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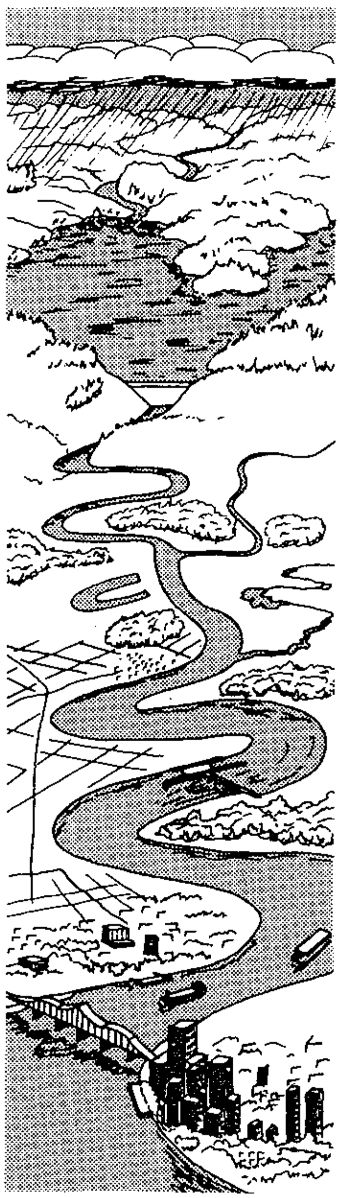

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# RIVERINE WATER QUALITY MODELING

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## BACKGROUND

The construction and operation of water resource projects can affect impounded and downstream water quality. Techniques are needed to assess the potential impacts, to evaluate various alternatives for water quality management, and to determine cause-and-effect relationships of water quality problems. Numerical water quality modeling is an effective means for addressing these needs. A variety of water quality models exist for resolving water quality issues. Reservoir water quality models developed within the Environmental and Water Quality Operational Studies (EWQOS) were discussed in EWQOS Information Exchange Bulletin Vol E-84-3. This article discusses developments for riverine water quality studies resulting from EWQOS Task IC.3, Improve and Verify Riverine Water Quality and Ecological Predictive Techniques.

There are many factors that influence water quality in rivers, such as amount, type, and location of waste loads; geometric and hydraulic characteristics of the river; and biochemical and physicochemical processes. There are many types of riverine configurations that can influence water quality, such as braided streams, pool-and-riffle streams, and run-of-the-river reservoirs.

A variety of modeling tools must be made available to address the diversity of water quality conditions that can arise. The scope of EWQOS Task IC.3 covered the range of modeling activities from analytical equations that can be solved on a calculator to two-dimensional (2-D) numerical models.

Some riverine water quality problems can be solved with hand-held calculators. The initial mixing and subsequent transport and dispersion of a pollutant discharge can often be defined with such methods. These methods usually do not consider biological and chemical transformations, thus their use would pertain primarily to questions about mixing and dilution. The type of analytical solution used depends on physical characteristics of the discharge and the receiving water. Guidance on the selection and application of analytical methods has been developed and will be published this year (Holley and Jirka In Preparation).

When biochemical transformations and complicating physical processes are considered in the analyses, it is necessary to use numerical simulation models. Numerical models are generally classified by dimensionality. Many riverine water quality issues can and should be addressed with a one-dimensional (1-D) numerical model. In other words, the only significant changes in water quality occur along the longitudinal axis (streamwise direction) of the river. Cross-sectional homogeneity, or complete mixing laterally and vertically, is assumed for 1-D riverine models. This is a valid assumption for most riverine applications.

There is another major distinction in riverine water quality models that is related to the change in flow or water quality with respect to time. A steady-state analysis assumes that water quality and flow do not change with time. Some riverine water quality models permit time-varying water quality but require steady flow.

There are many 1-D riverine water quality models that can be used for steady-state and steady-flow analyses. To provide some guidance in model selection, four widely used 1-D models were evaluated with steady-state data sets obtained from three different river systems. From this study, it was determined that the EPA model, QUAL II (Roesner et al. 1977), was the easiest to use and gave good results (McCutcheon 1983).

