IMPROVEMENT OF RESERVOIR SIMULATION PROCESSES IN THE HYDROLOGIC SIMULATION PROGRAM FORTRAN (HSPF) WATERSHED WATER QUALITY MODEL

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INTRODUCTION

The Hydrologic Simulation Program Fortran (HSPF) watershed water quality model has been successfully applied to numerous watersheds throughout the world. The simulation output from the model provides information relating to the watershed hydrology and associated water quality (Johanson et al. 1984). Although the model has been validated on a wide variety of watersheds, it has been shown to be limited in handling the routing of water through reservoirs. The current version of HSPF allows for the simulation of reservoirs utilizing the RCHRES module. The primary limitation of this module is the completely mixed assumption. By incorporating the completely mixed assumption, reservoir processes such as thermal and chemical stratification fail to be addressed adequately.

CE-QUAL-W2 is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality reservoir model which is supported by the U.S. Army Corps of Engineers Waterways Experiment Station (WES) and is maintained in the Environmental Laboratory's Water Quality and Contaminant Modeling Branch (WQCMB). The model has been applied successfully to rivers, lakes, reservoirs, and estuaries (Cole and Buchak 1995). Both thermal and chemical stratification can be simulated in the model. In an effort to improve the limitation of the completely mixed assumption in HSPF, a project was initiated to investigate the feasibility of implementing CE-QUAL-W2 in place of the RCHRES module.

Currently, HSPF is being used to model the entire Chesapeake Bay watershed (Donigian 1995). The primary objective is to predict the loadings from watershed areas into the Chesapeake Bay. As part of the Chesapeake Bay Agreement, signed by the EPA Administrator and governors of the member states, a 40% reduction in nutrient loadings to the Bay to restore and maintain the living resources was to be quantified and evaluated with the HSPF model. Furthermore, the model was to allow the Chesapeake Bay Program Office (CBPO) to evaluate the impacts of various land use changes and best management practices (BMPs) within the watershed. Because of the potential implications of the HSPF modeling results to the various member states, an effort was made to apply the model as accurately as possible. The limitation of the completely mixed assumption was noted early in the study process, and an effort was made to improve reservoir processes in the HSPF model. One area of particular interest was the Conowingo Reservoir located in the Susquehanna river in Maryland. The reservoir is located in two Chesapeake Bay members states, Maryland and Pennsylvania. The primary concern was the model's ability to adequately model thermal and chemical stratifications, water quality constituents, and sediment loadings in the Conowingo Reservoir. Thus, the Conowingo Reservoir was selected as the test site to determine the improvements of using the CE-QUAL-W2 model in place of the RCHRES module in HSPF. The value added utilizing the CE-QUAL-W2 simulation over HSPF will be quantified. If it is determined that CE-QUAL-W2 does represent a significant improvement over the RCHRES module, CE-QUAL-W2 will be indirectly linked to the HSPF model to improve the reservoir simulation capabilities of the model.

OBJECTIVE

The overall objective of this study was to develop an improved reservoir simulation capability for the comprehensive watershed water quality model HSPF. To accomplish the objective, the study was segmented into two phases. The first phase, which is discussed in this paper, involved implementing CE-QUAL-W2 on the

Conowingo Reservoir and calibrating the model with flow and temperature data for selected years. Following the completion of the first phase, the developed CE-QUAL-W2 model will have selected nutrients added to the simulation, sediment transport, and the estimated value of improvements of the HSPF RCHRES module will be determined.

CE-QUAL-W2 MODELING APPROACH PHASE I

Introduction. Phase one of this study involved data acquisition, development of the computational grid, calibration to selected data, and evaluation of results. CE-QUAL-W2 is best suited for relatively long and narrow water bodies which exhibit longitudinal and vertical water quality gradients due to the lateral homogeneity assumption. The Conowingo Reservoir meets these requirements and is well suited for a CE-QUAL-W2 application.

