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Detailed Reservoir Water Quality Modeling (CE-QUAL-W2), Alabama-Coosa-Tallapoosa/Apalachicola-Chattahoochee-Flint (ACT/ACF) Comprehensive Water Resource Study

by Dorothy H. Tillman, Thomas M. Cole, Barry W. Bunch

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Prepared for U.S. Army Engineer District, Mobile

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Contents

List of Tables

Preface

This report documents the modeling results for three reservoirs in the Alabama-Coosa-Tallapoosa and Apalachicola-Chattahoochee-Flint River basins. The model CE-QUAL-W2 was calibrated for Walter F. George, Weiss, and Neely Henry Reservoirs. This report was prepared in the Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, a complex of five laboratories of the Engineer Research and Development Center (ERDC). The study was sponsored by the U.S. Army Engineer District, Mobile, and was funded under the Military Interdepartmental Purchase Request No. FC-93-0071 dated 9 Aug 1993.

The Principal Investigators of this study were Mr. Thomas M. Cole, Ms. Dorothy H. Tillman, and Dr. Barry W. Bunch of the Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Effects Division, EL. This report was prepared by Ms. Tillman and Mr. Cole under the direct supervision of Dr. Mark S. Dortch, Chief, WQCMB, and under the general supervision of Mr. Richard E. Price, Chief, EPED, and Dr. John W. Keeley, Director, EL. Technical reviews by Dr. Barry W. Bunch and Ms. Lillian T. Schneider, WQCMB, are gratefully acknowledged. Mr. Fred C. Herrmann, DynTel, Vicksburg, MS, and Ms. Melissa Williams, contract student with WQCMB, are gratefully acknowledged for generation of all figures in this report.

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1 Introduction

Background

Future water uses and operations of water resources projects within the Alabama-Coosa-Tallapoosa and Apalachicola-Chattahoochee-Flint River basins (ACT/ACF) may have an impact on water quality. Changes, especially in operation procedures in the system, have caused concern for future water quality conditions affecting allowable waste loads, thus impacting future development. A systemwide water quality model (HEC-5Q) was used to address these concerns. However, this model is too limited to allow detailed examination of reservoir water quality. HEC-5Q uses a one-dimensional (1-D) longitudinal and vertical spatial discretization for the river reaches and reservoirs, respectively, which is satisfactory for temperature, but can miss important processes affecting other water quality variables, especially nutrients, algae, and dissolved oxygen (DO) in reservoirs that exhibit strong longitudinal water quality gradients.

Since three of the participating states have expressed concerns about several reservoirs within the system, it was decided to model these reservoirs using CE-QUAL-W2 for a more realistic and accurate analysis by including more spatial dimensionality. The three reservoirs specifically discussed at the Water Quality Modeling Workshop, 21-22 June 1993, in Dothan, AL, were Weiss and Neely Henry, located on the Coosa River, and Walter F. George (WFG), located on the lower Chattahoochee River.

CE-QUAL-W2 is a two-dimensional (2-D) longitudinal and vertical, laterally averaged, reservoir hydrodynamic and water quality model that has been in use for a number of years. This model will allow a more detailed look at conditions within the reservoirs of concern in this system than HEC-5Q. Results from the modeling effort on Weiss, Neely Henry, and Walter F. George, are presented in this report.

Study Objective

The objective of this study is to provide calibrated and verified 2-D water quality models for Weiss, Neely Henry, and Walter F. George, capable of predicting future water quality conditions resulting from potential changes in upstream water allocations, upstream waste loads, and/or reservoir operations.

Approach

The 2-D (laterally averaged) hydrodynamic and water quality model, CE-QUAL-W2, was applied to three reservoirs, Weiss, Neely Henry, and Walter F. George, within the ACT/ACF river basins. CE-QUAL-W2 is recognized as the state of the art for 2-D (longitudinal and vertical) water quality modeling of reservoirs. CE-QUAL-W2 contains a hydrodynamic module that predicts water surface elevations and horizontal and vertical velocities. The predicted velocities are used for transporting constituents in the water quality module. The hydrodynamics are influenced by variable water density (i.e., stratification) resulting from variations in temperature, salinity (or total dissolved solids), and suspended solids. Seventeen transported state variables are included in the water quality module.

Site Description

Two of the reservoirs, Neely Henry and Weiss, are located in Alabama on the Coosa River and are privately owned by the Alabama Power Company (APC). The third reservoir, Walter F. George, is located on the Alabama-Georgia border on the lower Chattahoochee River and is operated by the U.S. Army Engineer District, Mobile.

Neely Henry

Neely Henry, located on the Coosa River, was privately constructed by the APC. It is part of the Alabama-Coosa River Navigation project and along with five other dams provides a continuous series of pools. In ascending order the dams are Walter Bouldin (an auxiliary impoundment off Jordan reservoir), Mitchell, Lay, Logan Martin, Neely Henry, and Weiss. The series of reservoirs begins at river mile (RM) 8.9 (Walter Bouldin) and ends at RM 225.7 (Weiss). The authorized projects on the Alabama-Coosa River and its tributaries provide for development of the system, navigation, flood control, power generation, and other purposes (U.S. Army Engineer District, Mobile, 1977).

Neely Henry Dam, located approximately 25.7 km (16 miles) south of Gadsden, AL (Figure 1), on the Coosa River, was completed in 1966. The dam consists of the powerhouse and intake, a gated spillway, two concrete nonoverflow walls, and two earth dikes connecting the concrete structures with high ground on each side of the river (U.S. Army Engineer District, Mobile, 1977). The gated spillway has four tainter gates, 12 m (40 ft) wide by 8.9 m (29 ft) high, operated by individual motor hoists. The powerhouse has three generating units of 24,300-kW capacity each.

Weiss

Weiss is also located on the Coosa River and was privately constructed by the APC. It is the sixth reservoir of the Alabama-Coosa River Navigation project and is located at RM 225.7.

Weiss Dam is located approximately 114.2 km (71 miles) northeast of Birmingham, AL, near the town of Leesburg, AL (Figure 2), on the Coosa River. Construction of the dam was completed in 1961. The dam consists of a three-generator powerhouse, a gated spillway, and approximately 9 km (6 miles) of earth embankment dikes. The gated spillway has five tainter gates, 12.8 m (42 ft) wide by 11.6 m (38 ft) high, for control of flow over the crest and one trash gate at the west end. The trash gate is 4.9 m (16 ft) wide with a crest elevation of 550.0 ft.[1] The powerhouse is located about 6 km (4 miles) southwest of the gated spillway structure. The forebay for the powerhouse is connected to the spillway by a canal. This arrangement allows for an increase in generating head equal to the natural fall of 32 km (20 miles) of the river around an oxbow bend (U.S. Army Engineer District, Mobile, 1977).

Walter F. George

The third reservoir modeled during this study was Walter F. George located at RM 75.2 on the Chattahoochee River (Figure 3). Construction on this dam was completed in 1963. This reservoir is operated by the Mobile District. Some of the benefits derived from this project are hydropower, navigation, and recreation. The principle features of the dam are: (a) a 130,000-kW powerhouse (four units), with an intake section constituting a portion of the dam; (b) a concrete gravity-type ogee spillway, 211 m (692 ft) long with crest at el 163.0 ft, surmounted by 14 tainter gates, each 12.8 m (42 ft) long by 8.8 m (29 ft) high; (c) a single-lift lock, 25 m (82 ft) wide and 137 m (450 ft) long, with top of lock walls at el 197.0 ft; and (d) a grout-protected, riprapped, rolled-fill earth embankment with top at el 215.0 ft, which flanks the concrete structure and extends to high ground on each side (U.S. Army Engineer Waterways Experiment Station 1959).

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[1] All elevations (el) are given in feet referred to the National Geodetic Vertical Datum (NGVD). To convert elevations to meters, multiply by 0.3048.

2 Model Description

CE-QUAL-W2 is a two-dimensional model that predicts vertical and longitudinal variations in hydrodynamics, temperature, and constituents in a water body through time (Cole and Buchak 1995). The model is based upon the Generalized Longitudinal-Vertical Hydrodynamics and Transport (GLVHT) model of rivers, reservoirs, and estuaries (Buchak and Edinger 1984). Earlier versions were known as the Laterally Averaged Reservoir Model (LARM) (Buchak and Edinger 1982). Development of the GLVHT model has continued since 1975 by the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, and J. E. Edinger and Associates, Wayne, PA. The GLVHT has been previously used to simulate temperature distributions and circulation patterns in water bodies and has been applied to a variety of systems (Buchak and Edinger 1984). The main modification to the GLVHT model resulting in CE-QUAL-W2 was the inclusion of the algorithms to simulate water quality constituents.

CE-QUAL-W2 is based upon a finite difference solution of the laterally averaged equations of fluid motion including: (a) the free water surface, (b) hydrostatic pressure, (c) horizontal momentum, (d) continuity, (e) constituent transport, and (f) an equation of state relating density and constituents including temperature and solids concentrations (dissolved and suspended). By solving for the water surface elevation implicitly, the model removes the restrictive Courant surface gravity wave criterion, allowing simulation of reasonable time frames for field applications, such as entire stratification cycles. An explicit scheme is then used to transport heat and chemical/biological constituents. The model has the capability of including head or flow boundary conditions, branches, multiple withdrawals, and other features that allow its application to a variety of situations.

CE-QUAL-W2 has the following basic features:

a. Two-dimensional (laterally averaged) simulations of temperatures, constituents, and flow fields.

b. Hydrodynamic computations influenced by variable water density caused by temperature and dissolved and suspended solids.

c. Simulation of the interactions of numerous biological/chemical factors influencing water quality.

d. Allowance for multiple inflow loadings and withdrawals from tributaries, point and nonpoint sources, precipitation, branch inflows, and outflows from a dam.

e. Allowance for multiple branches.

f. Allowance for ice cover computations.

g. Allowance for variable time steps.

h. Allowance for flow or head boundary conditions, making it applicable for reservoir or estuarine modeling.

i. Simulation of circulation patterns.

j. Restart capability.

k. Inclusion of evaporation in water balance.

l. Heat transfer computations.

m. Variety of output options.

n. Selective withdrawal capabilities.

CE-QUAL-W2 conceptualizes the reservoir as a grid consisting of a series of vertical columns (segments) and horizontal rows (layers), with the number of cells equal to the number of segments times the number of rows. The basic parameters used to define the grid are the longitudinal spacing Δx, in meters, and the vertical spacing h, in meters. The vertical spacing and the longitudinal spacing may vary spatially. Each cell also has an associated width that represents an average value.

CE-QUAL-W2 currently simulates 20 water quality constituents in addition to temperature and circulation patterns. Many of the constituents are simulated simply to include their effects upon other constituents of interest. The constituents are separated into four levels of complexity, listed in Table 1, permitting flexibility in model application. The first level includes materials that are conservative or noninteractive, or do not affect other materials in the first level. The second level allows the user to simulate the interactive dynamics of oxygen-phytoplankton-nutrients. The third level allows simulation of pH and carbonate species, and the fourth level allows simulation of total iron, which is important during anoxic conditions. The model calculates in-pool water volumes, surface elevations, densities, vertical and longitudinal velocities, temperatures, and constituent concentrations as well as downstream release concentrations.

Table 1
Water Quality Constituent Levels

Level 1	Level 2
Conservative tracer	Labile dissolved organic matter
Inorganic suspended solids	Refractory dissolved organic matter
Coliform bacteria	Phytoplankton
Total dissolved solids or salinity	Detritus
	Phosphate-phosphorus
	Ammonia-nitrogen
	Nitrate-nitrogen
	Dissolved oxygen
	Organic sediments
Level 3	**Level 4**
Dissolved inorganic carbon	Total iron
Alkalinity	
pH	
Carbon dioxide	
Bicarbonates	
Carbonates	

3 Input Data

CE-QUAL-W2 requires reservoir geometry (bathymetry), initial conditions, reservoir operations, outlet descriptive data (e.g., port elevation, width, etc.), and time sequences of inflow rates and water quality, meteorological data, and water surface elevations. Calibration/verification is highly dependent on the availability of observed in-pool water quality constituent concentrations at several locations within the reservoir. Observed release water quality data are also needed to evaluate predicted release conditions. Various parameters (e.g., rate coefficients) are also required input. Of the water quality constituents listed in Table 1, the following constituents were of interest in this study:

a. Dissolved oxygen (DO).

b. Phytoplankton (algae).

c. Phosphorus (ortho-P or PO_4).

d. Ammonium-nitrogen (NH_3).

e. Nitrate-nitrite nitrogen (NO_2NO_3).

f. Total organic carbon (TOC).

At the beginning of the study, a data inventory was conducted on Walter F. George, Neely Henry, and Weiss.[1] From these data, calibration years were chosen for each reservoir. Table 2 lists for each reservoir the in-pool lake stations, collection date, location, and observed water quality constituents used for comparisons to computed data. Because these data were lacking in vertical profiles for algal/nutrient constituents of interest, it was recommended to the

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[1] The observed data were obtained from Dr. Bob Kennedy of the Environmental Laboratory, Ecosystem Processes and Effects Branch, USAE Waterways Experiment Station (CEWES-ES-Q). Of the observed data available, data collected by Dr. David Bayne of the University of Auburn as part of the U.S. Environmental Protection Agency's Clean Lakes Study were the most suitable for study needs.

Table 2
Observed Water Quality Data Collected at WFG, N Henry, and Weiss

Reservoir	Station #	River Mile	Dates Collected	Temp	DO	PO_4	NH_3	NO_2NO_3	TOC	Chlorophyll a
WFG	8	120.3	5/26/92	X	X	X	X	X	X	X
			6/16/92	X	X	X	X	X	X	X
			7/14/92	X	X	X	X	X	X	X
			8/4/92	X	X	X	X	X	X	X
			9/3/92	X	X	X	X	X	X	X
WFG	6	112.7	5/26/92	X	X	X	X	X	X	X
			6/16/92	X	X	X	X	X	X	X
			7/14/92	X	X	X	X	X	X	X
			8/4/92	X	X	X	X	X	X	X
			9/3/92	X	X	X	X	X	X	X
WFG	5	101.7	5/26/92	X	X	X	X	X	X	X
			6/16/92	X	X	X	X	X	X	X
			7/14/92	X	X	X	X	X	X	X
			8/4/92	X	X	X	X	X	X	X
			9/3/92	X	X	X	X	X	X	X
WFG	4	94.9	5/26/92	X	X	X	X	X	X	X
			6/16/92	X	X	X	X	X	X	X
			7/14/92	X	X	X	X	X	X	X
			8/4/92	X	X	X	X	X	X	X
			9/3/92	X	X	X	X	X	X	X
WFG	2	82.3	5/26/92	X	X	X	X	X	X	X
			6/16/92	X	X	X	X	X	X	X
			7/14/92	X	X	X	X	X	X	X
			8/4/92	X	X	X	X	X	X	X
			9/3/92	X	X	X	X	X	X	X
WFG	1	75.4	5/26/92	X	X	X	X	X	X	X
			6/16/92	X	X	X	X	X	X	X
			7/14/92	X	X	X	X	X	X	X
			8/4/92	X	X	X	X	X	X	X
			9/3/92	X	X	X	X	X	X	X
WEISS	12	564.6	1/9/91	X		X		X	X	
			3/12/91	X		X		X	X	
			4/17/91	X		X		X	X	
			5/16/91	X		X		X	X	
			6/11/91	X		X	X	X	X	

(Sheet 1 of 7)

Table 2 (Continued)

Reservoir	Station #	River Mile	Dates Collected	Temp	DO	PO_4	NH_3	NO_2NO_3	TOC	Chlorophyll a
WEISS	12	564.6	7/9/91	X		X	X	X	X	
			8/6/91	X		X	X	X	X	
			9/10/91	X		X	X	X	X	
WEISS	11	562.8	1/9/91	X		X		X	X	
			3/12/91	X		X		X	X	
			4/17/91	X		X		X	X	
			5/16/91	X		X		X	X	
			6/11/91	X		X	X	X	X	
			7/9/91	X		X	X	X	X	
			8/6/91	X		X	X	X	X	
			9/10/91	X		X	X	X	X	
WEISS	3	547.8	1/9/91	X		X		X	X	
			3/12/91	X		X		X	X	
			4/17/91	X		X		X	X	
			5/16/91	X		X		X	X	
			6/11/91	X		X	X	X	X	
			7/9/91	X		X	X	X	X	
			8/6/91	X		X	X	X	X	
			9/10/91	X		X	X	X	X	
WEISS	2	542.8	1/9/91	X		X		X	X	
			3/12/91	X		X		X	X	
			4/17/91	X		X		X	X	
			5/16/91	X		X		X	X	
			6/11/91	X		X	X	X	X	
			7/9/91	X		X	X	X	X	
			8/6/91	X		X	X	X	X	
			9/10/91	X		X	X	X	X	
WEISS	1	539.3	1/9/91	X		X		X	X	
			3/12/91	X		X		X	X	
			4/17/91	X		X		X	X	
			5/16/91	X		X		X	X	
			6/11/91	X		X	X	X	X	
			7/9/91	X		X	X	X	X	
			8/6/91	X		X	X	X	X	
			9/10/91	X		X	X	X	X	
NEELY	10	514.8	4/20/93	X	X	X	X	X	X	

(Sheet 2 of 7)

Table 2 (Continued)

Reservoir	Station #	River Mile	Dates Collected	Temp	DO	PO_4	NH_3	NO_2NO_3	TOC	Chlorophyll a
			5/18/93	X	X	X	X	X	X	
NEELY	10	514.8	6/15/93	X	X	X	X	X	X	
			7/20/93	X	X	X	X	X	X	
			8/20/93	X	X	X	X	X	X	
NEELY	8	508.8	4/20/93	X	X	X	X	X	X	
			5/18/93	X	X	X	X	X	X	
			6/15/93	X	X	X	X	X	X	
			7/20/93	X	X	X	X	X	X	
			8/20/93	X	X	X	X	X	X	
NEELY	6	504.8	4/20/93	X	X	X	X	X	X	
			5/18/93	X	X	X	X	X	X	
			6/15/93	X	X	X	X	X	X	
			7/20/93	X	X	X	X	X	X	
			8/20/93	X	X	X	X	X	X	
NEELY	4	500.3	4/20/93	X	X	X	X	X	X	
			5/18/93	X	X	X	X	X	X	
			6/15/93	X	X	X	X	X	X	
			7/20/93	X	X	X	X	X	X	
			8/20/93	X	X	X	X	X	X	
NEELY	2	491.8	4/20/93	X	X	X	X	X	X	
			5/18/93	X	X	X	X	X	X	
			6/15/93	X	X	X	X	X	X	
			7/20/93	X	X	X	X	X	X	
			8/20/93	X	X	X	X	X	X	
NEELY	1	486.8	4/20/93	X	X	X	X	X	X	
			5/18/93	X	X	X	X	X	X	
			6/15/93	X	X	X	X	X	X	
			7/20/93	X	X	X	X	X	X	
			8/20/93	X	X	X	X	X	X	
WFG	8	120.3	7/27/94	X	X					
			7/28/94	X	X	X	X	X	X	X
			8/24/94	X	X					
			8/25/94	X	X	X	X	X	X	X
			9/14/94	X	X					
			9/15/94	X	X	X	X	X	X	X
			10/19/94	X	X					

(Sheet 3 of 7)

Table 2 (Continued)

Reservoir	Station #	River Mile	Dates Collected	Temp	DO	PO_4	NH_3	NO_3NO_2	TOC	Chlorophyll a
			10/20/94	X	X	X	X	X	X	X
WFG	6	112.7	7/27/94	X	X					
WFG	6	112.7	7/28/94	X	X	X	X	X	X	X
			8/24/94	X	X					
			8/25/94	X	X	X	X	X	X	X
			9/14/94	X	X					
			9/15/94	X	X	X	X	X	X	X
			10/19/94	X	X					
			10/20/94	X	X	X	X	X	X	X
WFG	5	101.7	7/27/94	X	X					
			7/28/94	X	X	X	X	X	X	X
			8/24/94	X	X					
			8/25/94	X	X	X	X	X	X	X
			9/14/94	X	X					
			9/15/94	X	X	X	X	X	X	X
			10/19/94	X	X					
			10/20/94	X	X	X	X	X	X	X
WFG	4	94.9	7/27/94	X	X					
			7/28/94	X	X	X	X	X	X	X
			8/24/94	X	X					
			8/25/94	X	X	X	X	X	X	X
			9/14/94	X	X					
			9/15/94	X	X	X	X	X	X	X
			10/19/94	X	X					
			10/20/94		X	X	X	X	X	X
WFG	3	82.3	7/27/94	X	X					
			7/28/94	X	X	X	X	X	X	X
			8/24/94	X	X					
			8/25/94	X	X	X	X	X	X	X
			9/14/94	X	X					
			9/15/94	X	X	X	X	X		
			10/19/94	X	X					
			10/20/94			X	X	X	X	X
WFG	1	75.4	7/27/94	X	X					
			7/28/94	X	X	X	X	X	X	X
			8/24/94	X	X					

(Sheet 4 of 7)

Table 2 (Continued)

Reservoir	Station #	River Mile	Dates Collected	Temp	DO	PO$_4$	NH$_3$	NO$_2$NO$_3$	TOC	Chlorophyll a
			8/25/94	X	X	X	X	X	X	X
			9/14/94	X	X					
			9/15/94	X	X	X	X	X	X	X
WFG	1	75.4	10/19/94	X	X					
			10/20/94	X	X	X	X	X	X	X
WEISS	6	564.6	6/2/94	X	X	X	X	X	X	X
			7/13/94	X	X					
			7/14/94	X	X	X	X	X	X	X
			8/10/94	X	X					
			8/11/94	X	X	X	X	X	X	X
			10/5/94	X	X					
			10/6/94	X	X	X			X	X
WEISS	5	562.8	6/1/94	X	X					
			6/2/94	X	X	X	X	X	X	X
			7/13/94	X	X					
			7/14/94	X	X	X	X	X	X	X
			8/10/94	X	X					
			8/11/94	X	X	X	X	X	X	X
			10/5/94	X	X					
			10/6/94	X	X	X			X	X
WEISS	3	547.8	6/1/94	X	X					
			6/2/94	X	X	X	X	X	X	X
			7/13/94	X	X					
			7/14/94	X	X	X	X	X	X	X
			8/10/94	X	X					
			8/11/94	X	X	X	X	X	X	X
			10/5/94	X	X					
			10/6/94	X	X	X			X	X
WEISS	2	542.8	6/1/94	X	X					
			6/2/94	X	X	X	X	X	X	X
			7/13/94	X	X					
			7/14/94	X	X	X	X	X	X	X
			8/10/94	X	X					
			8/11/94	X	X	X	X	X	X	X
			10/5/94	X	X					
			10/6/94	X	X	X			X	X