For some studies the steady-flow assumption may not be valid, and it may be necessary to use an unsteady-flow riverine model. An example of such a need would be a water quality study of a riverine reach below a peaking hydropower project. An efficient and accurate 1-D unsteady-flow riverine water quality model was developed by Bedford, Sykes, and Libicki.* Through Task IC.3, several improvements were made to the model, such as the provision to handle hydraulic control structures.

## CE-QUAL-RIV1

The revised Bedford et al. model, referred to as CE-QUAL-RIV1, shows wide general applicability to unsteady-flow riverine water quality studies. Model features and test results are described in the following paragraphs.

CE-QUAL-RIV1 is a dynamic 1-D numerical riverine model that consists of two codes: a code (RIV1H) for dynamic hydraulic routing and a code (RIV1Q) for water quality simulation. RIV1H is a stand-alone code that can be used to simulate river flows, water surface elevations (stage), depths, cross-sectional areas, and top widths. RIV1Q requires output from RIV1H (or a similar hydraulic model) to drive the transport algorithms for water quality simulations.

RIV1H is patterned after the National Weather Service Dambreak Model (Fread 1978). The model permits relatively unequal space and time steps and allows simulation of branched river systems with the inclusion of hydraulic control structures, such as reregulation dams and locks and dams. Boundary conditions may be provided in terms of flows, stages, or rating curves. Cross-sectional area and discharge are the dependent variables of the hydrodynamic equations. Once these variables are computed, stage, depth, and width can be determined. Time histories of all these variables can be output for each node of the river model. Additionally, all of these variables are used by RIV1Q to calculate dynamic changes in temperature and concentrations of water quality variables. Other hydraulic codes similar to RIV1H could be used to develop hydraulic information for RIV1Q.

After computing hydraulic conditions, RIV1Q is applied for water quality predictions. A solution technique developed by Holly and Preissman (1978) is used in RIV1Q to provide highly accurate advective transport of water quality constituents. The program originally could calculate up to seven given water quality variables: temperature, dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), organic nitrogen, ammonia nitrogen, nitrate nitrogen, and phosphate (phosphorus), as well as a user-selected variable. Additionally, the effects of phytoplankton and macrophyte growth and decay on nutrient balances and DO were included. The program was recently modified to include dissolved iron, dissolved manganese, and coliform bacteria as modeled variables.

Temperature computations are done with a direct energy balance (Roesner et al. 1977). The temperature computations include the effects of net short- and long-wave radiation, back radiation, evaporative cooling, conduction, and thermal loadings from inflow boundaries and lateral inputs. Computed temperatures are used to control the reaction rates for other water quality constituents.

Computing DO concentration is a primary function of the model. Reaeration and photosynthesis are sources of oxygen, while organic matter decay, nitrification, plant respiration, and iron and manganese oxidation deplete DO. Reaeration in the river itself follows the Tsivoglou formulation (Tsivoglou and Wallace 1972), and reaeration through gated structures is according to a relationship developed by Wilhelms and Smith (1981).

CE-QUAL-RIV1 was tested with a data set from the Chattahoochee River, Georgia, between Buford Dam and Peachtree Creek (48 river miles). This application was made in conjunction with a study (Zimmerman and Dortch 1984) funded by the Savannah District to determine the effects on water quality of a proposed reregulation dam to be sited about six miles downstream from Buford Dam.

Buford Dam is a peaking hydropower dam with discharges varying from 550 to 8400 cfs. Approximately 36 river miles below Buford Dam is Morgan

* K. W. Bedford, R. M. Sykes, and C. Libicki. 1982. "A Dynamic One-Dimensional Riverine Water Quality Model," report prepared by Ohio State University for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Falls Dam, which is a small shallow run-of-the-river hydropower project. Although Morgan Falls Dam is not specifically a reregulation project, it does reregulate somewhat the releases from Buford Dam.

