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14. ABSTRACT
The capability exists within the Corps to evaluate the water quality impacts of alternative proposals for river and/or reservoir projects. The capability and example applications of the various water quality models available from the Hydrologic Engineering Center are described.

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Papers in this series have resulted from technical activities of the Hydrologic Engineering Center. Versions of some of these have been published in technical journals or in conference proceedings. The purpose of this series is to make the information available for use in the Center's training program and for distribution with the Corps of Engineers.

RIVER AND RESERVOIR SYSTEMS WATER QUALITY MODELING CAPABILITY[1/]

R. G. WILLEY[2/]

INTRODUCTION

Background

During the late 1960's and early 1970's, water quality mathematical modeling consisted of reservoir temperature and stream temperature, dissolved oxygen and biochemical oxygen demand analysis. The U.S. Army Corps of Engineers was extremely active in the area of reservoir temperature analysis during this period.

Several reservoir temperature models were developed either by or for the Corps [1, 2, 3 and 4]. These same models are not only still available today, but also are widely used for water temperature studies within the Corps and by consulting engineering firms worldwide.

Changing Objectives

By the mid-1970's, the Corps became involved in Urban Studies (formerly called Wastewater Management Studies). A need was apparent for a water quality model capable of analyzing more water quality parameters both within the reservoir and in the stream system. The stream analysis requirements suggested a need for nonsteady, nonuniform hydraulics.

These needs were met by contracting with a consulting firm to develop a comprehensive package of computer programs called "Water Quality for River-Reservoir Systems," (WQRRS) [5]. The evolution of the WQRRS package of programs is discussed elsewhere by the author [6].

In general, the WQRRS programs perform one dimensional analysis of rivers or reservoirs for a variety of water quality parameters. The hydraulics and hydrodynamics of the system are first calculated and then the water quality parameters are modeled. The water quality parameters are interrelated to approximately model an aquatic ecological system.

A less complex river water quality model has also been developed for studying long periods (i.e., many years) of water quality conditions. This model, called "Receiving Water Quality" (RWQM) [7] has been used very little and must be considered as relatively untested.

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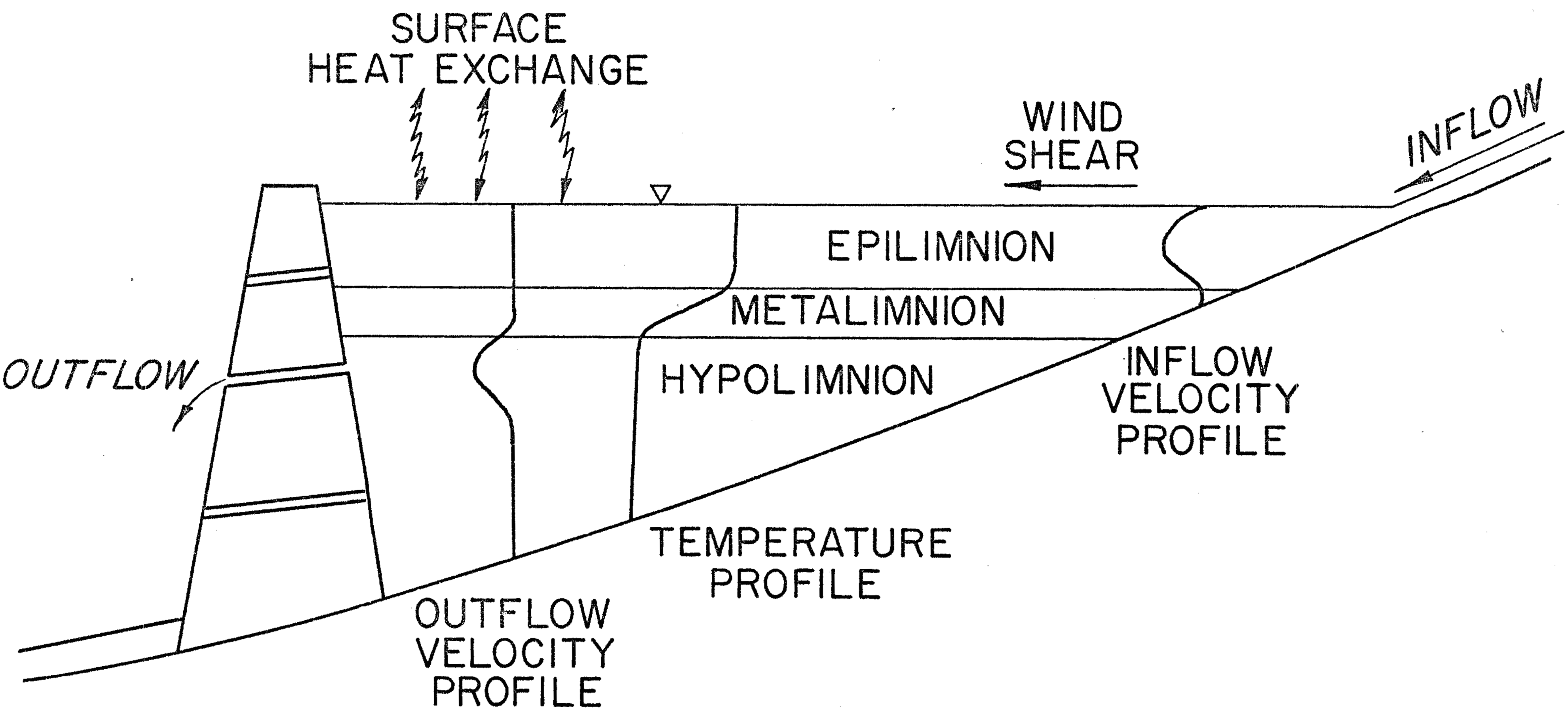

