)
      COMMON/BLOCKZ/IY
      DATA IX/0/
      IF (IARG.EQ.IX) GO TO 3
      IX=IARG
      IY=IX
    3 IY=IY*262147
      IF(IY.LT.0) IY=IY+34359738367+1
      RAN=IY
      RAN=RAN*.2910383E-10
      RETURN
      END
@FOR,IS GNFLO,GNFLO
      SUBROUTINE GNFLO(NYRG,KIP,IFLOW,IYEAR)
C     FIVE STATION VERSION DIMENSIONED FOR 100 YEARS
      COMMON/BLOCKA/ Q(1201,5)
      COMMON/BLOCKZ/IY
      DIMENSION ALCFT(12,5),AV(12,5),BETA(12,5,5),DQ(12,5),IQ(15),
     1ISTA(5),MO(12),NCAB(12,5),NLOG(12,5),          QM(12),QPREV(10),
     2R(10,11),RA(12,5,10),SD(12,5),SKEW(13,5),SQA(12,10),SQB(12,10),
     3SUMA(12,10),SUMB(12,10),X(10),XPAB(12,10),          NLG(12,5),AVG(12
     4,5),SDV(12,5),AA(12,5,10),AB(12,5,10),AC(10),B(20),QR(1201,5)
C      23-C*-L267 MONTHLY STREAMFLOW SIMULATION HEC, C OF E, USA   8-18-67
C INDEXES I=CALENDAR MONTH J=YEAR K=STA L=RELATED STA M=SUCCESSIVE MONTH
C
      DOUBLE PRECISION R,B
      DATA LTRA/1HA/,BLANK/1H /,E/1HE/,KENT/1/
      NYMXG=NYRG
      IF(KENT.EQ.2) GO TO 1091
      KENT=2
      KSTA=5
      C=.0004356*7.48
      IARG=IY
```

```
      KYR=100
      KM=KYR*12+1
      IENDF=0
      IDGST=0
    1 FORMAT(1X,I7,9I8)
    2 FORMAT(1X,A3,9A4,10A4)
    3 FORMAT(1H0)
    4 FORMAT(I6,4X,I4,12F5.0)
    6 FORMAT(1X,I3,I4,12I6)
    7 FORMAT(1X,I3,I4,12F6.3)
C                WASTE CARDS UNTIL AN A IN COLUMN 1, FIRST TITLE CARD
   10 READ(5,12) IA,(Q(M,1),M=1,20)
      IF (IA.NE.LTPA) GO TO 10
      IF(IENDF.GT.0) GO TC 1271
      IENDF=IENDF+1
   11 FORMAT(1H ,I4,I6,12I8,I10)
   12 FORMAT (A1,A3,9A4,10A4)
      WRITE(6,3)
      IF(KIP.EQ.2) GO TO 13
      WRITE(6,2)   (Q(M,1),M=1,20)
   13 PEAD(5,1) IYRA,IMNTH,IMSNG,ITEST,IRCON,NSTA,IPCHQ
      ITMP=IRCON+NYRG
      IF(ITMP.GT.0)GO TO 30
      GO TO 10
   20 WRITE (6,25)
      STOP
   25 FORMAT(/19H DIMENSION EXCEEDED)
   30 IF(KIP.EQ.2) GO TO 42
      WRITE(6,40)
   40 FORMAT(1H0,'IYRA  IMNTH IMSNG ITEST IRCON NYRG  NSTA  IPCHQ NYMXG'
     1)
      WRITE(6,41) IYRA,IMNTH,IMSNG,ITEST,IRCON,NYRG,NSTA,IPCHQ,NYMXG
   41 FORMAT (20I6)
C                SET CONSTANTS
   42 T=99999999.
      TM=T-1.0
      IYRA=IYRA-1
      IMNTH=IMNTH-1
      DO 50 I=1,12
      ITMP=KSTA*2
      DO 46 K=1,KSTA
      DO 45 L=1,ITMP
      AA(I,K,L)=0.
   45 AB(I,K,L)=0.
   46 CONTINUE
      MO(I)=IMNTH+I
      IF(MO(I).LT.13)GO TO 50
      MO(I)=MO(I)-12
   50 CONTINUE
   58 NYRS=0
      DO 70 K=1,KSTA
      ISTA(K)=1000-K
C                INITIATE -1, NO RECORD FOR ALL FLOWS
      DO 60 M=1,KM
   60 Q(M,K)=-1.
      DO 65 I=1,12
      NLOG(I,K)=0
      DQ(I,K)=0.
   65 CONTINUE
   70 CONTINUE
C * * * * * * READ AND PROCESS 1 STATION-YEAR OF DATA * * * * * * * * * * * * *
      NSTA=0
   75 READ(5,4)ISTAN,IYR,(QM(I),I=1,12)
C                BLANK CARD INDICATES END OF FLOW DATA
   78 IF(ISTAN.LT.1)GO TO 130
      IF(NSTA.LT.1)GO TO 90
C                ASSIGN SUBSCRIPT TO STATION
      DO 80 K=1,NSTA
      IF(ISTAN.EQ.ISTA(K)) GO TO 100
   80 CONTINUE
   90 NSTA=NSTA+1
      K=NSTA
      ISTA(K)=ISTAN
C                ASSIGN SUBSCRIPT TO YEAR
  100 J=IYR-IYRA
      IF(NYRS.LT.J)NYRS=J
      IF(J.GT.0)GO TO 110
      WRITE (6,105)IYR
  105 FORMAT (/18H UNACCEPTABLE YEAR I5)
      STOP
C                STOPE FLOWS IN STATION AND MONTH ARRAY
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```
  110 M=J*12-11
      DO 120 I=1,12
      M=M+1
      IZ=QM(I)
      IF(IZ.EQ.-1) GO TO 120
      NLOG(I,K)=NLOG(I,K)+1
C CONVERT THE FLOWS TO B.G./MONTH
      GO TO (506,507,505,508),IFLOW
  505 QM(I)=QM(I)*C
      GO TO 508
  506 QM(I)=QM(I)*.646317
  507 GO TO (511,512),IYEAP
  511 GO TO (502,503,502,502,504,502,503,502,503,502,502,503),I
  512 GO TO (502,504,502,503,502,503,502,502,503,502,503,502),I
  502 QM(I)=QM(I)*.031
      GO TO 508
  503 QM(I)=QM(I)*.030
      GO TO 508
  504 QM(I)=QM(I)*.028
  508 DQ(I,K)=DQ(I,K)+QM(I)
      Q(M,K)=QM(I)
  120 CONTINUE
      GO TO 75
  130 NSTAA=NSTA+1
      IF(NYRS.GT.KYR) GO TO 20
      NSTAX=NSTA+NSTA
C * * * * * * COMPUTE FREQUENCY STATISTICS * * * * * * * * * * * * * * * * * *
      GO TO(131,316),KIP
  131 WRITE(6,314)
  314 FORMAT (/21H FREQUENCY STATISTICS)
      WRITE(6,315)(MO(I),I=1,12)
  315 FORMAT(/14H    STA    ITEM I7,11I8)
C                MISSING FLOW PRECEDING FIRST RECORD MONTH
  316 DO 317 K=1,NSTA
      Q(1,K)=T
  317 CONTINUE
      DO 421 K=1,NSTA
  318 DO 320 I=1,12
      AV(I,K)=0.
      SD(I,K)=0.
      SKEW(I,K)=0.
      TEMP=NLOG(I,K)
      DQ(I,K)=DQ(I,K)*.012/TEMP
      IF(DQ(I,K).LT..01) DQ(I,K)=.01
  320 CONTINUE
      M=1
      DO 350 J=1,NYRS
      DO 340 I=1,12
      M=M+1
      IZ=Q(M,K)
      IF(IZ.EQ.-1) GO TO 330
C                REPLACE FLOW ARRAY WITH LOG ARRAY
      TEMP=ALOG(Q(M,K)+DQ(I,K))/2.3026
      Q(M,K)=TEMP
C                SUM, SQUARES, AND CUFES
      AV(I,K)=AV(I,K)+TEMP
      SD(I,K)=SD(I,K)+TEMP*TEMP
      SKEW(I,K)=SKEW(I,K)+TEMP*TEMP*TEMP
      GO TO 340
C                MISSING FLOWS EQUATED TO T
  330 Q(M,K)=T
  340 CONTINUE
  350 CONTINUE
      DO 360 I=1,12
      TEMP=NLOG(I,K)
      TMP=AV(I,K)
      AV(I,K)=TMP/TEMP
      IF(SD(I,K).LE.0.)GO TO 355
      TMPA=SD(I,K)
      SD(I,K)=(SD(I,K)-AV(I,K)*TMP)/(TEMP-1.)
      SD(I,K)=SD(I,K)**.5
      SKEW(I,K)=(TEMP*TEMP*SKEW(I,K)-3.*TEMP*TMP*TMPA+2.*TMP*TMP*TMP)
     1/(TEMP*(TEMP-1.)*(TEMP-2.)*SD(I,K)**3.)
      IF (SKEW(I,K).GT.5.) SKEW(I,K)=5.
      IF (SKEW(I,K).LT.(-5.)) SKEW(I,K)=(-5.)
      GO TO 360
  355 SD(I,K)=0.
      SKEW(I,K)=0.
  360 CONTINUE
C * * * * * * OUTPUT FREQUFNCY STATISTICS * * * * * * * * * * * * * * *
      TMP=SKEW(12,K)
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      SKEW(13,K)=SKEW(1,K)
      GO TO(361,421),KIP
  361 WRITE(6,362)ISTA(K),(AV(I,K),I=1,12)
  362 FORMAT(/I6,8H    MEAN 12F8.3)
      WRITE(6,364)(SD(I,K),I=1,12)
  364 FORMAT(7X,7HSTD DEV 12F8.3)
      WRITE(6,366)(SKEW(I,K),I=1,12)
  366 FORMAT(10X,4HSKEW 12F8.3)
      WRITE(6,368)(DQ(I,K),I=1,12)
  368 FORMAT (8X6HINCRMT F7.2,11F8.2)
  421 CONTINUE
C * * * * * * TRANSFORM TO STANDARDIZED VARIATES * * * * * * * * * * * * * * *
  440 DO 490 K=1,NSTA
      M=1
      DO 480 J=1,NYRS
      DO 470 I=1,12
      M=M+1
      IF(Q(M,K).GT.TM) GO TO 470
      IZ=SD(I,K)+0.999
      IF(IZ.EQ.0) GO TO 460
      Q(M,K)=(Q(M,K)-AV(I,K))/SD(I,K)
C                PEARSON TYPE III TRANSFORM
      IZ=ABS(SKEW(I,K))+0.9999
      IF(IZ.EQ.0) GO TO 470
      TEMP=.5*SKEW(I,K)*Q(M,K)+1.
      TMP=1.
      IF(TEMP.GE.0.)GO TO 450
      TEMP=-TEMP
      TMP=-1.
  450 Q(M,K)=6.*(TMP*TEMP**(1./3.)-1.)/SKEW(I,K)+SKEW(I,K)/6.
      GO TO 470
  460 Q(M,K)=0.
  470 CONTINUE
  480 CONTINUE
  490 CONTINUE
C * * * * * * COMPUTE SUMS OF SQUARES AND CROSS PRODUCTS * * * * * * * * * * *
      DO 600 K=1,NSTA
      KX=K+1
      DO 510 L=KX,NSTAX
      DO 500 I=1,12
      RA(I,K,L) =(-4.)
