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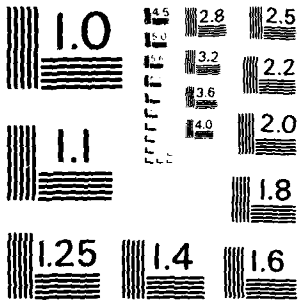
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The Hydrologic Engineering Center

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Reservoir System Regulation for Water Quality Control

by

R. G. Willey

Technical Paper No. 88

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A computer model capable of evaluating water quality conditions in large reservoir systems was recently developed by the Corps of Engineers. The model, Simulation of Flood Control and Conservation Systems (Including Water Quality Analysis), HEC-5Q, provides a comprehensive water quantity model with fairly simple water quality routines. The HEC-5Q can evaluate how to operate each reservoir in a system for the best overall regulation to meet both water quantity and water quality objectives at all points of interest in the system.

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RESERVOIR SYSTEM REGULATION FOR WATER QUALITY CONTROL[1/]

R. G. Willey[2/]

Introduction

By Legislative mandate and official Office of the Chief of Engineers policy, the Corps of Engineers is responsible for providing the best water quality possible from all Corps reservoir projects. Current reservoir system modeling techniques emphasize the importance of a systems approach to water quality control rather than an individual project approach.

Since 1979, one of the Corps research tasks, "Reservoir System Regulation for Water Quality Control," has had an objective of developing a mathematical model for the operation and management of a system of reservoirs to satisfy water quality goals and other water resource purposes. This model was developed to analyze very large reservoir systems for planning studies. Although its initial purpose was concerned with planning studies, it is very likely that in the future it will have significant potential for use in regulation or operation studies as well. In addition, it should be pointed out that development of this model provides the comprehensive water quantity model HEC-5 with fairly simple water quality routines. The combined model is called HEC-5Q.

The phased development of the HEC-5Q model started in 1979, as shown in Figure 1, as a simple reservoir water temperature algorithm appended to the HEC-5 model. The second phase of development, in 1980, expanded this version into a two reservoir, eight water quality parameter model. In the following year, it was decided to delay the Phase III development and field-test the model on sample test data and develop a few minor modifications that were initially intended but never seemed to get accomplished. In 1982, Phase III of the model development involved expanding the HEC-5Q to analyze a maximum

1/ Presented at the 1982 Corps of Engineers Environmental and Water Quality Operational Studies project review meeting and the HEC Reservoir Systems Analysis Training Course, January 1983.
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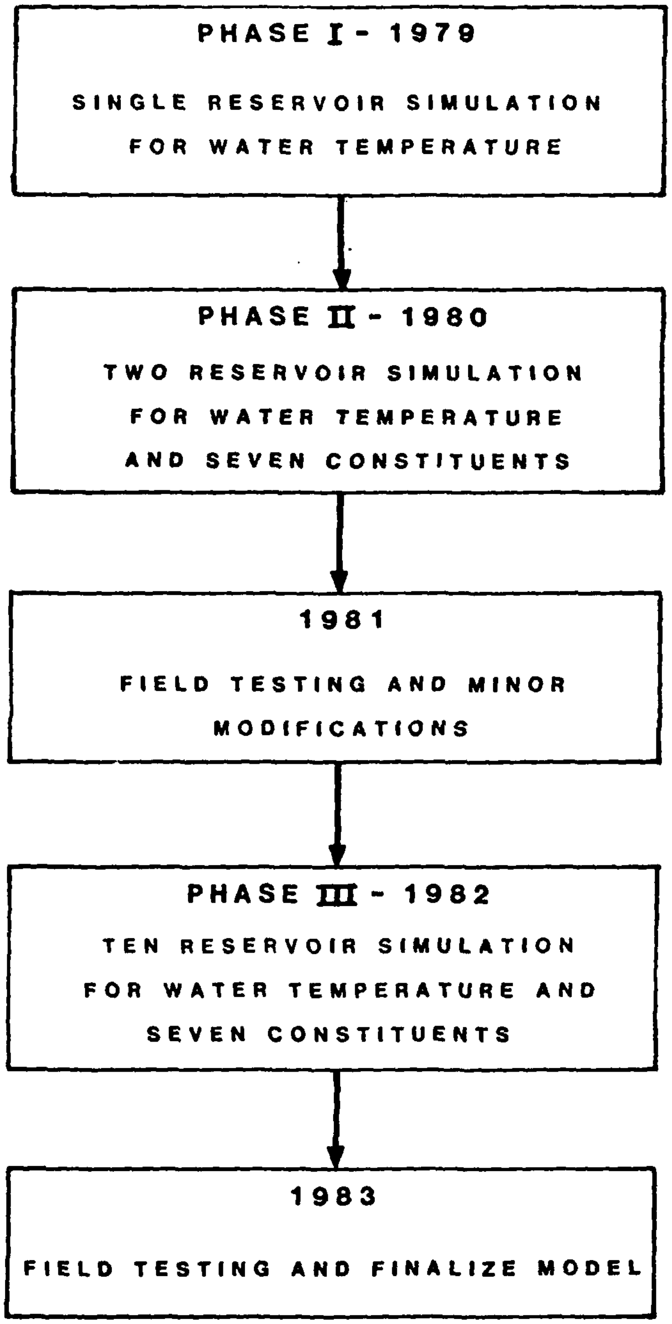