The test application showed that the model could accurately simulate the transient flow and thermal conditions of the existing system. Figures 1 and 2 show part of the records that compare computed and observed stage and temperature at the Atlanta gage (about two miles above Peachtree Creek) for the week 12-19 July 1976. Figure 3 is a comparison of computed and observed dye tracer concentration at two stations during a dynamic flow event.

Although the Chattahoochee data set did not permit a detailed confirmation of other water quality variables, model results were consistent with values obtained from monthly grab samples. The model has been confirmed for other water quality variables under steady-state conditions as shown in Figure 4 (Bedford et al. 1983).

Several improvements are being made to the CE-QUAL-RIV1 code and user's manual. The user's manual will be available sometime in the future.

## CE-QUAL-RIV2

In some cases strong lateral gradients in water quality may exist and the study may require a 2-D

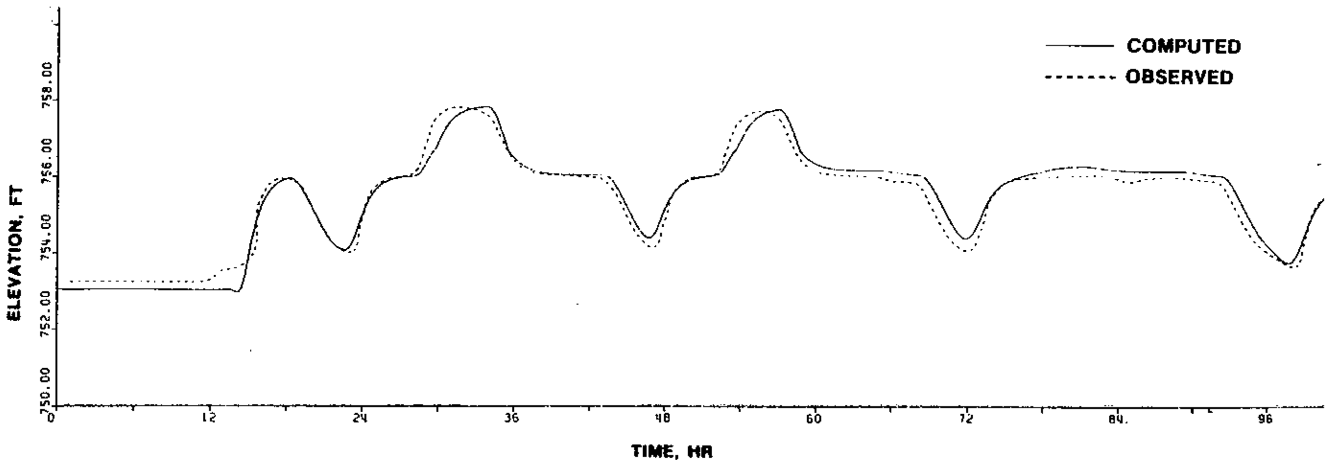



**Figure 1. Computed and observed stage history, 12-16 July 1976 (River Mile 302.96, Atlanta gage)**

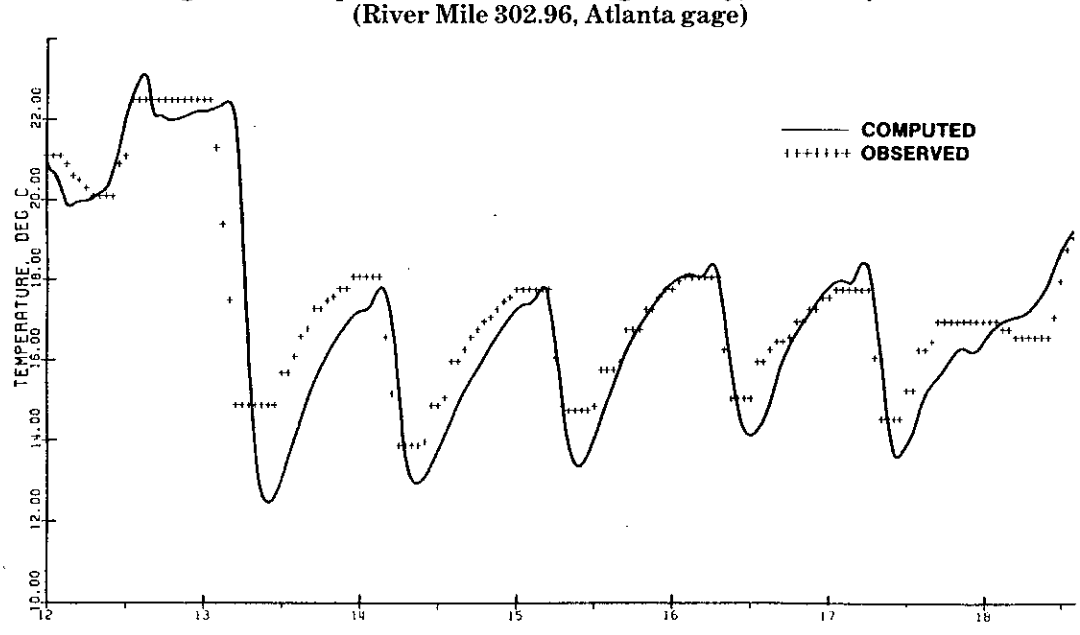
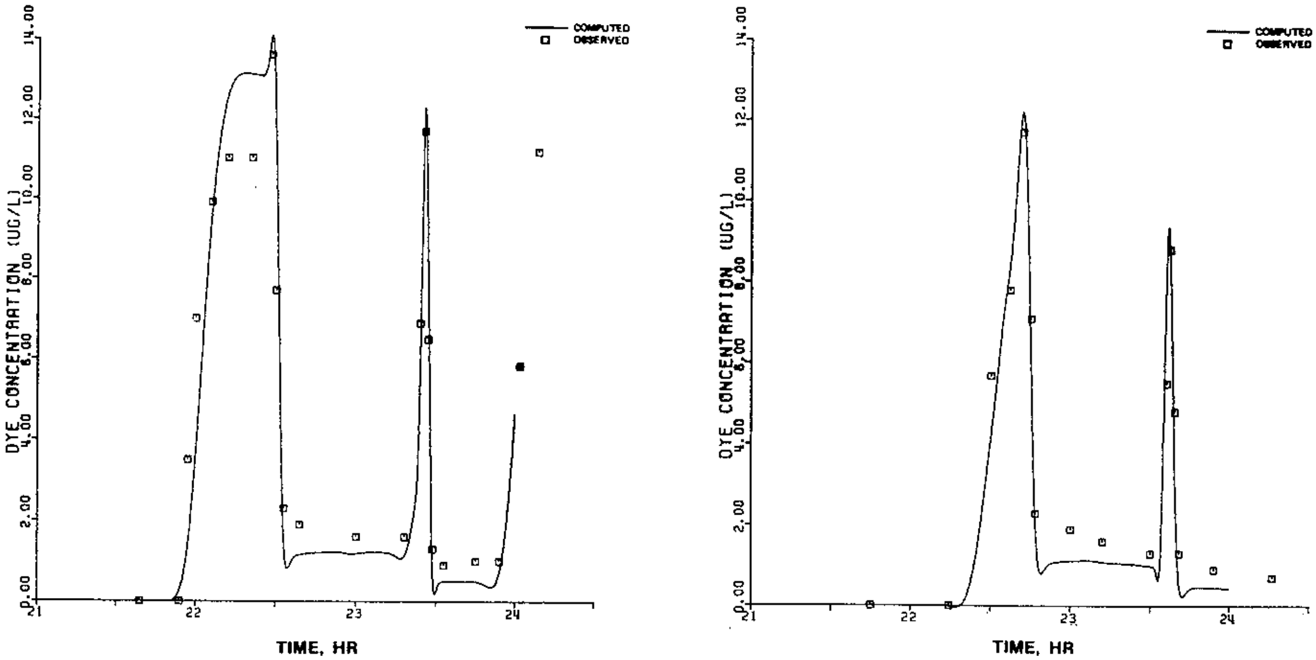



**Figure 2. Computed and observed temperature history, 12-18 July 1976 (River Mile 302.96, Atlanta gage)**




a. Sampled at River Mile 339.86 (Littles Ferry Bridge)

b. Sampled at River Mile 330.76 (Georgia Highway 141)