Figure 1

STRATIFIED RESERVOIR

By the late 1970's, the Corps interest in modeling hydropower and real-time operations problems influenced the expanded development of an existing computer model which was capable of simulating reservoir system operations for flood control [8]. The expanded version was called "Simulation of Flood Control and Conservation Systems - HEC-5" [9].

In general, the HEC-5 program is capable of simulating multipurpose reservoir systems having up to 35 impoundments. A system operation method is used which maintains a balance of storage in the various impoundments. The balance is achieved by user input specification of reservoir storage levels.

In 1979, contracting was initiated to develop and interface water quality routines with the HEC-5 program. The program version which includes water quality is called HEC-5Q [10]. It was decided to have the capability to analyze up to eight water quality parameters at ten reservoirs and thirty control points. The water quality routines begin the analysis with a "best" set of simulated flows from HEC-5 for the reservoir system. Determination is then made of the best level of outlets to use at each reservoir to take advantage of water quality stratification in the reservoir, if a multilevel outlet structure exists for providing water quality control. If this set of flows can't meet the user-specified target water quality conditions at each control point, a modified pattern of impoundment releases is determined. This calculation uses a nonlinear optimization which will release desired flows but also meet (if practical) the desired water quality conditions.

RESERVOIR TEMPERATURE ANALYSIS

The state-of-the-art in reservoir temperature models has changed very little since the mid-1970's. The models previously referenced are all readily available within the Corps. These models have varying degrees of documentation available and user support.

The "Thermal Simulation of Lakes" program (THERM) [4] is probably the most popular, and has good documentation and user-assistance availability. This program can satisfactorily be used for most design-oriented engineering studies without program modification. THERM evaluates the thermal vertical stratification of the impoundment including the effects of the inflow and discharge as shown in Figure 1. The heat exchange at the surface layer due to atmospheric conditions is evaluated and a resultant water temperature profile is determined. The THERM program is readily available for distribution with documentation or is available at the Corps' Boeing Computer System (BCS) library which is accessible by virtually all Corps offices. This program has been successfully applied to numerous projects for many years.

RIVER-RESERVOIR ECOLOGICAL ANALYSIS

The development of the WQRRS package [5] has evolved over a ten year period into a set of complex, comprehensive water quality models. The WQRRS users manual documents three separate but integrable computer programs as shown in Figure 2: reservoir water quality, stream hydraulics and stream water quality.

The stream hydraulics program has two steady flow computation methods and four hydrologic and hydraulic routing techniques for the users selection.