Figure 1

PHASED DEVELOPMENT OF HEC-5Q

of ten reservoirs for the same eight water quality parameters. During the present year, major effort is involved with field testing the model and again making some minor modifications. Fiscal year 1983 tasks will be discussed in detail below.

Model Capabilities

Figure 2 describes a series of capabilities of the HEC-5Q model, some of which will be discussed below. Figure 2, item b, describes a characteristic of the HEC-5Q model that is probably unique among all water quality models. Most water quality models can operate a multiple level reservoir outlet structure for a specified total discharge and a target water temperature at a point immediately downstream of the dam. However, HEC-5Q has the capability of operating the structure to meet water quality needs at all downstream control points that are affected by the operation of a specific project. Both streamflow routing effects and water quality constituent decay reactions are considered as the flow is transported from the dam to the downstream control points. All the tributary inflows and their associated water quality constituents, between the dam and all downstream control points, are included in the analysis.

The forecasting capability referenced in Figure 2, item e, allows the HEC-5Q model to look ahead in time, evaluate the magnitudes of tributary inflows below projects, and attempt to account for the water quality dilution and decay relationships that exist. The impact of the tributary inflows upon the main channel water quality as it flows downstream to the control points will be properly evaluated in attempting to meet downstream control point target constituent concentrations or temperatures.

Figure 2, item j, describes the model's capability of accepting changing reservoir storage for flood control or water supply conservation pools on a seasonal basis, such as monthly time steps. System diversions can also be modified on a seasonal time basis. Item k describes the capability to divert water from an upstream area, use it for irrigation, and return the unused flow into a downstream portion of the system.

Figure 2

HEC-5Q CAPABILITIES

a. Any configuration of reservoir system (most upstream locations must be reservoirs)

b. Operate gated reservoir outlets based on downstream flows considering routing effects

c. Variable time steps (mixture monthly and short interval)

d. Hydrologic routing methods

e. Forecasting ability will limit operational efficiency

f. Users override on any or all reservoir releases

Figure 2 (Continued)

HEC-5Q CAPABILITIES

g. Multiflood option - any number of floods read in - up to nine ratios of each - unlimited number of time periods

h. Inflows can be incremental or cumulative

i. Variable channel capacity

j. Seasonal operation for reservoir storages, demands, diversions (monthly)

k. Diversions (from any location to any downstream location)

l. Flood damages or average annual damage - annual peaks or seasonal and duration effects

Figure 2 (Continued)

HEC-5Q CAPABILITIES

m. Hydropower

   (1) Energy demands - monthly, daily, hourly

   (2) Tailwater - block loading, tailwater rating, D.S. reservoir

   (3) Peaking capability

   (4) Benefits - primary, secondary, shortage, capacity

n. System power - two systems - any time period - 15 levels for balancing

o. Pumped storage - any time period

p. Optimization for conservation reservoirs

q. Flexible output - user designed, sequential, annual summaries, flood summaries, etc.

r. Water Quality Analysis - with or without flow alteration

Figure 2, item p, refers to the method of calculating the best discharge quantities from any single reservoir in the system of reservoirs. Item r, water quality analysis with and without flow alteration, refers to the methods of computing either a best water quantity simulation (with its associated water quality) or a best water quality simulation for all control points. The difference in these two methods will be described below.