(Sheet 5 of 7)

Table 2 (Continued)

Reservoir	Station	River Mile	Dates Collected	Temp	DO	PO_4	NH_3	NO_3NO	TOC	Chlorophyll a
WEISS	1	539.3	6/1/94	X	X					
			6/2/94	X	X	X	X	X	X	X
			7/13/94	X	X					
			7/14/94	X	X	X	X	X	X	X
WEISS	1	539.3	8/10/94	X	X					
			8/11/94	X	X	X	X	X	X	X
			10/5/94	X	X					
			10/6/94	X	X	X			X	X
NEELY	10	514.8	6/22/94	X	X					
			6/23/94	X	X	X	X	X	X	X
			8/16/94	X	X	X	X	X	X	X
			9/20/94	X	X	X	X	X	X	X
			10/25/94	X	X	X	X	X	X	X
NEELY	8	508.8	6/22/94	X	X					
			6/23/94	X	X	X	X	X	X	X
			8/16/94	X	X	X	X	X	X	X
			8/17/94	X	X					
			9/20/94	X	X	X	X	X	X	X
			9/21/94	X	X					
			10/25/94	X	X	X	X	X	X	X
			10/26/94	X	X					
NEELY	6	504.8	6/22/94	X	X					
			6/23/94	X	X	X	X	X	X	X
			8/16/94	X	X	X	X	X	X	X
			8/17/94	X	X					
			9/20/94	X	X	X	X	X	X	X
			9/21/94	X	X					
			10/25/94	X	X	X	X	X	X	X
			10/26/94	X	X					
NEELY	4	500.3	6/22/94	X	X					
			6/23/94	X	X	X	X	X	X	X
			8/16/94	X	X	X	X	X	X	X
			8/17/94	X	X					
			9/20/94	X	X	X	X	X	X	X
			9/21/94	X	X					
			10/25/94	X	X	X	X	X	X	X

(Sheet 6 of 7)

Table 2 (Concluded)

Reservoir	Station #	River Mile	Dates Collected	Temp	DO	PO4	NH3	NO2N-	TOC	Chlorophyll a
			10/26/94	X	X					
NEELY	2	491.8	6/22/94	X	X					
			6/23/94	X	X	X	X	X	X	X
			8/16/94	X	X	X	X	X	X	X
			9/20/94	X	X	X	X	X	X	X
NEELY	2	491.8	10/25/94	X	X	X	X	X	X	X
NEELY	1	486.8	6/22/94	X	X					
			6/23/94	X	X	X	X	X	X	X
			8/16/94	X	X	X	X	X	X	X
			9/20/94	X	X	X	X	X	X	X
			10/25/94	X	X	X	X	X	X	X

(Sheet 7 of 7)

tri-state study partners in January 1994 that collecting additional data would provide more confidence in model predictions for management scenarios. Not having algal/nutrient profiles made it difficult to determine if the model was accurately representing vertical algal/nutrient dynamics.

The study partners agreed to collect data beginning in the summer of 1994 at all reservoirs. Personnel from the Alabama Department of Environmental Management (ADEM) and U.S. Environmental Protection Agency (EPA) conducted the field studies. With agreement to collect more data, it was decided to use these data for model refinement or verification as will be later discussed. The following seventeen water quality constituents were collected for in-pool main stem and tributary stations:

Constituent	Constituent
Water temperature	Total phosphorus
Specific conductance	TOC
DO	Total inorganic carbon
pH	Dissolved organic carbon
NH_3	Alkalinity
NO_2NO_3	Chlorophyll
Total Kjeldahl nitrogen	Total suspended solids
Total organic nitrogen	Total dissolved solids
Ortho-P	

Pertinent information for in-pool lake stations for each reservoir (i.e., date, location, station number, time of collection, etc.) are also listed in Table 2 for this year. Of the 17 constituents, all but chlorophyll were collected as profile samples having data measured at three depths within the profile. As during the Clean Lakes Study, chlorophyll was collected as photic zone averages.

During the 1994 sampling, some of the stations were numbered differently from those of the previous years (Table 2) at Walter F. George and Weiss (e.g., at Weiss stations 11 and 12 in 1991 became stations 5 and 6, respectively, in 1994). In addition, data were not always measured at the same location as before, but in the general area.

Bathymetry

CE-QUAL-W2 requires that the reservoir be discretized into longitudinal segments and vertical layers that may vary in length and height. An average width must then be defined for each active cell where an active cell is defined as potentially containing water. Additionally, every branch has inactive cells at the upstream and downstream segments and top layer. Inactive cells are also located below the bottom active cell in each segment.

Segment layer heights for all three reservoirs were constant while segment lengths varied. Once the segment lengths and layer heights were finalized for each reservoir, average widths were determined for each cell. Average widths for Walter F. George were determined from sediment range survey data taken in 1988 and provided by the Mobile District. Average widths for Neely Henry were determined from cross-section data taken by the Mobile District during the Coosa Navigation Study and were provided by the APC. Average widths at Weiss were determined from preproject cross-section data measured in 1954 and provided by the APC. These data had to be supplemented with additional cross-section data estimated from quad maps obtained from the U.S. Geological Survey so that the whole reservoir could be represented. A computer program was written to average widths for each cell using linear interpolation.

Walter F. George

Walter F. George had the simplest grid of the three reservoirs. It consisted of a single branch having 37 segments longitudinally and 16 layers vertically each layer 2 m thick. Figure 4 shows the configuration of the grid. The computed volume-elevation curve and Mobile District data are compared in Figure 5.

Neely Henry

The grid for Neely Henry consisted of four branches having a total number of 52 segments and a maximum of 16 vertical layers each 1 m thick. Branch 1 was the main stem portion of Neely Henry and had 36 segments; branch 2, representing Big Wills Creek, had six longitudinal segments; and branches 3 and 4, representing Big Canoe Creek and Shoal Creek, respectively, had five longitudinal segments each. Branches 2-4 were included in the grid mainly to account for volume attributed by these areas. No flows were assigned to these branches, except for branch 2, which had gauged flows available. Flows for these branches were accounted for in the calculated inflows obtained from APC. Figure 6 illustrates this grid showing layer numbers in each segment and double lines indicating where branches begin and end. The volume-elevation curve and the APC data are compared in Figure 7.

Weiss

The Weiss grid was the most complex, having seven branches in all with a total of 83 segments and a maximum of 13 vertical layers, 2 m thick. The breakdown of segments into branches was as follows: the main branch, representing the main stem reach, had 40 longitudinal segments; branch 2, representing the section of the Coosa River near Howells Crossroad, had 5 longitudinal segments; branch 3, representing Spring Creek, had 8 longitudinal segments; branch 4, representing Cowans Creek, had 7 longitudinal segments; branch 5, representing Spring Creek, had 10 longitudinal segments; branch 6, representing Chattooga River, had 8 longitudinal segments; and branch 7, representing a section of the Little River close to Round Mountain, had 5 longitudinal segments. Similar to Neely Henry, Branches 2-7 were included in the grid mainly to account for volume attributed by these areas. No flows were assigned to these branches, except for branch 7, which had gauged flows available. Again, flows for these branches were accounted for in the calculated inflows obtained from APC. Figure 8 shows the grid layout with the double lines again indicating where branches begin and end. The number of layers in each segment is also shown. The volume-elevation curve and the APC data are compared in Figure 9.

In-pool Data

As discussed at the beginning of this Chapter, the model was calibrated for each reservoir using observed in-pool profile data[1] and verified using data collected in 1994 by ADEM and EPA. Observed data were collected on a monthly basis for all reservoirs during the EPA's Clean Lakes Study and more often during the 1994 collection (see dates in Table 2). Observed profile data at each reservoir were available only for

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[1] Collected by Dr. David Bayne of the University of Auburn, Auburn, AL.

temperature and DO for the calibration year, but available for all water quality constituents except algae in 1994. Observed data used during calibration for nutrients, algae (collected only at George), and total organic carbon at each reservoir were collected as photic zone averages (Table 2). During the 1994 data collection, only algae was collected as photic zone averages. The photic zone depth was four times Secchi depth.[1]

Reservoir Operations Data

The Mobile District provided hourly release flows, water surface elevations, reservoir elevation-area-capacity table, and calculated inflow data for Walter F. George for years modeled. Likewise, APC provided similar project operation data (i.e., hourly release flows, water surface elevations, etc.) for Neely Henry and Weiss for years modeled.

Constituent Boundary/Initial Data

Inflow temperature

There were minimal values of inflow temperature data for the main branches of all the reservoirs, branch 2 of Neely Henry, and branch 7 of Weiss; thus, to supplement these data, temperature values were estimated using a program called the Response Temperature Calculator (RTC) developed by J. E. Edinger Associates, Inc. (1984). The RTC uses meteorological data and depth of the stream to calculate water temperatures based on equilibrium temperatures (Cole and Buchak 1995).

Inflow water quality

Water quality inflow concentrations for other constituents of the main branch for all of the reservoirs were set to observed concentrations at the most upstream station of each reservoir. These stations were station 10 for Walter F. George, station 10 for Neely Henry, and station 7 for Weiss. Station 10 at Walter F. George and station 7 at Weiss were upstream of the grid boundary. Because of this, adjustments were made to the inflow concentrations based on how well predictions compared with observed data at the most upstream station in each reservoir grid. Inflow water quality concentrations for branch 2 on Neely Henry and branch 7 on Weiss were set to observed values measured at station 14 (on Big Wills Creek) and station 11 (on Little River), respectively.

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[1] Dr. David Bayne, Personal Communication.

Although Labile dissolved organic matter (LDOM), Refractory dissolved organic matter (RDOM), and detritus were not monitored as such, their inflow boundary concentrations were estimated from TOC. The portioning of the TOC into LDOM, RDOM, and detritus was a trial and error procedure. Sensitivity analyses were run for different proportioning percentages to get the best predictions for TOC. The majority of the TOC was assumed to be refractory. To alleviate the uncertainty of these assumptions, data would have to be collected for the different forms. The equations used in estimating these constituents from TOC were:

$$LDOM = [(TOC - algae)] * 0.75) * 0.30 \tag{1}$$

$$RDOM = [((TOC - algae)] * 0.75) * 0.70 \tag{2}$$

$$Detritus = (TOC - algae) * 0.25 \tag{3}$$

Inflow algal concentrations were estimated from chlorophyll data. CE-QUAL-W2 requires algal concentrations in units of grams of organic matter per cubic meters (gm OM/m^3). Measured chlorophyll concentrations were in units of milligrams of chlorophyll per cubic meter (mg chl-a/m^3) and were converted to gm OM/m^3 using the conversion factor 65 as recommended by the QUAL2E and CE-QUAL-W2 user manuals (Brown and Barnwell 1987 and Cole and Buchak 1995, respectively). The conversion equation is written as:

$$\frac{mg\ chl\text{-}a}{m^3} * \frac{gm}{10^3 mg} * 65\frac{gm\ OM}{gm\ chl\text{-}a} * \frac{10^3\ l}{m^3} = \frac{0.065\ gm\ OM}{m^3}$$

It was assumed that the chlorophyll measurements were corrected for pheophytin according to procedures in American Public Health Association (1985).

For the 1994 verification runs, a number of major point sources and withdrawals on Weiss and Neely Henry were included as tributaries (CE-QUAL-W2 models point sources as tributaries) or withdrawals:[1]

a. Alabama Power Company - Gadsden Stream Plant

b. Gulf States Steel (effluent only)

c. Tyson Poultry

d. Gadsden East Publicly Owned Treatment Works (POTW)

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[1] Mr. Bill Lott of ADEM provided the data that were used as boundary conditions for these point sources and withdrawals.

e. Gadsden West POTW

f. Attalla POTW

g. Rainbow City POTW

h. Southside POTW

Initial conditions

There are several options in setting initial conditions in CE-QUAL-W2:

Option 1:
a. Use the same concentration for temperature and constituents throughout the reservoir.

Option 2:
b. Use vertical varying profile of temperature at the dam to initialize all segments in the grid.

Option 3:
c. Use vertical profiles of temperature and constituents varying longitudinally for each segment in the grid.

The simulation start date for all calibration years 1991, 1992, and 1993 was January 1; however if observed data were not available on or close to the start date, initial conditions were estimated from an average of historical in-pool data. Since simulations were started in January, option 1 was chosen to initialize each reservoir (isothermal conditions). During these calibration years, initial in-pool conditions at all reservoirs for temperature and all other water quality constituents were set to values occurring on the first observed date that data were collected (Table 2).

For the 1994 verification year, simulation start date and initial conditions at each reservoir were set to the first date that observed data were collected (Table 2). For all reservoirs, initial conditions for algae, LDOM, RDOM, and detritus were set using option 1. Initial conditions for ammonia (NH_3) at all reservoirs were set using option 2 because ammonia concentrations changed vertically but less longitudinally. At Neely Henry initial conditions for phosphorus and nitrate-nitrite were also set using option 2 for the same reason. Phosphorus and nitrate-nitrite at Walter F. George and Weiss were set using option 3 because of changes in concentrations vertically as well as longitudinally. For all reservoirs, temperature and DO initial conditions were set using option 3 for these same reasons.

Meteorological Data

Meteorological data for all modeled years were obtained from the U.S. Air Force Environmental Technical Applications Center in Asheville, NC, for Rome, GA, Birmingham, AL, and Columbus, GA, first-order meteorological stations. Data requested were air temperature, dew-point temperature, wind speed and wind direction, cloud cover, and barometric pressure.

4 Calibration/Verification

The concept of calibration/verification of a model has changed in recent years. Previously, calibration was performed first for a chosen year with coefficients being adjusted to give best results. Then, verification was simply applying the model to another year using the same coefficients as determined during calibration but changing boundary conditions and seeing how well the model performed. Now, the calibration/verification process is performed simultaneously, resulting in the same coefficients for all years simulated that give the best results statistically. During this study, calibration had to be conducted first since data used for verification were not collected until summer 1994. Consequently, the calibration/verification process was not conducted simultaneously until late in the study when all data were available. Since calibration was conducted first, the original calibration rate coefficients were refined once verification simulations could be made. The resulting rate coefficients (to be discussed later) produced the best results for both years.

Ideally, it would have been preferable to calibrate all reservoirs for the same year. However, from the data inventory, the calibration year for each reservoir was chosen based on data availability as follows: (a) Walter F. George, 1992; (b) Neely Henry, 1993; and (c) Weiss, 1991. These years were chosen because they were the years with the most observed data necessary for calibration.

Each reservoir was verified using the 1994 data. Because substantially more data were collected in 1994, there is greater confidence in the 1994 predictions. For this reason, model coefficients established for the 1994 simulations supersede any values set during the initial calibrations, and the 1994 models are used to conduct all scenario testing.

Graphical comparisons of computed versus observed data were made to evaluate model performance for calibration and verification. Results for profiles at each reservoir are presented for each observed day beginning with the most downstream station (closest to the dam) and ending with the most upstream station (closest to the inflow boundary). For comparisons of profile data, computed profile data could be compared directly to observed data. In addition, a root mean square error (RMS) was calculated also to evaluate model performance and is indicated on each graph. The RMS was calculated as:

$$RMS = \sqrt{\frac{\sum (Predicted - Observed)^2}{number\ of\ observations}} \qquad (5)$$

The RMS is a measure of variability between predicted and observed concentrations (e.g., an RMS of 0.50 means predicted data are within ± 0.50 of the observed value 67 percent of the time).

Also indicated on each plot is the mean error (ME) and absolute mean error (AME). ME is calculated as the arithematic average using the equation:

$$ME = \frac{\sum (Predicted - Observed)}{number\ of\ observations} \qquad (6)$$

The sign of the ME (±) indicates whether the predicted results average higher or lower than the observed. The AME represents the absolute average error as compared with observed data and is calculated as:

$$AME = \frac{\sum \mid Predicted - Observed \mid}{number\ of\ observations} \qquad (7)$$

The AME gives an indication of how close on either side of the observed values the predicted values are. For example, an AME of 0.5 means that the computed values are, on the average, within ± 0.5 of the observed value. For temperature, this value would approach the accuracy of many temperature probes.

For photic zone averages, comparisons of computed to observed data could not be directly made. Averages over computed layers representing the photic zone depth were calculated before comparisons were made. It was impossible to get an exact photic zone depth average because of the way CE-QUAL-W2 discretizes the reservoir and computes predictions over length, height, and width of a layer. For example, at Walter F. George if the photic zone depth was 2.75 m at station 8, the computed average for a constituent was calculated for the top two layers since layer thickness was set to 2 m. This introduced some errors in the comparisons.

In each graph presenting comparisons of observed and computed photic averages of constituents, the most upstream station is plotted closest to the origin of the graph and ending with the most downstream station. For Walter F. George, station 8 was the most upstream station and is plotted closest to the origin of the graph with the rest of the stations plotted in decreasing numerical order to station 1. For Neely Henry, station 10 was the most upstream station and is plotted closest to the origin of the graph with the rest of the stations plotted in decreasing numerical order to station 1. For Weiss, station 12 was the most upstream station and is plotted closest to the origin of the graph with the rest of the stations plotted in decreasing numerical order to station 1.

Computed and observed photic zone averages were also compared by calculating an RMS using Equation 5. The RMS was calculated for each date of observed data and included all station results longitudinally through the reservoir for a particular date. Table 3 lists the RMS calculated for each constituent and all dates per reservoir.

Even though algae concentrations were collected as photic zone averages in 1994, computed profile results were graphically compared with the photic zone averages. The statistics (e.g., RMS) indicated on the algal plots were ignored since there was only one observed value per plot with which to perform the statistical calculations, which require more than one point.

To distinguish between observed and computed data in profile plots, the dashed line represents computed values, and × represents observed values. In plots presenting observed and computed photic zone averaged data, the × represents observed data, and the solid circle represents computed data.

For each reservoir, coefficient rate settings applied to the entire reservoir except for sediment oxygen demand rates (SOD), which varied longitudinally per segment. The SOD rates were adjusted per segment or by increasing or decreasing all rates universally with the fraction of SOD (FSOD) parameter. For example, SOD rates for segments 20 through 30 could be doubled by changing 0.5 to 1.0 but to double all segment rates, FSOD was increased from 1.0 to 2.0.

Table 4 shows final values of all coefficients that affect temperature. Temperature predictions were most sensitive to changes in the wind sheltering coefficient. Tables 5 and 6 show final values of all coefficients adjusted during water quality calibration of all reservoirs. DO predictions were affected by changes in SOD rates, algae growth and respiration rate, and release of phosphorus and ammonia from the sediments. Phosphorus predictions were affected by changes in the release of phosphorus from the sediments, algal growth, respiration, and mortality rates, and organic matter decay. Ammonia predictions were most sensitive to changes in the release rates of ammonia from the sediments, algal growth, respiration, and mortality rates, ammonia nitrification, and organic matter decay. Nitrate-nitrite predictions were affected by changes in the release rates of ammonia from the sediments, algal growth rates, ammonia nitrification, and nitrate-nitrite decay. Algae predictions were most affected by changes in algal growth rate, extinction coefficients, and nutrient concentrations. TOC is not a modeled constituent but was estimated by adding computed algae, LDOM, RDOM, and detritus concentrations. TOC estimates were affected by changes in algal concentrations, LDOM decay, RDOM decay, and detrital decay and settling.

Table 3
RMS Values Calculated for Each Date of Measured Data at WFG, Neely Henry, and Weiss

Reservoir	Constituent	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
WFG	PO_4	-	-	-	-	0.001	0.002	0.003	0.002	0.002	-	-	-
	NH_3	-	-	-	-	0.054	0.038	0.043	0.055	0.061	-	-	-
	$NO_2 + NO_3$	-	-	-	-	0.291	0.274	0.370	0.314	0.256	-	-	-
	Algae	-	-	-	-	4.119	2.733	5.188	3.226	1.456	-	-	-
	TOC	-	-	-	-	0.663	0.597	1.001	0.778	0.523	-	-	-
Weiss	PO_4	0.016	-	0.014	0.008	0.005	0.014	0.006	0.016	0.012	0.018	0.033	0.029
	NH_3	-	-	-	-	-	0.063	0.058	0.068	0.081	0.049	0.014	0.038
	$NO_2 + NO_3$	0.097	-	0.051	0.108	0.133	0.144	0.115	0.087	0.072	0.122	0.060	0.066
	TOC	1.02	-	0.266	0.806	0.325	0.558	0.568	1.125	0.747	1.102	0.567	0.651
Neely Henry	PO_4	-	-	-	0.001	0.004	0.004	0.001	0.001	-	-	-	-
	NH_3	-	-	-	0.021	0.024	0.035	0.055	0.018	-	-	-	-
	$NO_2 + NO_3$	-	-	-	0.014	0.027	0.023	0.020	0.008	-	-	-	-
	TOC	-	-	-	0.860	0.759	0.801	0.692	0.361	-	-	-	-

Table 4
Final Values for Coefficients Adjusted During Calibration at WFG, Neely Henry, and Weiss

Coefficient	Value
Horizontal eddy viscosity	1.0 $m^2 s^{-1}$
Minimum vertical eddy viscosity	1.4 x $10^{-7} m^2 s^{-1}$
Horizontal eddy diffusivity	1.0 $m^2 s^{-1}$
Minimum vertical eddy diffusivity	1.4 x $10^{-6} m^2 s^{-1}$
Bottom frictional resistance	70.0 $m^{1/2} s^{-1}$
Fraction of solar radiation absorbed at the water surface	0.45
Light extinction - water	0.25 m^{-1}
Wind sheltering coefficient	1.0
Sediment (ground) temperature	17.0

Calibration

Walter F. George 1992

Water surface elevations. During hydraulic calibration, calculated inflow data provided by the Mobile District were used to account for ungauged tributary flows. The 1992 water surface elevations at Walter F. George varied between 56.5 and 58 m for the year. Predicted water surface elevations were well within the 0.5 m error considered acceptable (Cole and Buchak 1995). As seen in Figure 10, predicted water surface elevations were following the behavior trends of observed WSEL but were approximately 0.3 m or less overpredicted.