The Conowingo Hydroelectric Station was completed in 1928 and impounds the Conowingo Reservoir. The Conowingo Reservoir is the last of a series of reservoirs located on the Susquehanna River which flows into the uppermost portion of the Chesapeake Bay. The Conowingo Hydroelectric Station is located in Cecil and Hartford Counties, Maryland, and is 10 river miles from the Chesapeake Bay. The pool formed by the impoundment reaches 14 miles to the Holtwood Hydro-Steam Electric Station at river mile 24. The reservoir has approximately 9,000 surface acres with a storage capacity of 322,000 acre-feet (Mathur et al. 1988). Average depth in the reservoir is 20 feet with an average width of one mile. Depth of the water at the dam ranges from 60 to 90 feet. The intake structures are located at a depth of 40 feet and extend to the bottom of the station. The facility is typically operated as a "run of the river" facility. Flows of the Susquehanna River are wide ranging. Mathur et al. (1988) determined that over a historical period (1952-1980), the annual river flow was approximately 35,000 cfs. The daily river flows, however, varied from 1,500 to 941,000 cfs. Retention time in the reservoir can vary from 1 to 2 days during periods of high flow greater than 100,000 cfs, to 30 to 40 days during period of low flow less than 4,000 cfs. Flows from the Susquehanna River account for the largest portion of flows into the Chesapeake Bay.

Two power plants are located in the Conowingo Reservoir. The Muddy Run Pumped Storage Station is located at river mile 23. This facility typically pumps water into a storage reservoir during off peak hours and produces power during periods of peak demand during which water is pumped back into the reservoir. The other power plant is the Peach Bottom Atomic Power Plant which is located at river mile 17. Peach Bottom Atomic Power Plant utilizes water from the Conowingo Reservoir for cooling. Thus, this power plant has a flow and temperature effect in the Conowingo pool. The effects of these two plants utilizing water in the Conowingo Reservoir are included in the simulation.

Data Acquisition. CE-QUAL-W2 requires numerous types of data for each application site. The data required includes geometric data, initial conditions, boundary conditions, hydraulic parameters, kinetic parameters, meteorological data, and calibration data. Geometric data is used to define the finite difference representation of the water body. Types of geometric data are sediment range surveys and volume-area-elevation tables. This information enables an accurate computational grid to be created for the water body. Initial and boundary conditions are used to provide startup conditions for the simulations. Types of initial conditions are time, temperatures and concentrations, and inflows/outflows. Boundary conditions are information relating to inflows, precipitation, and outflows from the reservoir or water body. Dispersion and chezy coefficients are hydraulic parameters that are required for each simulation. Kinetic parameters are optional, but 60 coefficients are included which can be used to describe constituent kinetics. Meteorological data needed for CE-QUAL-W2 simulations include air temperature, dewpoint temperature, wind speed, wind direction, and cloud cover. Perhaps the most important model requirement is the calibration data. Model results need to be calibrated to observed data. Observed data should be obtained for in-pool and boundary conditions. For this phase of the study, both flow and temperature data were required. Data were obtained from several sources for this study. The USGS, RMC-Environmental Services, Safe Harbor Water Power Corporation, Pennsylvania Electric Company (PECO), and the Peach Bottom Atomic Energy Plant all provided data used in this study. Data acquired included bathymetry, inflows and outflows and corresponding temperatures to the Conowingo Reservoir, Muddy Run Pumped Storage Station operation rules, and Peach Bottom Atomic Energy plant operation within the pool. Meteorological data were obtained from the EarthInfo Inc. database for Baltimore, Maryland. This data base contains USGS values for the selected site for the required parameters.