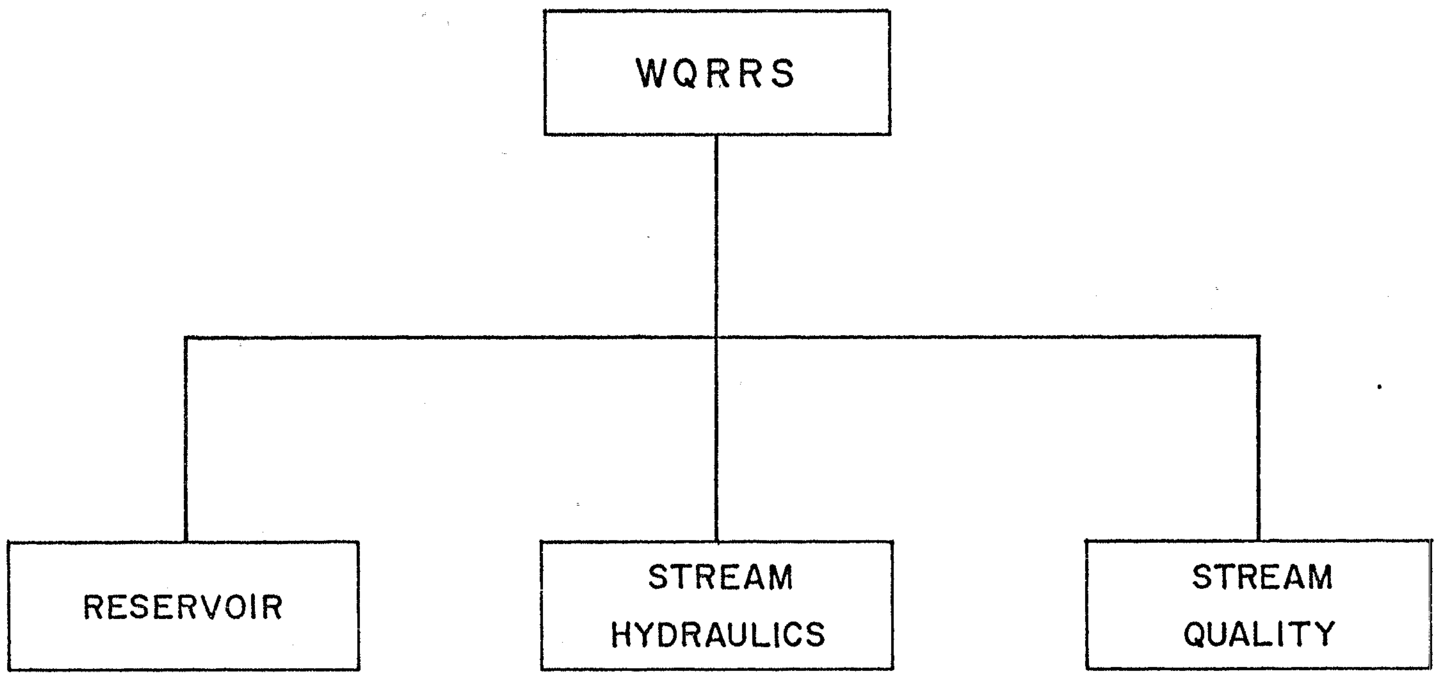

Figure 2 WATER QUALITY FOR RIVER-RESERVOIR SYSTEMS MODEL

The water quality programs are one dimensional aquatic ecologic type models. The user selects the model structure for any of the more than 23 water quality parameters depending on the choice of river or reservoir programs. River and reservoir systems like those shown in Figure 3 can be easily evaluated with WQRRS. The reservoir model evaluates isoquality horizontal layers and the river model uses isoquality longitudinal elements as shown in Figures 4 and 5 respectively.

The model structure can be anything from a water temperature only calculation to a chemical-biological model. The biologic analysis is an engineering approximation approach to allow satisfactory interface with the comprehensive chemical interactions in the model.

Additional programs [11] for summarizing the stream water quality program outputs include a statistics program and a graphics program for time series analysis and a second graphics program for stream profile plots as shown in Figures 7 and 8 respectively. The time series statistics program shows minimum and maximum simulated results, errors of reproducing observed data and percent of time the simulated data exceeded the minimum and maximum stream standards.

These programs are readily available for individual distribution with documentation or are available at the Corps' BCS library. These programs have been successfully applied on several projects.

RESERVOIR SYSTEM WATER QUALITY ANALYSIS

The development of the HEC-5Q program has evolved over a three year period with an ultimate objective of evaluating up to ten reservoirs, 30 control points and eight water quality parameters. The eight parameters include water temperature, three conservative and three nonconservative (two of which can be oxygen demanding constituents) parameters, and dissolved oxygen. The model is capable of simulating a comprehensive multipurpose reservoir system for evaluation of a "best operation" for each individual reservoir discharge to meet desired water quantity and quality target objectives at user specified control points throughout the drainage basin [12].

The currently available model will perform as described above for two reservoirs only. The complete capability discussed above will be available in 1983. The HEC-5Q model is presently a research tool undergoing extensive testing and the user should carefully evaluate the model output.

APPLICATIONS

The Hydrologic Engineering Center and others have used the models described above on numerous applications. These models have been used for river and/or reservoir water quality analysis at the various locations and types of jobs described in Table 1.

SUMMARY

All of the models described above are available from the HEC. These models are maintained at state-of-the-art status. Users should be in contact with HEC at the initiation of any new project and routinely during the