      SUMA(I,L)=0.
      SUMB(I,L)=0.
      SQA(I,L)=0.
      SQB(I,L)=0.
      XPAB(I,L)=0.
  500 NCAB(I,L)=0
  510 CONTINUE
      DO 520 I=1,12
      DO 515 L=1,K
  515 NCAB(I,L)=-1
  520 RA(I,K,K)=1.
      M=1
      DO 550 J=1,NYRS
      DO 540 I=1,12
      M=M+1
      TEMP=Q(M,K)
      IF(TEMP.GT.TM) GO TO 540
      DO 530 L=KX,NSTAX
C                SUBSCRIPTS EXCEEDING NSTA RELATE TO PRECEDING MONTH
      LX=L-NSTA
      IF(LX.LT.1) TMP=Q(M,L)
      IF(LX.GT.0) TMP=Q(M-1,LX)
      IF(TMP.GT.TM)  GO TO 530
C                COUNT AND USE ONLY RECORDED PAIRS
      NCAB(I,L)=NCAB(I,L)+1
      SUMA(I,L)=SUMA(I,L)+TEMP
      SUMB(I,L)=SUMB(I,L)+TMP
      SQA(I,L)=SQA(I,L)+TEMP*TEMP
      SQB(I,L)=SQB(I,L)+TMP*TMP
      XPAB(I,L)=XPAB(I,L)+TEMP*TMP
  530 CONTINUE
  540 CONTINUE
  550 CONTINUE
C * * * * * * COMPUTE CORRELATION COEFFICIENTS * * * * * * * * * * * * * * * *
      DO 598 I=1,12
      IF(IDGST.LE.0) GO TO 575
      WRITE(6,560)MO(I),ISTA(K)
  560 FORMAT(/39H RAW CORRELATION COEFFICIENTS FOR MONTHI3, 12H  AT STAT
     1IONI6)
      WRITE(6,570)(ISTA(L),L=1,NSTA)
  570 FORMAT(9H WITH STA I13,11I10)
  575 DO 580 L=KX,NSTAX
C                ELIMINATE PAIRS WITH LESS THAN 3 YRS DATA
      IF(NCAB(I,L).LE.2)GO TO 580
      TEMP=NCAB(I,L)
      AA(I,K,L)=SUMA(I,L)/TEMP
      AB(I,K,L)=SUMB(I,L)/TEMP
      TMP=(SQA(I,L)-SUMA(I,L)*SUMA(I,L)/TEMP)*(SQB(I,L)-SUMB(I,L)*SUMB
     1(I,L)/TEMP)
C                ELIMINATE PAIRS WITH ZERO VARIANCE PRODUCT
      IF(TMP.LE.0.)GO TO 580
      TMPB=1.
      TMPA=XPAB(I,L)-SUMA(I,L)*SUMB(I,L)/TEMP
C                RETAIN ALGEBRAIC SIGN
      IF(TMPA.LT.0.)TMPB=-TMPB
      TMPA=TMPA*TMPA/TMP
      TMPA=1.-(1.-TMPA)*(TEMP-1.)/(TEMP-2.)
      IF(TMPA.LT.0.)TMPA=0.
      RA(I,K,L)=TMPB*TMPA**.5
      IF(L.GT.NSTA) GO TO 580
      RA(I,L,K)=RA(I,K,L)
      AA(I,L,K)=AB(I,K,L)
      AB(I,L,K)=AA(I,K,L)
  580 CONTINUE
      IF(IDGST.LE.0) GO TO 596
      WRITE(6,590)(NCAB(I,L),RA(I,K,L),L=1,NSTA)
  590 FORMAT(12H  THIS MONTH 12(I4,F6.3))
      WRITE(6,595)(NCAB(I,L),RA(I,K,L),L=NSTAA,NSTAX)
  595 FORMAT(12H  LAST MONTH 12(I4,F6.3))
C                ELIMINATE NEGATIVE CORRELATIONS
  596 DO 597 L=1,NSTAX
      IZ=RA(I,K,L)
      IF(RA(I,K,L).LT.0. .AND.IZ.NE.-4) RA(I,K,L)=0.
  597 CONTINUE
  598 CONTINUE
  600 CONTINUE
  612 TEMP=0.
      IF(IDGST.LE.0) GO TO 885
      WRITE(6,3)
C * * * * * * PRINT CORRELATION MATRIX * * * * * * * * * * * * * * * * * * * *
  815 DO 880 I=1,12
      WRITE(6,820)MO(I)
  820 FORMAT(//40H CONSISTENT CORRELATION MATRIX FOR MONTH I3)
      WRITE(6,825)(ISTA(K),K=1,NSTA)
  825 FORMAT(/3X,3HSTA 18I7)
      WRITE(6,830)
  830 FORMAT(20X,19H WITH CURRENT MONTH)
      DO 840 K=1,NSTA
  840 WRITE(6,850) ISTA(K),(RA(I,K,L),L=1,NSTA)
  850 FORMAT(I6,18F7.3)
      WRITE(6,860)
  860 FORMAT(20X38H WITH PRECEDING MONTH AT ABOVE STATION)
      ITP=NSTA+1
      DO 870 K=1,NSTA
  870 WRITE(6,850)ISTA(K),(RA(I,K,L),L=ITP,NSTAX)
  880 CONTINUE
  885 IF (IRCON.LE.0) GO TO 1015
      WRITE(6,3)
      M=1
      NVAR=NSTA+1
C                USE AVERAGE FOR MONTH PRECEDING RECORD
      DO 931 K=1,NSTA
  931 Q(1,K)=0.
      DO 990 J=1,NYRS
      DO 980 I=1,12
      M=M+1
      DO 970 K=1,NSTA
      QR(M,K)=BLANK
      IF(Q(M,K).LT.TM) GO TO 970
      NINDP=0
C                FORM CORRELATION MATRIX FOR EACH MISSING FLOW
      DO 950 L=1,NSTA
      LX=L+NSTA
      IF(L-K) 934,932,933
  932 NINDP=NINDP+1
      X(NINDP)=Q(M-1,L)
      AC(NINDP)=AB(I,K,LX)-AA(I,K,LX)
      R(L,NVAR)=RA(I,K,LX)
      GO TO 935
  933 IF(Q(M,L).GT.TM) GO TO 950
  934 NINDP=NINDP+1
```

```
      X(NINDP)=Q(M,L)
      AC(NINDP)=AB(I,K,L)-AA(I,K,L)
      R(NINDP,NVAR)=RA(I,K,L)
  935 ITP=NINDP
      R(ITP,ITP)=1.
      DO 940 LA=L,NSTA
      IF(LA.EQ.L) GO TO 940
      JX=LA+NSTA
      IF(L.EQ.K) GO TO 936
      IF(Q(M,LA).GT.TM.AND.LA.NE.K) GO TO 940
      ITP=ITP+1
      IF(LA.EQ.K)R(NINDP,ITP)=RA(I,L,JX)
      IF(LA.NE.K)R(NINDP,ITP)=RA(I,L,LA)
      GO TO 939
  936 IF(Q(M,LA).GT.TM) GO TO 940
      ITP=ITP+1
      R(NINDP,ITP)=RA(I,LA,LX)
C               ADD SYMMETRICAL ELEMENTS
  939 R(ITP,NINDP)=R(NINDP,ITP)
  940 CONTINUE
  950 CONTINUE
      ITMP=NINDP+1
      DO 952 L=1,NINDP
  952 R(L,ITMP)=P(L,NVAR)
C     ======
      CALL CROUT(R,DTRMC,NINDP,B)
C     ======
C               ADD RANDOM COMPONENT TO PRESERVE VARIANCE
      TEMP=RAN(IARG)
      TMP=RAN(IARG)
      TEMP=(-2.*ALOG(TEMP))**.5*SIN(6.2832*TMP)
C               COMPUTE FLOW
      IF (DTRMC.LE.1..AND.DTRMC.GE.0.) GO TO 955
      WRITE (6,7) I,K,DTRMC
      IF (DTRMC.GT.1.) DTRMC=1.
      IF (DTRMC.LT.0.) DTRMC=0.
  955 AL=(1.-DTRMC)**.5
      TEMP=TEMP*AL
      DO 960 L=1,NINDP
  960 TEMP=TEMP+B(L)*(X(L)-AC(L))
      Q(M,K)=TEMP
      QR(M,K)=E
  970 CONTINUE
  980 CONTINUE
  990 CONTINUE
      IF(KIP.EQ.2) GO TO 1994
      WRITE (6,993)
  993 FORMAT(33H RECORDED AND RECONSTITUTED FLOWS)
 1994 ANYRS=NYRS
      DO 1011 K=1,NSTA
      IF(KIP.EQ.2) GO TO 1995
      WRITE(6,995)(MO(I),I=1,12)
  995 FORMAT(/11H  STA  YEAR 12I8,6X,5HTOTAL )
 1995 M=1
      DO 1999 J=1,NYRS
      ITP=0
      DO 997 I=1,12
      M=M+1
      TEMP=Q(M,K)
C               CONVERT STANDARD DEVIATES TO FLOWS
      TMP=SKEW(I,K)
      IF(TMP)2000,2001,2000
 2000 TEMP=((TMP*(TEMP-TMP/6.)/6.+1.)**3 -1.)*2./TMP
 2001 IF(QR(M,K).NE.E) GO TO 992
      IF(TEMP.GT.2..AND.SD(I,K).GT..3) TEMP=2.+(TEMP-2.)*.3/SD(I,K)
      TMP=(-2.)/SKEW(I,K)
      IF(SKEW(I,K)) 991,992,994
  991 IF(TEMP.GT.TMP) TEMP=TMP
      GO TO 992
  994 IF(TEMP.LT.TMP) TEMP=TMP
  992 TMP=TEMP*SD(I,K)+AV(I,K)
      Q(M,K)=10.**TMP-DQ(I,K)
      IF(Q(M,K).LT.0.) Q(M,K)=0.
      QM(I)=QR(M,K)
  996 IQ(I)=Q(M,K)+.5
  997 ITP=ITP+IQ(I)
      IYR=IYRA+J
      IF(KIP.EQ.2)GO TO 1999
      IF(IPCHQ.LE.0)GO TO 998
      WRITE (7,6) ISTA(K),IYR,(IQ(I),I=1,12)
  998 WRITE(6,999)ISTA(K),IYR,(IQ(I),QM(I),I=1,12) ,ITP
  999 FORMAT(1X,I4,I6,I8,A1,11(I7,A1),I10)
 1999 CONTINUE
C  * * * * *RECOMPUTE MEAN AND STANDARD DEVIATION * * * * * * * * * * * * * * *
 1000 DO 1001 I=1,12
      AV(I,K)=0.
 1001 SD(I,K)=0.
      M=1
      DO 1003 J=1,NYRS
      DO 1002 I=1,12
      M=M+1
      TEMP=ALOG(Q(M,K)+DQ(I,K))
      AV(I,K)=AV(I,K)+TEMP
 1002 SD(I,K)=SD(I,K)+TEMP*TEMP
 1003 CONTINUE
      DO 1004 I=1,12
      TEMP=AV(I,K)
      TMP=(SD(I,K)-TEMP*TEMP/ANYRS)/(ANYRS-1.)