Figure 3. Computed and observed dye concentration history

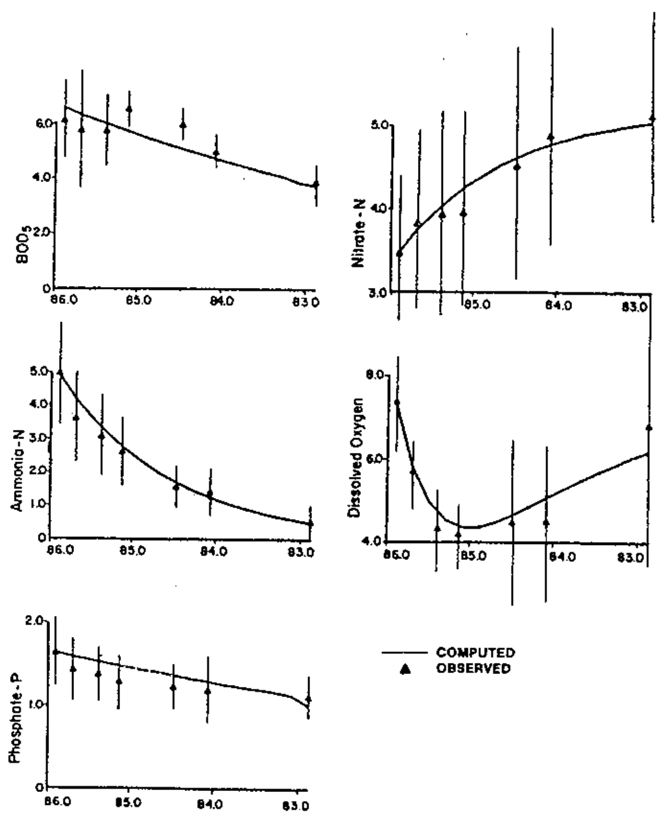



Figure 4. Comparison of steady state model prediction with time-averaged data collected from upper Olentangy River, July-August 1979 (Bedford, Sykes, and Libicki 1983)

riverine model. CE-QUAL-RIV2 is a 2-D depth-integrated unsteady-flow water quality simulation code. Although the emphasis during the development was on riverine conditions, the code permits the evaluation of lateral and longitudinal water quality gradients in any shallow vertically-mixed water body.

CE-QUAL-RIV2 must also use output from a hydrodynamic code to drive it. Presently, a hydrodynamic code developed by Johnson (1980) known as VAHM, Vertically Averaged Hydrodynamic Model, is used to drive the water quality code. However, other codes similar to VAHM could be used. The water quality compartments of CE-QUAL-RIV2 are similar to those of CE-QUAL-RIV1. A grid technique known as boundary-fitted coordinates is employed in these two codes to facilitate application to complex geometrical configurations. A user's manual for CE-QUAL-RIV2 will be published during 1985.

## SUMMARY

When selecting a riverine water quality model, one should choose the model that will address the issues with the least effort. For questions dealing with pollutant mixing, transport, and disperson, a desk-top analytical solution may suffice. For steady-flow, one-dimensional, riverine water quality problems, a model like QUAL II should be used. CE-QUAL-RIV1 would be used for unsteady-flow 1-D riverine water quality issues. In less frequent cases, a 2-D model such as CE-QUAL-RIV2 may be necessary.

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# Catalog of EWQOS Information Exchange Bulletin Articles

A catalog of the EWQOS articles published to date is shown below. The articles have been grouped in the following categories: predictive techniques, engineering techniques, operational techniques, environmental assessment, waterway design/operation, field studies, and general.

The fundamental objective of the EWQOS Information Exchange Bulletin is to provide condensed reports of new or improved technology to solve selected environmental quality problems associated with the Civil Works activities of the Corps of Engineers. As EWQOS research extends into specific areas or when innovative procedures are developed, articles are written to enhance technology transfer and use. The articles represent major program goals and objectives. Approximately 14 articles were published during the last year.

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