Figure 3 depicts the vertical structure in a multiple purpose reservoir used for computational purposes in the HEC-5 portion of the model. The conservation pool, or more appropriately called the water supply pool, can include a buffer zone. The water from the buffer zone will be rationed for downstream purposes once the pool falls into the buffer zone. An inactive or dead storage zone may also be included. Above the conservation pool, the flood control and surcharge pools can be defined.

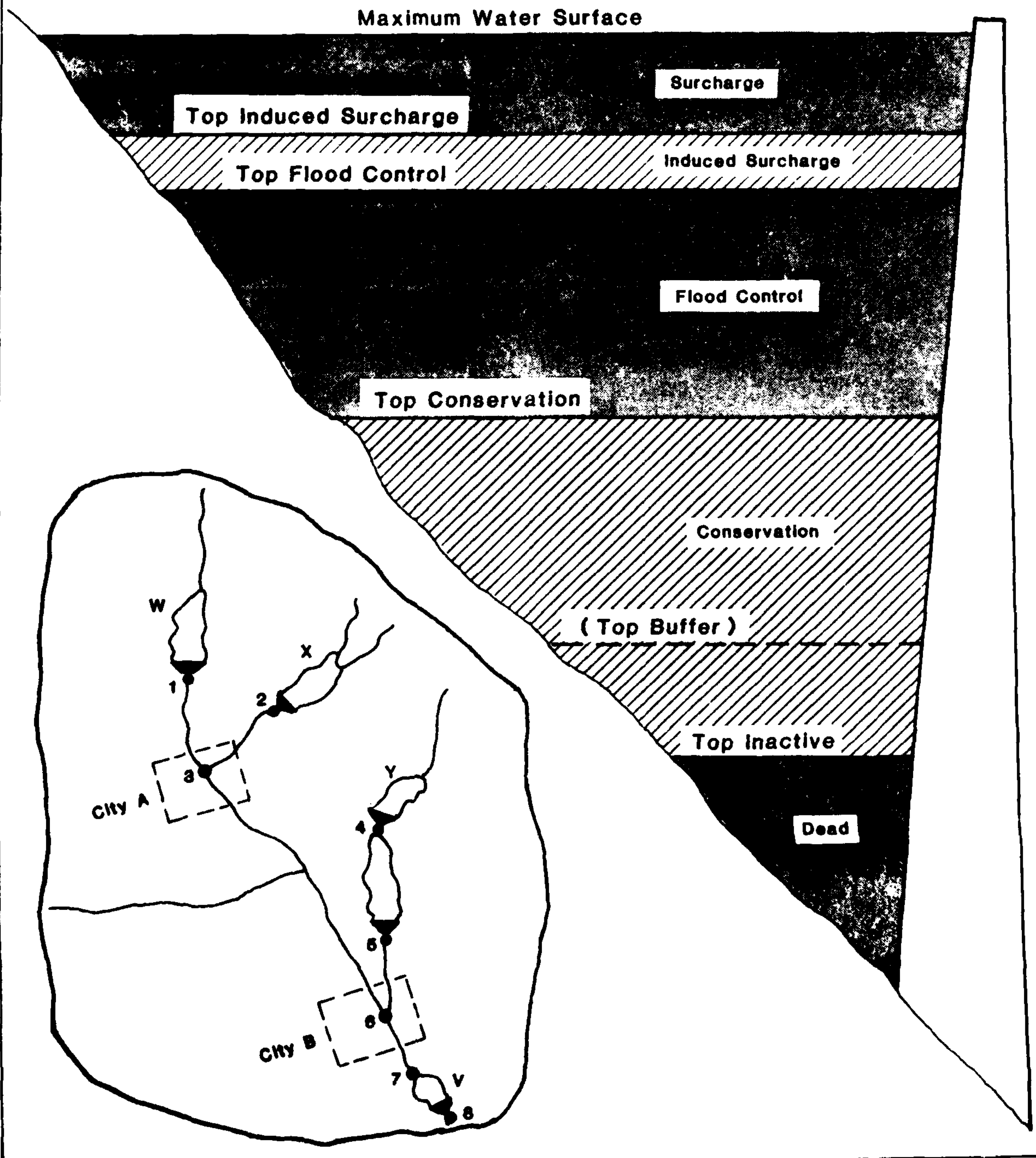
The balanced pool computations are handled differently for storage elevations in the flood control pool than those in the conservation pool. The model will maintain as high a conservation pool as possible. On the other hand, when the actual pool is in the flood control zone, the model will minimize the amount of water stored. These two sets of computations are actually opposite in their method of operation.