      SD(I,K)=TMP**.5*.4342945
 1004 AV(I,K)=TEMP/ANYRS*.4342945
 1011 CONTINUE
C               PRINT ADJUSTED FREQUENCY STATISTICS
      IF(KIP.EQ.2) GO TO 1015
      WRITE(6,3)
      WRITE(6,1012)
 1012 FORMAT(/30H ADJUSTED FREQUENCY STATISTICS)
      DO 1013 K=1,NSTA
      WRITE (6,315) (MO(I),I=1,12)
      WRITE (6,362) ISTA(K),(AV(I,K),I=1,12)
      WRITE (6,364) (SD(I,K),I=1,12)
      WRITE (6,366) (SKEW(I,K),I=1,12)
      WRITE (6,368) (DQ(I,K),I=1,12)
 1013 CONTINUE
C  * * * * * * FLOW GENERATION EQUATIONS * * * * * * * * * * * * * * * * * *
 1015 NINDP=NSTA
      NVAR=NSTA+1
      DO 1090 I=1,12
      IP=I-1
      IF (IP.LT.1) IP=12
      DO 1080 K=1,NSTA
      DO 1060 L=1,NSTA
C               CORRELATIONS IN CURRENT MONTH
      IF (L.GE.K) GO TO 1055
      R(L,NVAR)=RA(I,K,L)
      DO 1052 LA=L,NSTA
      LX=LA+NSTA
      IF (LA.LT.K) R(L,LA)=RA(I,L,LA)
      IF (LA.GE.K) R(L,LA)=RA(I,L,LX)
 1052 R(LA,L)=R(L,LA)
      GO TO 1060
C               CORRELATIONS WITH PRECEDING MONTH
 1055 LX=L+NSTA
      R(L,NVAR)=RA(I,K,LX)
      DO 1057 LA=L,NSTA
      R(L,LA)=RA(IP,L,LA)
 1057 R(LA,L)=R(L,LA)
 1060 CONTINUE
C     ======
 1065 CALL CROUT(R,DTRMC,NINDP,B)
C     ======
      DO 1070 L=1,NSTA
 1070 BETA(I,K,L)=B(L)
      IF(DTRMC.LE.1.) GO TO 1078
       WRITE(6,1072)I,K,DTRMC
 1072 FORMAT (34H INCONSISTENT CORREL MATRIX FOR I= I3,4H  K=I2,
     1 8H  DTRMC= F6.3)
      DTRMC=1.
 1078 IF(DTRMC.GE.0.) GO TO 1079
      WRITE(6,7)I,K,DTRMC
      DTRMC=0.
 1079 ALCFT(I,K)=(1.-DTRMC)**.5
 1080 CONTINUE
 1090 CONTINUE
C  * * * * * * GENERATE FLOWS * * * * * * * * * * * * * * * * * * * * * * * * *
 1091 JA=1
      N=0
      MA=0
 1095 DO 1100 K=1,NSTA
 1100 QPREV(K)=0.
C               GENERATE 2 YEARS FOR DISCARDING
      NJ=2
      JX=-2
```

```
      GO TO 5106
C                 N = SEQUENCE NO., M = MONTH NO., JX = YEAR NO.
 1105 WRITE(6,3)
      N=N+1
      IF(KIP.EQ.2) GO TO 5106
      WRITE(6,1106)
 1106 FORMAT(16H GENERATED FLOWS)
 5106 JXTMP=JX
      DO 3107 K=1,NSTA
      DO 3106 I=1,12
      NLG(I,K)=0
      AVG(I,K)=0.
      SDV(I,K)=0.
 3106 CONTINUE
 3107 CONTINUE
 1108 DO 3125 J=JA,NJ
      M=12*(J-1)+1
      JX=JX+1
      DO 1125 I=1,12
      M=M+1
      DO 1120 K=1,NSTA
C                 RANDOM COMPONENT
 1111 TEMP=RAN(IARG)
      TMP=RAN(IARG)
      TEMP=(-2.*ALOG(TEMP))**.5*SIN(6.2832*TMP)
      TEMP=TEMP*ALCFT(I,K)
C                 GENERATE CORRELATED STANDARD DEVIATE
      DO 1110 L=1,NSTA
      TMP=QPREV(L)
      IF(L.LT.K)TMP=Q(M,L)
 1110 TEMP=TEMP+BETA(I,K,L)*TMP
      NLG(I,K)=NLG(I,K)+1
      AVG(I,K)=AVG(I,K)+TEMP
      SDV(I,K)=SDV(I,K)+TEMP*TEMP
      Q(M,K)=TEMP
      QPREV(K)=TEMP
 1120 CONTINUE
 1125 CONTINUE
 3125 CONTINUE
      DO 1130 K=1,NSTA
 1122 IF(NJ+JXTMP.GT.0.AND.KIP.EQ.1) WRITE(6,995) (MO(I),I=1,12)
      DO 3126 I=1,12
      TEMP=NLG(I,K)
      AVG(I,K)=AVG(I,K)/TEMP
      SDV(I,K)=((SDV(I,K)-AVG(I,K)**2*TEMP)/TEMP)**.5
      IF(NLG(I,K).GT.19.AND.KIP.EQ.1) WRITE(6,5126) ISTA(K),MO(I),AVG(I,
     1K),SDV(I,K)
 3126 CONTINUE
 5126 FORMAT (4H STAI4,8H   MONTHI3,7H   MEANF6.3,10H   STD DEVF5.3)
      JX=JXTMP
      DO 3129 J=JA,NJ
      JX=JX+1
      M=12*J-11
      IF (JX.LE.0) GO TO 3129
      ITP=0
      DO 1129 I=1,12
      M=M+1
C                 TRANSFORM TO LOG PEARSON TYPE III VARIATE (FLOW)
      TMP=SKEW(I,K)
      IZ=ABS(SKEW(I,K))+0.9999
      IF(IZ.EQ.0) GO TO 1126
      IF (NLG(I,K).GT.19) Q(M,K)=(Q(M,K)-AVG(I,K))/SDV(I,K)
      TMP=((TMP*(Q(M,K)-TMP/6.)/6.+1.)**3 -1.)*2./TMP
      TEMP=(-2.)/SKEW(I,K)
      IF(SKEW(I,K)) 1123,1126,1124
 1123 IF(TMP.GT.TEMP)TMP=TEMP
      GO TO 1127
 1124 IF(TMP.LT.TEMP) TMP=TEMP
      GO TO 1127
 1126 TMP=Q(M,K)
 1127 IF(TMP.GT.2..AND.SD(I,K).GT. .3) TMP=2.+(TMP-2.)*.3/SD(I,K)
      TMP=TMP*SD(I,K)+AV(I,K)
      Q(M,K)=10.**TMP-DQ(I,K)
 3128 IF(Q(M,K).LT.0.) Q(M,K)=0.
 1128 IQ(I)=Q(M,K)+.5
      ITP=ITP+IQ(I)
 1129 CONTINUE
      IQ(13)=ITP
      IF(KIP.EQ.2) GO TO 3129
      WRITE (6,11) ISTA(K),JX,(IQ(I),I=1,13)
      IF(IPCHQ.LE.0)GO TO 3129
      WRITE (7,6) ISTA(K),JX,(IQ(I),I=1,12)
 3129 CONTINUE
 1130 CONTINUE
 1250 NJ = NYMXG
C                 GO TO NEW JOB
 1270 IF(NYRG.LE.0) GO TO 1271
      IF(NJ.GT.NYRG)NJ=NYRG
      NYRG=NYRG-NJ
      GO TO 1105
 1271 IF(NSTA.EQ.1) GO TO 1275
      M=1
      DO 1273 J=1,NYMXG
      DO 1273 I=1,12
      M=M+1
      TEMA=Q(M,3)*0.50
      TEMB=Q(M,2)*0.50
      IF(TEMA.GT.2.1350)TEMA=2.1350
      IF(TEMB.GT.2.1350)TEMB=2.1350
      Q(M,1)=Q(M,1)+TEMA+TEMB
 1273 CONTINUE
 1275 RETURN
      END
@FOR,IS CROUT,CROUT
      SUBROUTINE CROUT(RX,DTRMC,NINDP,B)
      DIMENSION B(20),R(10,11),RX(10,11)
      DOUBLE PRECISION R,B,RX
      NVAR=NINDP+1
      DO 5 J=1,NINDP
      DO 4 K=1,NVAR
    4 R(J,K)=RX(J,K)
    5 CONTINUE
      IF(NINDP.GT.1)GO TO 10
      B(1)=R(1,2)/R(1,1)
      DTRMC=B(1)*B(1)
      RETURN
C * * * * * * DERIVED MATRIX * * * * * * * * * * * * * * * * * * * * * * * * *
   10 DO 20 K=2,NVAR
   20 R(1,K)=R(1,K)/R(1,1)
      DO 60 K=2,NINDP
      ITP=K-1
      DO 40 J=K,NINDP
      DO 30 I=1,ITP
      L=K-I
   30 R(J,K)=R(J,K)-R(J,L)*R(L,K)
      IF(J.EQ.K) GO TO 40
      R(K,J)=R(J,K)/R(K,K)
   40 CONTINUE
      DO 50 I=1,ITP
      L=K-I
   50 R(K,NVAR)=R(K,NVAR)-R(L,NVAR)*R(K,L)
   60 R(K,NVAR)=R(K,NVAR)/R(K,K)
C * * * * * * BACK SOLUTION * * * * * * * * * * * * * * * * * * * * * * * * *
      B(NINDP)=R(NINDP,NVAR)
      DO 80 I=2,NINDP
      J=NVAR-I
      IX=I-1
      B(J)=R(J,NVAR)
      DO 70 L=1,IX
      K=J+L
   70 B(J)=B(J)-B(K)*R(J,K)
   80 CONTINUE
      DTRMC=0.
      DO 90 J=1,NINDP
   90 DTRMC=DTRMC+B(J)*RX(J,NVAR)
      RETURN
      END
```

Suggestions for More Efficient Use of the Operating Rule Program

The user may be somewhat bewildered as to the proper formulation of certain input parameters to achieve the desired objectives. Therefore a few suggestions are made for getting started on a computation.

The projected water demand is satisfied by two components: (1) the natural yield of the system, and (2) the supplement from the desalting plant. The natural yield of the system is determined by the program and is not known beforehand. This makes selection of the trial plant size somewhat difficult. If the plant size selected is too small, then even the high yield producing rules fall short of the required demand. On the other hand, if the plant selected is too large, the lower yield producing rules exceed the target demand. In either case, the set of feasible rules cannot be determined and the computer time involved is wasted. Experience with the program has shown that a plant size 1.30 times the required increase in firm yield is usually near optimal.

To decrease the wasted computer time, a pilot run should be made utilizing the best information available about the physical system under study and with the trial plant size suggested above. Select one or two operating rules and make a run using two or three periods. If one high and one low yield producing rule are used, the results will indicate an upper and lower limit on the firm yield for the given plant size. Actually, the information gained is twofold. First, the ability of the selected plant to produce the required yield can be judged, and second, if the plant is adequate, information is gained for formulating the operating rules. If the required demand is in the range of the high yield producing rules, then the lower yield producing rules need not be considered, and vice versa. By judicious selection of the operating rules, the computational effort can be greatly reduced.