Development of the Computational Grid. A sediment range survey of the Conowingo Reservoir was obtained from the USGS. The sediment range survey utilized for this study was completed in 1993. This information was used to create the computational grid required for the operation of CE-QUAL-W2. The grid created included 32 layers with a vertical spacing of 2.95 feet and 42 segments covering a distance of 10 miles. The computational grid was checked for accuracy by comparing the CE-QUAL-W2 calculated volume - elevation curve versus the curve provided by PECO. The results of the comparison are shown in Figure 1. The figure shows the close agreement between predicted and observed volume and elevation levels for the Conowingo Reservoir. As an additional check, the observed elevations of the Conowingo pool for the 1992 water year (1OCT92-30SEP93) were plotted against those predicted in the CE-QUAL-W2 model. As seen in Figure 2, the simulated data match well to those observed during the time period. It was determined that the computational grid of the Conowingo Reservoir was accurate and was ready for the calibration process.

Calibration to Selected Data. The next step in the modeling process was to calibrate flow and temperature to selected data. In order to calibrate the model, it was necessary to utilize a data base that contained in-pool temperature profiles. RMC-Environmental Services were able to provide data from a project conducted in water year 1981 (1OCT81-30SEP82). Vertical samples were collected at several locations in the Conowingo Reservoir. Three selected calibration stations are described in this paper. The stations include 601, 611, and at the Conowingo Dam. Station 601 is located one mile below the Muddy Run Pumped Storage Plant near the headwater of the reservoir, and 611 is 3,000 feet upstream from the Conowingo Dam. Stations near the edge of the reservoir were not used based on CE-QUAL-W2 being a vertically averaged model and the lack of mixing of water samples taken from shallow edge areas.

The simulation was run for the 1981 water year. Flow from the Muddy Run Pumped Storage Plant was included as well as the thermal effects of the Peach Bottom Atomic Power Plant. The power plant had the effect of a change in the temperature of inflow and outflow from the facility of plus five degrees centigrade. Inflow temperatures recorded at the Holtwood Dam were used for the simulation; however, flow data were not available. Thus, the observed flow data at Conowingo Dam were used and inflow was set equal to outflow. This assumption holds well for the Conowingo Reservoir which operates as a run-of-the-river operation.

Evaluation of Results. The one year simulation for the Conowingo Reservoir required approximately two hours of CPU time on a 486-66Mhz IBM compatible personal computer. Simulation results were compared to the observed data for corresponding times during the 1981 water year. Station 601, 611, and the Conowingo Dam are shown in Figures 3, 4, and 5, respectively. It can be seen from these three figures that there is no thermal stratification in the Conowingo Reservoir, even during the summer months. The CE-QUAL-W2 model captures the temperature profiles at each of the stations quite well. Because the HSPF RCHRES module assumes a complete mixing assumption, it does not produce any output that can be used to predict vertical temperature profiles in a reservoir. However, a comparison was made of outflow temperatures for the Conowingo Reservoir, and both the HSPF and CE-QUAL-W2 model output produced reasonable results. Results from Phase I of the Conowingo Reservoir simulation indicated that the modeling processes is ready to move into the next phase.

CE-QUAL-W2 MODELING APPROACH PHASE II

The second phase of this study will involve the addition of selected nutrients, sediment transport, and quantifying the value added or improvements of utilizing CE-QUAL-W2 in lieu of the HSPF RCHRES module. The CE-QUAL-W2 reservoir model will also be used to provide loading values to the CE-QUAL-ICM Chesapeake Bay Eutrophication model currently being used by the Chesapeake Bay Program Office (CBPO). Results from the CE-QUAL-W2 simulation will be compared to those produced with HSPF. Input parameters for CE-QUAL-W2 will be provided from the HSPF model. Linkage will be accomplished external to the models for this study. Current research plans will utilize flow and concentration data for the 1984-1991 time period. These data are being provided by the CBPO. The expected completion date for this phase of the project is December 1996.

CONCLUSIONS

A research project has been initiated to investigate the feasibility of improving the reservoir simulation capabilities of the watershed water quality model HSPF. The CE-QUAL-W2 reservoir model was selected as a possible alternative to the RCHRES module currently being used in HSPF. The study was divided into two phases. Phase I involved the initial set up of the CE-QUAL-W2 model and calibration to flow and temperature for selected years. The second phase will involve the addition of selected nutrients, sediment transport, and evaluation of utilizing CE-QUAL-W2 for reservoir simulations in place of the RCHRES module in HSPF.