The kinds of systems that can be analyzed with HEC-5Q are also shown in Figure 3. This example system has a series of three parallel reservoirs W, X, and Y and two tandem reservoirs; reservoir Z is in tandem with reservoir Y, and reservoir V is in tandem with all of the upstream reservoirs. The control points can be numbered as shown. A control point must be located at each reservoir project and at each confluence of two or more streams, if those channels are being analyzed as part of the system.

Control points can also be included at locations where there is interest in model output and control for water quantity or water quality such as City A and City B. Control points 3 and 6 are both located as shown since they are confluence points for the stream network being analyzed, as well as the fact that there is a good deal of interest in controlling flood flows and water supply flows for both City A and City B.

Figure 3

FLOW SIMULATION MODULE



The HEC-5 model operates the reservoirs X, Y, Z, and V in an attempt to balance the pools, either in the conservation or flood control pools. If they are operating in a flood control manner, the discharges are constrained to the maximum channel capacities allowed at control points 1 through 8. The model will decide how much of the channel capacity at control point 7, for example, should be used for making discharges from reservoir W in contrast to the discharge from any other reservoir by maintaining an equal percentage of the possible flood control pools. If the reservoirs are operating in the conservation pool, the minimum channel flow requirements will be used. Once the water quantity analysis is completed, the discharges are fixed for all the reservoirs.

The water quality analysis begins by evaluating the multi-level discharge capability at each of the reservoirs. The model will determine the vertical location to withdraw water from each reservoir in order to meet the target water quality conditions at control points 1 through 8. This type of analysis is referred to as the water quality analysis without flow alteration. This is the best operation for water quality that can be expected at all the control points using the balanced pool concept for reservoir regulation.

The second kind of analysis that can be performed is a user option for flow alteration. With the flow alteration option, the balanced pool constraint is relaxed, and the model is allowed to deviate from the discharge values previously calculated for each of the reservoirs. The altered discharge values will be calculated with a linear programming routine to operate the system of reservoirs to best meet all downstream water quality targets at control points 1 through 8.

If the user chooses the flow alteration method, the output from the model for both methods is provided, and the user is free to decide on an adopted operation. The user should look at the difference of the amount of flow for each of the reservoirs, what the calculated discharges do to the pool level, and the resulting water qualities at all the target control points. The user can then decide whether to operate with the balanced pool concept or the flow alteration method.

Figure 4 describes the vertical layered system that is used for computation in most water quality models including HEC-5Q. The model is capable of analyzing 50 horizontal, completely mixed layers within the reservoir and a maximum of 10 parallel and tandem reservoirs.

Figure 5 shows the structural computation elements for the river water quality module. A maximum of 300 elements can be located along the stream channel. Each element has a node point at each end. Water quality computations are performed at each node point. The control points are also shown at the end of each reach. Streamflow routing is initially performed between control points and later interpolated to each node point. The model can have a maximum of 30 control points.

Figure 6 describes the water quality constituents that can be analyzed in the model and the hierarchy of the computations. Temperature must always be analyzed by the model. The user cannot analyze other water quality constituents without also evaluating temperature. The model can analyze a maximum of 3 conservative parameters. These are constituents that are only affected by dilution and not by decay. Examples of conservative parameters are total dissolved solids, clorides, and alkalinity.