APPENDIX B

DETAILED DESCRIPTION OF THE NO STORAGE VERSION OF THE OPERATING RULE PROGRAM AND ITS APPLICATION

Input Data Required by the NOSTOR Program

A. Job identification card. The first card contains from 1 to 80 columns of hollerith information specified by the program user to identify a particular job.

B. Specification card. This card contains the parameters that control the operation of the program.

Variable Name	Card Columns	Definition
NPER	1-2	number of periods of generated streamflow used in the determination of the required desalting plant capacity.
NYP	3-4	number of years in a period.
NPSC	5-6	number of periods of generated streamflow used in the simulation for determining costs.
IYEAR	8	specifies the type year used in the study. 1=calendar year (January to December). 2=water year (October to September).
IFLOW	10	input option for the historical streamflow data. 1=monthly flow values are in cubic feet per second (cfs). 2=monthly flow values are in million gallons per day (MGD).
NMOD	11-12	number of modules desired to build the plant up to its required capacity.
NSTD	13-14	number of standard deviations to be added to $\bar{D}$ for determining the required desalting plant capacity ($-3 \leq \text{NSTD} \leq 3$).
KIP	16	printout option for generated streamflow values. 1=printout statistics of historic data and the monthly values of the generated streamflow for each period. 2=no printout.
KIO	18	printout option in the simulation analysis. 1=output a summary by year of the plant operation. 2=suppress the printout.

C. Design demand rate and monthly demand coefficients.

DDR	design demand rate, i.e., end of planning period demand rate expressed in millions of gallons per day (columns 1-10).
DC	array of monthly demand coefficients (12F5.0 starting in column 11).

D. Parameters for specifying the demand growth function.

KDF	2	specifies the nature of the demand growth. 1=constant. 2=constant slope, i.e., linear increase with time. 3=exponential function.
CDEM	11-20	design demand rate, used if KDF = 1.
AD	21-30	year zero (intercept) of the linear demand function, required if KDF = 2.
BD	31-40	slope of the linear demand function, required if KDF = 2.
UD	41-50	upper limit (asymptote) of the exponential demand function, required if KDF = 3.
WD	51-60	difference between UD and the demand rate in year zero, required if KDF = 3.

AF	61-70	exponent of e that defines the rate of growth, required if KDF = 3.

E. Coefficients that constrain the amount of water that can be withdrawn.

PSDA		monthly coefficients (decimal fractions) expressing the percentage of the natural flow that can be withdrawn for consumption (12F5.0 starting in column 1).

F. Data required for generating streamflow sequences.

(a) Identification card contains hollerith information specified by the user to identify the data being used. Must have an A in column 1.

(b) Control parameters (right hand justified in their respective fields).

IYRA	5-8	earliest year of record at any of the stations for which flows are to be generated.
IMNTH	15-16	calendar month number of first month of year being used, ex., if water year is specified IMNTH = 10.
IMSNG	23-24	indicator, any positive number for estimating missing correlation coefficients.
ITEST	31-32	indicator, any positive number calls for a consistency test of correlation matrices.
IRCON	39-40	indicator, any positive number calls for reconstitution of missing data.
NSTA	47-48	number of streamflow stations at which flows are to be generated.
IPCHQ	55-56	indicator, any number greater than o calls for output of the generated flows on magnetic tape.

(c) Historic streamflow data.

ISTAN	1-6	station number (right hand justified).
IYR	11-14	year of record.
QM	15-74	array of monthly flows for year IYR (12F5.0).

Repeat (c) for each year of streamflow and for each station.

(d) Blank card, terminates the streamflow input.

G. Desalting plant cost data.

(a) Operating load factors.

NOFF	1-2	number of load factors to be used in the cost analysis.
FACT	6-45	yearly operational load factors expressed in percent of a year that a plant or module operates (8F5.0).

(b) Operating and maintenance cost coefficients.

COEF	1-80	multiplicative coefficients for determining yearly operating and maintenance costs as a function of load factor. Either the coefficients or data from which coefficients are derived were furnished by ORNL (8F10.0).

(c) Desalting plant cost equations (constants and exponents).

CNO	1-10	constant in the equation for computing operating and maintenance costs at zero load factor.
EXNO	11-20	exponent of plant size in the zero load factor operating equation.
CTN	21-30	constant in the equation for computing turn-on and turn-off costs.
EXTN	31-40	exponent of plant size in the equation for computing the turn-on and turn-off costs.

COP	41-50	constant in the equation for computing operating costs for load factors > 0.	CCP	61-70	constant in the equation for computing capital cost of the module.
EXOP	51-60	Exponent of plant size in the operating cost equations.	EXCP	71-80	exponent of plant size in the capital cost equation.

```
@FOR,IS NOSTOR,NOSTOR
C   NO STORAGE IMPLEMNETATION
      COMMON/BLOCA/Q(601,5)
      COMMON/BLOCB/ MSUM(10,50),KON(50),KOFF(50),MYEAR(10),NMODO(10),
     1NODOP(50)
      COMMON/BLOC7/IY
      DIMENSION DC(12),PSDA(12),MNTHA(12),MNTHB(12),DMAX(100),FLOW(100),
     1MONTH(100),MODOP(13),DFCIT(50),MMD(50),ANCST(50),MODAV(50),FMT(20)
      DATA MNTHA/4HJAN ,4HFEB ,4HMAR ,4HAPR ,4HMAY ,4HJUNE,4HJULY,
     14HAUG ,4HSEPT,4HOCT ,4HNOV ,4HDEC /
      DATA MNTHB/4HOCT ,4HNOV ,4HDEC ,4HJAN ,4HFEB ,4HMAR ,4HAPR ,
     14HMAY ,4HJUNE,4HJULY,4HAUG ,4HSEPT/
      DATA FA/5H(1H ,/,FSKP/4H10X,/,FT/4HI10,/,FF/3HI5,/,FC/2H )/
    1 READ(5,1000)
 1000 FORMAT(80H
     1                              )
      WRITE(6,1000)
      READ(5,1001) NPER,NYP,NPSC,IYEAR,IFLOW,NMOD,NSTD,KIP,KIO
 1001 FORMAT(9I2)
      READ(5,1005) DDR,(DC(I),I=1,12)
 1005 FORMAT(F10.0,12F5.0)
      READ(5,1010) KDF,CDEM,AD,BD,UD,WD,AF
 1010 FORMAT(I2,8X,6F10.0)
      READ(5,1006) (PSDA(I),I=1,12)
 1006 FORMAT(12F5.0)
    5 WRITE(6,2000) NPER,NYP,NPSC,IYEAR,IFLOW,DDR,KIO,KIP
 2000 FORMAT(1H0,'NO. OF PERIODS IN ANALYSIS= 'I3,/1H ,'NO. OF YEARS IN
     1EACH PERIOD='I3,/1H ,'NO. OF PERIODS IN COST SIM='I3,/1H 'IYEAR='
     2I2,/1H ,'IFLOW='I2,/1H ,'DESIGN DEMAND RATE='F7.0,/1H ,'KIO='I2,/1
     3H ,'KIP='I2)
      GO TO (10,11),IYEAR
   10 WRITE(6,2001) (MNTHA(I),I=1,12)
 2001 FORMAT(1H0,27X,12A6)
      GO TO 12
   11 WRITE(6,2001) (MNTHB(I),I=1,12)
   12 WRITE(6,2002) (DC(I),I=1,12)
 2002 FORMAT(1H0,'DEMAND COEFFICIENTS '5X,12F6.2)
      WRITE(6,2003) (PSDA(I),I=1,12)
 2003 FORMAT(1H0,'STREAM DIVERSION COEFF.   ',12F6.3)
      WRITE(6,2004) KDF,CDEM,AD,BD,UD,WD,AF
 2004 FORMAT(1H0,'DEMAND FUNCTION DATA'/1H ,'CODE='I2,5X'CDEM='F6.0,5X
     1'AD='F6.0,5X'BD='F4.1,5X'UD='F6.0,5X'WD='F6.0,5X'AF='F6.3)
      FMT(1)=FA
      FMT(2)=FT
      FMT(3)=FT
      FMT(4)=FSKP
      J=5
      DO 15 I=1,NMOD
      FMT(J)=FF
      J=J+1
   15 CONTINUE
      FMT(J)=FT
      FMT(J+1)=FT
      FMT(J+2)=FT
      FMT(J+3)=FC
      IARG=798531
      DO 30 N=1,NPER
      NYG=NYP
      CALL GNFLO(NYG,KIP,IFLOW,IYEAR)
C   RETURN FROM GNFLO WITH NYP YEARS OF MONTHLY FLOWS IN M.G.D.
      TMAX=0.
      M=1
      DO 25 J=1,NYP
      DO 20 I=1,12
      M=M+1
      D=DDR*DC(I)-Q(M,1)*PSDA(I)
      IF(D.LT.TMAX) GO TO 20
      TMAX=D
      MX=M
      IX=I
   20 CONTINUE
   25 CONTINUE
      DMAX(N)=TMAX
      FLOW(N)=Q(MX,1)
      MONTH(N)=IX
   30 CONTINUE
      WRITE(6,2050)
 2050 FORMAT(1H1,'DMAX DATA')
      SDM=0.
      SDMS=0.
      DO 35 N=1,NPER
      WRITE(6,2010) DMAX(N),FLOW(N),MONTH(N)
 2010 FORMAT(1H ,2F15.2,I10)
      SDM=SDM+DMAX(N)
      SDMS=SDMS+DMAX(N)*DMAX(N)
   35 CONTINUE
      DMAXB=SDM/NPER
      STD=SQRT((SDMS-SDM*SDM/NPER)/(NPER-1))
      WRITE(6,2020) DMAXB,STD
 2020 FORMAT(1H0,'MEAN='F7.2,10X'STANDARD DEVIATION='F7.2)
      CAPT=DMAXB+NSTD*STD
      KAPM=CAPT/NMOD+0.999
      WRITE(6,2011) KAPM
 2011 FORMAT(1H0,'CALCULATED MODULE SIZE='I5)
C   DETERMINE THE MODULAR CONFIGURATION WITH RESPECT TO TIME
      MYEAR(1)=1
      NMODO(1)=1
      FYWO=DDR-DMAXB
      NM=1
      N=0
      DO 50 J=1,NYP
      IF(NM.EQ.6) GO TO 49
      K=J+1
      YD=DEMF(KDF,K,CDEM,AD,BD,UD,WD,AF)
      KFLAG=1
   46 TEM=FYWO+NM*KAPM
      IF(YD.LT.TEM) GO TO 49
      IF(KFLAG.EQ.1) N=N+1
      KFLAG=2
      NM=NM+1
      MYEAR(N)=J
      NMODO(N)=NM
      GO TO 46
   49 MODAV(J)=NM
   50 CONTINUE
C   OUTPUT THE MODULAR CONSTRUCTION SCHEDULE
      NMC=N
      WRITE(6,2040) (MYEAR(N),NMODO(N),N=1,NMC)
 2040 FORMAT(1H0,'MODULAR CONSTRUCTION SCHEDULE'/1H0,'YEAR OF PERIOD'10X
     1'MODULES IN OPERATION'// (I10,25X,I2))
      AVCST=0.