Temperature. When temperature predictions from CE-QUAL-W2 were interpreted for this study, a number of key points were considered. First, temperature predictions from CE-QUAL-W2 are averaged over the length, height, and width of a cell. Observed data represented temperature at a specific point within the reservoirs. Secondly, meteorological data from a nearby station were applied over the entire reservoir. In this study, each meteorological station used for a project was approximately 80 km (50 miles) away. Thirdly, a computed temperature (or other water quality constituent) profile was not always output at the same time observed data were collected; thus, the effect of when computed and observed data were compared was considered. Finally, consideration was given to large differences that can occur between observed data and model predictions from the influence of rapidly changing boundary conditions.

Table 5
Final Values for Coefficients Adjusted During Water Quality Calibration at WFG, Neely Henry, and Weiss

Coefficient	WFG	Neely Henry	Weiss
Algal growth rate, day^{-1}	2.0	2.0	2.0
Algal mortality rate, day^{-1}	0.10	0.10	0.10
Algal excretion rate, day^{-1}	0.04	0.04	0.04
Algal dark respiration rate, day^{-1}	0.04	0.04	0.04
Algal setting rate, day^{-1}	0.10	0.10	0.10
Saturation intensity at maximum photosynthetic rate, W m^{-2}	100.0	100.0	100.0
Fraction of algal biomass lost by mortality to detritus	0.80	0.80	0.80
Lower temperature for algal growth, °C	5.0	5.0	5.0
Lower temperature for maximum algal growth, °C	25.0	25.0	25.0
Upper temperature for maximum algal growth, °C	35.0	35.0	35.0
Upper temperature for algal growth, °C	40.0	40.0	40.0
Fraction of algal growth rate at ALGT1	0.10	0.10	0.10
Fraction of maximum algal growth rate at ALGT2	0.99	0.99	0.99
Fraction of maximum algal growth rate at ALGT3	0.99	0.99	0.99
Fraction of algal growth rate at ALGT4	0.10	0.10	0.10
Labile DOM decay rate, day^{-1}	0.10	0.10	0.10
Labile to refractory decay rate, day^{-1}	0.01	0.01	0.01
Maximum refractory decay rate, day^{-1}	0.001	0.001	0.001
Particulate organic matter decay rate, day^{-1}	0.08	0.08	0.08
Particulate organic matter settling rate, day^{-1}	0.10	0.10	0.10
Lower temperature for organic matter decay, °C	5.0	5.0	5.0
Lower temperature for maximum organic matter decay, °C	25.0	25.0	25.0
Fraction of organic matter decay rate at OMT1	0.1	0.1	0.1
Fraction of organic matter decay rate at OMT2	0.99	0.99	0.99
Sediment release rate of phosphorous	0.003	0.003	0.003
Phosphorus partitioning coefficient for suspended solids	1.2	1.2	1.2
Algal half-saturation constant for phosphorus, g m^{-1}	0.003	0.003	0.003

(Continued)

Table 5 (Concluded)

Coefficient	WFG 1992	Neely Henry 1993	Weiss 1991
Sediment release rate of ammonia (fraction of SOD)	0.005	0.005	0.005
Ammonia decay rate, day^{-1}	0.30	0.30	0.3
Ammonia partitioning coefficient for suspended solids	1.0	1.0	1.0
Algal half-saturation constant for ammonia	0.014	0.014	0.014
Lower temperature for ammonia decay, °C	5.0	5.0	5.0
Lower temperature for maximum ammonia decay, °C	25.0	25.0	25.0
Fraction of nitrification rate at NH4T1	0.1	0.1	0.1
Fraction of nitrification rate at NH4T2	0.99	0.99	0.99
Nitrate decay rate, day^{-1}	0.12	0.12	0.12
Lower temperature for nitrate decay, °C	5.0	5.0	5.0
Lower temperature for maximum nitrate decay, °C	25.0	25.0	25.0
Fraction of denitrification rate at NO3T1	0.10	0.10	0.10
Fraction of denitrification rate at NO3T2	0.99	0.99	0.99
Oxygen stoichiometric equivalent for ammonia decay	4.57	4.57	4.57
Oxygen stoichiometric equivalent for organic matter decay	1.4	1.4	1.4
Oxygen stoichiometric equivalent for dark respiration	1.1	1.1	1.1
Oxygen stoichiometric equivalent for algal growth	1.4	1.4	1.4
Stoichiometric equivalent between organic matter and phosphorous	0.005	0.005	0.005
Stoichiometric equivalent between organic matter and nitrogen	0.08	0.08	0.08
Stoichiometric equivalent between organic matter and carbon	0.45	0.45	0.45
Dissolved oxygen concentration at which anaerobic processes begin, g m^{-3}	0.1	0.1	0.1
Sediment decay rate, day^{-1}	0.08	0.08	0.08
Fraction of SOD	1.4	1.0	1.0

Figures 11 through 16 present temperature profile results for Walter F. George at six stations indicated in Table 2. These figures show very little thermal stratification in the reservoir. Differences in epilimnetic and hypolimnetic temperatures at station 1 (Figure 11) were 5° C or less throughout the simulation period. Computed and observed profiles for all stations compared

Table 6
Calibrated Sediment Oxygen Demand Rates for the Main Branch of all Reservoirs

Reservoir	Segment Number(s)	SOD, $gm^{-2}day^{-1}$
WFG	1-20	0.4
	21	0.6
	22	0.8
	23	1.0
	24	1.2
	25	1.4
	26	1.6
	27-36	1.8
N Henry	1-19	0.2
	20	0.4
	21	0.6
	22	0.8
	23	1.0
	24	1.2
	25	1.4
	26	1.6
	27	1.8
	28	2.0
	29-35	2.2
Weiss	1-4	0.5
	5-23	0.9
	24-27	1.1
	28-31	1.3
	24-27	1.1
	28-31	1.3
	32-39	1.5

favorably for most dates (RMS ≤ 1° C). Since stations 6 and 8 (Figures 15 and 16, respectively) are the most upstream stations, they are more influenced by inflow temperatures. The figures show estimated inflow temperatures used were close to observed. Most differences between observed and computed temperatures at the other stations (Figures 11-14) were due to using meteorological data from Columbus, GA.

Dissolved oxygen. Figures 17 through 22 present DO results for Walter F. George at six stations indicated in Table 2. Profile results for stations closer to the dam (Figures 17 through 20) show strong chemical stratification even though there is not strong thermal stratification. Computed and observed profiles for all stations were generally in close agreement (RMS usually less than 1.0 mg/ℓ). In Figures 21 and 22 (stations 6 and 8, respectively), differences in computed and observed DO concentrations were attributed to low estimated inflow DO concentrations. As explained for temperature results, these two stations are more influenced by inflow concentrations than the others. Differences in computed and observed DO profiles for stations closest to the dam (Figures 17-20) occur mostly in the epilimnion where computed concentrations are being underpredicted. High observed DO values in the epilimnion are probably the results of algal photosynthesis causing saturated or supersaturated DO concentrations. CE-QUAL-W2 in past studies has not been able to predict DO at/or above saturation in the epilimnion. This is a shortcoming of the kinetics and is being addressed in Version 3 of the model. Overall, trends of DO behavior through the simulation period are following the observed trends quite well as illustrated during warmer months (May - August) when hypolimnetic DO concentrations approach or become anoxic.

Phosphorus. Figure 23 compares computed and observed phosphorus photic zone averages for all observed dates at all stations longitudinally through the reservoir. Computed averaged concentrations (Figure 23) are in close agreement with observed concentrations at most stations for all dates (RMS ≈ 0.002 mg/ℓ). More importantly, trends in observed data are being predicted as well. Some differences between computed and observed concentrations actually resulted from how computed photic zone averages were calculated to make comparisons and not from any inadequacies of the model. Although photic zone averages compare favorably, there is no way to determine if computed concentrations in the hypolimnion are comparable to observed. This is very important in accurately modeling nutrient dynamics.

Ammonia. Figure 24 compares computed and observed ammonia photic zone averages for all observed dates at all stations (listed in Table 2) longitudinally through the reservoir. Computed averaged concentrations are in close agreement with observed concentrations at most stations for all dates (RMS ≈ 0.05 mg/ℓ). As in the case of phosphorus, trends in observed data are being predicted (e.g., decrease in ammonia through the reservoir longitudinally). Errors were introduced by the averaging technique used in making comparisons with observed data as previously mentioned. Nevertheless, photic zone averages compare favorably with observed. However, there was no way to tell if computed concentrations in the hypolimnion are comparable to observed.

Nitrate-nitrite. Figure 25 compares computed versus observed nitrate-nitrite concentrations for all observed dates and stations (listed in Table 2) longitudinally through the reservoir. As seen in the figure, computed averaged concentrations were not comparing well with observed concentrations downstream of station 4 (RMS ≥ 0.3 mg/ℓ). The trend in observed concentrations shows nitrate-nitrite decreasing longitudinally while the computed average concentrations are increasing longitudinally downstream. In the model kinetics of nitrate, ammonia nitrification is the only source of nitrate-nitrite besides boundary inflow concentrations. From Figure 25, estimated inflow conditions for nitrate-nitrite are close to observed because computed in-pool concentrations at the most upstream station are in close agreement to that observed in each graph. However, if inflow concentrations decreased between measured dates, CE-QUAL-W2 will not be able to capture this.

Algae. Figure 26 compares computed versus observed algal data for all monitored dates at all stations (listed in Table 2) longitudinally through the reservoir. Computed averaged concentrations are in close agreement with observed data at most stations for all dates (RMS ≈ 3.0 ug/l). Even though there are slight differences between computed and observed data, trends in observed data are being predicted by the model. Again, having algae profiles would have helped in calibrating and understanding differences between computed and observed concentrations.

Total organic carbon. TOC was not a modeled constituent but was estimated by adding computed photic zone averages of algae, LDOM, RDOM,and detritus. This value was then compared with observed data. Figure 27 compares TOC computed photic zone averages versus observed for all monitored dates at all stations (listed in Table 2) longitudinally through the reservoir. Computed photic zone averaged concentrations are in fairly close agreement with observed data at most stations for all dates (RMS ≈ 0.7 mg/ℓ). Underpredicting occurs at stations 1 through 6 for most dates. Underpredicting TOC concentrations may have resulted from how TOC was originally proportioned into particulate (detritus) and dissolved (LDOM and RDOM) organic matter in inflow boundary concentrations and initial conditions; however, this would be hard to determine from information available. Also, one cannot ignore the error introduced by the averaging technique used in finding a photic zone average of each constituent making up TOC.

Neely Henry 1993

Water surface elevations. Computed and observed 1993 water surface elevations are shown in Figure 28. Observed water surface elevations show an increase of approximately 1-1/2 m during the spring with a slight decrease in late summer. Predicted water surface elevations followed this behavior and were within the acceptable error range.

Temperature. Figures 29 through 34 present temperature profile results for Neely Henry at six stations indicated in Table 2. In these figures, very little thermal stratification can be seen in Neely Henry. Neely Henry has run-of-the-river flow conditions; thus residence time is only approximately 6 days leaving little time to set up a strong thermal stratification. Computed and observed profiles for all stations compared favorably for most dates. The RMS for profiles were less than 1 ° C at most stations. At stations 8 and 10 on June 15 (Figures 33 and 34, respectively), differences in computed and observed temperatures were due to high estimated inflow temperatures. Comparable to upstream stations at Walter F. George, these stations were influenced more by inflow temperatures than the others. Differences occurring at stations closest to the dam (Figures 29-32) were due to using meteorological data from Birmingham, AL.

Dissolved oxygen. Figures 35 through 40 present the DO results for Neely Henry at six stations listed in Table 2. Profiles of DO show that chemical stratification is more pronounced in the warmer months than thermal stratification, especially at stations closer to the dam (Figures 35-38). Computed and observed profiles for all stations were generally in close agreement having RMS values ≤ 1 mg/ℓ. In Figures 39 and 40, differences in computed and observed DO concentrations were small indicating estimated inflow DO concentrations were close to observed. In Figures 35 through 38 on August 17, differences in computed and observed DO concentrations were mostly in the epilimnion where computed concentrations are too low. As discussed previously for Walter F. George, CE-QUAL-W2 has difficulty predicting DO concentrations at/or above saturation in the epilimnion.

Other noticeable differences between computed and observed DO profiles occur at stations 2 and 4 (Figures 36 and 37, respectively) in June, July, and August when computed hypolimnetic DO concentrations were too low. There are several reasons predicted DO was too low: (a) SOD too high, (b) ammonia release rates set too high, and/or (c) estimated inflow DO concentrations too low between observed dates. Without having observed profile data for ammonia in the hypolimnion, it is difficult to determine whether the ammonia release rate was too high creating too much DO demand.

Phosphorus. Figure 41 compares computed and observed phosphorus photic zone averages for all observed dates at all stations longitudinally through the reservoir. Computed averaged concentrations are in close agreement with observed concentrations at most stations for all dates (RMS ≤ 0.001 mg/ℓ). More importantly trends in observed data are being predicted as well. As discussed for Walter F. George, most of the differences between computed and observed were due to how computed averages were calculated to make comparisons. Overall, photic zone averages are in agreement. However, without profile data, it is impossible to determine how well hypolimnetic concentrations compare. As mentioned before, this is very important in predicting nutrient dynamics.

Ammonia. Figure 42 compares computed and observed ammonium photic zone averages for all observed dates at all stations (listed in Table 2) longitudinally through the reservoir. Computed averaged concentrations are in close agreement with observed concentrations at most stations for all dates (RMS ≈ 0.02). Trends in observed data are being predicted longitudinally (e.g., very little change in ammonia concentrations longitudinally). Like phosphorus, most of the differences between computed and observed data were due to how computed averages were calculated to make comparisons. Again, there is no way to determine how hypolimnetic concentrations compare with observed data since there are no observed data. Not only is this comparison important in predicting nutrient dynamics, it is equally important in predicting DO dynamics correctly.

Nitrate-nitrite. Figure 43 compares computed versus observed nitrate-nitrite photic zone averages for all observed dates and stations (listed in Table 2) longitudinally through the reservoir. Computed average concentrations were comparing well with observed concentrations at all stations and monitored dates (RMS ≈ 0.02 mg/ℓ). The trend in observed concentrations shows little variation in values from one month to the next.

Algae. Figure 44 shows computed concentrations of algae for all stations (listed in Table 2) longitudinally through the reservoir. Computed algal concentrations were fairly constant for all months with slight increases in concentrations during May and August at the stations closest to the dam. Since no chlorophyll measurements were collected in 1993 at Neely Henry, comparisons could not be made to computed data to verify predictions.

Total organic carbon. Figure 45 compares computed versus observed TOC photic zone averages for all monitored dates at all stations (listed in Table 2) longitudinally through the reservoir. Figure 45 illustrates that at most stations and dates TOC is being overpredicted. Overprediction of algae is the probable cause for predicting too much TOC since algae is a major portion of the estimated TOC concentration. However, without having observed algal concentrations, it is impossible to determine if this is the cause.

Weiss 1991

Water surface elevations. Computed and observed 1991 water surface elevations are shown in Figure 46. Observed water surface elevations for 1991 are characterized by a 2-m increase in early March and a slight decrease in late summer. Predicted water surface elevations did not reflect as much increase in early March and remained off by this amount for the rest of the simulation. This was still within the 0.5-m error allowed.

Temperature. Figures 47-51 present temperature profile results for Weiss at five stations indicated in Table 2. In these figures, very little thermal stratification can be seen in Weiss. Like Neely Henry, Weiss is not a deep reservoir, so wind-induced circulation probably prevents a strong thermal gradient from forming. Computed and observed profiles for all stations compared favorably for most dates. The RMS values for most profiles were less than 1 °C at most stations. At stations 11 and 12 (Figure 50 and 51, respectively) noticeable differences occur between computed and observed temperatures during fall months (October through December) due to using low estimated inflow temperatures. As discussed previously for the other reservoirs, the most upstream stations are more influenced by inflow temperatures than stations closer to the dam. Differences occurring at stations closest to the dam are usually attributed to rapidly changing outflows and/or meteorological conditions. However, the continuous use of low estimated inflow temperatures has caused differences at stations closer to the dam (Figures 47-49) during October to December as well.

Dissolved oxygen. Figures 52-56 present the DO results for Weiss at five stations listed in Table 2. Like Walter F. George and Neely Henry, profiles of DO in these figures show more chemical stratification than thermal stratification, especially at stations closer to the dam (Figures 52-54). Computed and observed profiles for all stations were generally in close agreement (RMS ≤ 1 mg/ℓ). In Figures 55 and 56, differences in computed and observed DO concentrations were small indicating that estimated inflow DO concentrations were close to observed. Most noticeable differences in stations closer to the dam can be seen in Figures 53 and 54 for the months of April through August. At station 2 (Figure 53), CE-QUAL-W2 consistently predicts a stronger stratification than was observed. At station 3 (Figure 54), CE-QUAL-W2 is correctly predicting the stratification behavior of the observed profile, but it is shifted either to the left or right of the actual curve. As discussed previously, interpretation of model results must consider the effect of when computed and observed data were compared. Computed results are subject to large variations based on how rapidly inflows and outflows are changing.

Phosphorus. Figure 57 compares computed and observed phosphorus photic zone averages for all observed dates at all stations longitudinally through the reservoir. Although trends in observed data are being predicted (decrease longitudinally through the reservoir), computed averages were too high at most stations for all dates (RMS ≈ 0.02 mg/ℓ). As discussed for Walter F. George and Neely Henry, differences between computed and observed were attributed to: (a) not having chlorophyll data to model algal effects on phosphorus accuartely and/or (b) averaging computed results by layers to estimate a photic zone average for comparisons.

Ammonia. Figure 58 compares computed and observed ammonia photic zone averages for all observed dates at all stations (listed in Table 2) longitudinally through the reservoir. Note that there are no observed values for the months of January through May. For months having observed data, computed averages were predicted slightly too high; nevertheless, compared favorably with observed data (RMS ≈ 0.03 mg/ℓ). Reasons for differences between computed and observed photic zone averages were the same as discussed previously for phosphorus.

Nitrate-nitrite. Figure 59 compares computed versus observed nitrate-nitrite concentrations for all observed dates and stations (listed in Table 2) longitudinally through the reservoir. Computed averages did not compare well with observed concentrations for stations closest to the dam. For these stations, computed photic zone averages were being overpredicted (RMS ≈ 0.1 mg/ℓ). This could have resulted from CE-QUAL-W2 using inflow concentrations between observed values that were too high as a result of the interpolation procedure employed.

Algae. Figure 60 shows computed algal photic zone averages for all stations (listed in Table 2) longitudinally through the reservoir. Chlorophyll concentrations are fairly constant longitudinally through the reservoir except during April, May, and September when stations closer to the dam increase in chlorophyll concentrations. Since no chlorophyll measurements were collected in 1991, comparisons could not be made to computed data.

Total organic carbon. Figure 61 compares computed versus observed TOC photic zone averages for all monitored dates at all stations (listed in Table 2) longitudinally through the reservoir. In Figure 61 TOC concentrations compare favorably with observed at most stations and dates. This indicates that algal predictions may be closer to observed than previously thought based on phosphorus and ammonia predictions. Since algal concentrations are a major proportion of the TOC estimate, changes in algal concentrations affect TOC concentrations more than changes in the other constituents of TOC. If observed algae concentrations had been available for comparison, this observation could have been verified.

Verification

Walter F. George 1994

Water surface elevations. Computed and observed 1993 water surface elevations are shown in Figure 62. Water surface elevations in 1994 are characterized by two cycles: (a) an increase from 56.5 to 57.75 m in early January decreasing to 56.5 m by early June and (b) an immediate increase to 58.5 m in June gradually decreasing to 57.5 m by early November. Predicted water surface elevations follow this trend.

Temperature. Figures 63-68 present temperature profile results for Walter F. George at six stations indicated in Table 2. Similar to 1992 (Figures 11-16), Figures 63-68 show very little thermal stratification in Walter F. George. Differences in epilimnetic and hypolimnetic temperatures at station 1 (Figure 63), the closest to the dam were 5 °C or less throughout the simulation period. Computed and observed temperatures for all stations and dates compared favorably. The RMS values for most profiles were 1 °C or less. Like 1992 results, most differences between observed and computed temperatures occurred at stations closest to the dam (Figures 63-66). This was attributed to using meteorological data from Columbus, GA, and/or estimate inflow temperatures being slightly off.

Dissolved oxygen. Figures 69-74 present DO results for Walter F. George at six stations indicated in Table 2. Figures 69-72, representing stations closer to the dam, show strong chemical stratification even though there is very little thermal stratification. Computed and observed profiles for stations 6 and 8 were in close agreement (RMS usually less than 1.0 mg/ℓ). However, for the other stations (Figures 69-72) the RMS values for the warmer months (July and August) were between 1 and 2 mg/ℓ. Although comparisons between computed and observed profiles for these dates were not as favorable as was observed in 1992, the trend of observed profiles was being predicted (e.g., hypolimnetic DO concentrations approach or become anoxic).