The model can also analyze a maximum of 3 non-conservative parameters. One of these can be a non-oxygen demanding constituent like fecal or total coliform. The other two non-conservative parameters are reserved for oxygen demanding parameters one and two. Examples of their use are carbonaceous biochemical oxygen demand and nitrogenous biochemical oxygen demand or ammonia. If either of these two oxygen demanding parameters is used, dissolved oxygen can also be simulated.

Temperature impacts on all reaction rates and the reaeration rate for dissolved oxygen.

Figure 4

RESERVOIR WATER QUALITY SIMULATION MODULE

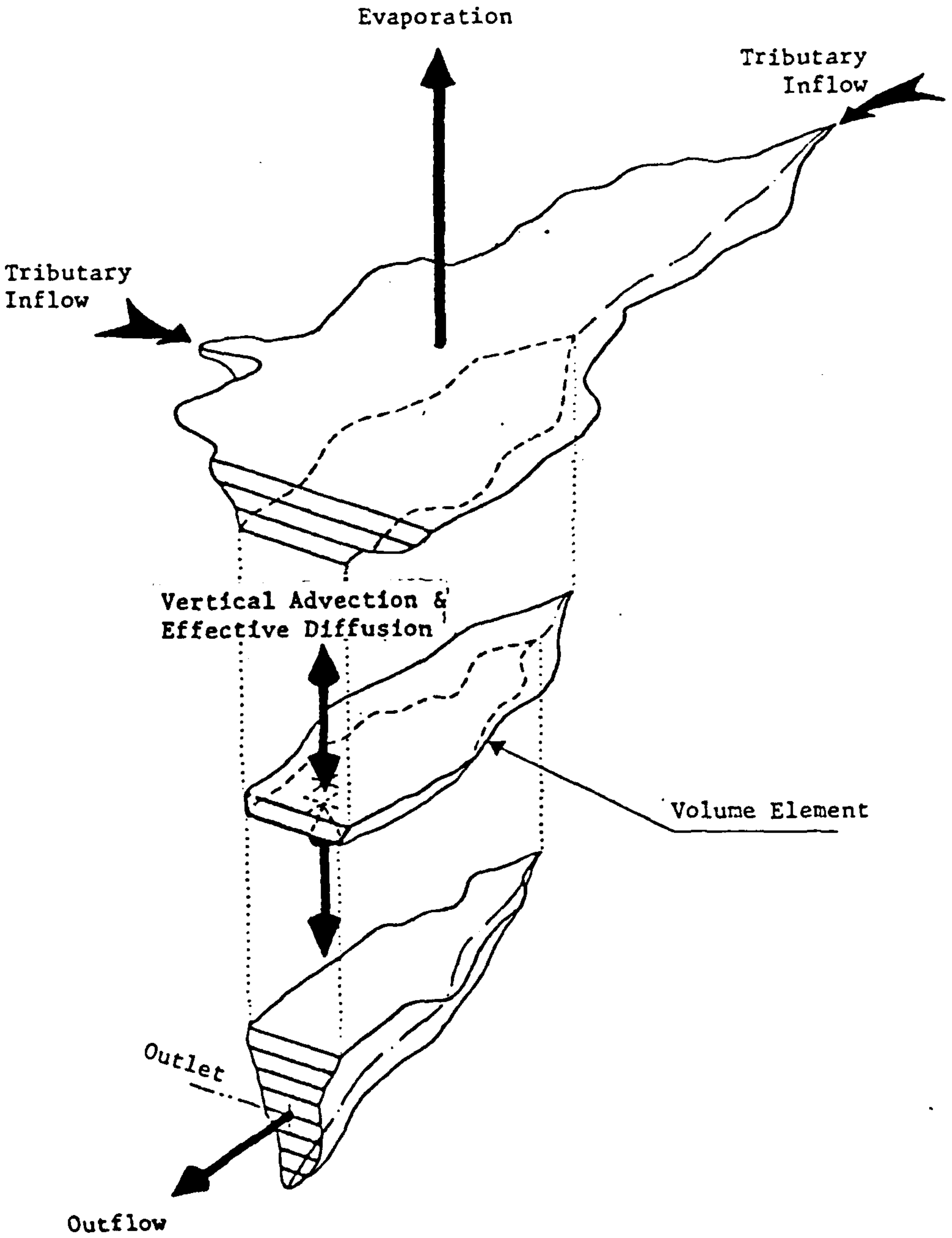


Figure 5

RIVER WATER QUALITY SIMULATION MODULE

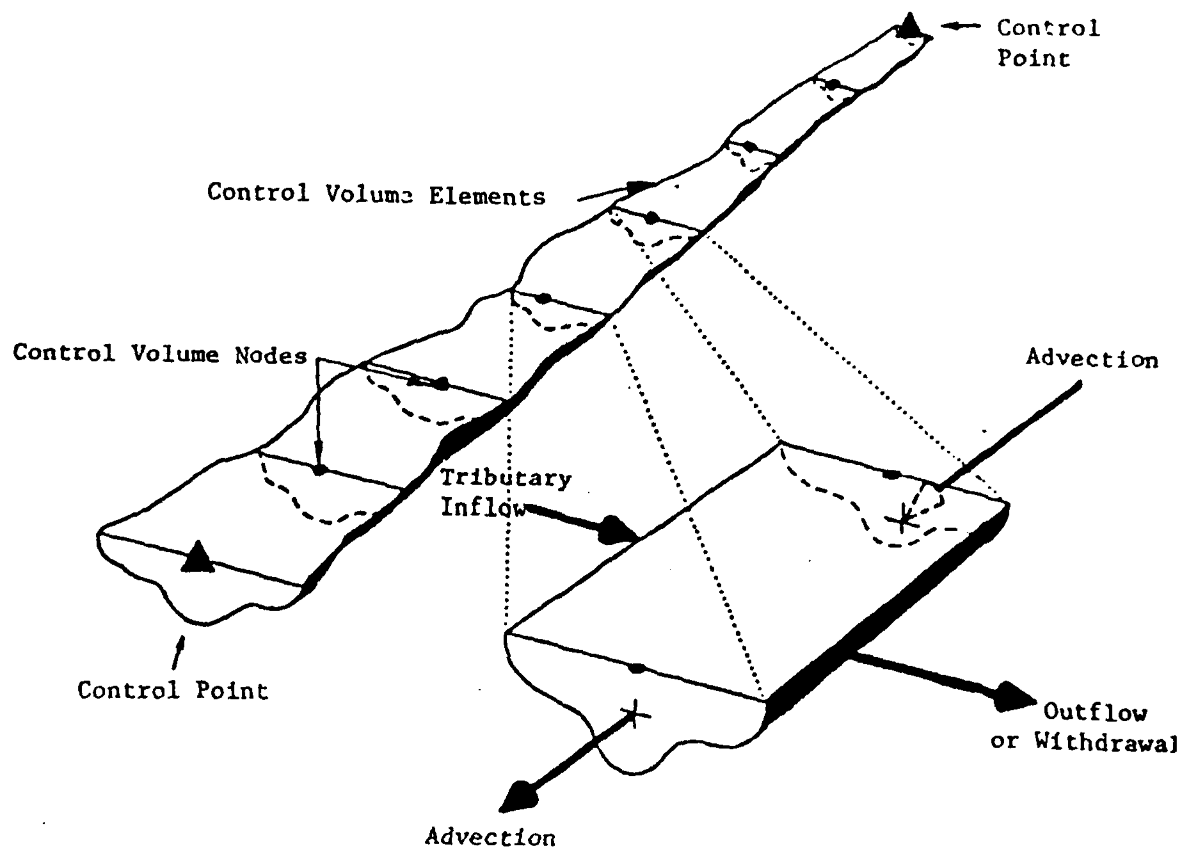
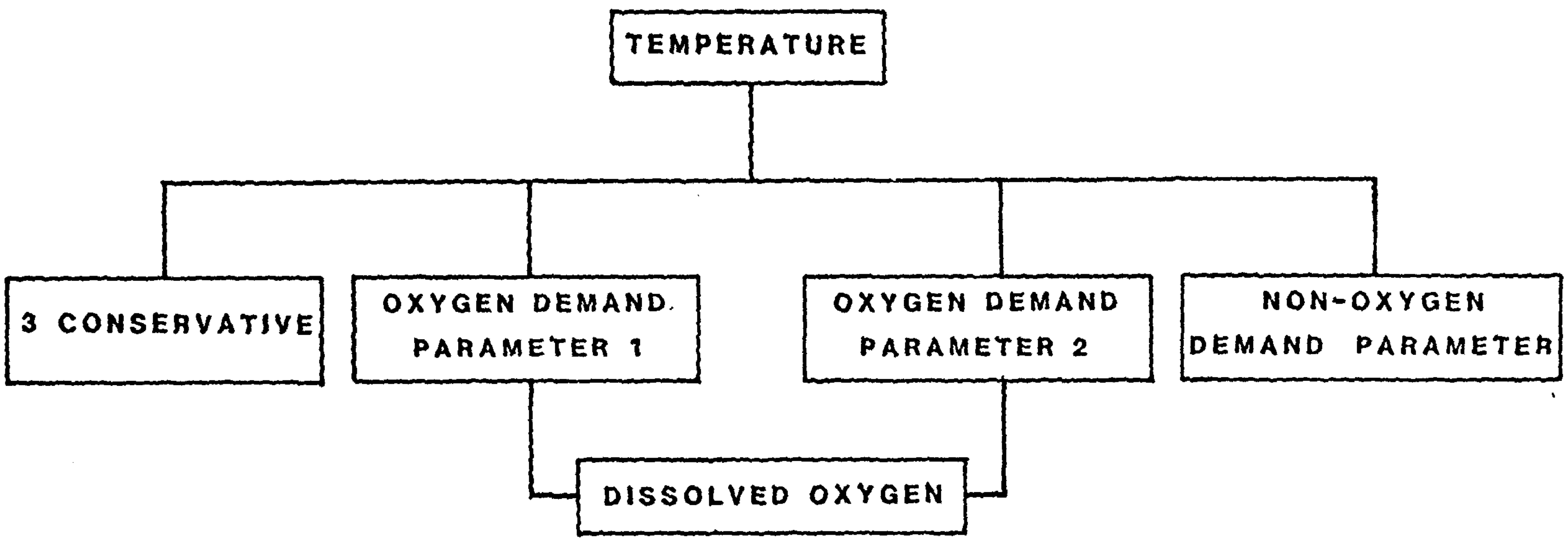