      IY=798531
      DO 150 N=1,NPSC
C   SIMULATE OPERATION TO OBTAIN THE COST *****************************
      ND=0
      DO 55 J=1,NYP
      KON(J)=0
      KOFF(J)=0
      DO 54 L=1,10
      MSUM(L,J)=0
   54 CONTINUE
   55 CONTINUE
      NYG=NYP
      CALL GNFLO(NYG,KIP,IFLOW,IYEAR)
      MODOP(1)=0
      M=1
      DO 95 J=1,NYP
      DO 85 I=1,12
      M=M+1
      DD=DEMF(KDF,J,CDEM,AD,BD,UD,WD,AF)*DC(I)
      MODOP(I+1)=0
      D=DD-Q(M,1)*PSDA(I)
      IF(D.LT.0.) GO TO 85
C   DETERMINE THE NUMBER OF MODULES NEEDED TO PREVENT A DEFICIT
      TEM=D/KAPM
      KTEM=TEM
      FM=TEM-KTEM
      IF(FM.GT.0.1) KTEM=KTEM+1
      MODOP(I+1)=KTEM
      IF(KTEM.LE.MODAV(J)) GO TO 85
      ND=ND+1
      AV=MODAV(J)*KAPM +Q(M,1)*PSDA(I)
      DFCIT(ND)=DD-AV
      MMD(ND)=M
      MODOP(I+1)=MODAV(J)
   85 CONTINUE
C   SUMMARIZE THE OPERATION FOR THE YEAR
      MMAX=MODOP(2)
      DO 90 I=2,13
      K=MODOP(I)-MODOP(I-1)
      IF(K.EQ.0.AND.MODOP(I).EQ.0) GO TO 90
      IF(K.LT.0) GO TO 86
```

```
      KON(J)=KON(J)+K
      GO TO 87
   86 KOFF(J)=KOFF(J)-K
   87 KK=MODOP(I)
      IF(KK.LE.MMAX) GO TO 89
      MMAX=KK
   89 IF(KK.EQ.0) GO TO 90
      DO 88 L=1,KK
      MSUM(L,J)=MSUM(L,J)+1
   88 CONTINUE
   90 CONTINUE
      MODOP(1)=MODOP(13)
      NODOP(J)=MMAX
   95 CONTINUE
      CALL COST(NYP,UAC,KAPM)
      IF(KIO.EQ.2) GO TO 149
C  OUTPUT THE SUMMARY OF TH MODULE OPERATION
      WRITE(6,2021) N
 2021 FORMAT(1H1,'OPERATION OF THE MODULAR PLANT FOR PERIOD NO.'I3,//)
      DO 100 J=1,NYP
      WRITE(6,FMT) J,MODAV(J),(MSUM(L,J),L=1,NMOD),KON(J),KOFF(J),NODOP
     1(J)
  100 CONTINUE
      WRITE(6,2022) NMOD
 2022 FORMAT(1H0,'COL. 1 IS THE YEAR'/1H ,'COL. 2 IS THE NUMBER OF MODUL
     1ES AVAILABLE'/1H ,'THE NEXT'I3,' COLUMNS ARE THE NO. OF MONTHS THA
     2T EACH MODULE OPERATED'/1H ,'THE LAST 3 COLUMNS ARE THE MODULE TUR
     3N-ON, TURN-OFF, AND NO. OPERATED RESPECTIVELY')
      IF(ND.EQ.0) GO TO 149
      WRITE(6,2023) ND,N,(DFCIT(L),MMD(L),L=1,ND)
 2023 FORMAT(1H0,'THERE WERE'I3,2X'DEFFECITS IN PERIOD'I3/1H0,
     1'AMOUNT        MONTH OCCURED'/1H ,(F6.2,14XI3))
  149 ANCST(N)=UAC
      AVCST=AVCST+UAC
  150 CONTINUE
      AVCST=AVCST/N
      WRITE(6,2024) (ANCST(N),N=1,NPSC)
 2024 FORMAT(1H0,10F12.0)
      WRITE(6,2025) AVCST
 2025 FORMAT(1H0,'UNIFORM ANNUAL COST='F12.0)
      STOP
      END
@FOR,IS COST,COST
      SUBROUTINE COST(NYP,UAC,KAPM)
      COMMON/BLOCB/ MSUM(10,50),KON(50),KOFF(50),MYEAR(10),NMODO(10),
     1NODOP(50)
      DIMENSION COEF(10),FACT(10)
      DATA KENT/1/,A/1H*/,F/2H**/
      REAL INT
      IF(KENT.EQ.2) GO TO 10
      KENT=2
      READ(5,1000) NOFF,(FACT(J),J=1,NOFF)
      READ(5,1001) (COEF(J),J=1,NOFF)
 1000 FORMAT(I2,3X,8F5.0)
 1001 FORMAT(8F10.0)
      READ(5,1001) CNO,EXNO,CTN,EXTN,COP,EXOP,CCP,EXCP
      CAP=CCP*KAPM**EXCP
      READ(5,1002) FIX,INT,DSLF
 1002 FORMAT(3F10.0)
C    OUTPUT THE COST DATA
      WRITE(6,2000) DSLF
 2000 FORMAT(1H0,'COST DATA FOR A DESIGN LOAD FACTOR OF',F4.0)
      WRITE(6,2001) (FACT(J),J=1,NOFF)
      WRITE(6,2101)(COEF(J),J=1,NOFF)
 2001 FORMAT(1H0,'OPERATING LOAD FACTORS ARE'8F12.0)
 2101 FORMAT(1H ,'THE COST COEFFICIENTS ARE '8F12.3,//)
      WRITE(6,2002) CNO,A,F,EXNO
 2002 FORMAT(1H0,'EQUATION USED IN TH COST COMPUTATIONS'/1H0,'OPER. AT Z
     1ERO LOAD FACTOR'10X'COST='F8.0,A1,'S'A2,F6.4)
      WRITE(6,2003) CTN,A,F,EXTN
 2003 FORMAT(1H0,'TURN-ON AND TURN-OFF'15X'COST='F8.0,A1,'S'A2,F6.4)
      WRITE(6,2004) COP,A,F,EXOP,A
 2004 FORMAT(1H0,'OPERATING AND MAINTENANCE ' 9X'COST='F8.0,A1,'S'A2,F6.
     14,A1,'C(I)')
      WRITE(6,2005) CCP,A,F,EXCP
 2005 FORMAT(1H0,'CAPITAL COST IN MILL. $  '10X'COST='F8.0,A1,'S'A2,F6.4
     1,//1H ,'WHERE S IS THE MODULE OR THE PLANT SIZE AND C(I) IS THE IN
     2TERPOLATED COEF.'//)
      WRITE(6,2006) FIX,INT
 2006 FORMAT(1H0,'FIXED CHARGE RATE='F5.2,10X'DISCOUNT RATE='F5.2)
   10 S=0.
```

```
      PWTH=0.
      I=1
      DO 40 J=1,NYP
      IF(J.NE.MYEAR(I)) GO TO 15
      NOM=NMODO(I)
      CAPTC=NOM*CAP*FIX
      I=I+1
   15 CSTOP=0.
      M=NODOP(J)
      DO 20 L=1,M
      OLF=MSUM(L,J)/12.0*100.0
      IF(OLF.LT.5.0) GO TO 25
      DO 16 K=1,NOFF
      IF(OLF.LT.95.0) GO TO 13
      C=COEF(NOFF)
      GO TO 17
   13 IF(OLF.GT.FACT(K+1)) GO TO 16
      FRAC=(OLF-FACT(K))/(FACT(K+1)-FACT(K))
      C=COEF(K)+FRAC*(COEF(K+1)-COEF(K))
      GO TO 17
   16 CONTINUE
   17 CSTOP=CSTOP+COP*KAPM**EXOP*C
   20 CONTINUE
   25 NMNOP=NOM-M
      S=NMNOP*KAPM
      CSTNOP=0.
      IF(NMNOP.EQ.0) GO TO 26
      CSTNOP=CNO*S**EXNO
   26 CTURN=(KON(J)+KOFF(J))/2.*CTN*KAPM**EXTN
      DFAC=1.0/((1.0+INT)**J)
      PWTH=PWTH+(CSTOP+CSTNOP+CTURN+CAPTC)*DFAC
   40 CONTINUE
      F=1.0/DFAC
      UAC=PWTH*INT*F/(F-1.0)
      RETURN
      END
@FOR,IS RAN,RAN
      FUNCTION RAN (IARG)
      COMMON/BLOCZ/IY
      DATA IX/0/
      IF (IARG.EQ.IX) GO TO 3
      IX=IARG
      IY=IX
    3 IY=IY*262147
      IF(IY.LT.0) IY=IY+34359738367+1
      RAN=IY
      RAN=RAN*.2910383E-10
      RETURN
      END
@FOR,IS DEMF,DEMF
      FUNCTION DEMF(L,JY,C,A,B,U,W,AF)
      GO TO(1,2,3),L
    1 DEMF=C
      GO TO 5
    2 DEMF=A+B*JY
      GO TO 5
    3 DEMF=U-W*EXP(-AF*JY)
    5 RETURN
      END
@FOR,IS GNFLO,GNFLO
      SUBROUTINE GNFLO(NYRG,KIP,IFLOW,IYEAR)
C     FIVE STATION VERSION DIMENSIONED FOR 50 YEARS
      COMMON/BLOCA/Q(601,5)
      DIMENSION ALCFT(12,5),AV(12,5),BETA(12,5,5),DQ(12,5),IQ(15),
     1ISTA(5),MO(12),NCAB(12,5),NLOG(12,5),          QM(12),QPREV(10),
     2R(10,11),RA(12,5,10),SD(12,5),SKEW(13,5),SQA(12,10),SQB(12,10),
     3SUMA(12,10),SUMB(12,10),X(10),XPAB(12,10),         NLG(12,5),AVG(12
     4,5),SDV(12,5),AA(12,5,10),AB(12,5,10),AC(10),B(20),QR(601,5)
C     23-C*-L267 MONTHLY STREAMFLOW SIMULATION HEC, C OF E, USA  8-16-67
C INDEXES I=CALENDAR MONTH J=YEAR K=STA L=RELATED STA M=SUCCESSIVE MONTH
C
      DOUBLE PRECISION R,B
      DATA LTRA/1HA/,BLANK/1H /,E/1HE/,KENT/1/
      NYMXG=NYRG
      IF(KENT.EQ.2) GO TO 1091
      KENT=2
      KSTA=5
      IARG=798531
      C=.0004356*7.48
      KYR=50
      KM=KYR*12+1
```

```
      IENDF=0
      IDGST=0
    1 FORMAT(1X,I7,9I8)
    2 FORMAT(1X,A3,9A4,10A4)
    3 FORMAT(1H0)
    4 FORMAT(I6,4X,I4,12F5.0)
    6 FORMAT(1X,I3,I4,12I6)
    7 FORMAT(1X,I3,I4,12F6.3)
C               WASTE CARDS UNTIL AN A IN COLUMN 1, FIRST TITLE CARD
   10 READ(5,12) IA,(Q(M,1),M=1,20)
      IF (IA.NE.LTRA) GO TO 10
      IF(IENDF.GT.0) GO TO 1271
      IENDF=IENDF+1
   11 FORMAT(1H ,I4,I6,12I8,I10)
   12 FORMAT (A1,A3,9A4,10A4)
      WRITE(6,3)
      IF(KIP.EQ.2) GO TO 13
      WRITE(6,2)   (Q(M,1),M=1,20)
   13 READ(5,1) IYRA,IMNTH,IMSNG,ITEST,IRCON,NSTA,IPCHQ
      ITMP=IRCON+NYRG
      IF(ITMP.GT.0)GO TO 30
      GO TO 10
   20 WRITE (6,25)
      STOP
   25 FORMAT(/19H DIMENSION EXCEEDED)
   30 IF(KIP.EQ.2) GO TO 42
      WRITE(6,40)
   40 FORMAT(1H0,'IYRA  IMNTH IMSNG ITEST IPCON NYRG  NSTA  IPCHQ NYMXG'
     1)
      WRITE(6,41) IYRA,IMNTH,IMSNG,ITEST,IPCON,NYRG,NSTA,IPCHQ,NYMXG
   41 FORMAT (20I6)
C               SET CONSTANTS
   42 T=99999999.
      TM=T-1.0
      IYRA=IYRA-1
      IMNTH=IMNTH-1
      DO 50 I=1,12
      ITMP=KSTA*2
      DO 46 K=1,KSTA
      DO 45 L=1,ITMP
      AA(I,K,L)=0.