Phosphorus. Figures 75-80 present phosphorus results for Walter F. George at six stations indicated in Table 2. Computed and observed profiles of phosphorus are in agreement for most stations and dates (RMS ≈ 0.01 mg/ℓ). At stations 1 and 3, differences between computed and observed concentrations occur in August when computed phosphorus concentrations in the hypolimnion are too high indicating too much sediment release caused by low DO concentrations (less than 1 mg/ℓ). By September, phosphorus concentrations in the hypolimnion are closer to observed.

Ammonia. Figures 81-86 present ammonia results for Walter F. George at six stations indicated in Table 2. For most stations and dates, computed concentrations are matching observed favorably (RMS of 0.02). The most noticeable differences occur at stations 5, 6, and 8 for October 20. At station 5, observed hypolimnetic concentrations are higher than predicted. Apparently not enough ammonia is released from the sediments, which is triggered by anoxia above the sediment-water interface. At stations 6 and 8, instead of profile concentrations following the trend of the observed data (high ammonia concentrations in the metalimnion), computed profile concentrations for both stations are closer to the boundary concentration. These stations are highly influenced by inflow boundary concentrations.

Nitrate-nitrite. Figures 87-92 present nitrate-nitrite results for Walter F. George at six stations indicated in Table 2. For most dates and stations, computed versus predicted are in fairly good agreement (RMS ≈ 0.20 mg/ℓ). For most dates where noticeable differences occur, the model is slightly underpredicting nitrate concentrations (e.g., Figure 88 and 89 on September 15 and October 20, and Figure 90 on September 15). This was attributed to possibly not having enough ammonia nitrification since ammonia is being slightly overpredicted.

Algae. Figures 93-98 present algae results for Walter F. George at six stations indicated in Table 2. The dashed line represents a computed profile, and the single × represents the observed photic zone average concentration. Comparisons were made between the computed profile and observed photic zone average instead of calculating an averaged computed photic zone concentration as was done previously. One can visually estimate an average value from this knowing that the photic zone was approximately 2.5 to 3 m at all stations.

Computed algal concentrations compared favorably to observed photic averages for all stations and dates (Figures 93-98) except at station 5 (Figure 96). At this station algal concentrations were overpredicted especially during

September and October. Since observed algal boundary conditions are snapshot samples, they may not represent lower concentrations that could be occurring between sample dates. For example, if samples were collected on September 15 and October 16 with concentrations equal to 0.525 g/m^3 and 0.72 g/m^3, respectively, an inflow concentration of 0.245 g/m^3 could have occurred between these dates but was not measured. Consequently, since CE-QUAL-W2 interpolates between observed dates of data, inflow concentrations would never be lower than 0.525 g/m^3 for this time period. Thus, unless algae is lost from processes such as algal respiration, the model will not predict the correct concentrations.

Total organic carbon. As mentioned previously, TOC is not a modeled constituent but was estimated by adding computed algae, LDOM, RDOM, and detritus concentrations together. Figures 99-104 present TOC results for Walter F. George at six stations indicated in Table 2. The dashed line represents computed values, and × represents observed values. In general, computed concentrations were in agreement with observed. The greatest differences occur on July 27 for most stations.

Neely Henry 1994

Water surface elevations. Computed and observed 1994 water surface elevations are shown in Figure 105. Observed data during the simulation period were characterized by a fairly constant water surface elevation until around Julian day 220 when it began to decrease. Predicted water surface elevations were within the 0.5-m error considered acceptable (Cole and Buchak 1995).

Temperature. Figures 106-111 present temperature profile results for Neely Henry at six stations indicated in Table 2. As in 1993 (Figures 29-34) Figures 106-111 show very little thermal stratification in Neely Henry. Differences in epilimnetic and hypolimnetic temperatures at station 1, which is closest to the dam (Figure 106), were 1 °C or less throughout the simulation period. Computed and observed profiles for all stations compared favorably. Most differences between observed and computed temperatures at stations closest to the dam (Figures 106-109) were caused by using meteorological data from Birmingham, AL.

Dissolved oxygen. Figures 112-117 present DO results for Neely Henry at six stations indicated in Table 2. Figures 112-117 representing stations closer to the dam show stronger chemical stratification than at other stations even though there is very little thermal stratification. Computed and observed concentrations for all stations were generally in close agreement (RMS usually less than 1.0 mg/ℓ). In Figures 116 and 117 (stations 8 and 10, respectively) most differences were the result of using estimated inflow DO concentrations that were too high or too low. As mentioned previously, these two stations are more influenced by inflow concentrations, so any discrepancies between estimated and observed DO inflow data will be revealed at these stations.

On August 16 in most figures (Figures 112-117), computed DO concentrations in the hypolimnion are too low, but by August 17 are comparing favorably with observed. When considering possible explanations for this behavior, one must consider that water quality predictions can exhibit a fairly large change from day to day depending on the boundary conditions.

Phosphorus. Figures 118-123 present phosphorus results for Neely Henry at six stations indicated in Table 2. Computed and observed profiles of phosphorus are in agreement for most stations and dates (RMS is 0.01) demonstrating that coefficients for processes affecting phosphorus concentrations were correctly set. Examination of observed phosphorus concentrations shows that for all stations throughout the simulation period phosphorus concentrations do not vary a great deal (between 0.01 to 0.025 mg/ℓ).

Ammonia. Figures 124-129 present ammonia results for Neely Henry at six stations indicated in Table 2. For most stations and dates, computed concentrations match observed very well (RMS of 0.02). The most noticeable differences occur on August 16 in the hypolimnion at stations 1, 2, and 6 (Figures 124, 125, and 127, respectively). At these stations, comparison of observed data to computed results shows a slight increase in computed hypolimnetic concentrations. Since computed DO concentrations are anoxic at these stations, too much ammonia may have been released from the sediments.

Nitrate-nitrite. Figures 130-135 present nitrate-nitrite results for Neely Henry at six stations indicated in Table 2. For most dates and stations computed versus predicted values are in close agreement (RMS ≈ 0.03 mg/ℓ or less) with observed.

Algae. Figures 136-141 present algae results for Neely Henry at six stations indicated in Table 2. Instead of calculating photic zone averages, algal results were presented like results at Walter F. George for 1994: the dashed line represents computed profile values, and the single × represents the observed photic zone average value. Again, knowing that the photic zone was approximately 2.5 to 3 m at all stations, a photic average was estimated from the computed profile for comparison.

Computed concentrations of algae compared favorably to observed photic averages only at the most upstream stations (Figures 140 and 141). At the other stations algae concentrations were under predicted for all dates except October.

Total organic carbon. Figures 142-147 present TOC results for Neely Henry at six stations indicated in Table 2. In general, computed concentrations were in agreement with observed for all stations and dates except at stations 1 and 2 (Figures 142 and 143, respectively) in August, September, and October. Since algae concentration makes up a large part of the TOC estimate, differences resulted from incorrectly predicting algae concentration for September and October. In August at station 1, observed TOC concentrations were very high in the epilimnion. The model was unable to predict this concentration in the epilimnion, but results compare favorably deeper in the profile.

Weiss 1994

Water surface elevations. Computed and observed 1994 Weiss water surface elevations are shown in Figure 148. For the simulation period, 1994 water surface elevations were relatively constant around 172.5 m. Predicted water surface elevations compared favorably to observed and were within the 0.5-m error.

Temperature. Figures 149-153 present temperature profile results for Weiss at five stations indicated in Table 2. Similar to 1991 temperature profiles, Figures 149-153 show very little thermal stratification in Weiss. As discussed for 1991 results, Weiss is not a deep reservoir, so wind-induced circulation probably keeps a strong thermal gradient from forming. Computed and observed profiles for all stations compared favorably for most dates. The RMS values for most profiles were 1 °C or less at most stations and dates. Most noticeable differences between computed and observed temperatures for all stations occurred in the epilimnion. Computed temperatures were too warm. This was due to meteorological conditions being used from Rome, GA. As stated previously, Rome is approximately 80 km (50 miles) away from Weiss.

Dissolved oxygen. Figures 154-158 present DO results for Weiss at five stations listed in Table 2. Like Walter F. George and Neely Henry, profiles of DO concentrations show more chemical stratification than thermal stratification, especially at stations closer to the dam (Figures 155-157). Computed and observed profiles for all stations were generally in close agreement (RMS of 1 mg/ℓ or less). In Figures 158 and 159 (stations 5 and 6, respectively), differences between computed and observed DO concentrations were small indicating that estimated inflow DO concentrations for these dates were close to observed. Some of the most notable differences occur at station 3 (Figure 156). CE-QUAL-W2 did not predict the shift in the depth of the metalimnion that occurred from June 2 to June 3. Such a drastic change may have been the result of a seiche the model did not pick up. Other evidence of this phenomenon occurred on July 14 and August 11 when low DO concentrations were observed in the hypolimnion but the model does not capture this. By July 15, observed DO concentrations in the hypolimnion increased making the computed DO concentrations match much better. However, on August 12 the observed profile is almost destratified and the computed profile is not. The computed profile is similar to the previous day's computed profile. Increasing SOD rates caused computed results not to match on the other observed dates. As mentioned, these strange trends being observed in DO concentrations are attributed to a low DO pocket being seiched out then resettling, since this is the deepest part of the reservoir. CE-QUAL-W2 completely misses this phenomenon.

Other notable differences occur at stations 1 and 2. Station 1 results (Figure 154) show DO concentrations being underpredicted during the months of July and August in the metalimnion and hypolimnion. At station 2 (Figure 155) underprediction occurred during June and July only in the metalimnion. Adjustments in SOD rates to improve predictions only made comparisons of other dates worse. At both stations, it is possible that low estimated inflow DO and temperature concentrations occurring between observed inflow boundary conditions caused low DO concentrations.

Phosphorus. Figures 159-163 present phosphorus results for Weiss at five stations indicated in Table 2. Computed and observed profiles of phosphorus are in agreement for most stations and dates (RMS around 0.02). Major differences occur on June 3 at stations 5 and 6 (Figures 162 and 163, respectively), which are influenced by inflow boundary concentrations.

Ammonia. Figures 164-168 present ammonia results for Weiss at five stations indicated in Table 2. For most stations and dates, computed concentrations matching observed very well (RMS around 0.03). The most noticeable differences occur at stations 2 and 3 (Figure 165 and 166) on July 15. At these stations, observed metalimnetic concentrations are much higher than predicted concentrations in the epilimnion and hypolimnion. High observed metalimnetic concentrations may occur from organic matter settling possibly resulting from an algal bloom and die-off. CE-QUAL-W2 was not able to predict this.

Nitrate-nitrite. Figures 169-173 present nitrate-nitrite results for Weiss at five stations indicated in Table 2. Nitrate-nitrite computed and observed concentrations are not in close agreement at stations 1, 2, and 3. The model predicted increases in metalimnetic and hypolimnetic concentrations that were not observed. The only mechanisms to account for increased nitrate-nitrite concentrations are through ammonia nitrification or inflow loadings. Since computed ammonia concentrations were in close agreement with observed, estimated inflow loadings were believed to be the cause.

Algae. Figures 174-178 present algae results for Weiss at five stations indicated in Table 2. The dashed line represents computed profile values, and the single × represents the observed photic zone average value. Estimating a photic zone average knowing that the photic zone was approximately 2.5 to 3 m at all stations was necessary for comparison.

Computed concentrations of algae compared favorably to observed photic averages for all stations and dates except at stations 1 and 2 (Figure 174 and 176, respectively). At both stations algal concentrations were overpredicted.

Total organic carbon. Figures 179-183 present TOC results for Weiss at five stations indicated in Table 2. In general, trends in computed concentrations were in agreement with observed (i.e., little stratification in the profiles), but computed TOC concentrations were overpredicted at stations closest to the dam. This behavior mimics algal concentrations at most stations, which is to be expected since as discussed previously algal concentrations are a major proportion of the TOC estimate.

5 Scenario Results

Demonstration or trial scenarios were conducted once calibration was completed for all years at each reservoir. The Water Quality Task Force (WQTF) recommended specific conditions to simulate during the scenario runs. The following three trial scenarios were identified:

a. Base conditions (1994 conditions) .

b. Future conditions of lower water allocations but with existing waste loads.

c. Future conditions of lower water allocations but 20 percent higher waste loads.

Reservoir inflow, outflow, initial, and water quality boundary conditions were simply set to 1994 verification conditions for scenario a for all reservoirs. Results from these runs were used as base conditions to compare with scenario *b* and *c* runs.

For scenarios b and c, reservoir initial conditions, meteorological conditions, and inflow temperatures were set to values used in the 1994 verification of all reservoirs. To represent future lower water allocations for both scenarios, the WQTF recommended using 1988 inflows and outflows at each reservoir (Figure 184). This year was chosen because it was a drought year, thus meeting the first requirement for lower water allocation. These flow conditions were used for both scenario *b* and c runs.

The second requirement for scenario b was to use existing loads from 1994. Waste load (units of mass/time) is calculated as the product of flow (units of volume/time) and concentration (units of mass/volume). Since CE-QUAL-W2 requires concentrations for constituents instead of waste loads, the following equation was used to calculate concentrations needed to produce the same waste load used in 1994:

$$C_{88} = \frac{Q_{94} * C_{94}}{Q_{88}} \tag{8}$$

where

C_{88} = calculated inflow concentrations for 1988

Q_{94} = inflows for 1994

C_{94} = inflow concentrations for 1994

Q_{88} = inflows for 1988.

DO concentrations were the only concentrations to remain the same as 1994 DO concentrations. Realistically, DO concentrations would not have been affected as much as the others.

Table 7 shows concentrations calculated for each constituent at all reservoirs necessary for scenario b. As seen in Table 7, estimated concentrations were very high and unrealistic. How concentrations will actually change when flows are reduced depends on environmental conditions. Reduced flow conditions may produce any of the following changes to constituent concentrations: (a) increased concentrations, (b) reduced concentrations, or (c) no change at all. Thus, for this study two assumptions were made for each scenario: first, that lower flows caused increased concentrations, and second, that lower flows caused no change in concentrations at all. This required making two scenario b runs: (a) Run 1 used C_{88} concentrations and Q_{88} flow conditions; and (b) Run 2 used C_{94} concentrations and Q_{88} flow conditions. Results from both runs were then compared with base condition results (scenario a) for all reservoirs.

Comparable to scenario *b,* scenario *c* also required reduced water allocations. In addition, the second condition of the scenario was to increase existing 1994 loads by 20 percent. This was done by simply multiplying concentrations C_{94} and C_{88} by 20 percent also listed in Table 7. Using the same assumptions as scenario b (increased inflow concentrations and no change in inflow concentrations), two scenario runs were simulated: (a) Run 1 used C_{88} concentrations increased 20 percent and Q_{88} flow conditions; and (b) Run 2 used C_{94} concentrations increased 20percent and Q_{88} flow conditions. Like scenario *b*, results from both runs were compared with base condition results (scenario *a*) for all reservoirs.

Table 7
Flows and Concentrations Used in Scenario Runs

Reservoir	Julian Day	FLOW		LDOM		RDOM		ALGAE		DETRITUS		PO_4		NH_3		NO_2NO_3		DO	
		Q_{88}	Q_{94}	C_{88}	C_{94}	C_{88}	C_{94}	C_{88}	C_{94}	C_{88}	C_{94}	C_{88}	C_{94}	C_{88}	C_{94}	C_{88}	C_{94}	C_{88}	C_{94}
WFG	208.00	46.36	691.14	8.35	0.56	19.53	1.31	3.13	0.21	9.39	0.63	0.22	0.01	0.22	0.01	6.26	0.42	104.36	7.00
	236.00	83.25	356.97	2.25	0.54	5.42	1.30	1.29	0.31	2.50	0.60	0.04	0.01	0.06	0.01	0.58	0.14	32.16	7.50
	257.00	90.90	234.76	1.21	0.47	2.87	1.11	1.08	0.42	1.37	0.53	0.02	0.01	0.04	0.01	1.08	0.42	21.44	8.30
	277.00	114.62	207.79	0.85	0.47	2.01	1.11	0.76	0.42	0.96	0.53	0.01	0.01	0.03	0.01	0.76	0.42	16.32	9.00
	292.00	153.64	212.29	0.64	0.46	1.52	1.10	0.47	0.34	0.75	0.54	0.02	0.02	0.02	0.01	0.64	0.46	11.88	8.60
N Henry	159.00	60.16	94.5	0.55	0.35	1.56	0.99	2.36	1.50	1.02	0.65	0.02	0.01	0.03	0.02	0.06	0.04	10.21	6.50
	173.00	103.57	160.03	0.40	0.26	0.94	0.61	3.28	2.12	0.45	0.29	0.01	0.00	0.02	0.01	0.03	0.02	9.12	5.90
	227.00	78.04	133.96	0.72	0.42	1.67	0.97	2.44	1.42	0.79	0.46	0.03	0.02	0.03	0.01	0.09	0.05	9.27	5.40
	262.00	282.72	166.33	0.18	0.31	0.42	0.72	0.90	1.53	0.20	0.34	0.01	0.01	0.01	0.01	0.03	0.04	3.35	5.70
	297.00	103.43	249.82	1.21	0.50	2.34	0.97	2.85	1.18	1.35	0.56	0.05	0.02	0.04	0.01	0.39	0.16	19.32	8.00
Weiss	151.00	9.38	93.31	2.19	0.22	5.17	0.52	15.62	1.57	2.49	0.25	0.60	0.06	0.15	0.01	3.98	0.40	74.61	7.50
	152.00	37.46	83.54	0.49	0.22	1.16	0.52	3.50	1.57	0.56	0.25	0.13	0.06	0.03	0.01	0.89	0.40	16.73	7.50
	194.00	35.79	223.10	2.43	0.39	5.67	0.91	5.17	0.83	2.68	0.43	0.37	0.06	0.09	0.01	1.87	0.30	43.64	7.00
	222.00	42.62	136.79	1.86	0.58	4.36	1.36	1.28	0.40	2.09	0.65	0.19	0.06	0.05	0.01	0.90	0.28	24.01	7.50
	265.00	80.99	414.09	2.97	0.58	6.95	1.36	3.63	0.71	4.81	0.94	0.26	0.05	0.08	0.01	1.33	0.26	33.23	6.50
	278.00	89.77	279.52	1.81	0.58	4.23	1.36	2.21	0.71	2.93	0.94	0.16	0.05	0.05	0.01	0.81	0.26	20.24	6.50

Scenario *b* Results

Scenario *b* results are presented in Figures 185-199 for Walter F. George, Figures 200-214 for Neely Henry, and Figures 215-229 for Weiss. For each reservoir, results from three stations were compared with base results. The following stations were chosen for each reservoir:

a. Walter F. George stations 1, 5, and 8.

b. Neely Henry stations 1, 6, and 10.

c. Weiss stations 1, 3, and 6.

These stations were chosen because their location represented conditions found closest to the dam, to the middle of the reservoir, and at the most upstream end of the reservoir, respectively.

Neely Henry was the only reservoir that had lower flows in 1994 than in 1988 for a period of time (see Table 7 inflow values for September). As a result, calculated C_{88} concentrations for all constituents were lower than C_{94} concentrations. Figures 200-214 show that for all constituents at Neely Henry, scenario results in September were lower than scenario a results, or comparisons showed very small differences.

Temperature. Comparison of temperature results between both scenario *b* runs at all reservoirs show very small or no differences (Figures 185-190 for Walter F. George, Figures 200-205 for Neely Henry, and Figures 215-220 for Weiss). This is understandable since only water quality boundary concentrations were adjusted and not inflow temperatures. However, when results of both runs were compared with scenario *a* results, noticeable differences occur. During warmer months, temperature results show slightly more stratification for both scenario *b* runs especially at Weiss (Figures 215-220). It was concluded that reduced flows of scenario *b* runs were producing slower travel time through each reservoir. This allowed more time for temperature stratification to set up.

DO, algae, and TOC. For both scenario *b* runs, DO results at all reservoirs showed reduced DO concentrations especially at stations closer to the dams. This is most noticeable beginning in August for most reservoirs when comparing results with scenario *a* results (Figures 191-196 for Walter F. George, Figures 206-211 for Neely Henry, and Figures 221-226 for Weiss). At Weiss, differences at the most upstream station (station 6) are greater than at the other reservoirs because it is not as close to the inflow boundary.

There are two reasons for reduced DO concentrations: (a) increased organic matter inflow concentrations and (b) slower travel time through each reservoirs. Effects of increased organic matter inflow concentrations are more evident at upstream stations at all reservoirs (Figures 190, 205, and 220) for Run 1 of scenario *b* versus scenario *a* results since this run used the higher inflow concentrations C_{88}. It is obvious that using extremely high organic matter inflow concentrations (see Table 7 for C_{88} concentrations of LDOM, RDOM, detritus, and algae) created a greater DO demand. By examining TOC results for all runs (Figures 197-199 for Walter F. George, Figures 212-214 for Neely Henry, and Figures 227-229 for Weiss), one can see the extent of the increase in organic matter for both scenario *b* runs over the base scenario *a* run. From this it is easy to understand why DO decay is more evident for Run 1 of scenario *b*.

Reduced flows used in both scenario *b* runs also produced slower travel time through each system (Cole and Hannan 1990). This allowed more time for DO decay to occur. This is best illustrated in comparing Run 2 results of scenario *b* with scenario *a* results since the only difference between these runs was reduced flows; all other boundary and initial conditions were the same. To conceptualize this, one would follow a parcel of water through the reservoir for both flow conditions considered Q_{88} and Q_{94}. At lower flows, it may take the same parcel of water 30 more days to reach the dam than at higher flows. Consequently, this gives processes affecting DO (e.g., organic matter decay, algal respiration, etc.) more time to react as evident from the figures (Figures 191-196 for Walter F. George, Figures 206-211 for Neely Henry, and Figures 221-226 for Weiss).