Figure 6

HEC-5Q WATER QUALITY PARAMETERS



Future Development

Further model development to be accomplished during 1983 is shown in Figure 7. The first 5 tasks involve contract modifications to the HEC-5Q model, and they include adding phytoplankton analysis and benthal material source and sink terms. These two modifications are important in an attempt to perform a better analysis of dissolved oxygen in the reservoirs. These additions will only be made to the reservoir portion of the model.

The third task is to modify the HEC-5Q model to analyze long-term record. This modification will allow the reservoir portion to accept input data for intervals longer than daily. The stream portions will be modified to perform steady state analysis for periods such as one week to one month rather than a dynamic daily analysis.

The fourth task adds graphic capability to the water quality portions of the model. The water quantity portions already have existing graphics capability.

The fifth task involves the improvement in the existing vertical geometric interpolation algorithm in an attempt to cause less problems for the user and provide more accurate interpolations.

The sixth task is completion of the test data deck. The test data deck was developed during 1982 without concern for calibration. During 1983, the data deck will be calibrated, including the use of the new capabilities that are being added during the fiscal year. The HEC-5Q Users Manual is available for distribution in draft form. By the end of the fiscal year, it will be modified to include the results of the 1983 tasks.

Figure 7

FY 83 TASKS

- Add phytoplankton analysis
- Add benthal material source / sink
- Modify to analyze long record (multiple years)
- Add graphics output
- Improve vertical geometric interpolation
- Complete test data calibration

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