Results from the first phase of the study have indicated that CE-QUAL-W2 can capture the vertical temperature profiles in the Conowingo Reservoir. Thermal stratification was not found in the reservoir even during the summer months. The model matched flows and temperature profiles exceptionally well during the calibration procedure. The CE-QUAL-W2 model was successfully calibrated to flow and temperature and is now ready for the second phase of the project.

It is anticipated that CE-QUAL-W2 will improve the reservoir modeling capabilities of the HSPF model. Although significant thermal stratification was not found to exist in the reservoir, it has been documented to have chemical stratification (dissolved oxygen). Based on the completely mixed assumption used in the HSPF RCHRES module, it would not be able to capture the chemical stratification. A thorough evaluation of the improvements incorporating the CE-QUAL-W2 model into HSPF will be completed in the next phase.

ACKNOWLEDGMENTS

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REFERENCES

Cole, T.M. and J.E. Edinger. 1995. CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, Version 2.0.Instruction Report; EL-95-1. Prepared by for U.S. Army Corps of Engineers, Washington, DC 20314-1000. p. 355.

Donigian, A. S., Jr., B. R. Bicknell, and R. V. Chinnaswamy. 1995.-Refinement of a comprehensive watershed water quality. Draft. Aqua Terra Consultants, Mountain View, CA 94043. p. 65.

Johanson, R. C., J. C. Imhoff, H. H. Davis, J. L. Kittle, and A.S. Donigian, Jr. 1984. User's manual for the hydrologic simulation program - Fortran (HSPF): Release 8.0. EPA/3-84-066. U.S. Environmental Protection Agency, Athens, GA. p. 767.

Mathur, D., E. S. McClellan, and S. A. Haney. 1988. Effects of variable discharge schemes on dissolved oxygen at a hydroelectric station. Water Resources Bulletin. American Water Resources Association. 24(1): 59-167.

