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# Real-Time Control for Matching Wastewater Discharges to the Assimilative Capacity of a Complex, Tidally Affected River Basin

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## ABSTRACT

A neural network model was applied to simulate the hydrodynamics and water quality of the Cooper and Wando Rivers in South Carolina. The evaluation of the model showed that predictions of salinity, water temperature, and dissolved-oxygen concentration for this complex estuarine system were accurate. Because neural network models execute without iteration, they are ideal for integrating with real-time information and control systems. In this study, the neural network model of the Cooper and Wando Rivers was coupled with an optimization routine to make maximum use of the assimilative capacity of the two-river system. Target dissolved-oxygen concentrations, set at the State water-quality standard, were matched by constraining effluent discharges. A prototype real-time control system for matching wastewater discharges to the continuously changing assimilative capacity of the Cooper and Wando Rivers is presented.

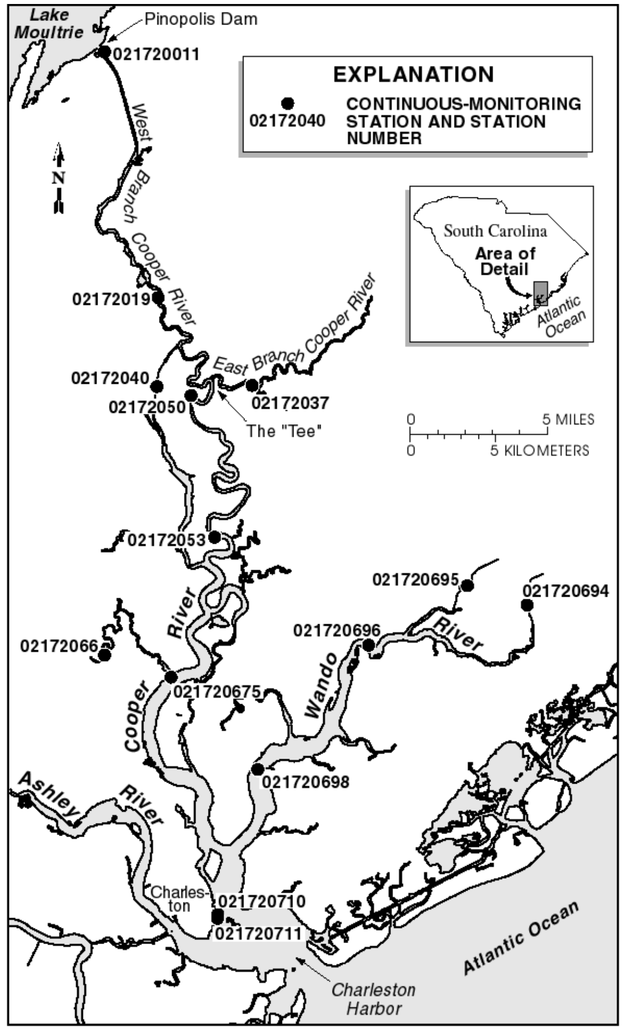


**Figure 1. Charleston Harbor and its tributaries.**

## INTRODUCTION

In 1997 the U.S. Geological Survey (USGS) participated in evaluating the use of neural network models for simulating natural systems, and compared the approaches and accuracy of neural network models and first-principles-based finite-difference models that had recently been developed for the Cooper and Wando Rivers, South Carolina (Conrads and Smith, 1996, 1997) (Figure 1). The finite-difference models predicted the hydrodynamic, mass transport, and water-quality phenomena of a system that is particularly difficult to model because of tidal effects, variable freshwater releases from a hydroelectric plant, large amounts of poorly defined overbank storage with unmeasureable flows, and wastewater discharges from municipal and industrial facilities. To support the modeling effort, a system of gaging stations is operated by the USGS that collects, via satellite, real-time measurements of water level, dissolved-oxygen concentration (DO), water temperature, and salinity. These data were used to develop both sets of models.