   45 AB(I,K,L)=0.
   46 CONTINUE
      MO(I)=IMNTH+I
      IF(MO(I).LT.13)GO TO 50
      MO(I)=MO(I)-12
   50 CONTINUE
   58 NYRS=0
      DO 70 K=1,KSTA
      ISTA(K)=1000-K
C               INITIATE -1, NO RECORD FOR ALL FLOWS
      DO 60 M=1,KM
   60 Q(M,K)=-1.
      DO 65 I=1,12
      NLOG(I,K)=0
      DQ(I,K)=0.
   65 CONTINUE
   70 CONTINUE
C * * * * * * READ AND PROCESS 1 STATION-YEAR OF DATA * * * * * * * * * * * * *
      NSTA=0
   75 READ(5,4)ISTAN,IYR,(QM(I),I=1,12)
C               BLANK CARD INDICATES END OF FLOW DATA
   78 IF(ISTAN.LT.1)GO TO 130
      IF(NSTA.LT.1)GO TO 90
C               ASSIGN SUBSCRIPT TO STATION
      DO 80 K=1,NSTA
      IF(ISTAN.EQ.ISTA(K))GO TO 100
   80 CONTINUE
   90 NSTA=NSTA+1
      K=NSTA
      ISTA(K)=ISTAN
C               ASSIGN SUBSCRIPT TO YEAR
  100 J=IYR-IYRA
      IF(NYRS.LT.J)NYRS=J
      IF(J.GT.0)GO TO 110
      WRITE (6,105)IYR
  105 FORMAT (/18H UNACCEPTABLE YEAR I5)
      STOP
C               STORE FLOWS IN STATION AND MONTH ARRAY
  110 M=J*12-11
      DO 120 I=1,12
      M=M+1
      IZ=QM(I)
      IF(IZ.EQ.-1) GO TO 120
      NLOG(I,K)=NLOG(I,K)+1
C CONVERT THE FLOWS TO MGD
      GO TO (506,507),IFLOW
  506 QM(I)=QM(I)*.646317
      GO TO 507
  507 DQ(I,K)=DQ(I,K)+QM(I)
      Q(M,K)=QM(I)
  120 CONTINUE
      GO TO 75
  130 NSTAA=NSTA+1
      IF(NYRS.GT.KYR) GO TO 20
      NSTAX=NSTA+NSTA
C * * * * * * COMPUTE FREQUENCY STATISTICS * * * * * * * * * * * * * * * * * *
      GO TO(131,316),KIP
  131 WRITE(6,314)
  314 FORMAT (/21H FREQUENCY STATISTICS)
      WRITE(6,315)(MO(I),I=1,12)
  315 FORMAT(/14H   STA    ITEM I7,11I8)
C               MISSING FLOW PRECEDING FIRST RECORD MONTH
  316 DO 317 K=1,NSTA
      Q(1,K)=T
  317 CONTINUE
      DO 421 K=1,NSTA
  318 DO 320 I=1,12
      AV(I,K)=0.
      SD(I,K)=0.
      SKEW(I,K)=0.
      TEMP=NLOG(I,K)
      DQ(I,K)=DQ(I,K)*.012/TEMP
      IF(DQ(I,K).LT..01)DQ(I,K)=.01
  320 CONTINUE
      M=1
      DO 350 J=1,NYRS
      DO 340 I=1,12
      M=M+1
      IZ=Q(M,K)
      IF(IZ.EQ.-1) GO TO 330
C               REPLACE FLOW ARRAY WITH LOG ARRAY
      TEMP=ALOG(Q(M,K)+DQ(I,K))/2.3026
      Q(M,K)=TEMP
C               SUM, SQUARES, AND CUBES
      AV(I,K)=AV(I,K)+TEMP
      SD(I,K)=SD(I,K)+TEMP*TEMP
      SKEW(I,K)=SKEW(I,K)+TEMP*TEMP*TEMP
      GO TO 340
C               MISSING FLOWS EQUATED TO T
  330 Q(M,K)=T
  340 CONTINUE
  350 CONTINUE
      DO 360 I=1,12
      TEMP=NLOG(I,K)
      TMP=AV(I,K)
      AV(I,K)=TMP/TEMP
      IF(SD(I,K).LE.0.)GO TO 355
      TMPA=SD(I,K)
      SD(I,K)=(SD(I,K)-AV(I,K)*TMP)/(TEMP-1.)
      SD(I,K)=SD(I,K)**.5
      SKEW(I,K)=(TEMP*TEMP*SKEW(I,K)-3.*TEMP*TMP*TMPA+2.*TMP*TMP*TMP)
     1/(TEMP*(TEMP-1.)*(TEMP-2.)*SD(I,K)**3.)
      IF (SKEW(I,K).GT.5.) SKEW(I,K)=5.
      IF (SKEW(I,K).LT.(-5.)) SKEW(I,K)=(-5.)
      GO TO 360
  355 SD(I,K)=0.
      SKEW(I,K)=0.
  360 CONTINUE
C * * * * * * OUTPUT FREQUENCY STATISTICS * * * * * * * * * * * * * * *
      TMP=SKEW(12,K)
      SKEW(13,K)=SKEW(1,K)
      GO TO(361,421),KIP
  361 WRITE(6,362)ISTA(K),(AV(I,K),I=1,12)
  362 FORMAT(/I6,8H    MEAN 12F8.3)
      WRITE(6,364)(SD(I,K),I=1,12)
  364 FORMAT(7X,7HSTD DEV 12F8.3)
      WRITE(6,366)(SKEW(I,K),I=1,12)
  366 FORMAT(10X,4HSKEW 12F8.3)
      WRITE(6,368)(DQ(I,K),I=1,12)
  368 FORMAT (8X6HINCRMT F7.2,11F8.2)
  421 CONTINUE
```

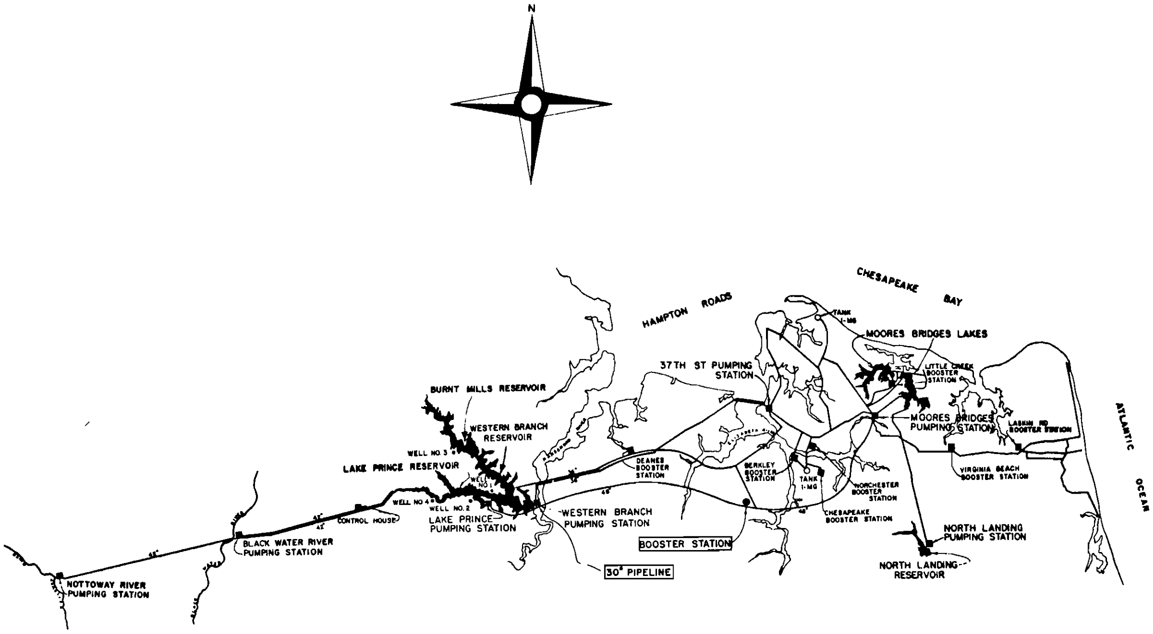
```
C  * * * * * * TRANSFORM TO STANDARDIZED VARIATES * * * * * * * * * * * * * * *
  440 DO 490 K=1,NSTA
      M=1
      DO 480 J=1,NYRS
      DO 470 I=1,12
      M=M+1
      IF(Q(M,K).GT.TM) GO TO 470
      IZ=SD(I,K)+0.999
      IF(IZ.EQ.0) GO TO 460
      Q(M,K)=(Q(M,K)-AV(I,K))/SD(I,K)
C                PEARSON TYPE III TRANSFORM
      IZ=ABS(SKEW(I,K))+0.9999
      IF(IZ.EQ.0) GO TO 470
      TEMP=.5*SKEW(I,K)*Q(M,K)+1.
      TMP=1.
      IF(TEMP.GE.0.)GO TO 450
      TEMP=-TEMP
      TMP=-1.
  450 Q(M,K)=6.*(TMP*TEMP**(1./3.)-1.)/SKEW(I,K)+SKEW(I,K)/6.
      GO TO 470
  460 Q(M,K)=0.
  470 CONTINUE
  480 CONTINUE
  490 CONTINUE
C  * * * * * * COMPUTE SUMS OF SQUARES AND CROSS PRODUCTS * * * * * * * * * * *
      DO 600 K=1,NSTA
      KX=K+1
      DO 510 L=KX,NSTAX
      DO 500 I=1,12
      RA(I,K,L) =(-4.)
      SUMA(I,L)=0.
      SUMB(I,L)=0.
      SQA(I,L)=0.
      SQB(I,L)=0.
      XPAB(I,L)=0.