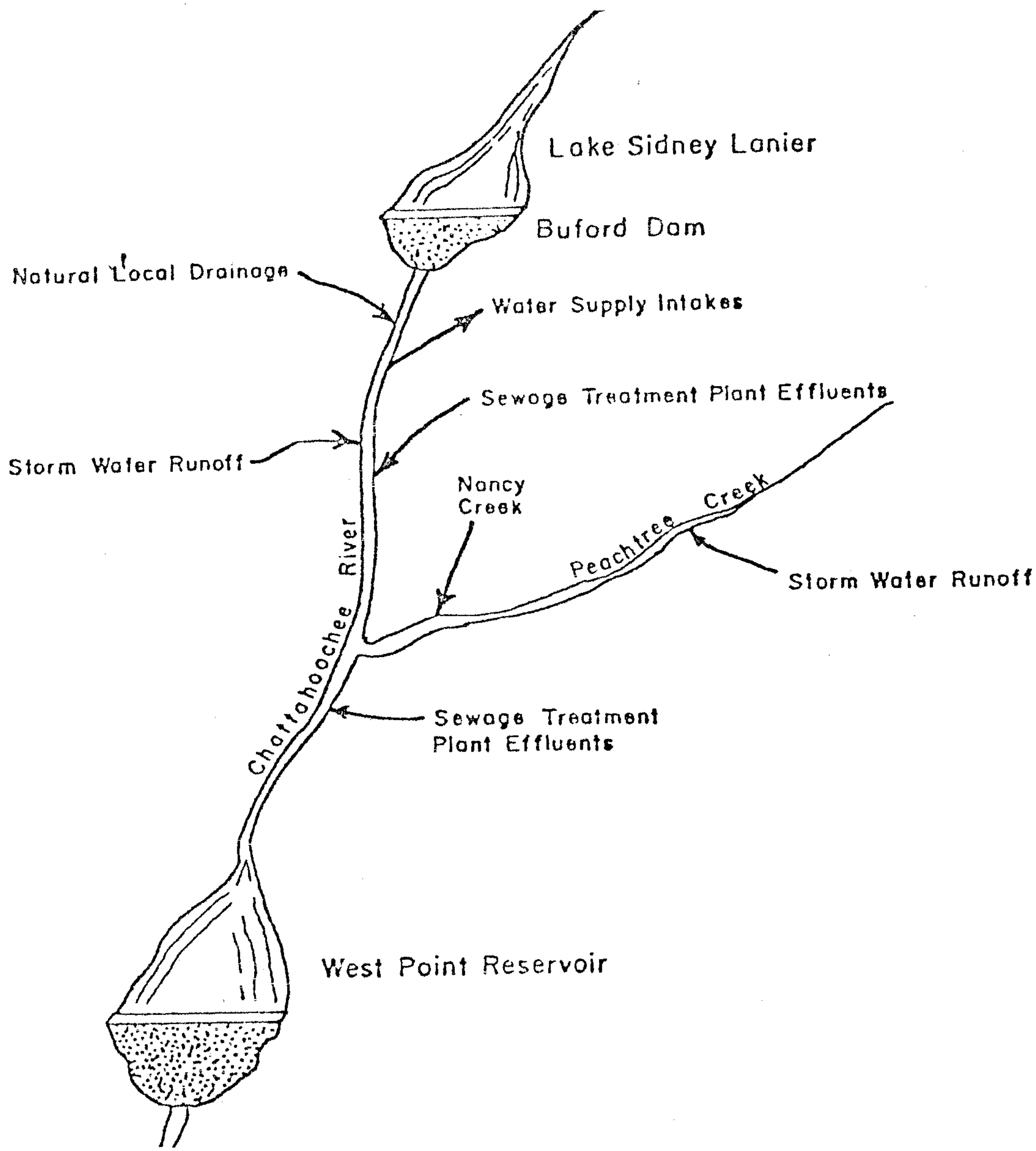

Figure 3
TYPICAL RIVER-RESERVOIR SYSTEM

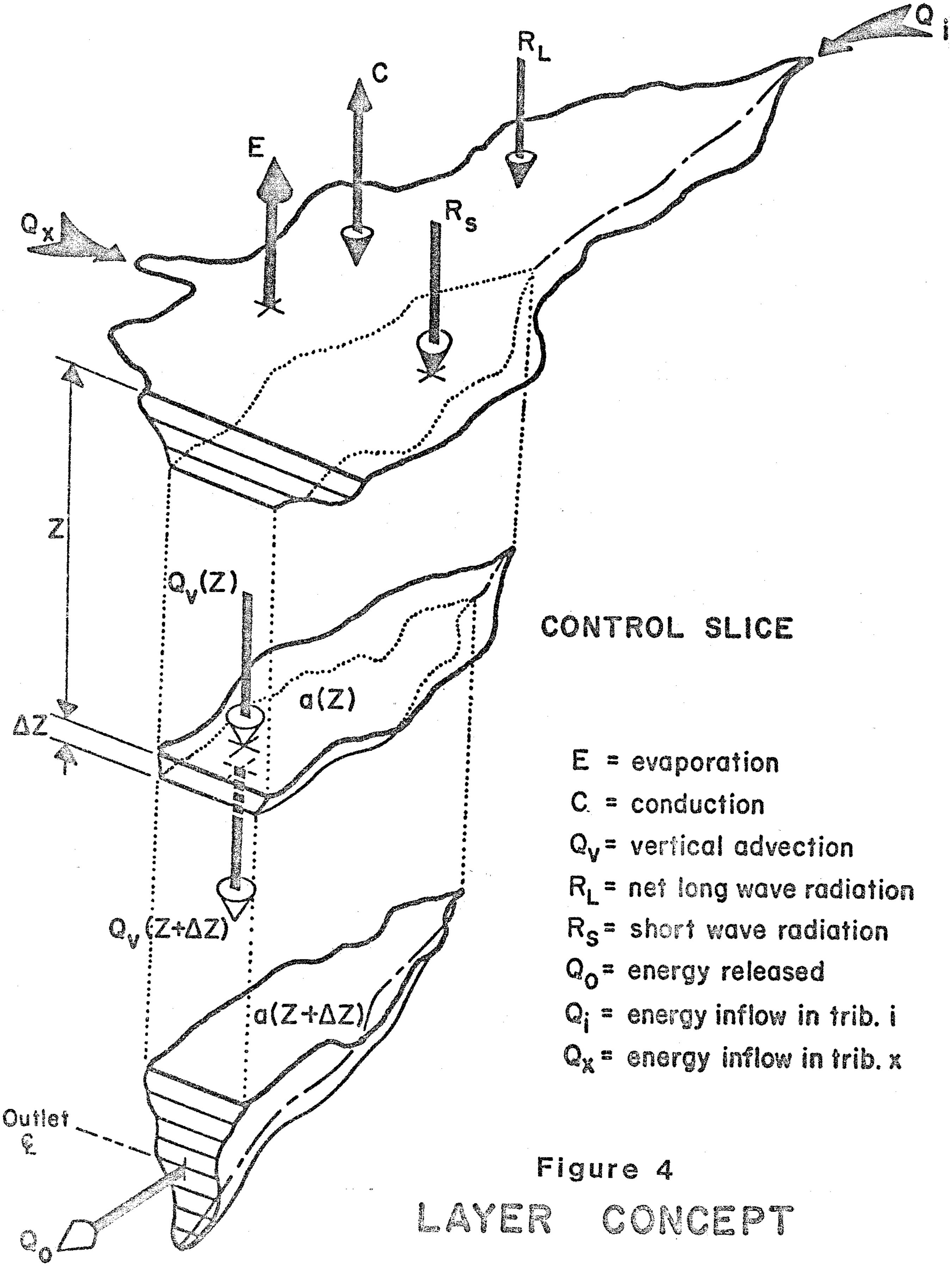

Figure 4

LAYER CONCEPT

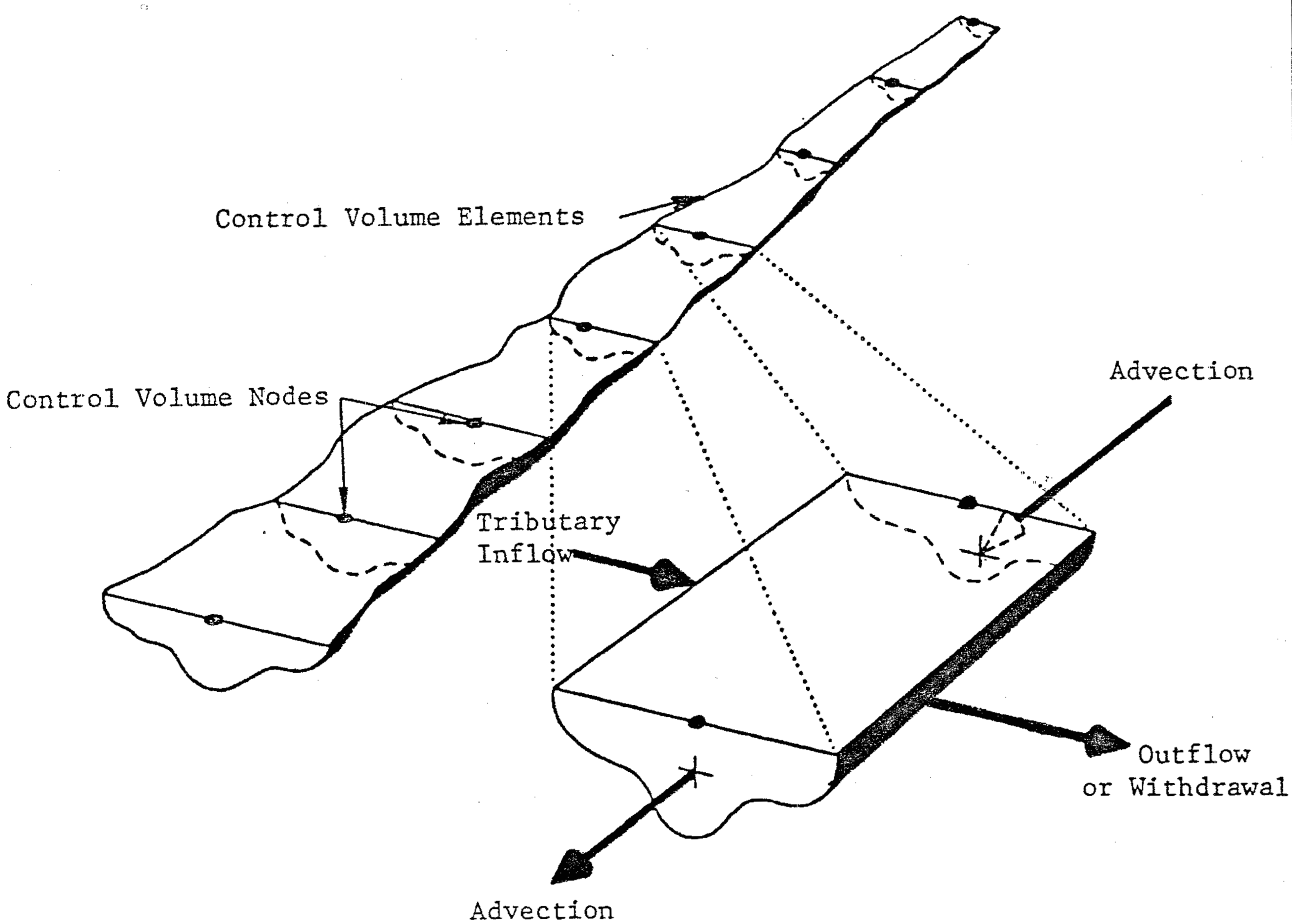

Figure 5

DISCRETIZED STREAM SYSTEM

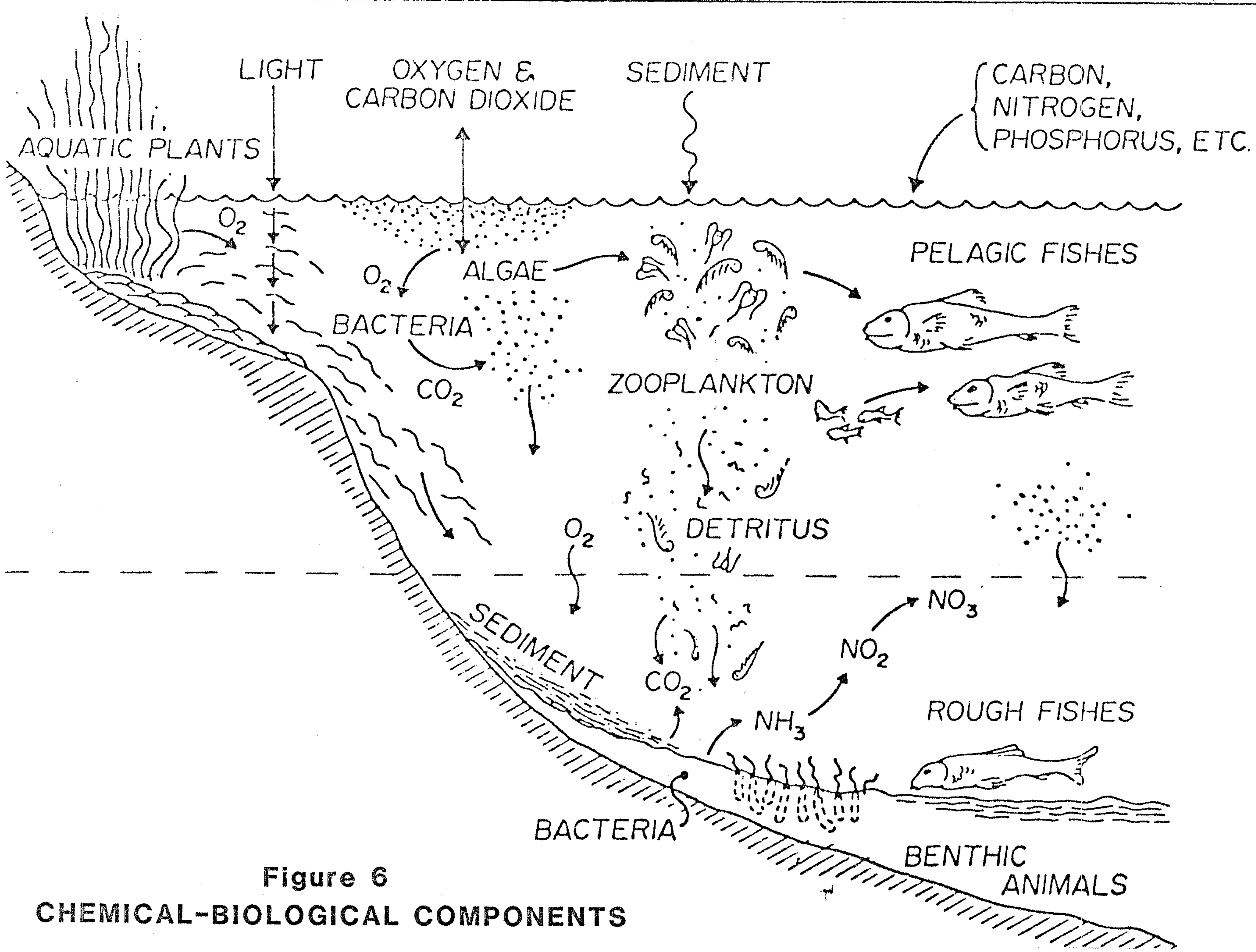

Figure 6
CHEMICAL-BIOLOGICAL COMPONENTS

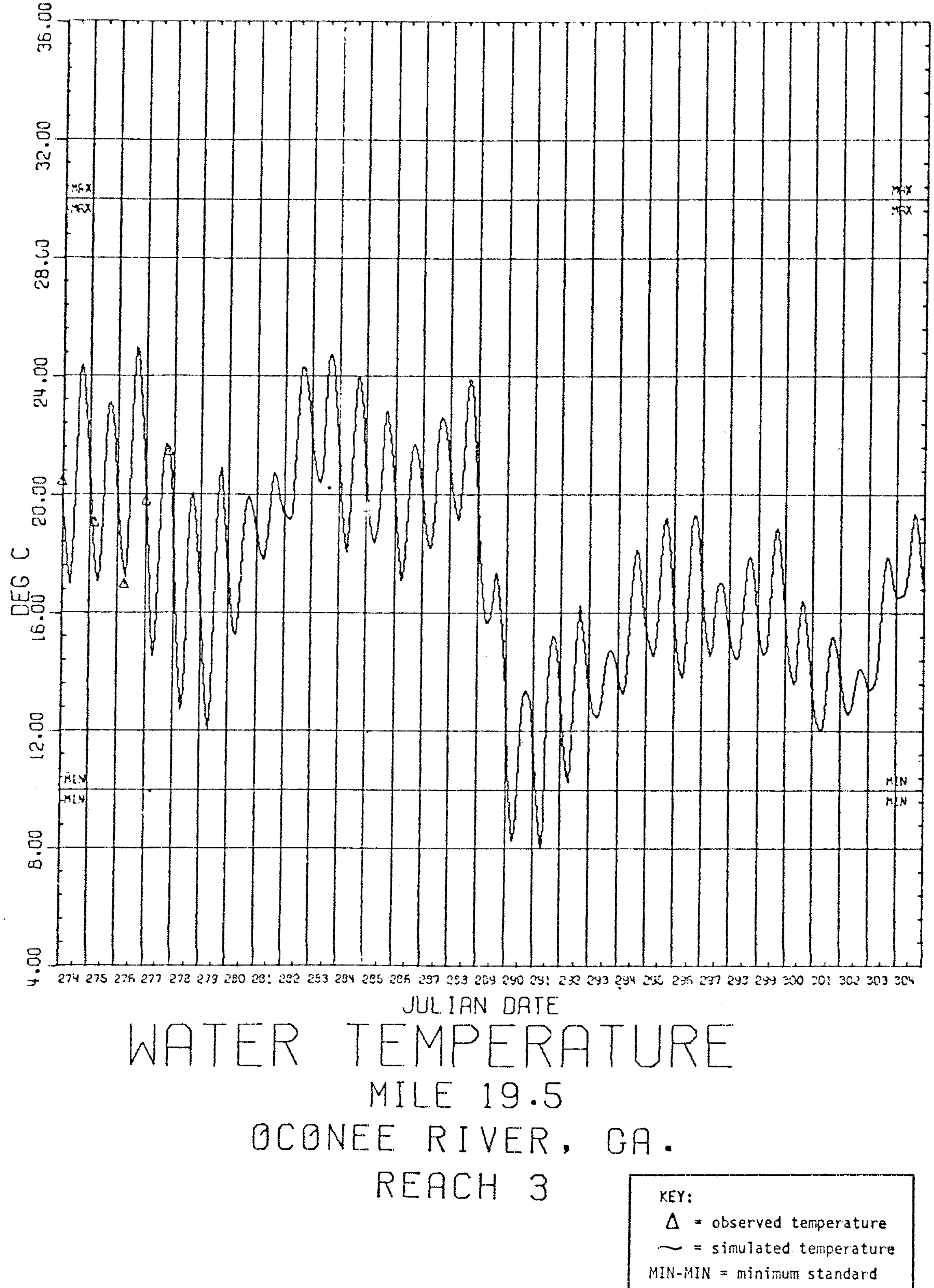

Figure 7 TIME SERIES OUTPUT

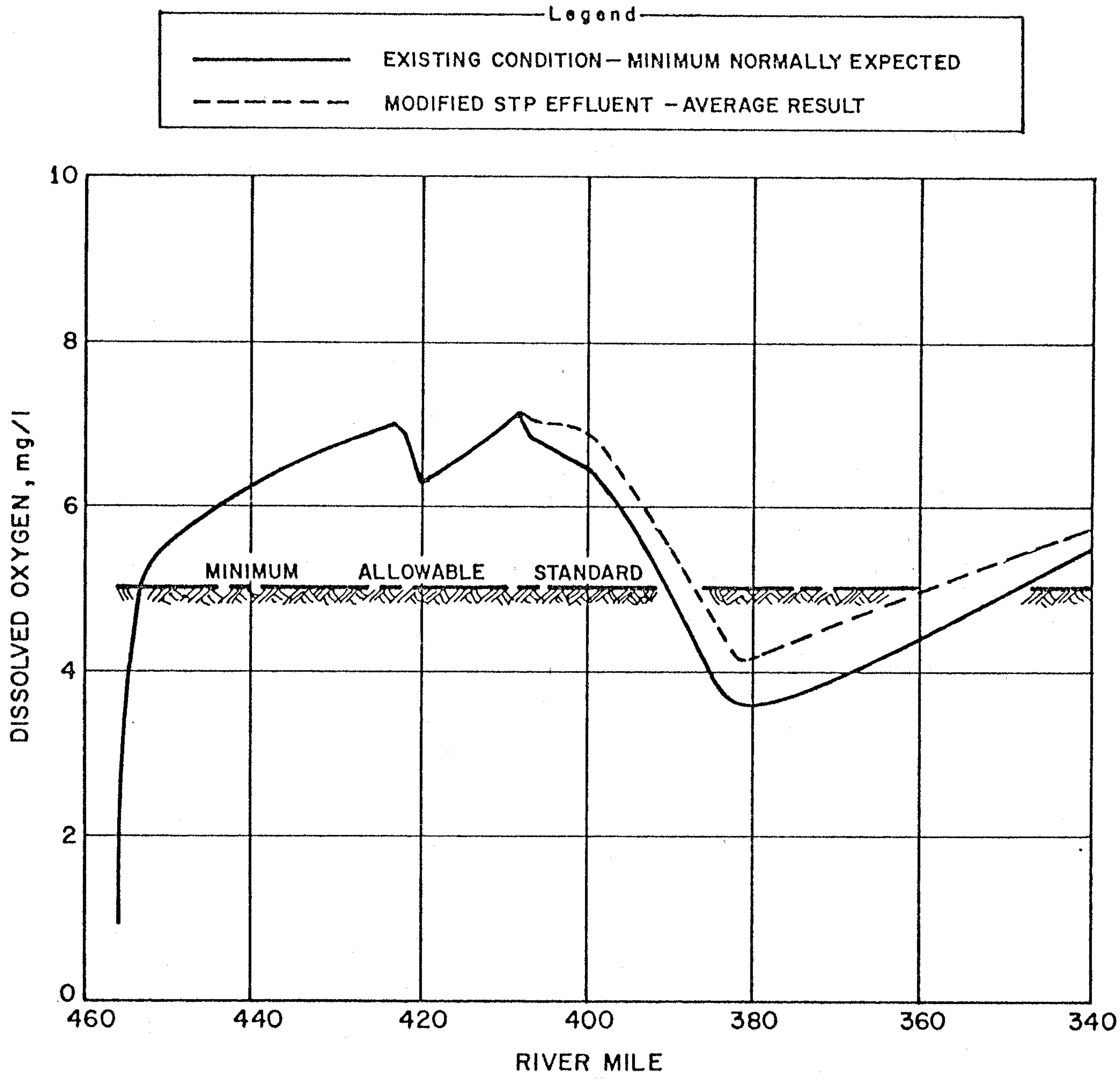

Figure 8 IMPACT ON D O DUE TO MODIFIED STP EFFLUENT

TABLE 1

EXAMPLE MODEL APPLICATIONS

Model	Parameters Used	Reservoir Analysis	River Analysis	Corps Office*
THERM	Temperature	X	-	Ohio River Division
WQRRS	Temp, DO, BOD	X	-	Tulsa District
WQRRS	Temp, pH, TDS, DO, BOD	-	X	Pittsburg District
WQRRS	Ecologic	-	X	Savannah District