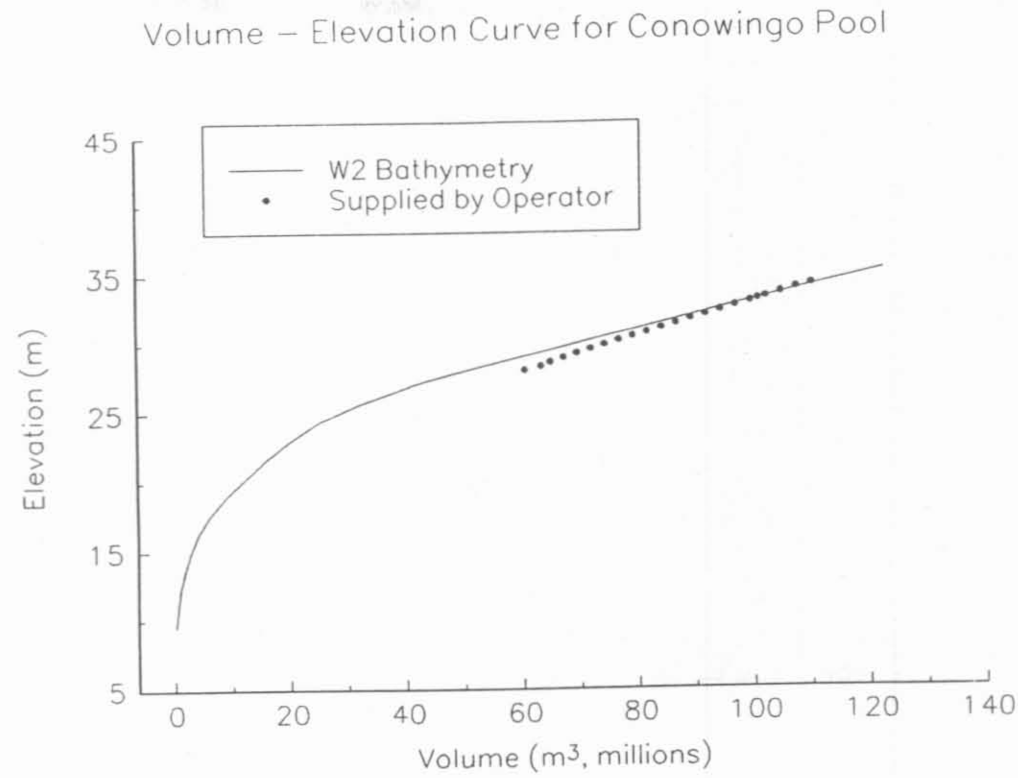

Figure 1. Observed versus CE-QUAL-W2 calculated volume elevation curve for the Conowingo Reservoir.

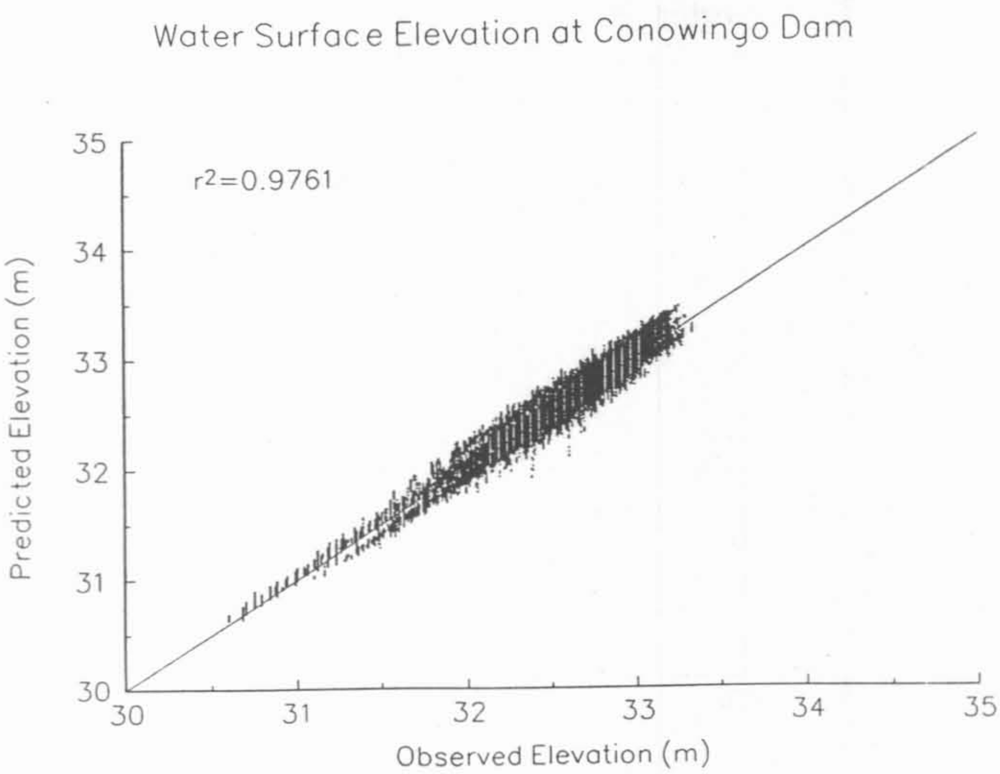

Figure 2. Observed versus predicted water surface elevations for the Conowingo Reservoir for water year 1992.