  500 NCAB(I,L)=0
  510 CONTINUE
      DO 520 I=1,12
      DO 515 L=1,K
  515 NCAB(I,L)=-1
  520 RA(I,K,K)=1.
      M=1
      DO 550 J=1,NYRS
      DO 540 I=1,12
      M=M+1
      TEMP=Q(M,K)
      IF(TEMP.GT.TM) GO TO 540
      DO 530 L=KX,NSTAX
C                SUBSCRIPTS EXCEEDING NSTA RELATE TO PRECEDING MONTH
      LX=L-NSTA
      IF(LX.LT.1) TMP=Q(M,L)
      IF(LX.GT.0) TMP=Q(M-1,LX)
      IF(TMP.GT.TM)  GO TO 530
C                COUNT AND USE ONLY RECORDED PAIRS
      NCAB(I,L)=NCAB(I,L)+1
      SUMA(I,L)=SUMA(I,L)+TEMP
      SUMB(I,L)=SUMB(I,L)+TMP
      SQA(I,L)=SQA(I,L)+TEMP*TEMP
      SQB(I,L)=SQB(I,L)+TMP*TMP
      XPAB(I,L)=XPAB(I,L)+TEMP*TMP
  530 CONTINUE
  540 CONTINUE
  550 CONTINUE
C  * * * * * * COMPUTE CORRELATION COEFFICIENTS * * * * * * * * * * * * * * * *
      DO 598 I=1,12
      IF(IDGST.LE.0) GO TO 575
      WRITE(6,560)MO(I),ISTA(K)
  560 FORMAT(/39H RAW CORRELATION COEFFICIENTS FOR MONTHI3, 12H  AT STAT
     1IONI6)
      WRITE(6,570)(ISTA(L),L=1,NSTA)
  570 FORMAT(9H WITH STA I13,11I10)
  575 DO 580 L=KX,NSTAX
C                ELIMINATE PAIRS WITH LESS THAN 3 YRS DATA
      IF(NCAB(I,L).LE.2)GO TO 580
      TEMP=NCAB(I,L)
      AA(I,K,L)=SUMA(I,L)/TEMP
      AB(I,K,L)=SUMB(I,L)/TEMP
      TMP=(SQA(I,L)-SUMA(I,L)*SUMA(I,L)/TEMP)*(SQB(I,L)-SUMB(I,L)*SUMB
     1(I,L)/TEMP)
C                ELIMINATE PAIRS WITH ZERO VARIANCE PRODUCT
      IF(TMP.LE.0.)GO TO 580
      TMPB=1.
      TMPA=XPAB(I,L)-SUMA(I,L)*SUMB(I,L)/TEMP
C                RETAIN ALGEBRAIC SIGN
      IF(TMPA.LT.0.)TMPB=-TMPB
      TMPA=TMPA*TMPA/TMP
      TMPA=1.-(1.-TMPA)*(TEMP-1.)/(TEMP-2.)
      IF(TMPA.LT.0.)TMPA=0.
      RA(I,K,L)=TMPB*TMPA**.5
      IF(L.GT.NSTA) GO TO 580
      RA(I,L,K)=RA(I,K,L)
      AA(I,L,K)=AB(I,K,L)
      AB(I,L,K)=AA(I,K,L)
  580 CONTINUE
      IF(IDGST.LE.0) GO TO 596
      WRITE(6,590)(NCAB(I,L),RA(I,K,L),L=1,NSTA)
  590 FORMAT(12H  THIS MONTH 12(I4,F6.3))
      WRITE(6,595)(NCAB(I,L),RA(I,K,L),L=NSTAA,NSTAX)
  595 FORMAT(12H  LAST MONTH 12(I4,F6.3))
C                ELIMINATE NEGATIVE CORRELATIONS
  596 DO 597 L=1,NSTAX
      IZ=RA(I,K,L)
      IF(RA(I,K,L).LT.0..AND.IZ.NE.-4) RA(I,K,L)=0.
  597 CONTINUE
  598 CONTINUE
  600 CONTINUE
  612 TEMP=0.
      IF(IDGST.LE.0) GO TO 885
      WRITE(6,3)
C  * * * * * * PRINT CORRELATION MATRIX * * * * * * * * * * * * * * * * * * * *
  815 DO 880 I=1,12
      WRITE(6,820)MO(I)
  820 FORMAT(//40H CONSISTENT CORRELATION MATRIX FOR MONTH I3)
      WRITE(6,825)(ISTA(K),K=1,NSTA)
  825 FORMAT(/3X,3HSTA 18I7)
      WRITE(6,830)
  830 FORMAT(20X,19H WITH CURRENT MONTH)
      DO 840 K=1,NSTA
  840 WRITE(6,850) ISTA(K),(RA(I,K,L),L=1,NSTA)
  850 FORMAT(I6,18F7.3)
      WRITE(6,860)
  860 FORMAT(20X38H WITH PRECEDING MONTH AT ABOVE STATION)
      ITP=NSTA+1
      DO 870 K=1,NSTA
  870 WRITE(6,850)ISTA(K),(RA(I,K,L),L=ITP,NSTAX)
  880 CONTINUE
  885 IF (IRCON.LE.0) GO TO 1015
      WRITE(6,3)
      M=1
      NVAR=NSTA+1
C                USE AVERAGE FOR MONTH PRECEDING RECORD
      DO 931 K=1,NSTA
  931 Q(1,K)=0.
      DO 990 J=1,NYRS
      DO 980 I=1,12
      M=M+1
      DO 970 K=1,NSTA
      QR(M,K)=BLANK
      IF(Q(M,K).LT.TM) GO TO 970
      NINDP=0
C                FORM CORRELATION MATRIX FOR EACH MISSING FLOW
      DO 950 L=1,NSTA
      LX=L+NSTA
      IF(L-K) 934,932,933
  932 NINDP=NINDP+1
      X(NINDP)=Q(M-1,L)
      AC(NINDP)=AB(I,K,LX)-AA(I,K,LX)
      R(L,NVAR)=RA(I,K,LX)
      GO TO 935
  933 IF(Q(M,L).GT.TM) GO TO 950
  934 NINDP=NINDP+1
      X(NINDP)=Q(M,L)
      AC(NINDP)=AB(I,K,L)-AA(I,K,L)
      R(NINDP,NVAR)=RA(I,K,L)
  935 ITP=NINDP
      R(ITP,ITP)=1.
      DO 940 LA=L,NSTA
      IF(LA.EQ.L) GO TO 940
      JX=LA+NSTA
      IF(L.EQ.K) GO TO 936
      IF(Q(M,LA).GT.TM.AND.LA.NE.K) GO TO 940
      ITP=ITP+1
```

```
      IF(LA.EQ.K)R(NINDP,ITP)=RA(I,L,JX)
      IF(LA.NE.K)R(NINDP,ITP)=RA(I,L,LA)
      GO TO 939
  936 IF(Q(M,LA).GT.TM) GO TO 940
      ITP=ITP+1
      R(NINDP,ITP)=RA(I,LA,LX)
C               ADD SYMMETRICAL ELEMENTS
  939 R(ITP,NINDP)=R(NINDP,ITP)
  940 CONTINUE
  950 CONTINUE
      ITMP=NINDP+1
      DO 952 L=1,NINDP
  952 R(L,ITMP)=R(L,NVAR)
C     ==========
      CALL CROUT(R,DTRMC,NINDP,B)
C     ==========
C               ADD RANDOM COMPONENT TO PRESERVE VARIANCE
      TEMP=RAN(IARG)
      TMP=RAN(IARG)
      TEMP=(-2.*ALOG(TEMP))**.5*SIN(6.2832*TMP)
C               COMPUTE FLOW
      IF (DTRMC.LE.1..AND.DTRMC.GE.0.) GO TO 955
      WRITE (6,7) I,K,DTRMC
      IF (DTRMC.GT.1.) DTRMC=1.
      IF (DTRMC.LT.0.) DTRMC=0.
  955 AL=(1.-DTRMC)**.5
      TEMP=TEMP*AL
      DO 960 L=1,NINDP
  960 TEMP=TEMP+B(L)*(X(L)-AC(L))
      Q(M,K)=TEMP
      QR(M,K)=E
  970 CONTINUE
  980 CONTINUE
  990 CONTINUE
      IF(KIP.EQ.2) GO TO 1994
      WRITE (6,993)
  993 FORMAT(33H RECORDED AND RECONSTITUTED FLOWS)
 1994 ANYRS=NYRS
      DO 1011 K=1,NSTA
      IF(KIP.EQ.2) GO TO 1995
      WRITE(6,995)(MO(I),I=1,12)
  995 FORMAT(/11H  STA  YEAR 12I8,6X,5HTOTAL )
 1995 M=1
      DO 1999 J=1,NYRS
      ITP=0
      DO 997 I=1,12
      M=M+1
      TEMP=Q(M,K)
C               CONVERT STANDARD DEVIATES TO FLOWS
      TMP=SKEW(I,K)
      IF(TMP)2000,2001,2000
 2000 TEMP=((TMP*(TEMP-TMP/6.)/6.+1.)**3 -1.)*2./TMP
 2001 IF(QR(M,K).NE.E) GO TO 992
      IF(TEMP.GT.2..AND.SD(I,K).GT..3) TEMP=2.+(TEMP-2.)*.3/SD(I,K)
      TMP=(-2.)/SKEW(I,K)
      IF(SKEW(I,K)) 991,992,994
  991 IF(TEMP.GT.TMP) TEMP=TMP
      GO TO 992
  994 IF(TEMP.LT.TMP) TEMP=TMP
  992 TMP=TEMP*SD(I,K)+AV(I,K)
      Q(M,K)=10.**TMP-DQ(I,K)
      IF(Q(M,K).LT.0.) Q(M,K)=0.
      QM(I)=QR(M,K)
  996 IQ(I)=Q(M,K)+.5
  997 ITP=ITP+IQ(I)
      IYR=IYRA+J
      IF(KIP.EQ.2) GO TO 1999
      IF(IPCHQ.LE.0)GO TO 998
      WRITE (7,6) ISTA(K),IYR,(IQ(I),I=1,12)
  998 WRITE(6,999)ISTA(K),IYR,(IQ(I),QM(I),I=1,12) ,ITP
  999 FORMAT(1X,I4,I6,I8,A1,11(I7,A1),I10)
 1999 CONTINUE
C * * * * *RECOMPUTE MEAN AND STANDARD DEVIATION * * * * * * * * * * * * * * *
 1000 DO 1001 I=1,12
      AV(I,K)=0.
 1001 SD(I,K)=0.
      M=1
      DO 1003 J=1,NYRS
      DO 1002 I=1,12
      M=M+1
      TEMP=ALOG(Q(M,K)+DQ(I,K))
      AV(I,K)=AV(I,K)+TEMP
 1002 SD(I,K)=SD(I,K)+TEMP*TEMP
 1003 CONTINUE
      DO 1004 I=1,12
      TEMP=AV(I,K)
      TMP=(SD(I,K)-TEMP*TEMP/ANYRS)/(ANYRS-1.)