The results of the comparison (Conrads and Roehl, 1999) showed that the neural network models gave more accurate predictions of the modeled variables, and that they required about 90% fewer person-hours to develop. An additional benefit is that trained neural network models can be deployed as compact programs that execute without iteration, making them suitable for integrating with real-time information and control systems. This paper describes a prototype real-time control system for matching wastewater discharges to the continuously changing assimilative capacity of the Cooper and Wando Rivers. Simulations, which demonstrate how the control system would predict assimilative capacity and modulate multiple discharge streams to avoid violating water-quality standards, and a deployment strategy for the control system are described.

## CONTROL SYSTEM APPROACH

The literature describes many uses of neural network models to monitor and control industrial processes. They are most often used as "soft sensors" to estimate quantities that cannot be measured directly, and as process models in model-based control schemes. Figure 2 shows an idealized implementation of a neural network-based process model for controlling DO in water. The input variables are of two types, state variables and manipulated variables, e.g., discharge levels. It is assumed that changes in the inputs will change the model's outputs, and that these changes are representative of the physical system's behavior. If the model predicts an undesirable outcome, e.g., DO below a standard, a set of values for the manipulated variables may exist such that the model will predict a more desirable outcome.

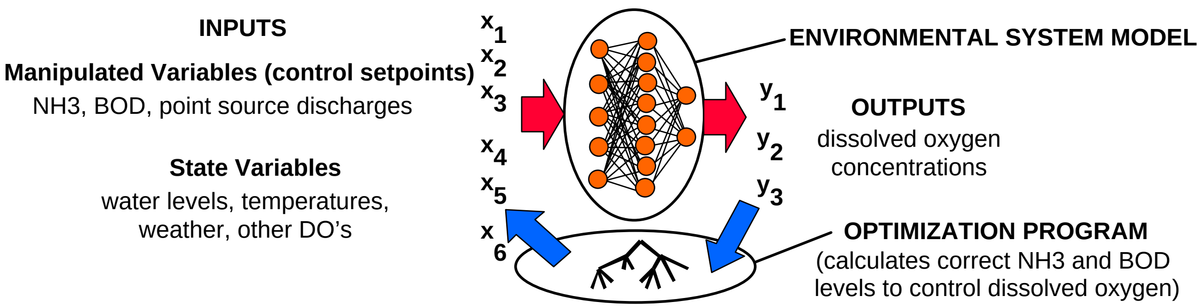


**Figure 2: Control Scheme Using a Neural Network Model with an Optimization Program**

Finding values for the manipulated variables so that an undesirable outcome can be avoided requires the use of an optimization program. As state variables change with time, the optimization program will search for manipulated variable values that allow the model to avoid an undesirable outcome. The optimization program adheres to specified "constraints" which place limits on values the manipulated variables can have. If it fails to obtain an acceptable outcome within a specified number of iterations, the program will return the values that provides the prediction that least deviates from a desirable outcome. Effectively, the optimization program "inverts" the model, so that by automatically adjusting the manipulated variables a specified outcome can be obtained.

An on-line control system would necessarily be more complicated than the scheme shown in Figure 2 because of the following constraints:

- Incoming real-time signals have to be conditioned to accommodate sensor failures. The signal from a failed sensor can be detected and reconstructed from correlated data by using specialized neural network models.
- Biochemical reaction kinetics that depend on climatic conditions require a probabilistic control strategy based on weather predictions. Neural network models that integrate multiple real-time signals to accurately predict future conditions are called "soft sensors." Multiple soft sensors would allow alternative scenarios, graded by likelihood of occurrence and degree of conservatism, to be evaluated before control actions are taken.
- A model that is integrated with an optimization program to control a process, called a "control model," must be tuned to insure that the functional relationships (gains) between the manipulated and

controlled variables match physical reality; for example, DO falls by a certain amount as discharged biochemical oxygen demand (BOD) increases. Because of their different purpose, control models are generally less accurate than soft sensors.