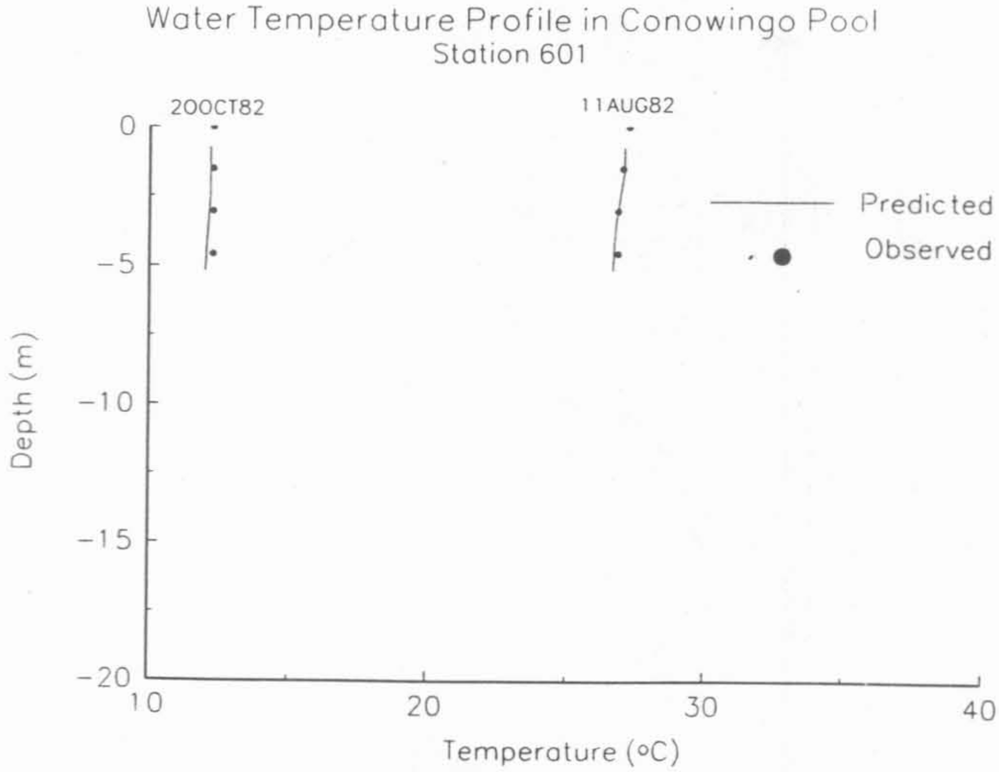

Figure 3. Vertical water temperature profiles at station 601 in the Conowingo Reservoir.