Algal concentrations were increased at the most upstream stations (Figures 196, 211, and 226) at each reservoir during both scenario *b* runs due to higher inflow concentrations (C_{88} run) and slower travel time (both runs). The slower travel time allowed a longer growth period at each station. At the upstream stations slower travel time allowed more time for nutrients to be utilized and to settle; thus, at the downstream stations algae concentrations were the same as or less than a scenario a's results (Figures 194, 209, and 224). Even though inflow algal concentrations were increased at all reservoirs (Figures 196, 211, and 226), this did not produce enough increase in photosynthesis to offset the DO demand created by the increased inflow organic matter.

Phosphorus, ammonium, and nitrate-nitrite. DO profiles show more chemical stratification during the warmer months at all reservoirs (Figures 188-190, 203-205, and 218-220). The DO concentrations in the metalimnion and hypolimnion approach anoxic conditions sooner than in scenario *a*. This caused more ammonia and phosphorus to be released from the sediments than before. This is most evident at Walter F. George and Weiss shown in Figures 191-193 for August and September and in Figures 221-223 for July and August, respectively. However, there is a slight indication of this process occurring at Neely Henry in August (Figures 206-208) for all stations. Higher concentrations of ammonia and phosphorus in the water column when anoxia was not present were due simply to higher inflow concentrations.

Increases in nitrate-nitrite concentrations were most noticeable at the upstream stations (Figures 193, 208, and 223). Very small increases or no change at all occurred at the downstream stations. As stated previously for ammonia and phosphorus, this is due simply to higher inflow concentrations.

Scenario *c* Results

Scenario *c* results are presented in Figures 230-244 for Walter F. George, Figures 245-259 for Neely Henry, and Figures 260-274 for Weiss. For each reservoir, results from the three stations discussed for scenario b were compared to base run results.

Constituent behavior for both scenario *c* runs followed the same behavior trends demonstrated during both scenario b runs for all constituents (e.g., reduced DO concentrations, release of ammonia and phosphorus from the sediments, etc.). Again, there were slight or no differences between temperature results (Figures 230-232 for Walter F. George, 245-247 for Neely Henry, and Figures 260-262 for Weiss) for both runs because inflow temperatures were the same for all runs. Differences occur between scenario *a* and *c* due only to reduced travel time through each reservoir. Water quality constituent differences were slightly greater for scenario c results than for scenario b when compared with scenario *a* results. This is solely because scenario c concentrations were essentially scenario *b* concentrations increased by 20 percent. Suffice it to say that scenario *c* and scenario *b* produced similar results.

6 Summary and Conclusions

CE-QUAL-W2 was applied to three reservoirs within the ACT/ACF River basins for 2 years. Walter F. George, Neely Henry, and Weiss reservoirs. The initial year chosen for calibration at each reservoir represented the year with the most complete data available for calibration. As discussed earlier in this report, these data lacked algal/nutrient profiles. For model refinement/verification, profile data collected by ADEM and EPA in the summer of 1994 improved simulation results for the models. The 1994 profile data provided more water column information that helped to describe processes of the algal/nutrient interactions (e.g., release of phosphorus and ammonia from the sediments).

Calibration results were affected by several shortcomings in the data used during calibration. The first was being limited by inadequate profile data in the original calibration runs (only temperature and DO profiles were available). As mentioned previously, this was addressed by refining rate coefficients using the 1994 data during verification. Secondly, calibration was limited by having insufficient "true" inflow boundary concentrations on the main branch for each constituent modeled. "True" inflow concentrations are considered those measured in the free-flowing riverine segment entering the reservoir. For all runs, inflow boundary concentrations of constituents were set to concentrations occurring at the most upstream lake station at each reservoir. Compounding this shortcoming was the fact that these stations were not always at the most up-stream segment in the grids. Lastly, calibration results were also affected by the update frequency of the inflow boundary concentrations. Since lake monitoring was conducted monthly, inflow boundary concentration data updates were monthly as well. CE-QUAL-W2 took these monthly values and linearly interpolated between them to get values for each time-step between the update dates. By doing this, any major increases or decreases in concentrations occurring between monitored dates were missed.

Water quality rate coefficients used for calibration and verification are listed in Tables 5 and 6. Most adjustments between the calibration and verification runs for all reservoirs were made to rates affecting release of phosphorus and ammonia from the sediments, ammonia decay, nitrate decay, LDOM decay, and SOD. Profile data during 1994 verification helped to identify processes affecting water quality (especially DO), thus providing justification for resetting the coefficients used during calibration. For this reason, the final values used for the 1994 verification are recommended for the scenario runs.

After verification was completed, three demonstration scenario runs were conducted:

a. A base condition (1994 verification results).

b. Future conditions of lower water allocations (1988 flow conditions) with existing loads.

c. Future conditions of lower water allocations (1988 flow conditions) with 20 percent higher waste loads.

For scenario b, inflow concentrations were calculated using the lower 1988 and 1994 flows to produce the same loads that occurred in 1994 (Equation 8). In some cases, the calculated concentrations C_{88} were unrealistically high. Therefore, both scenarios b and c were also run using the observed 1994 concentrations C_{94}, and a 20 percent increase in the C_{94} concentrations, respectively.

Scenario b results showed that water quality concentrations in all reservoirs are affected whether calculated inflow concentrations C_{88} or 1994 inflow concentrations C_{94} are used. Of course, use of the C_{88} concentrations yielded a greater impact on water quality since the loadings for this condition are greater than the loadings associated with using C_{94} concentrations. The effects of scenario b are summarized as follows:

a. Temperature results were affected mainly by increased stratification caused by slower travel times through the reservoir (inflow temperatures were not modified). Temperature results in the hypolimnion were decreased. Occasionally during the cooler months (September and October), temperature results for the profile were decreased.

b. DO concentrations were reduced mostly because of increased stratification and increased organic matter. At the most upstream stations in each reservoir, DO concentrations were periodically increased for runs using C_{94} inflow concentrations because of reduced loads, possibly more reaeration, and/or increased algal growth associated with longer residence time.

c. Phosphorus, ammonia, and nitrate-nitrite concentrations were increased as a result of increased anoxia caused by increased stratification and/or increased organic matter resulting from the increased loads of the C_{88} scenario.

d. Algal concentrations at the most upstream stations at all reservoirs increased due mostly to higher inflow concentrations and slower travel time through each reservoir allowing a longer growth period at each station. In some cases slower travel time allowed more time for nutrients to be utilized and settle; thus there were less algae at the downstream stations. This was especially noticeable at Neely Henry and Weiss. At Walter F. George's most downstream stations, the algal concentrations between scenario runs showed very small differences.

e. Like algae, TOC concentrations increased at the most upstream stations from using higher inflow concentrations for nutrients, algae, and organic matter. At the most downstream stations TOC concentrations were occasionally reduced because of the reduced algal concentrations (Figures 177-179 for Neely Henry and Figures 192-195 for Weiss).

Scenario *c* results were very similar to scenario *b* results. The trends in constituent behavior demonstrated by scenario *b* runs were mimicked by scenario *c* runs. Scenario *c* results usually showed greater differences from base run results. These results were appropriate since the only difference between scenario *b* and *c* runs was the 20 percent increase in inflow concentrations for all constituents except DO; all other boundary conditions (e.g., meteorological conditions, reduced flows, inflow temperatures, etc.) remained the same.

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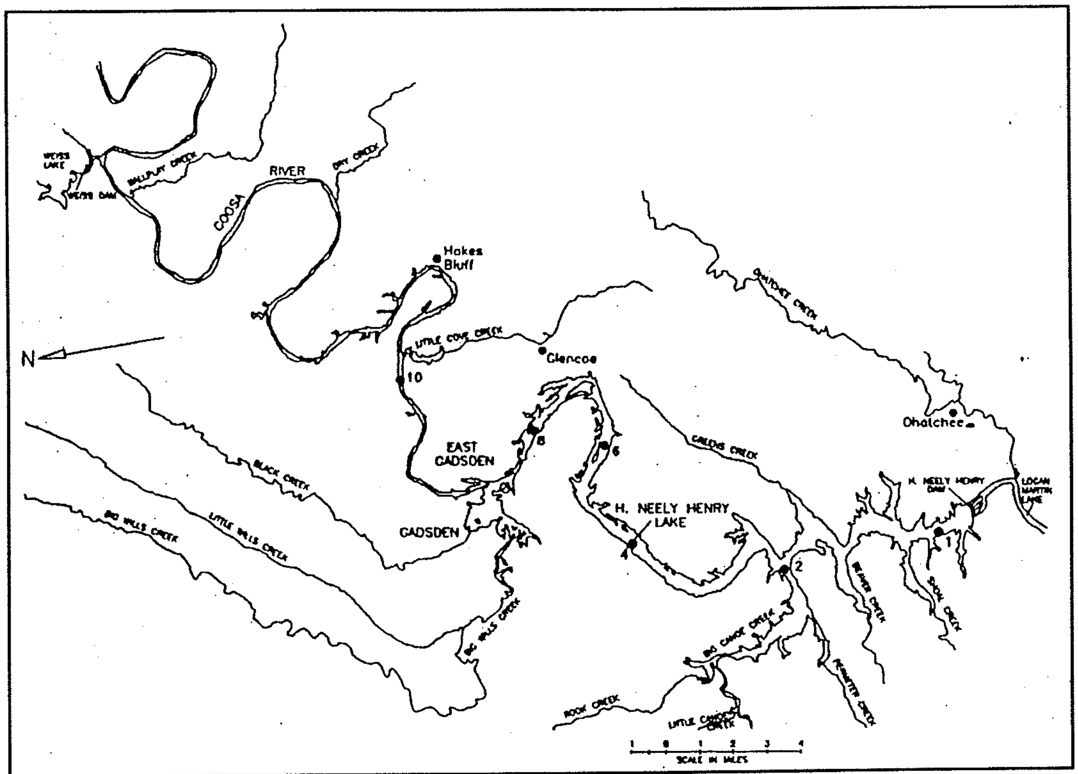


Figure 1. Neely Henry Reservoir site map. Numbers in lake represent station numbers (to convert miles to kilometers, multiply by 1.609)

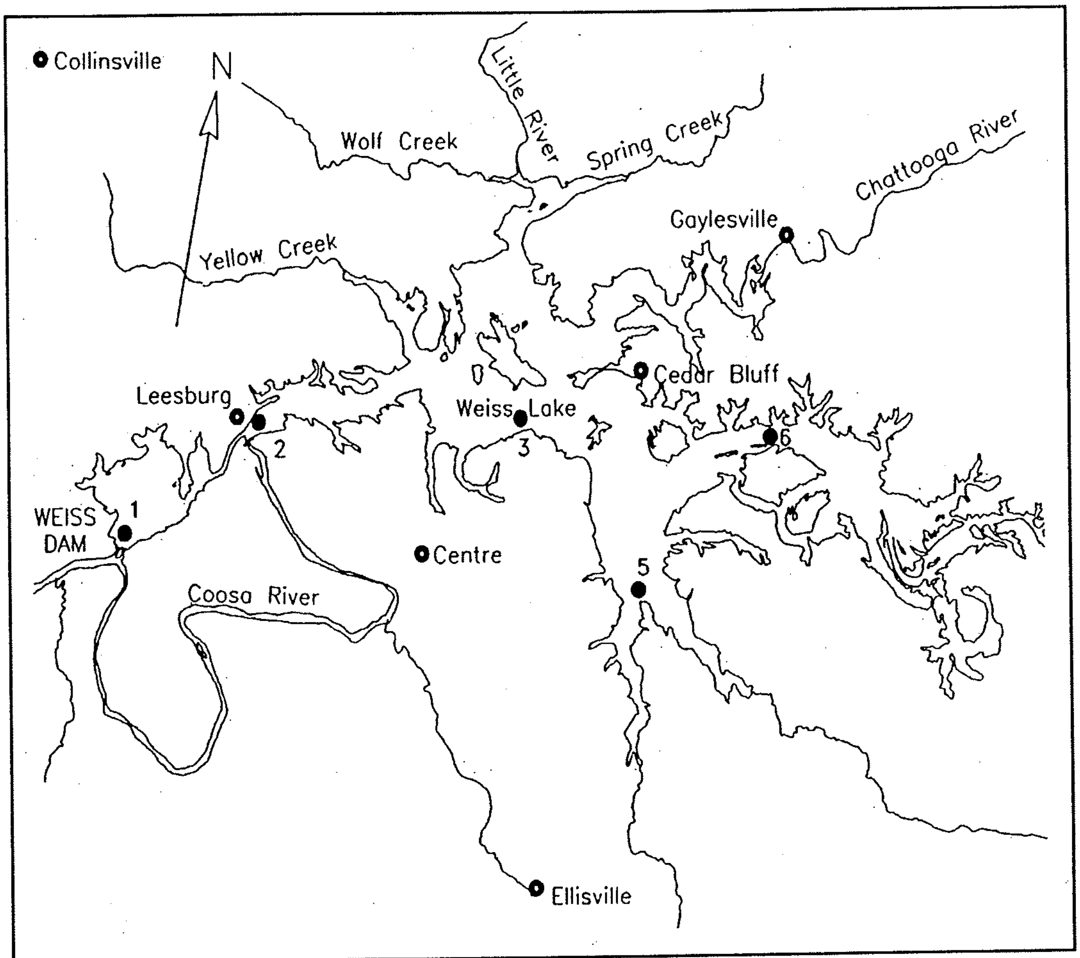


Figure 2. Weiss Reservoir site map. Numbers in lake represent station numbers

Figure 3. Walter F. George site map. Numbers in lake represent station numbers

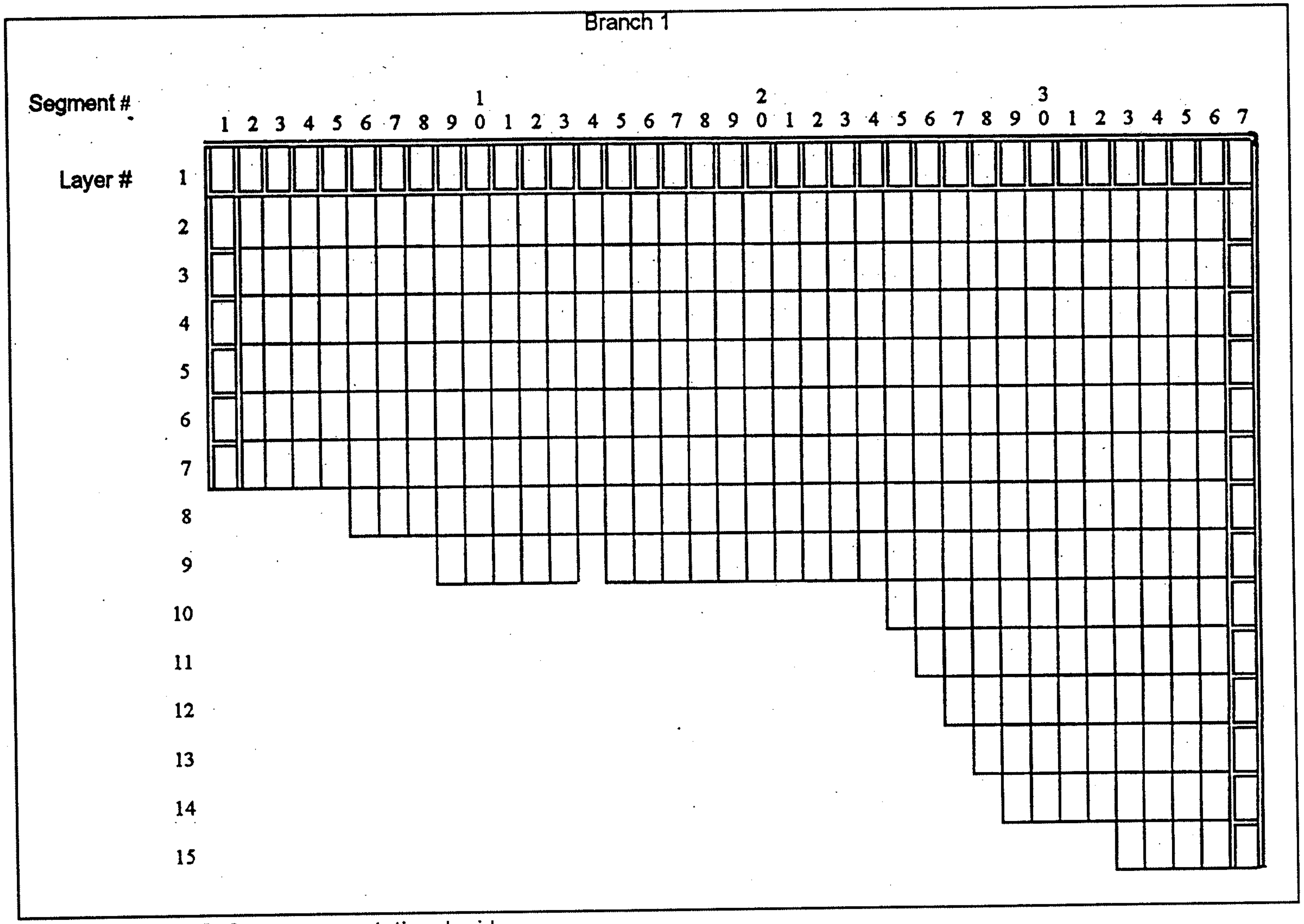


Figure 4. Walter F. George computational grid

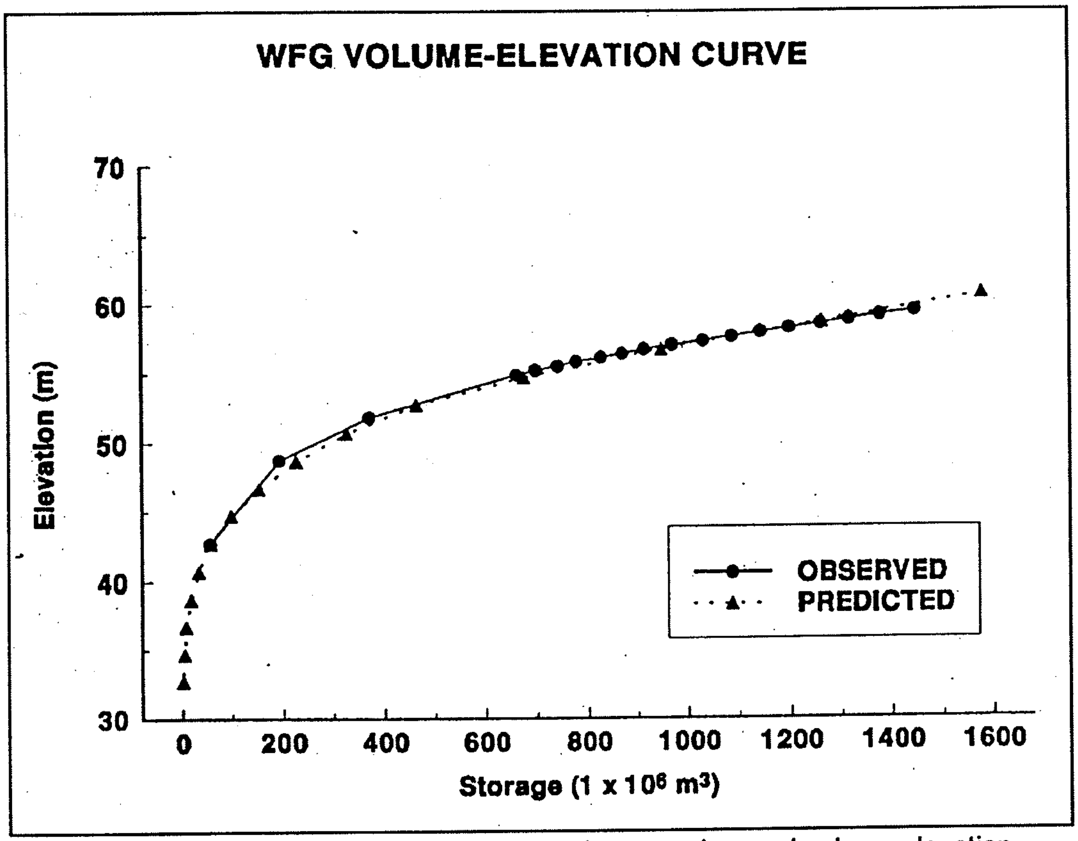


Figure 5. Walter F. George Reservoir computed versus observed volume elevation curve