## CONTROL SYSTEM DESCRIPTION AND PERFORMANCE

DO is the water-quality variable of primary interest to many water-resource managers, and is affected by environmental conditions such as temperature, rainfall, river flow, and tidal action. DO is also affected by the BOD of organic material from rainfall runoff, tidal overbank storage, and wastewater discharge streams. The largest municipal and industrial wastewater dischargers lie on the west bank of the Cooper River in the vicinity of station 021720675; therefore, the controlled variable chosen for the simulation was the DO at this station.

The prototype control system consisted of two neural network models, a soft sensor to give an accurate prediction of DO, and a control model tuned to have appropriate gains between the wastewater BOD and the modeled DO. The output of the control model was adjusted (biased) by the soft sensor prior to running the optimization program at each time step. Both models were configured to predict the DO at noon one day ahead of time. An on-line system could use a series of predictions with staggered time horizons to provide trend information that could be used in concert with a margin of safety to maintain the minimum standard. The inputs to both models consisted of the seven largest BOD and $NH_3$ discharge streams and a number of gage variables. The soft sensor predictions are compared to the actual DO in Figure 3.

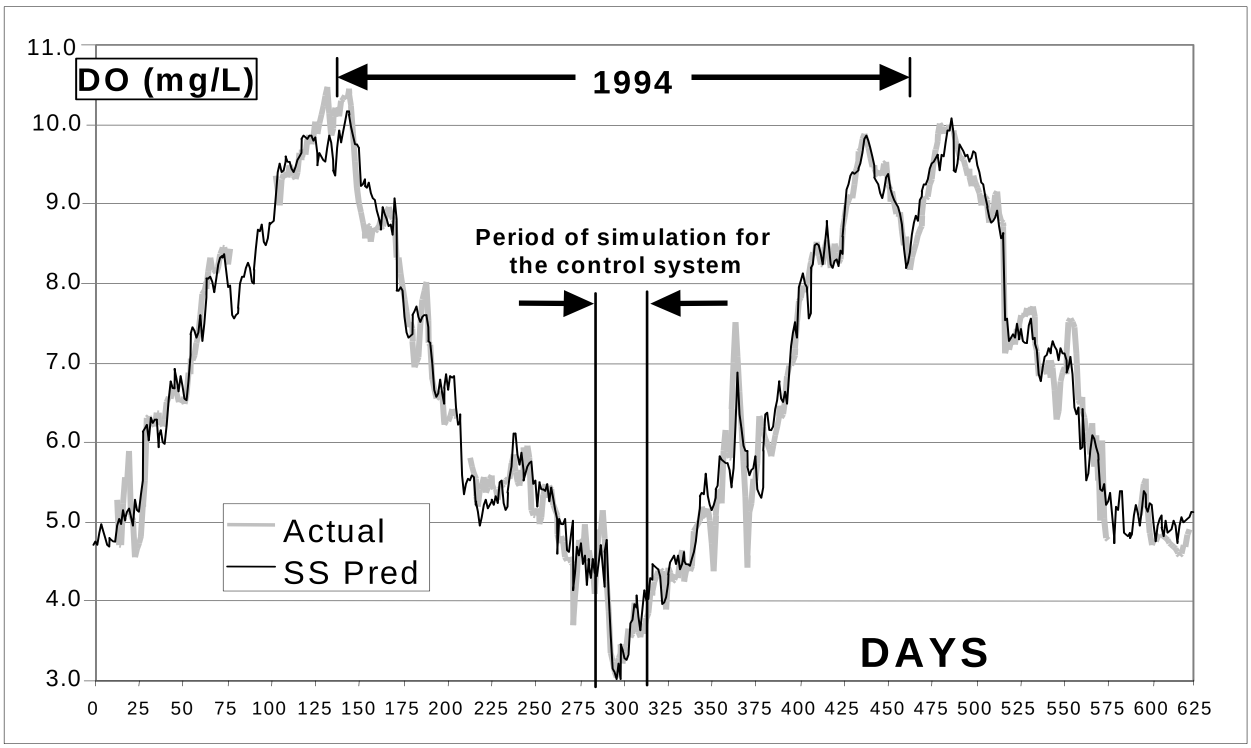


**Figure 3: Actual Data and Soft Sensor Predictions (SS Pred) of DO at Station 021720675.**

## RESULTS AND DISCUSSION

The control system simulation covered a period corresponding to the summer of 1994 when the DO fell below 5.0 mg/L. The control scheme was configured so that the historical discharges would not be modified unless the soft sensor predicted a DO below a threshold of 5.5 mg/L. In an on-line system, the constraints under which the optimization program operates would reflect the permitted wasteload allocations of the individual dischargers. The optimization constraints used for this simulation were (1) a discharge could not be set to a value less than its historical minimum, and (2) a discharge could not exceed the average of its historical maximum and its optimized value for the preceding day. The latter allowed for a gradual redistribution among dischargers of the BOD reductions.

Figure 4 shows the simulation during a 30-day period when the control scheme was engaged. Two sets of predictions, computed using the same soft sensor, but with different input discharge BODs, are shown. “SS Pred” uses the actual BODs and “SS Op. Pred” uses BODs computed by the optimization program. The control system approaches its target of 5.5 mg/L until day 290, when a severe drop in the actual DO to as low as 3.2 mg/L could not be fully corrected. However, SS Op. Pred predicts that the DO can be elevated to about 4.8 mg/L through reductions in BOD discharges. The drop in the actual DO was due to a combination of environmental conditions and discharge levels that have yet to be studied in detail.