WQRRS	Ecologic	X	X	Ft. Worth District
WQRRS	Temperature	X	X	Sacramento District
WQRRS	Temperature	X	-	Bureau of Reclamation
RWQM	Temp, DO, Nitrogen, Phosphorous, Coliform	-	X	Philadelphia District
HEC-5Q	Temp, DO, BOD, EC, Nitrogen	X	-	Savannah District
HEC-5Q	Temp, DO, BOD, EC, Ammonia	X	X	HEC Research

*except as noted

project to identify the latest version of the model and to be aware of any recent updates planned or in progress. The models limitations are documented in the users manuals and should be fully understood as to their effect on the specific project. The HEC is always willing to provide technical assistance in the use of any of these models.

The models discussed above provide an excellent package of programs to meet many of the normal needs for one dimensional modeling capability. Models of more dimensions are available and are discussed by other participants in this seminar but the user must remember that they require a more extensive data base and involve more complexity. When two-dimensional models are absolutely necessary, use the more complex model but always try to use the simplest model available to meet your objectives.

REFERENCES

1. "WRE Reservoir Temperature Simulation Model," Users Manual, U.S. Army Corps of Engineers, North Pacific Division, May 1973.

2. "WESTEX - A Reservoir Heat Budget Model," Users Manual, U.S. Army Corps of Engineers, Waterways Experiment Station.

3. "Reservoir Temperature Stratification," Users Manual, U.S. Army Corps of Engineers, The Hydrologic Engineering Center, January 1972.