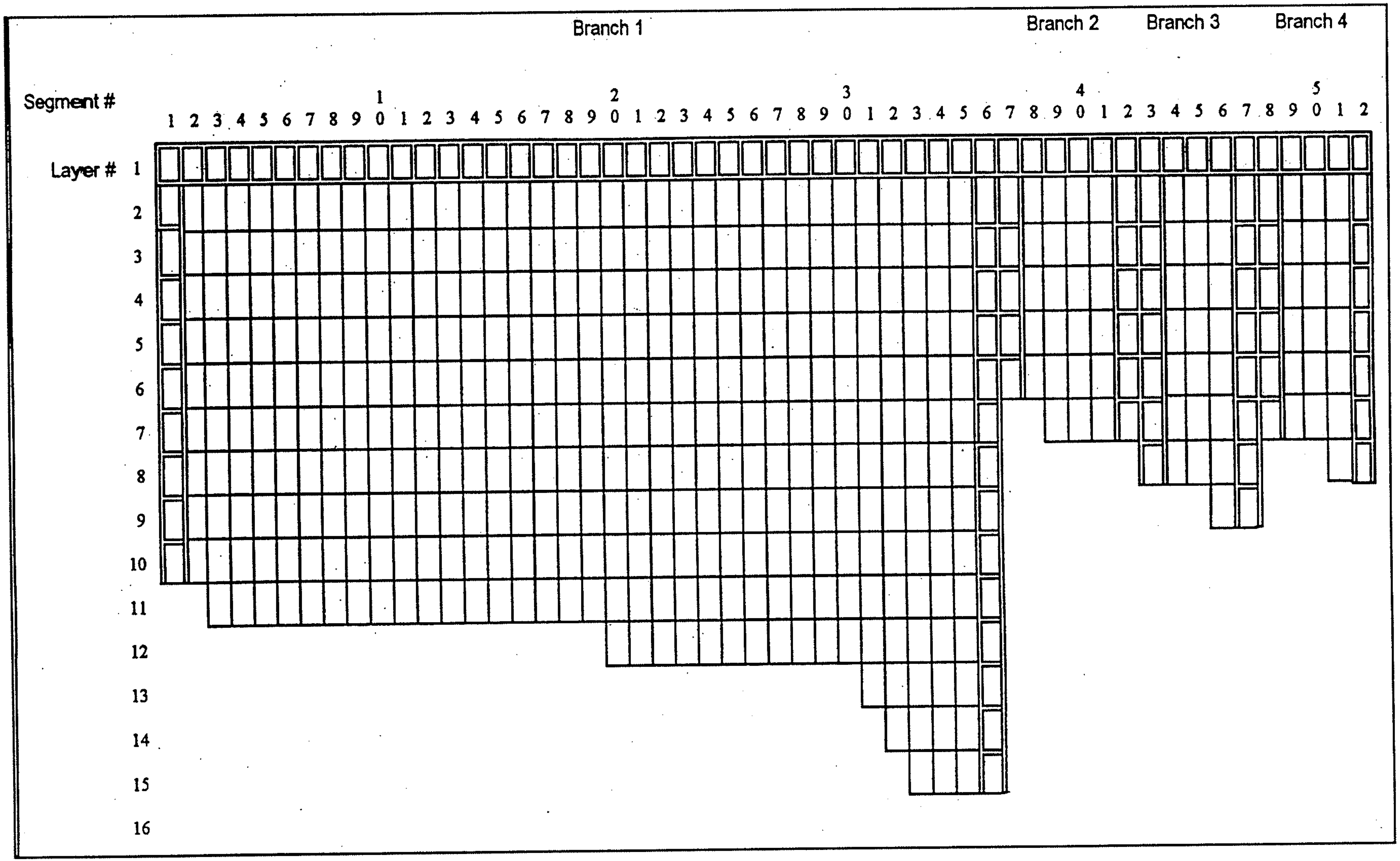


Figure 6. Neely Henry computational grid

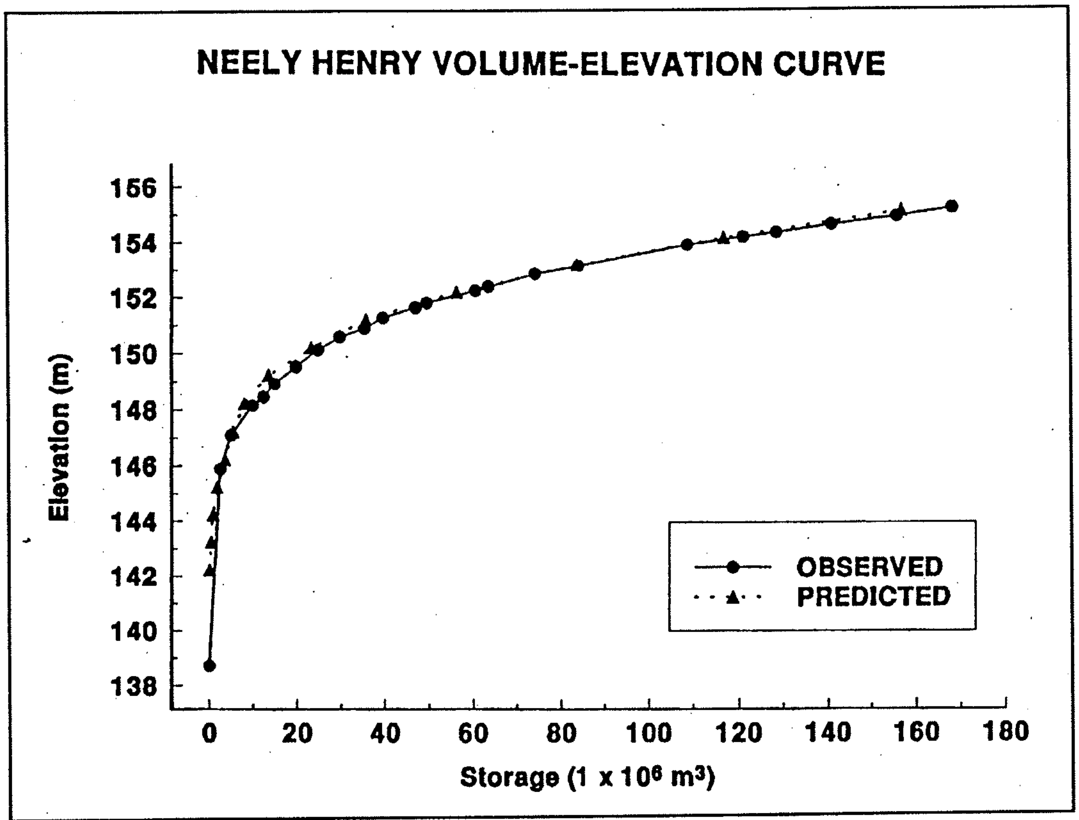


Figure 7. Neely Henry Reservoir computed versus observed volume-elevation curve

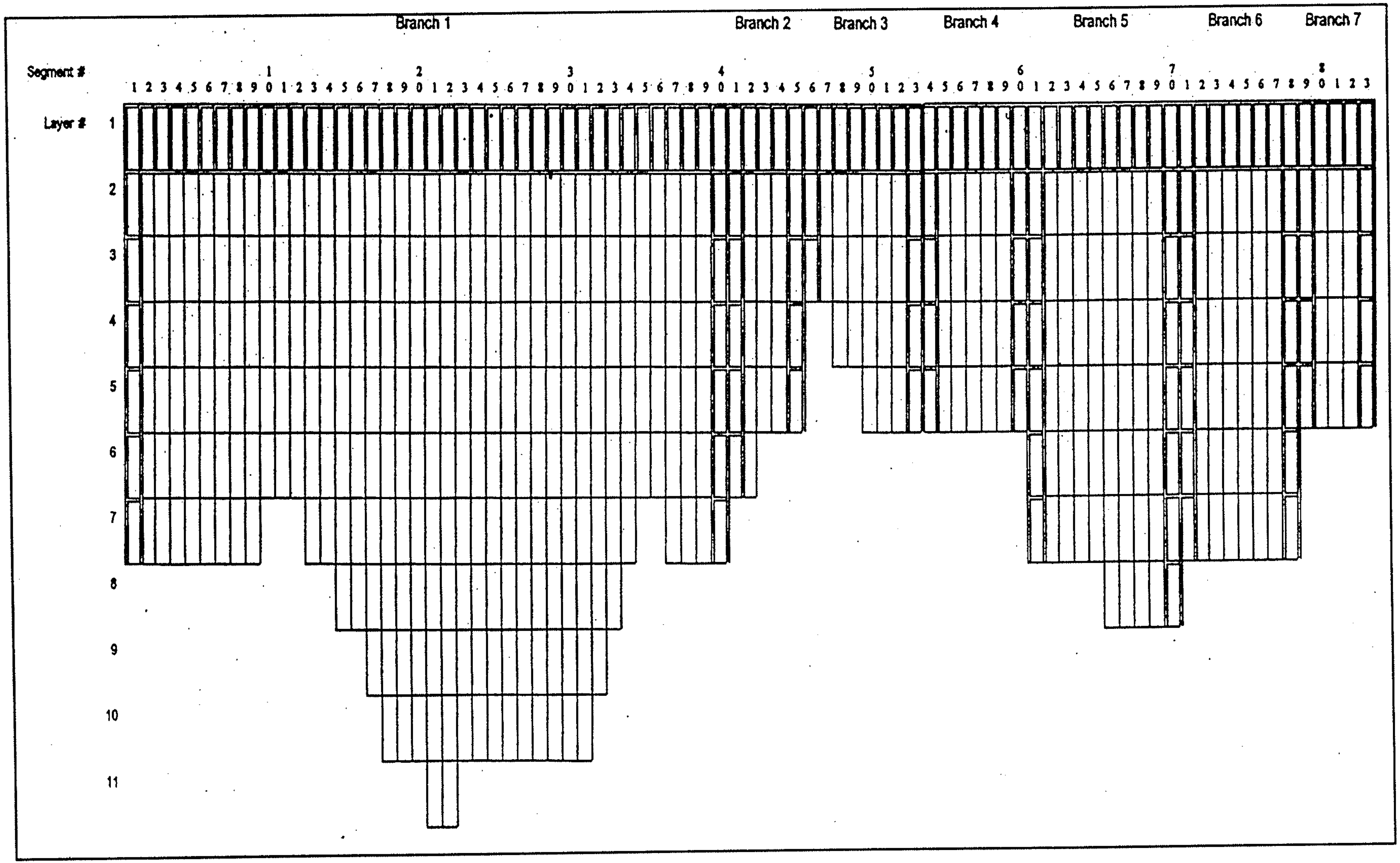


Figure 8. Weiss computational grid

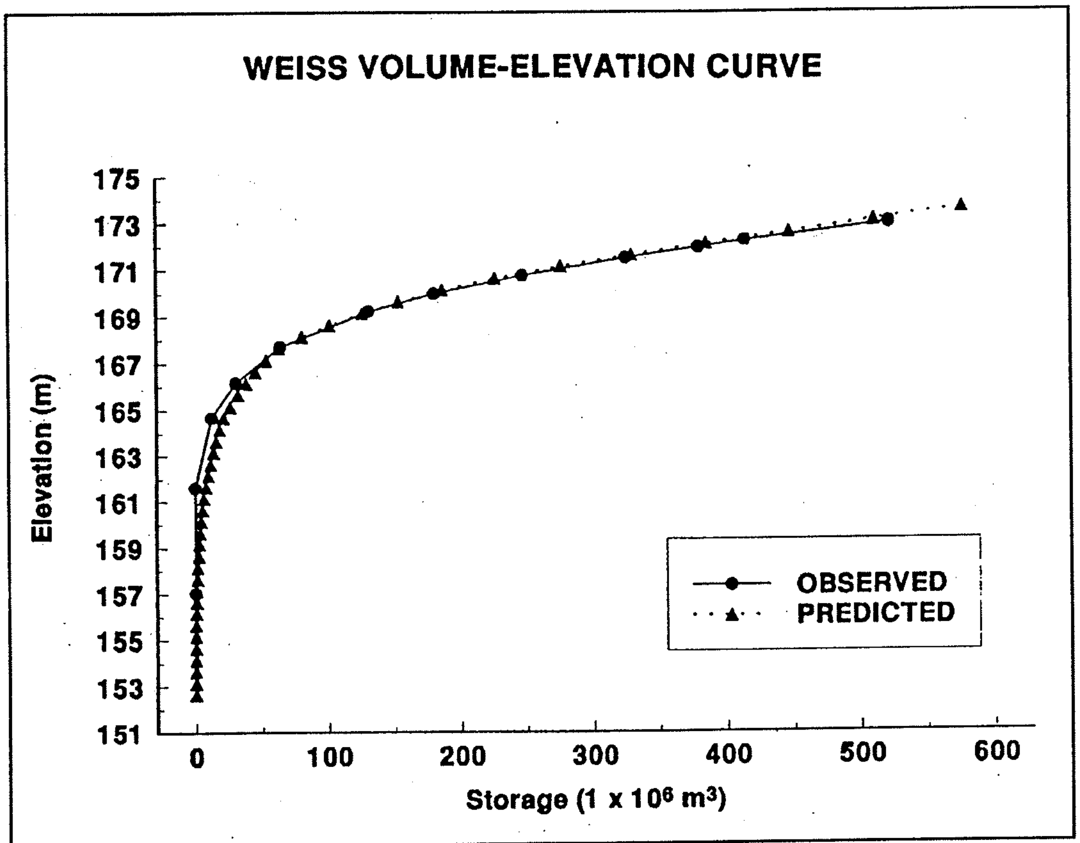


Figure 9. Weiss Reservoir computed versus observed volume-elevation curve

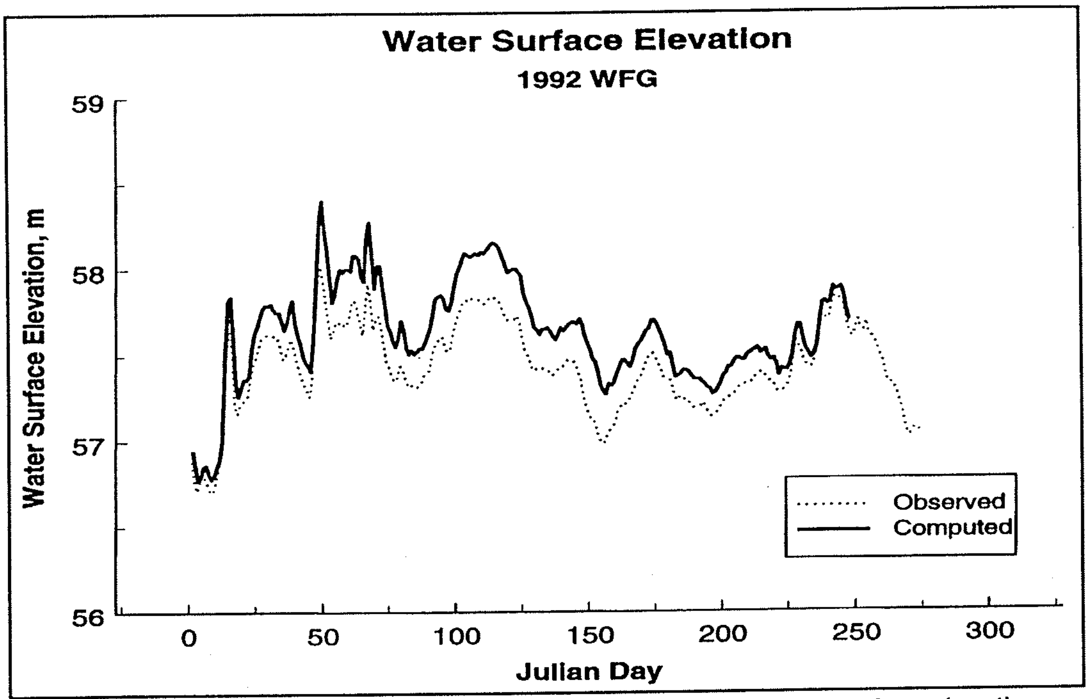


Figure 10. Walter F. George 1992 computed versus observed water surface elevations