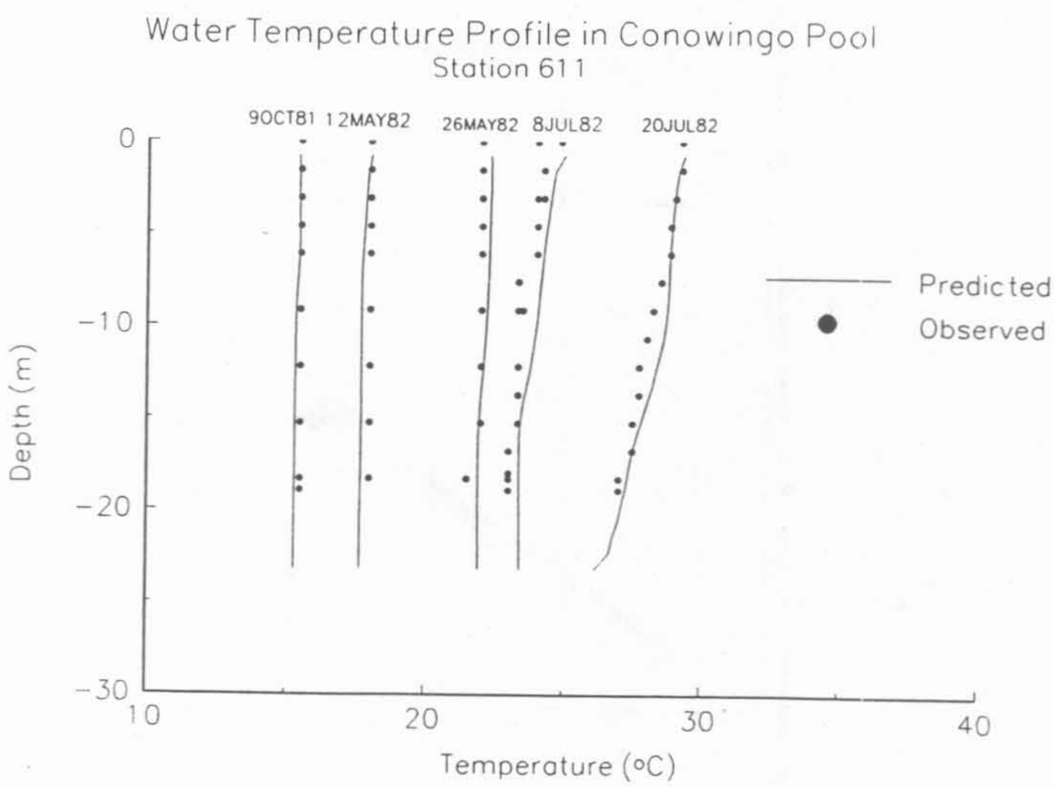

Figure 4. Vertical water temperature profiles at station 611 in the Conowingo Reservoir.

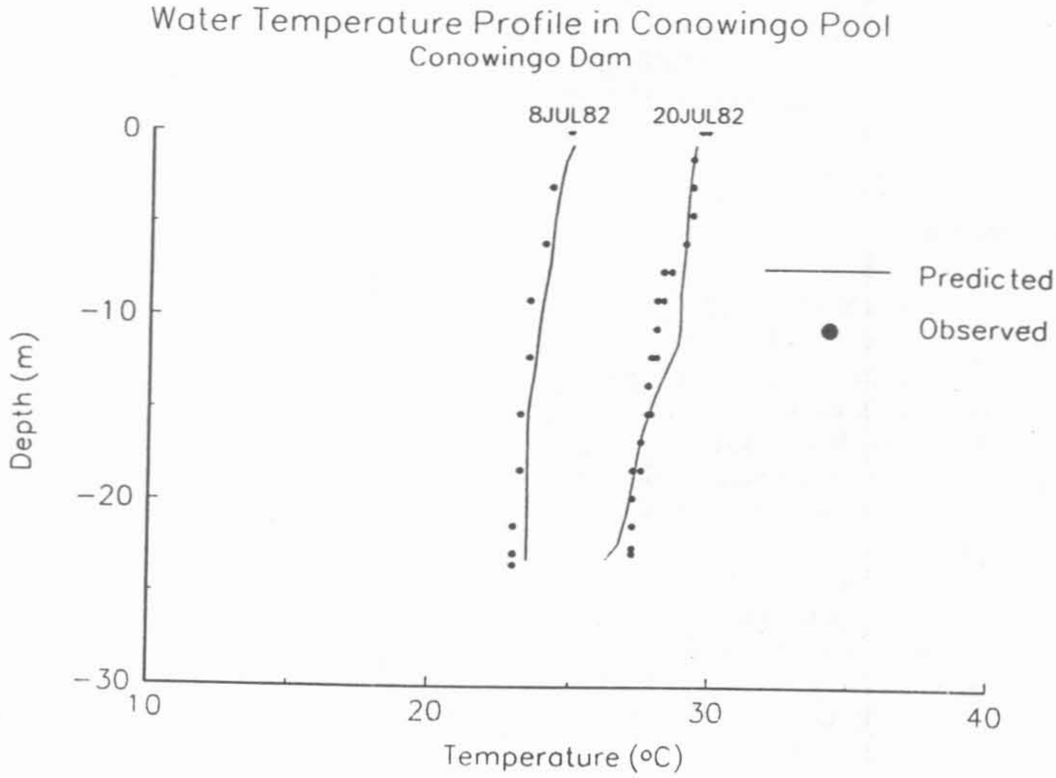

Figure 5. Vertical water temperature profiles at the Conowingo Reservoir Dam.