      SD(I,K)=TMP**.5*.4342945
 1004 AV(I,K)=TEMP/ANYRS*.4342945
 1011 CONTINUE
C               PRINT ADJUSTED FREQUENCY STATISTICS
      IF(KIP.EQ.2) GO TO 1015
      WRITE(6,3)
      WRITE(6,1012)
 1012 FORMAT(/30H ADJUSTED FREQUENCY STATISTICS)
      DO 1013 K=1,NSTA
      WRITE (6,315) (MO(I),I=1,12)
      WRITE (6,362) ISTA(K),(AV(I,K),I=1,12)
      WRITE (6,364) (SD(I,K),I=1,12)
      WRITE (6,366) (SKEW(I,K),I=1,12)
      WRITE (6,368) (DQ(I,K),I=1,12)
 1013 CONTINUE
C * * * * * * FLOW GENERATION EQUATIONS * * * * * * * * * * * * * * * * * *
 1015 NINDP=NSTA
      NVAR=NSTA+1
      DO 1090 I=1,12
      IP=I-1
      IF (IP.LT.1) IP=12
      DO 1080 K=1,NSTA
      DO 1060 L=1,NSTA
C               CORRELATIONS IN CURRENT MONTH
      IF (L.GE.K) GO TO 1055
      R(L,NVAR)=RA(I,K,L)
      DO 1052 LA=L,NSTA
      LX=LA+NSTA
      IF (LA.LT.K) R(L,LA)=RA(I,L,LA)
      IF (LA.GE.K) R(L,LA)=RA(I,L,LX)
 1052 R(LA,L)=R(L,LA)
      GO TO 1060
C               CORRELATIONS WITH PRECEDING MONTH
 1055 LX=L+NSTA
      R(L,NVAR)=RA(I,K,LX)
      DO 1057 LA=L,NSTA
      R(L,LA)=RA(IP,L,LA)
 1057 R(LA,L)=R(L,LA)
 1060 CONTINUE
C     ==========
 1065 CALL CROUT(R,DTRMC,NINDP,B)
C     ==========
      DO 1070 L=1,NSTA
 1070 BETA(I,K,L)=B(L)
      IF(DTRMC.LE.1.) GO TO 1078
       WRITE(6,1072)I,K,DTRMC
 1072 FORMAT (34H INCONSISTENT CORREL MATRIX FOR I= I3,4H  K=I2,
     1 8H  DTRMC= F6.3)
      DTRMC=1.
 1078 IF(DTRMC.GE.0.) GO TO 1079
      WRITE(6,7)I,K,DTRMC
      DTRMC=0.
 1079 ALPHA(I,K)=(1.-DTRMC)**.5
 1080 CONTINUE
 1090 CONTINUE
C * * * * * * GENERATE FLOWS * * * * * * * * * * * * * * * * * * * * * * * * *
 1091 JA=1
      N=0
      MA=0
 1095 DO 1100 K=1,NSTA
 1100 QPREV(K)=0.
C               GENERATE 2 YEARS FOR DISCARDING
      NJ=2
      JX=-2
      GO TO 5106
C               N = SEQUENCE NO., M = MONTH NO., JX = YEAR NO.
 1105 WRITE(6,3)
      N=N+1
      IF(KIP.EQ.2) GO TO 5106
      WRITE (6,1106) N
 1106 FORMAT (27H GENERATED FLOWS FOR PERIOD I3)
 5106 JXTMP=JX
      DO 3107 K=1,NSTA
      DO 3106 I=1,12
      NLG(I,K)=0
```

```
      AVG(I,K)=0.
      SDV(I,K)=0.
 3106 CONTINUE
 3107 CONTINUE
 1108 DO 3125 J=JA,NJ
      M=12*(J-1)+1
      JX=JX+1
      DO 1125 I=1,12
      M=M+1
      DO 1120 K=1,NSTA
C                RANDOM COMPONENT
 1111 TEMP=RAN(IARG)
      TMP=RAN(IARG)
      TEMP=(-2.*ALOG(TEMP))**.5*SIN(6.2832*TMP)
      TEMP=TEMP*ALCFT(I,K)
C                GENERATE CORRELATED STANDARD DEVIATE
      DO 1110 L=1,NSTA
      TMP=QPREV(L)
      IF(L.LT.K)TMP=Q(M,L)
 1110 TEMP=TEMP+BETA(I,K,L)*TMP
      NLG(I,K)=NLG(I,K)+1
      AVG(I,K)=AVG(I,K)+TEMP
      SDV(I,K)=SDV(I,K)+TEMP*TEMP
      Q(M,K)=TEMP
      QPREV(K)=TEMP
 1120 CONTINUE
 1125 CONTINUE
 3125 CONTINUE
      DO 1130 K=1,NSTA
 1122 IF(NJ+JXTMP.GT.0.AND.KIP.EQ.1) WRITE(6,995) (MO(I),I=1,12)
      DO 3126 I=1,12
      TEMP=NLG(I,K)
      AVG(I,K)=AVG(I,K)/TEMP
      SDV(I,K)=((SDV(I,K)-AVG(I,K)**2*TEMP)/TEMP)**.5
      IF(NLG(I,K).GT.19.AND.KIP.EQ.1) WRITE(6,5126) ISTA(K),MO(I),AVG(I,
     1K),SDV(I,K)
 3126 CONTINUE
 5126 FORMAT (4H STAI4,8H    MONTHI3,7H    MEANF6.3,10H    STD DEVF5.3)
      JX=JXTMP
      DO 3129 J=JA,NJ
      JX=JX+1
      M=12*J-11
      IF (JX.LE.0) GO TO 3129
      ITP=0
      DO 1129 I=1,12
      M=M+1
C                TRANSFORM TO LOG PEARSON TYPE III VARIATE (FLOW)
      TMP=SKEW(I,K)
      IZ=ABS(SKEW(I,K))+0.9999
      IF(IZ.EQ.0) GO TO 1126
      IF (NLG(I,K).GT.19) Q(M,K)=(Q(M,K)-AVG(I,K))/SDV(I,K)
      TMP=((TMP*(Q(M,K)-TMP/6.)/6.+1.)**3 -1.)*2./TMP
      TEMP=(-2.)/SKEW(I,K)
      IF(SKEW(I,K)) 1123,1126,1124
 1123 IF(TMP.GT.TEMP)TMP=TEMP
      GO TO 1127
 1124 IF(TMP.LT.TEMP) TMP=TEMP
      GO TO 1127
 1126 TMP=Q(M,K)
 1127 IF(TMP.GT.2..AND.SD(I,K).GT..3) TMP=2.+(TMP-2.)*.3/SD(I,K)
      TMP=TMP*SD(I,K)+AV(I,K)
      Q(M,K)=10.**TMP-DO(I,K)
 3128 IF(Q(M,K).LT.0.) Q(M,K)=0.
 1128 IQ(I)=Q(M,K)+.5
      ITP=ITP+IQ(I)
 1129 CONTINUE
      IQ(13)=ITP
      IF(KIP.EQ.2) GO TO 3129
      WRITE (6,11) ISTA(K),JX,(IQ(I),I=1,13)
      IF(IPCHQ.LE.0)GO TO 3129
      WRITE (7,6) ISTA(K),JX,(IQ(I),I=1,12)
 3129 CONTINUE
 1130 CONTINUE
 1250 NJ = NYMXG
C                GO TO NEW JOB
 1270 IF(NYRG.LE.0) GO TO 1271
      IF(NJ.GT.NYRG) NJ=NYRG
      NYRG=NYRG-NJ
      GO TO 1105
 1271 IF(NSTA.EQ.1) GO TO 1275
      M=1
      DO 1273 J=1,NYMXG
      DO 1273 I=1,12
      M=M+1
      TEMA=Q(M,2)*0.5
      TEMB=Q(M,3)*0.5
      IF(TEMA.GT.35.)TEMA=35.0
      IF(TEMB.GT.35.)TEMB=35.0
      Q(M,1)=Q(M,1)+TEMA+TEMB
 1273 CONTINUE
 1275 RETURN
      END

@FOR,IS CROUT,CROUT
      SUBROUTINE CROUT(RX,DTRMC,NINDP,B)
      DIMENSION B(20),R(10,11),RX(10,11)
      DOUBLE PRECISION R,B,RX
      NVAR=NINDP+1
      DO 5 J=1,NINDP
      DO 4 K=1,NVAR
    4 R(J,K)=RX(J,K)
    5 CONTINUE
      IF(NINDP.GT.1)GO TO 10
      B(1)=R(1,2)/R(1,1)
      DTRMC=B(1)*B(1)
      RETURN
C  * * * * * * DERIVED MATRIX * * * * * * * * * * * * * * * * * * * * * * * * *
   10 DO 20 K=2,NVAR
   20 R(1,K)=R(1,K)/R(1,1)
      DO 60 K=2,NINDP
      ITP=K-1
      DO 40 J=K,NINDP
      DO 30 I=1,ITP
      L=K-I
   30 R(J,K)=R(J,K)-R(J,L)*R(L,K)
      IF(J.EQ.K) GO TO 40
      R(K,J)=R(J,K)/R(K,K)
   40 CONTINUE
      DO 50 I=1,ITP
      L=K-I
   50 R(K,NVAR)=R(K,NVAR)-R(L,NVAR)*R(K,L)
   60 R(K,NVAR)=R(K,NVAR)/R(K,K)
C  * * * * * * BACK SOLUTION * * * * * * * * * * * * * * * * * * * * * * * * *
      B(NINDP)=R(NINDP,NVAR)
      DO 80 I=2,NINDP
      J=NVAR-I
      IX=I-1
      B(J)=R(J,NVAR)
      DO 70 L=1,IX
      K=J+L
   70 B(J)=B(J)-B(K)*R(J,K)
   80 CONTINUE
      DTRMC=0.
      DO 90 J=1,NINDP
   90 DTRMC=DTRMC+B(J)*RX(J,NVAR)
      RETURN
```

APPENDIX C



NORFOLK CITY WATER SUPPLY

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(a) Module analysis.

Plant Size	Operating Rule	Yield MGD	Cost $/yr/MGD
120	90 - 70	1409	92300
125	78 - 65	1410	91400
150	55 - 60	1410	97100
225	80 - 90	1483	90500
250	78 - 65	1485	86200
275	52 - 70	1485	86700
500	79 - 65	1635	79600

This analysis combined with that in section (1) indicates the module size should be 125 MGD.

(b) Six modules of 125 MGD per module.

Stage	Year Module Added	Total Plant Capacity	Operating Rule	Yield MGD
1	1	125	78 - 65	1410
2	6	250	78 - 65	1485
3	11	375	78 - 65	1560
4	16	500	79 - 65	1635
5	21	625	79 - 65	1710
6	26	750	79 - 65	1785

Average unit cost = $36800/year/MGD
Total cost = $496,800,000

4. Operating a 750 MGD plant in a growing demand condition with a varying rule.

Time Period Year	Demand at Start of Period	Operating Rule	Yield MGD
1- 6	1335	20 - 30	1430
7-11	1425	30 - 40	1495
12-18	1500	40 - 50	1610
19-23	1605	40 - 60	1699
24-27	1680	50 - 70	1743
28-30	1740	79 - 65	1785

Average unit cost = $51000/year/MGD
Total cost = $688,500,000

The basic conditions for the above computations are:

The firm yield analysis is based on the average of five periods of 75 years per period;

Firm yield defined at the 100% level;

Cost figures are the average of 10 useful life periods;

Useful life of the plant or any one module is 30 years;

Fixed charge rate = 8%, discount interest rate = 6%; and

Capital and operating costs for VTE plant as furnished by ORNL.