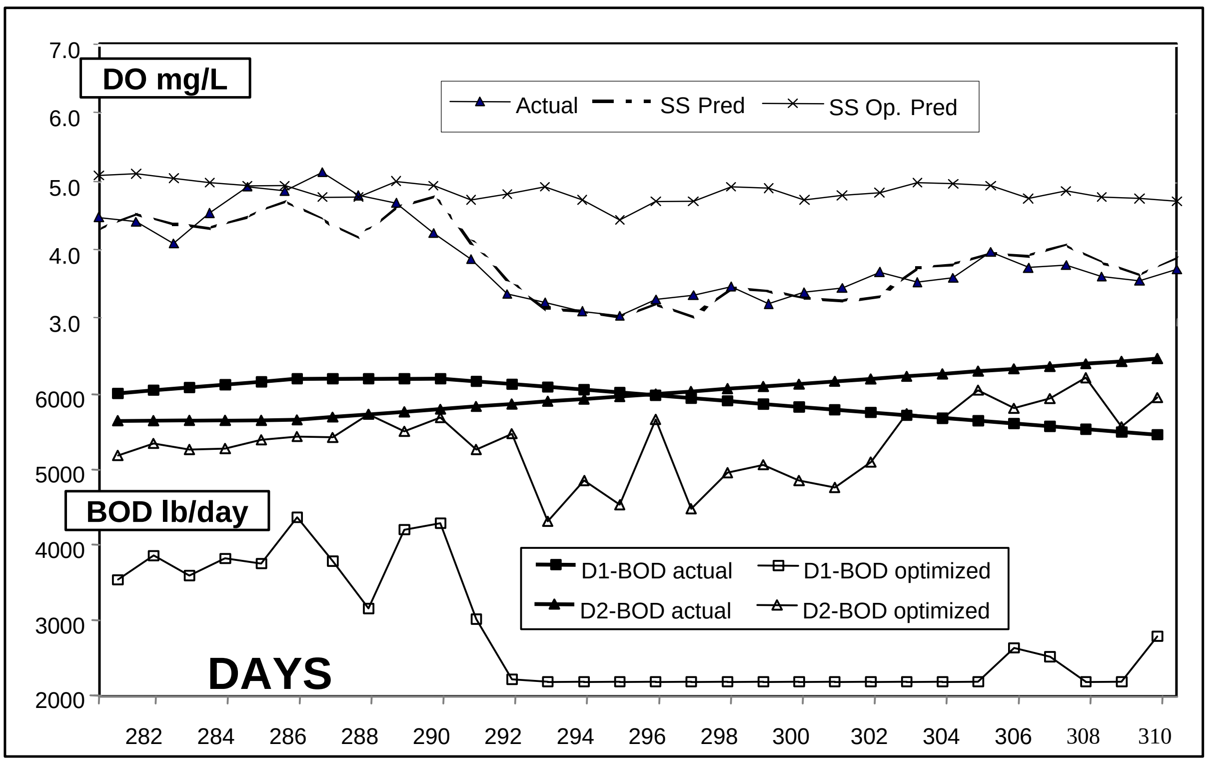


**Figure 4: Simulation Results at Station 021720675 for Days 280 to 310.**
ABOVE: Actual (historical) and Predictions of DO with Control System Engaged.
BELOW: Actual (historical) and Optimized Discharges for Dischargers D1 and D2.

Figure 4 also shows the modulated discharges for the two largest wastewater streams, D1 and D2. D1 is the most affected, being held at its historical minimum of 2,197 pounds per day from day 301 onward when the actual DO reached the lowest value in the entire time series shown in Figure 3. The optimization program obtained the balance of the needed discharge reductions from the five remaining discharge streams (not shown).

## DEPLOYMENT STRATEGY

The control scheme could be implemented in a real-time system as shown in Figure 5. The essential elements consist of the USGS gaging network, a computer system that operates the control software, and an Internet web site where real-time data, model predictions, and discharge recommendations are made accessible to stakeholders in the protection and use of the Cooper and Wando Rivers. System operation is as follows:

1. Real-time data are collected by the USGS gaging network, processed, and archived.