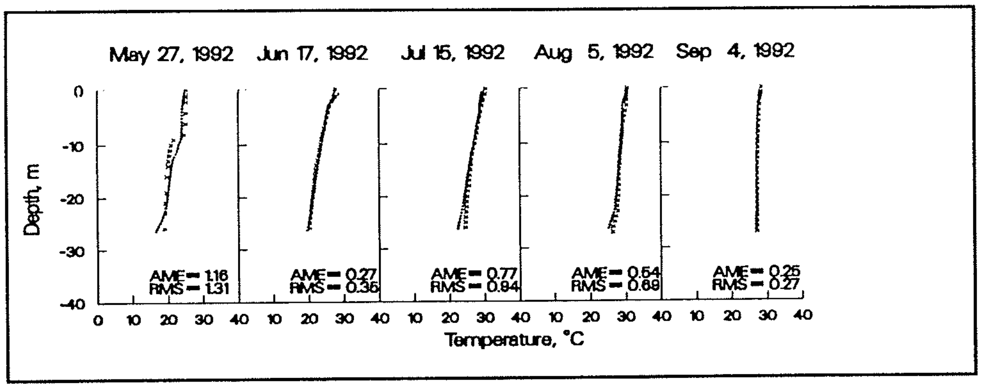


Figure 11. 1992 WFG temperature results for station 1

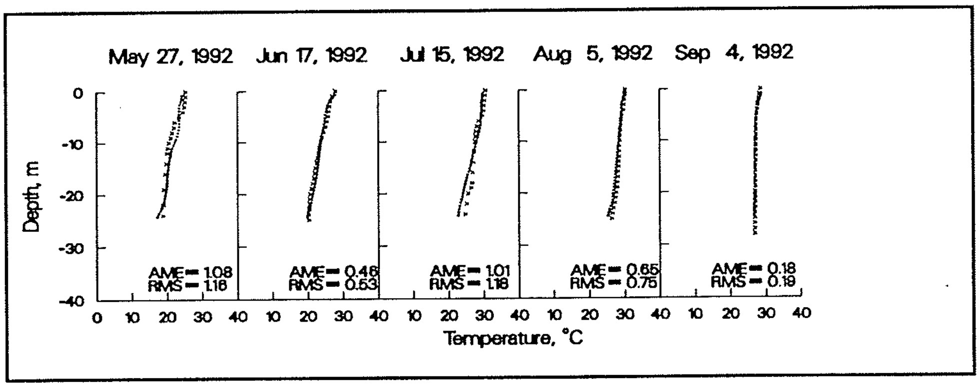


Figure 12. 1992 WFG temperature results for station 2

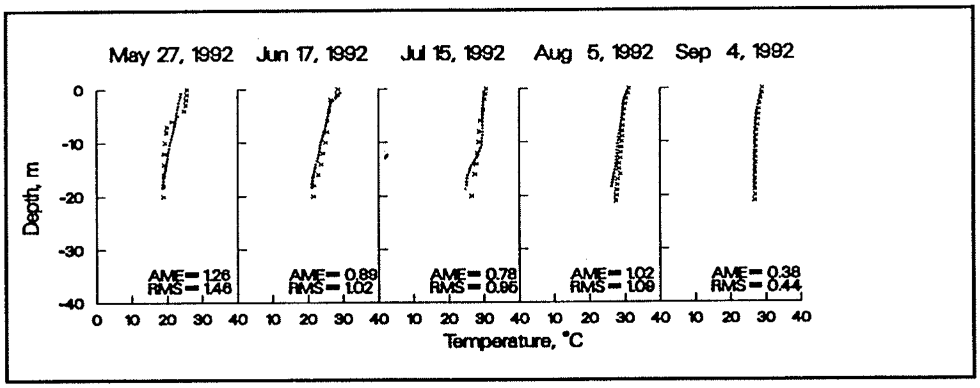


Figure 13. 1992 WFG temperature results for station 4

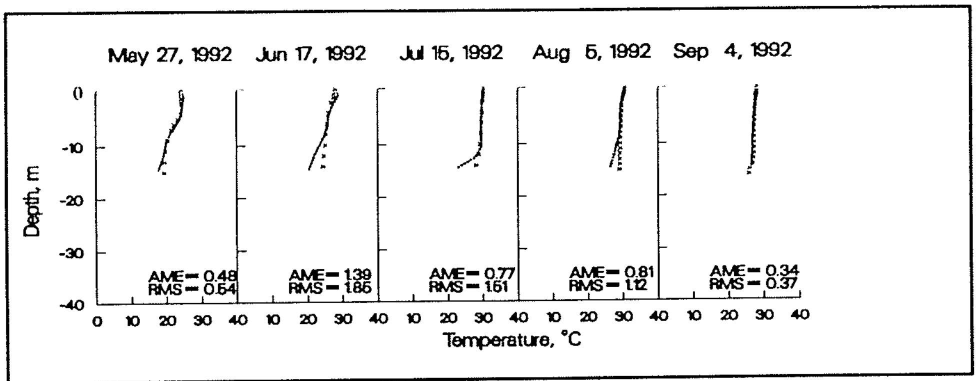


Figure 14. 1992 WFG temperature results for station 5

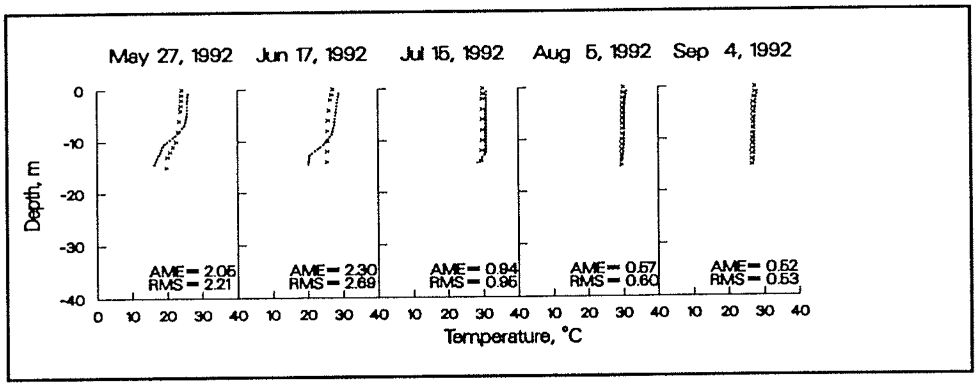


Figure 15. 1992 WFG temperature results for station 6

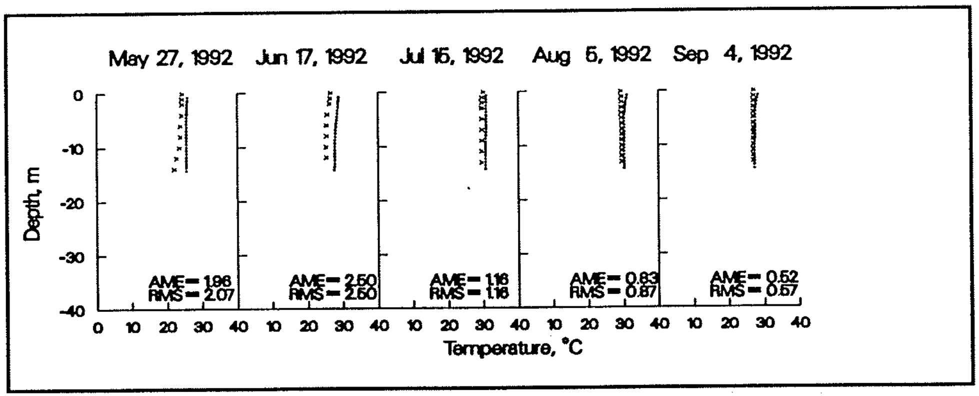


Figure 16. 1992 WFG temperature results for station 8

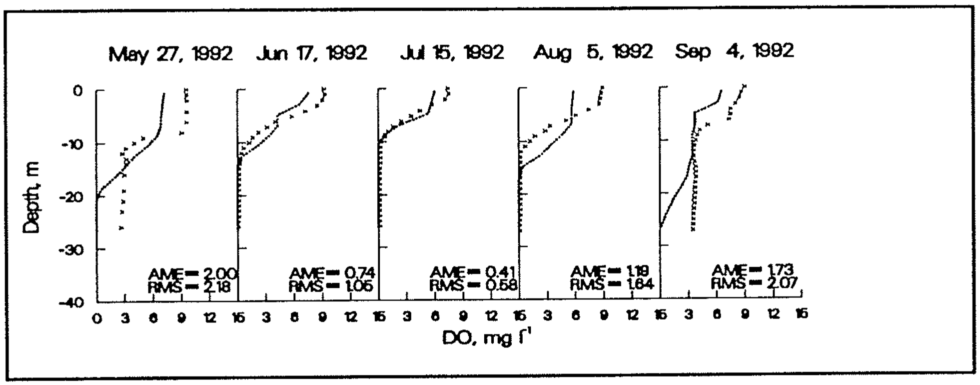


Figure 17. 1992 WFG DO results for station 1

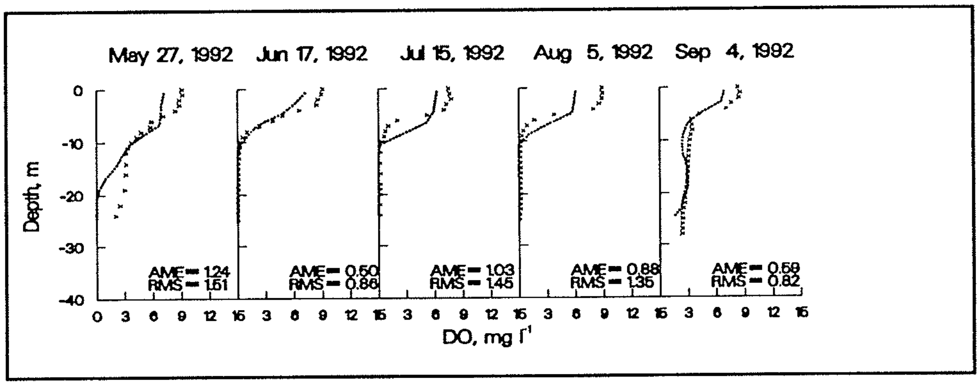


Figure 18. 1992 WFG DO results for station 2

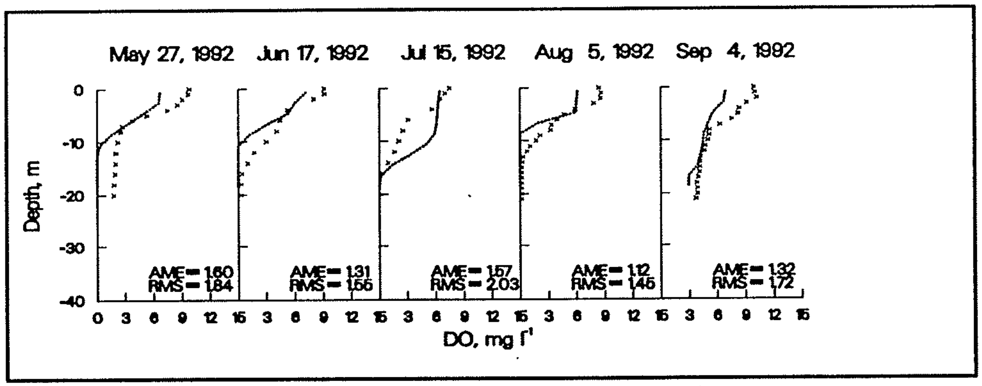


Figure 19. 1992 WFG DO results for station 4

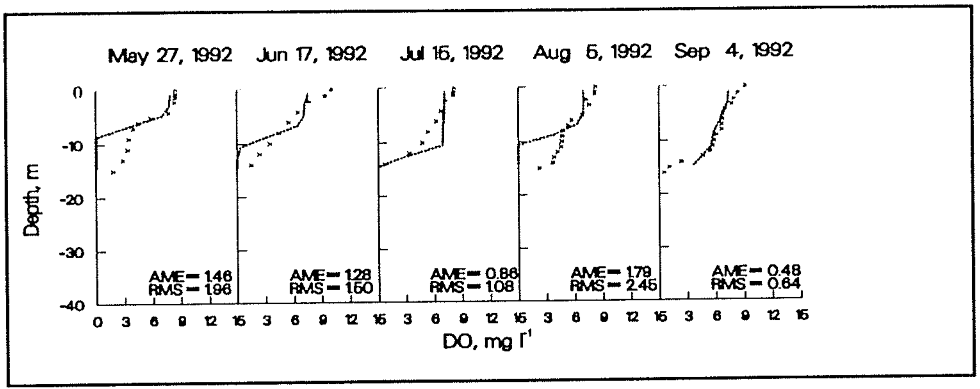


Figure 20. 1992 WFG DO results for station 5

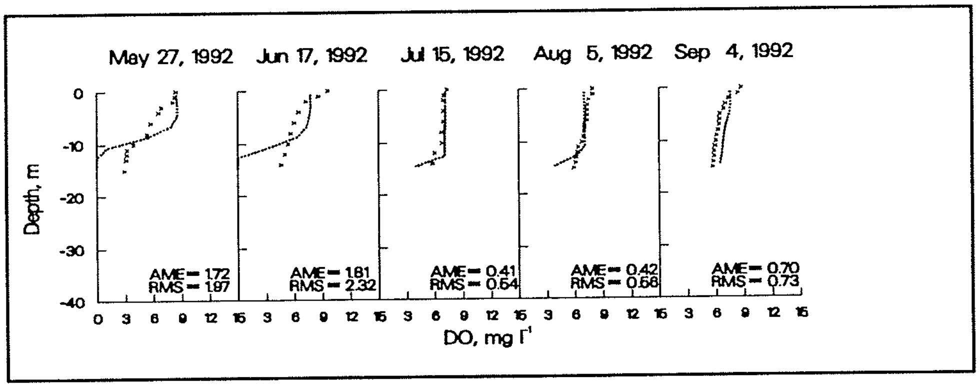


Figure 21. 1992 WFG DO results for station 6

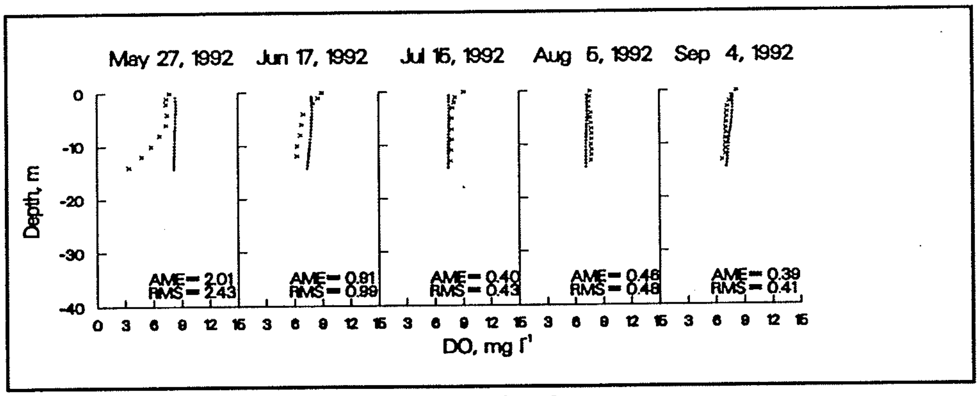


Figure 22. 1992 WFG DO results for station 8

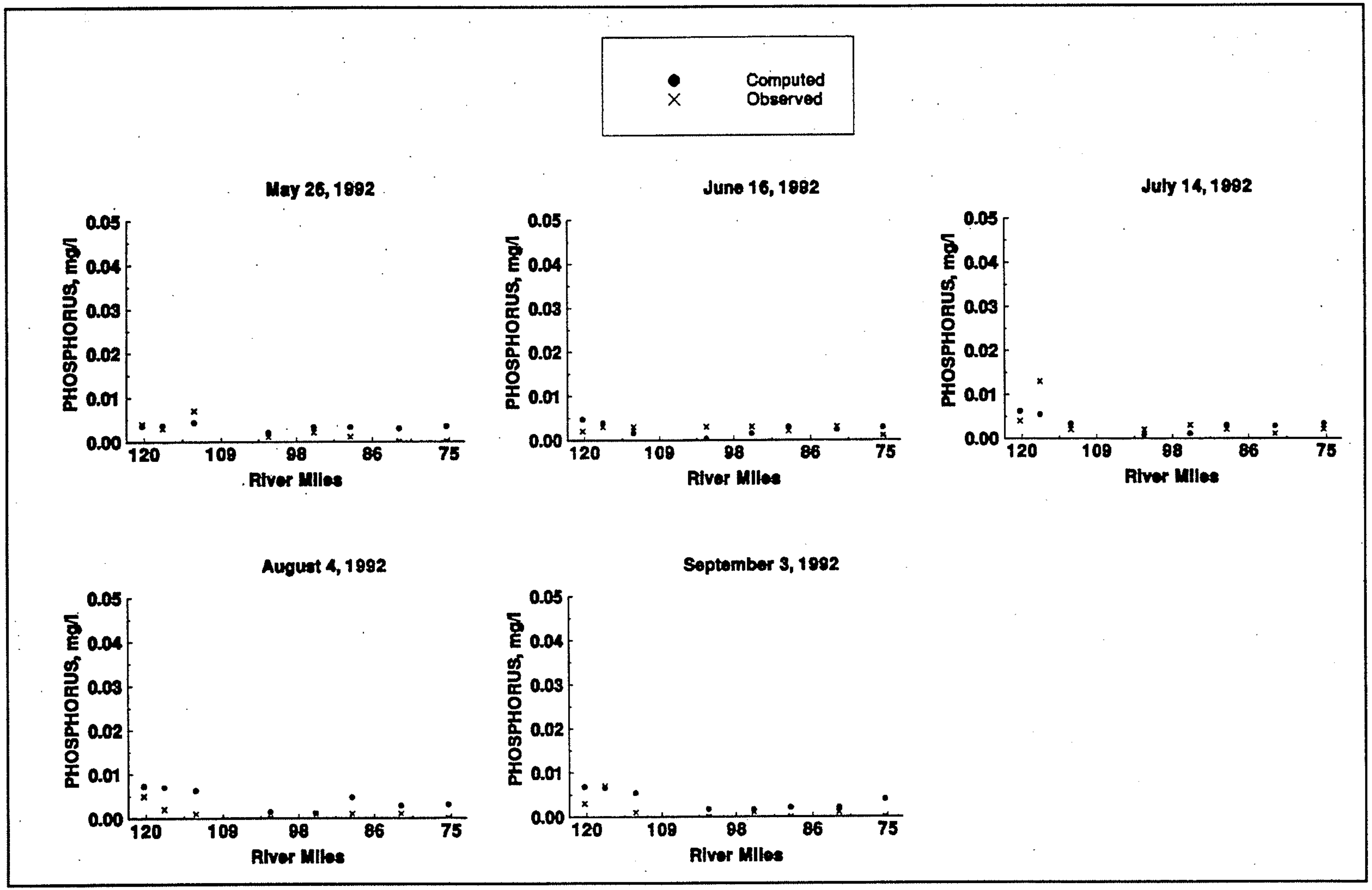


Figure 23. 1992 computed versus observed phosphorus at eight longitudinal locations within WFG

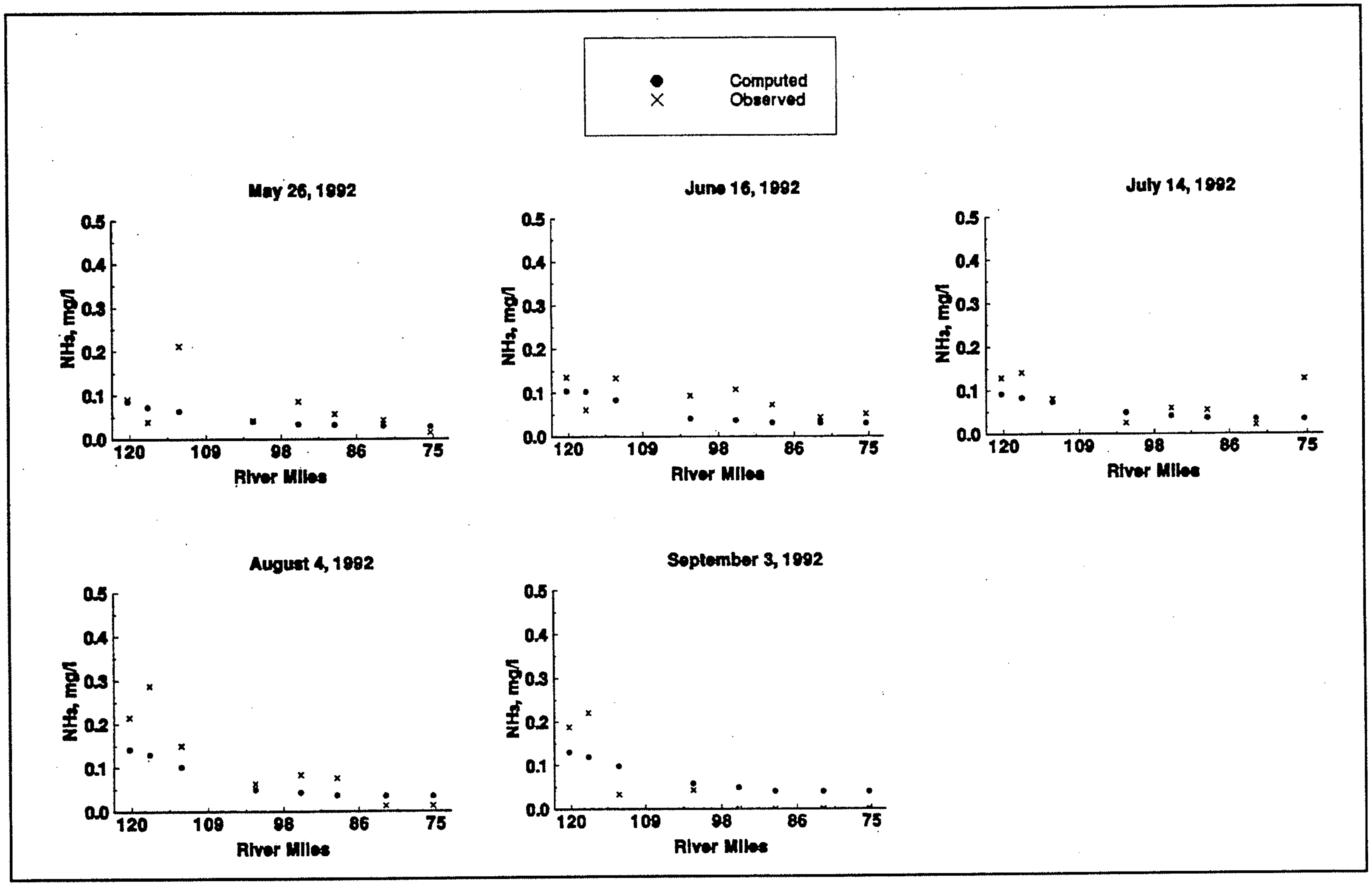


Figure 24. 1992 computed versus observed ammonium at eight longitudinal stations within WFG

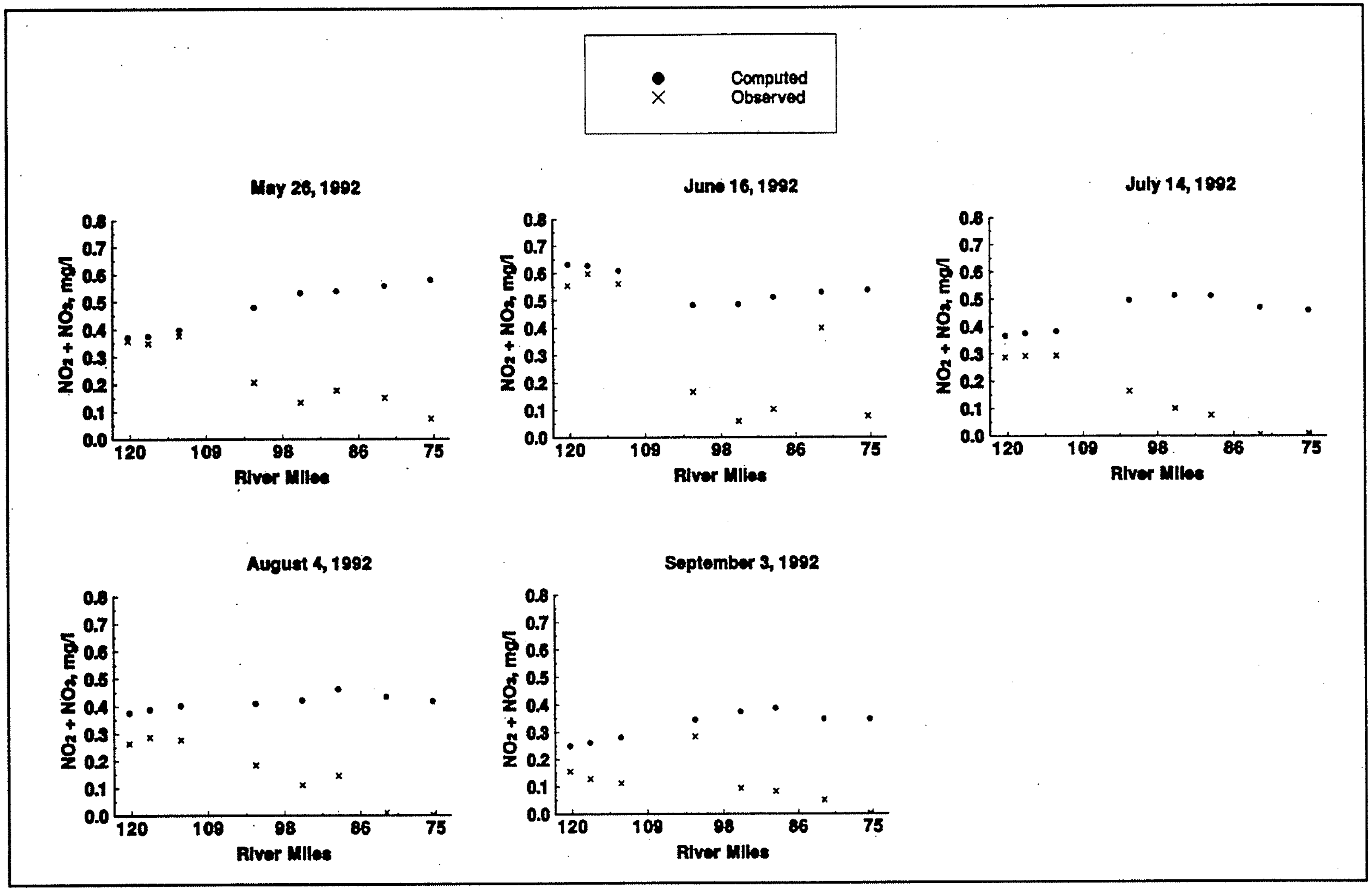


Figure 25. 1992 computed versus observed nitrate-nitrite at eight longitudinal locations within WFG

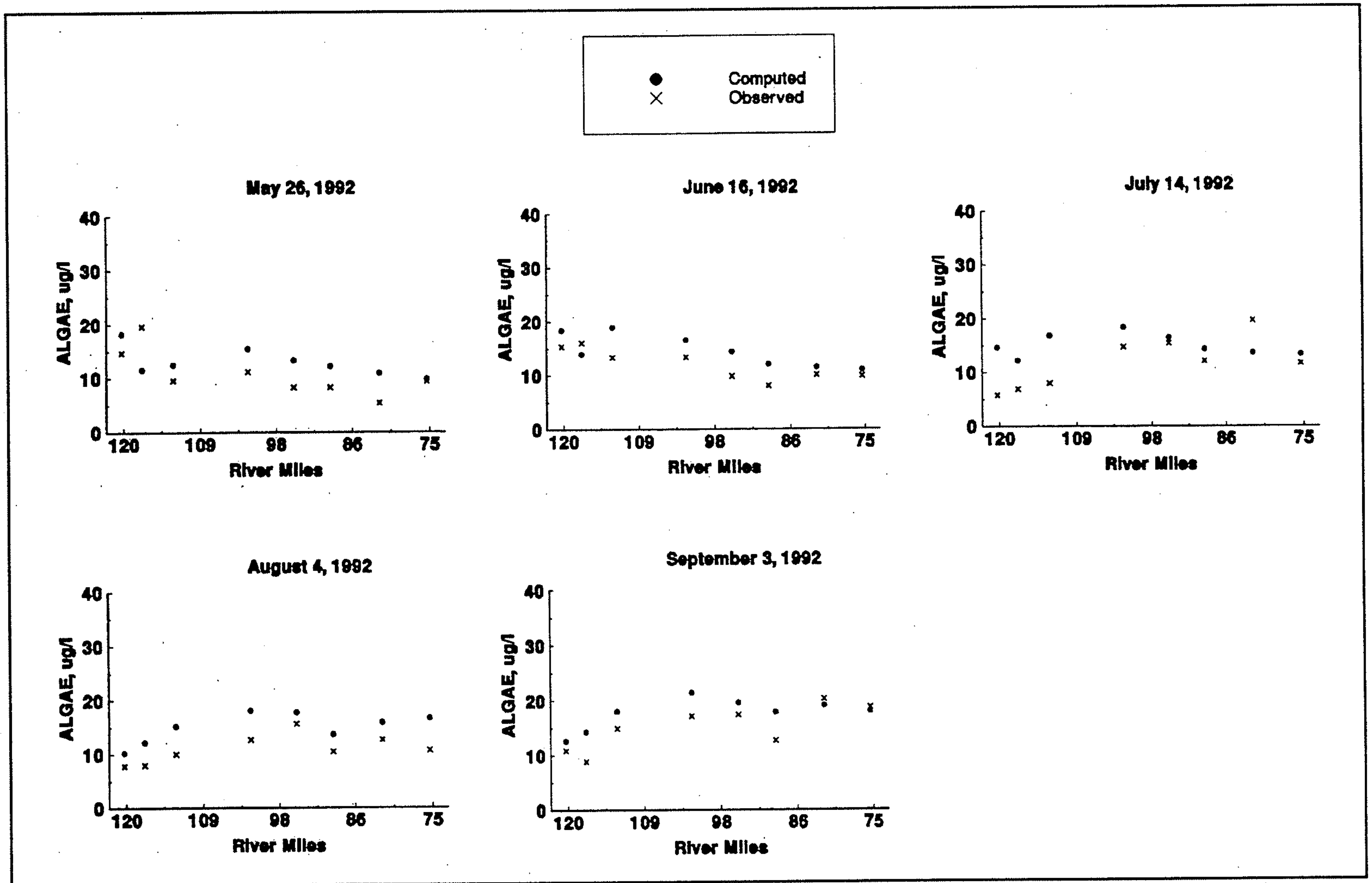


Figure 26. 1992 computed versus observed algae at eight longitudinal locations within WFG