4. "Thermal Simulation of Lakes," Users Manual, U.S. Army Corps of Engineers, Baltimore District, distributed by the Hydrologic Engineering Center, November 1977.

5. "Water Quality for River-Reservoir Systems," Computer Program Manual, U.S. Army Corps of Engineers, The Hydrologic Engineering Center, October 1978.

6. Willey, R. G., "Water Quality Evaluation of Aquatic Systems," Tech. Paper No. 38, The Hydrologic Engineering Center, April 1975.

7. "Receiving Water Quality Model," Computer Program Manual, U.S. Army Corps of Engineers, The Hydrologic Engineering Center, March 1979.

8. "Reservoir System Operation for Flood Control," Users Manual, U.S. Army Corps of Engineers, The Hydrologic Engineering Center, May 1973.

9. "Simulation of Flood Control and Conservation Systems, HEC-5," Users Manual, U.S. Army Corps of Engineers, The Hydrologic Engineering Center, June 1979.

10. "Simulation of Flood Control and Conservation Systems (including Water Quality Analysis), HEC-5Q," Users Manual (two volumes), U.S. Army Corps of Engineers, The Hydrologic Engineering Center, November 1980, Errata Sheets, August 1981.

11. "Statistical and Graphical Analysis of Stream Water Quality Data," Computer Program Manual, U.S. Army Corps of Engineers, The Hydrologic Engineering Center, October 1980.

12. Duke, J. H., D. J. Smith, and R. G. Willey, "Reservoir System Analysis for Water Quality," Draft Tech. Paper, U.S. Army Corps of Engineers, The Hydrologic Engineering Center, December 1981.

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