2. Data are sent to a computer that runs the control system, predicts water-quality trends, and recommends wastewater loadings.
3. The real-time data and control system recommendations are posted to the web site for review and use by regulators, dischargers, and other organizations.

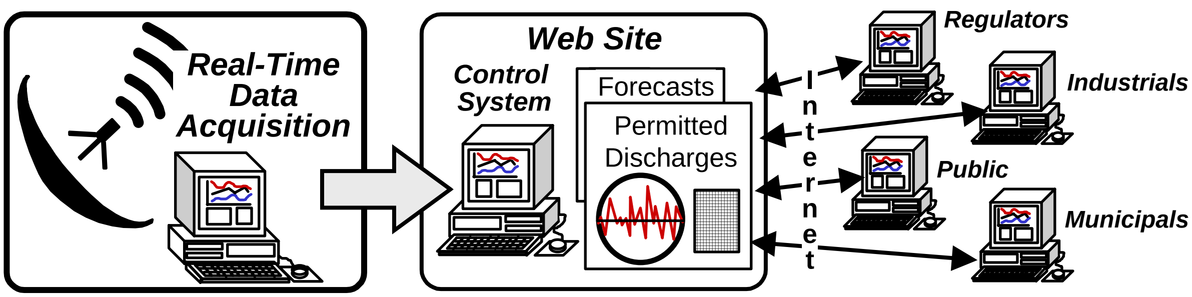


**Figure 5: Schematic of Real-Time Control Scheme.**

## CONCLUSIONS

Previous work has shown that neural network models can be very effective for modeling the complex water quality of the Cooper and Wando Rivers. The work described in this paper shows how these models can be deployed in a real-time control scheme that has the potential to match permitted wastewater discharges to the changing assimilative capacity and hydrologic conditions of the environment, thus avoiding or minimizing violations of the State water-quality standard. An additional benefit for all concerned with the protection and use of the Cooper and Wando Rivers would be derived from providing real-time open access to the data, models, and control recommendations via an online application.

## REFERENCES

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