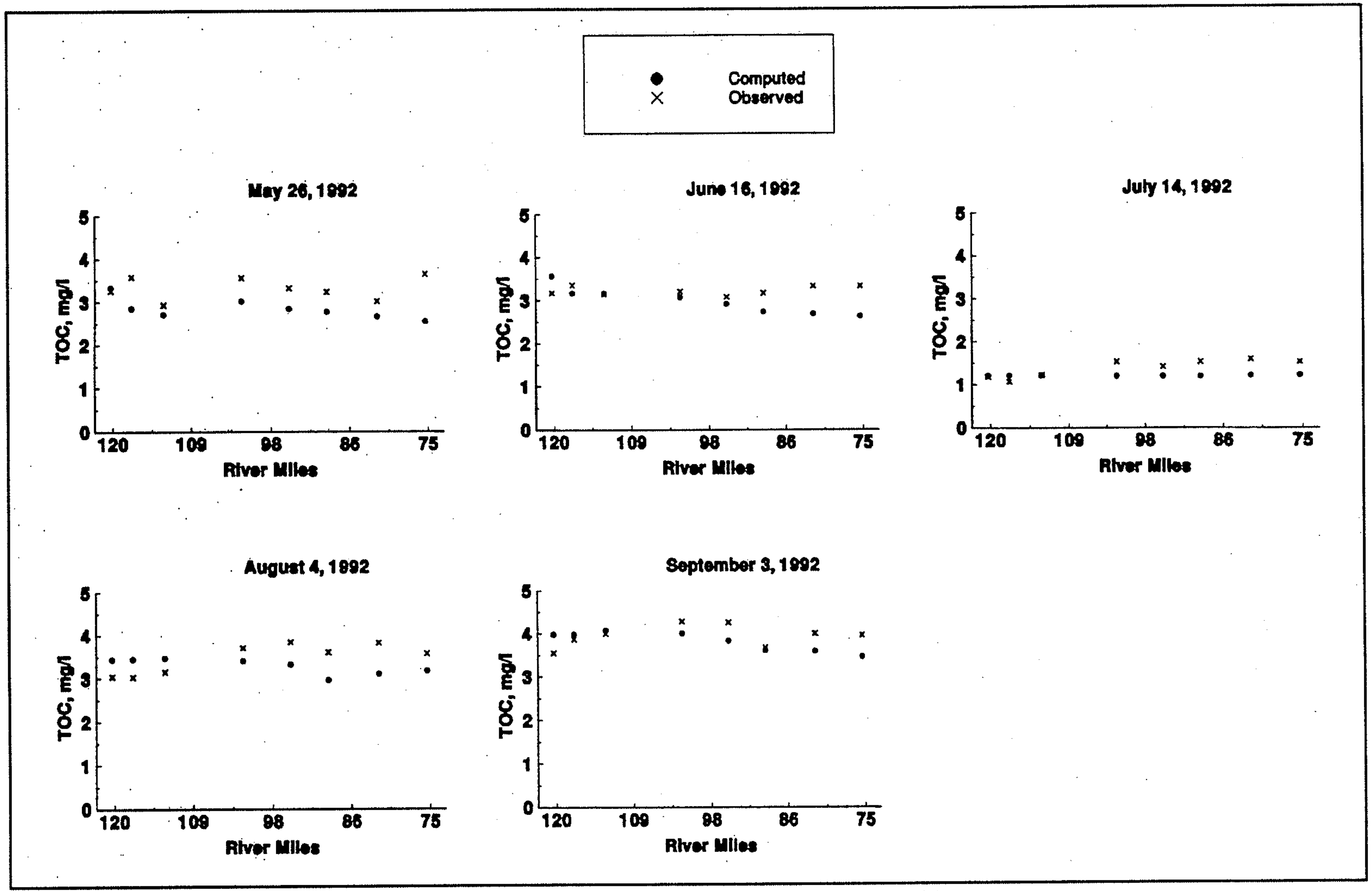


Figure 27. 1992 computed versus observed TOC at eight longitudinal locations within WFG

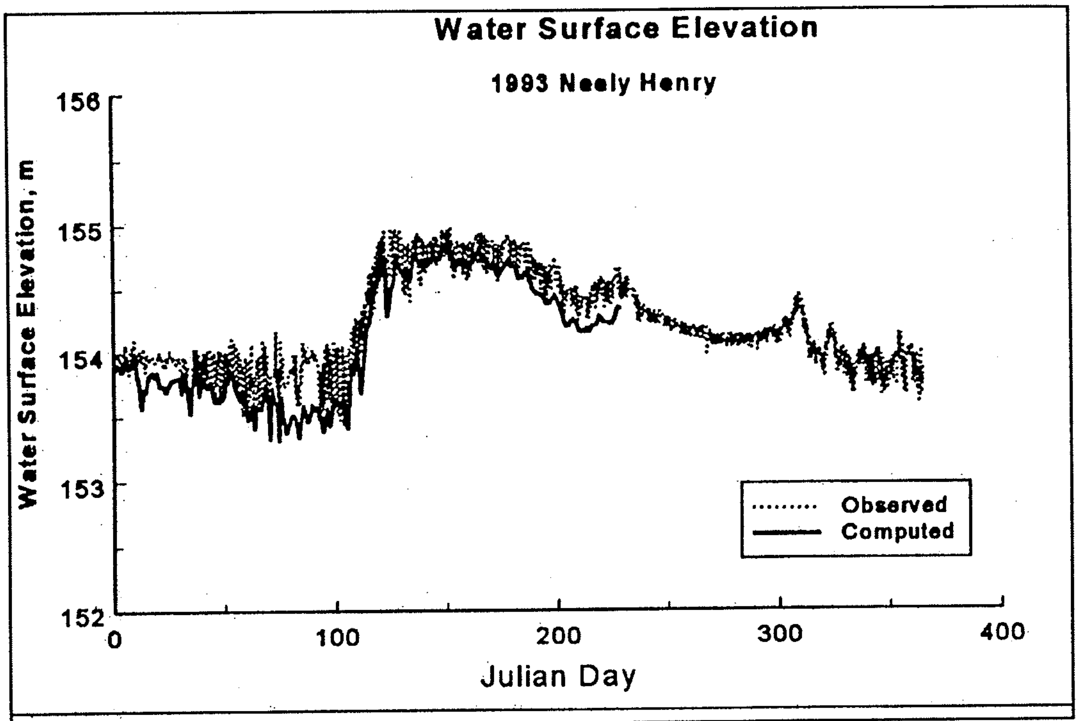


Figure 28. Neely Henry 1993 computed versus observed water surface elevations

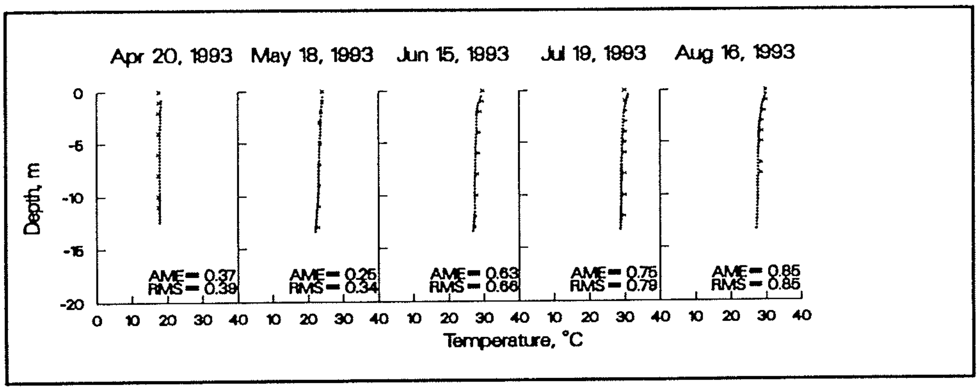


Figure 29. 1993 Neely Henry temperature results for station 1

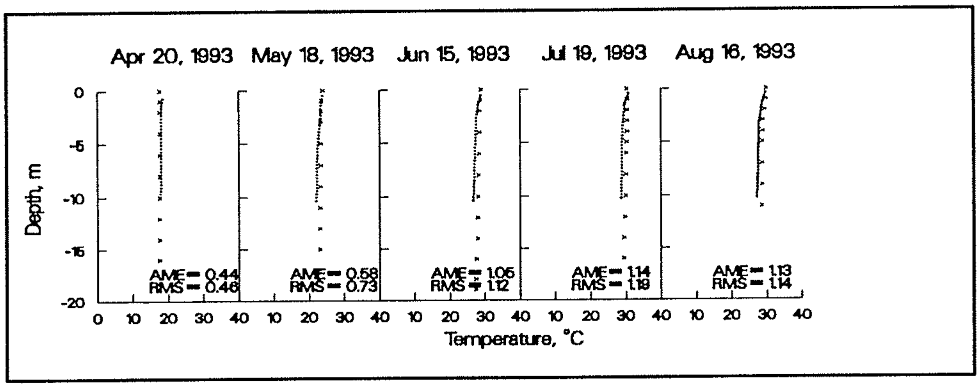


Figure 30. 1993 Neely Henry temperature results for station 2

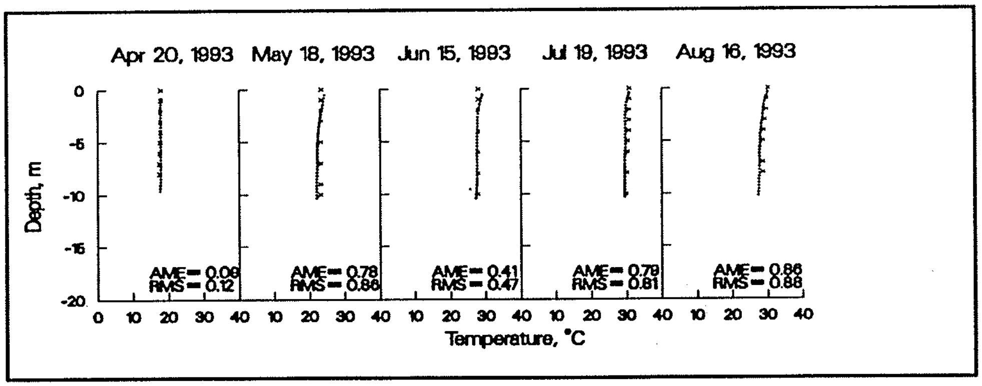


Figure 31. 1993 Neely Henry temperature results for station 4

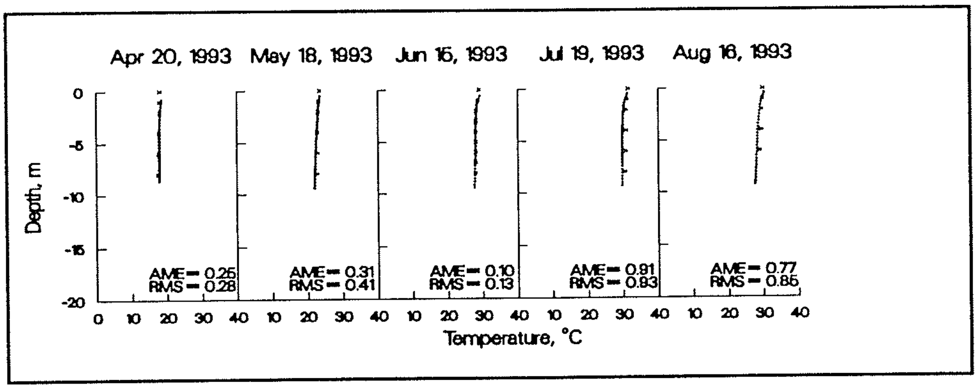


Figure 32. 1993 Neely Henry temperature results for station 6

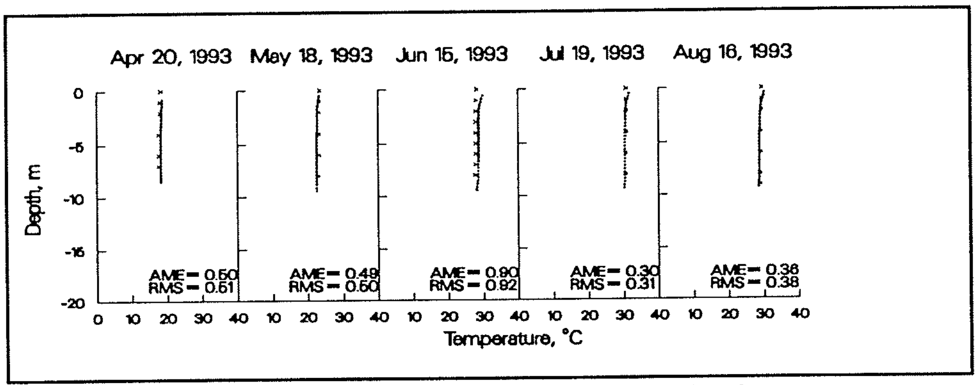


Figure 33. 1993 Neely Henry temperature results for station 8

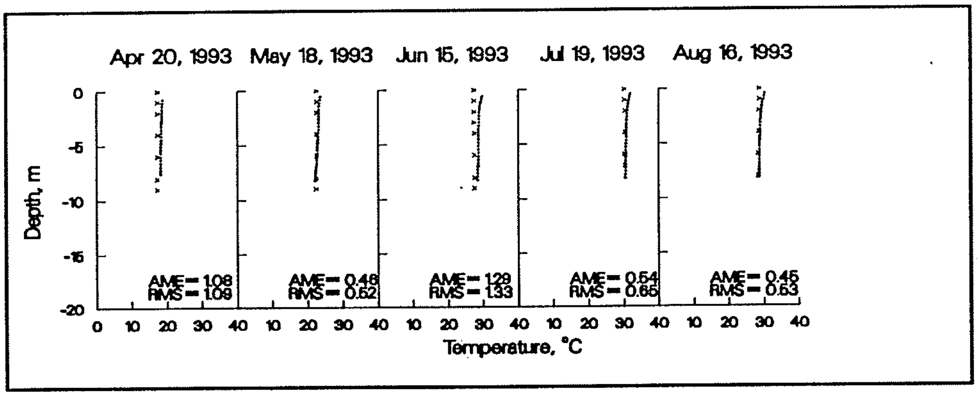


Figure 34. 1993 Neely Henry temperature results for station 10

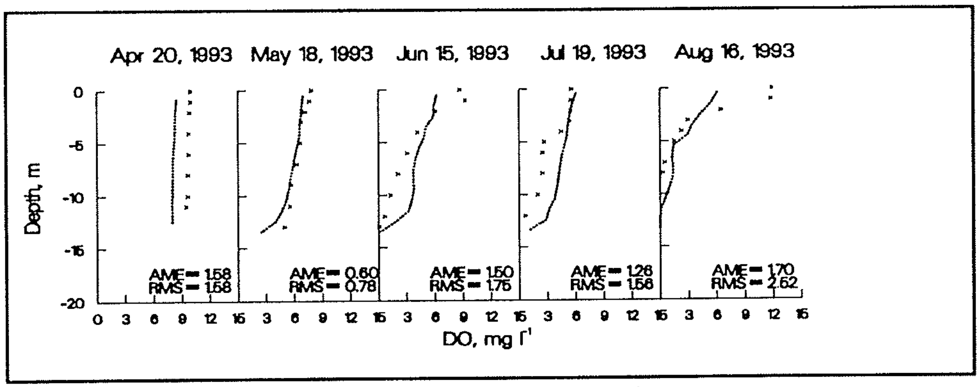


Figure 35. 1993 Neely Henry DO results for station 1

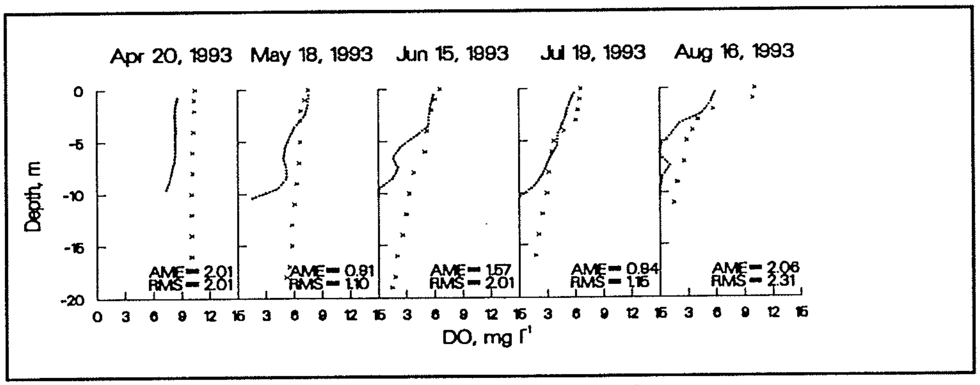


Figure 36. 1993 Neely Henry DO results for station 2

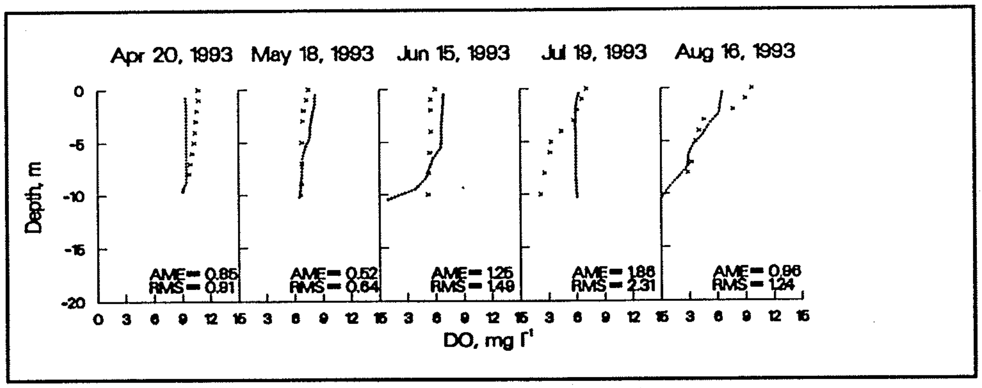


Figure 37. 1993 Neely Henry DO results for station 4

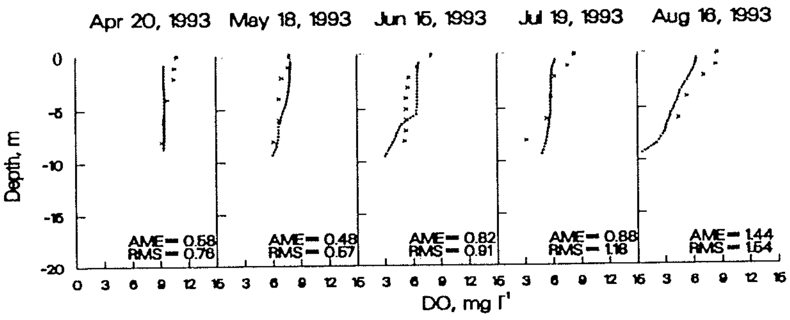


Figure 38. 1993 Neely Henry DO results for station 6

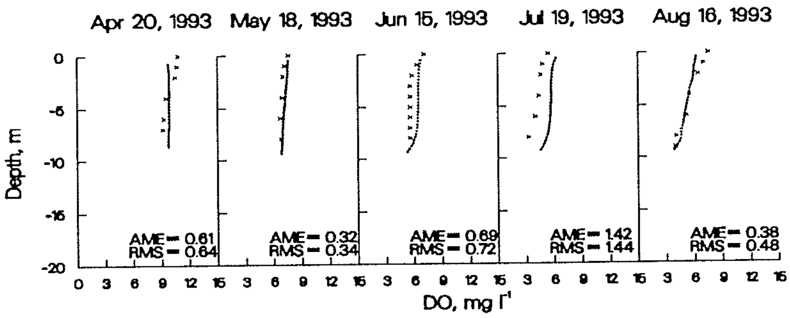


Figure 39. 1993 Neely Henry DO results for station 8

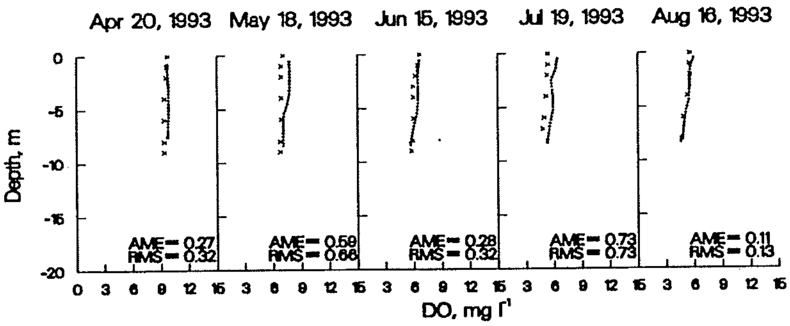


Figure 40. 1993 Neely Henry DO results for station 10

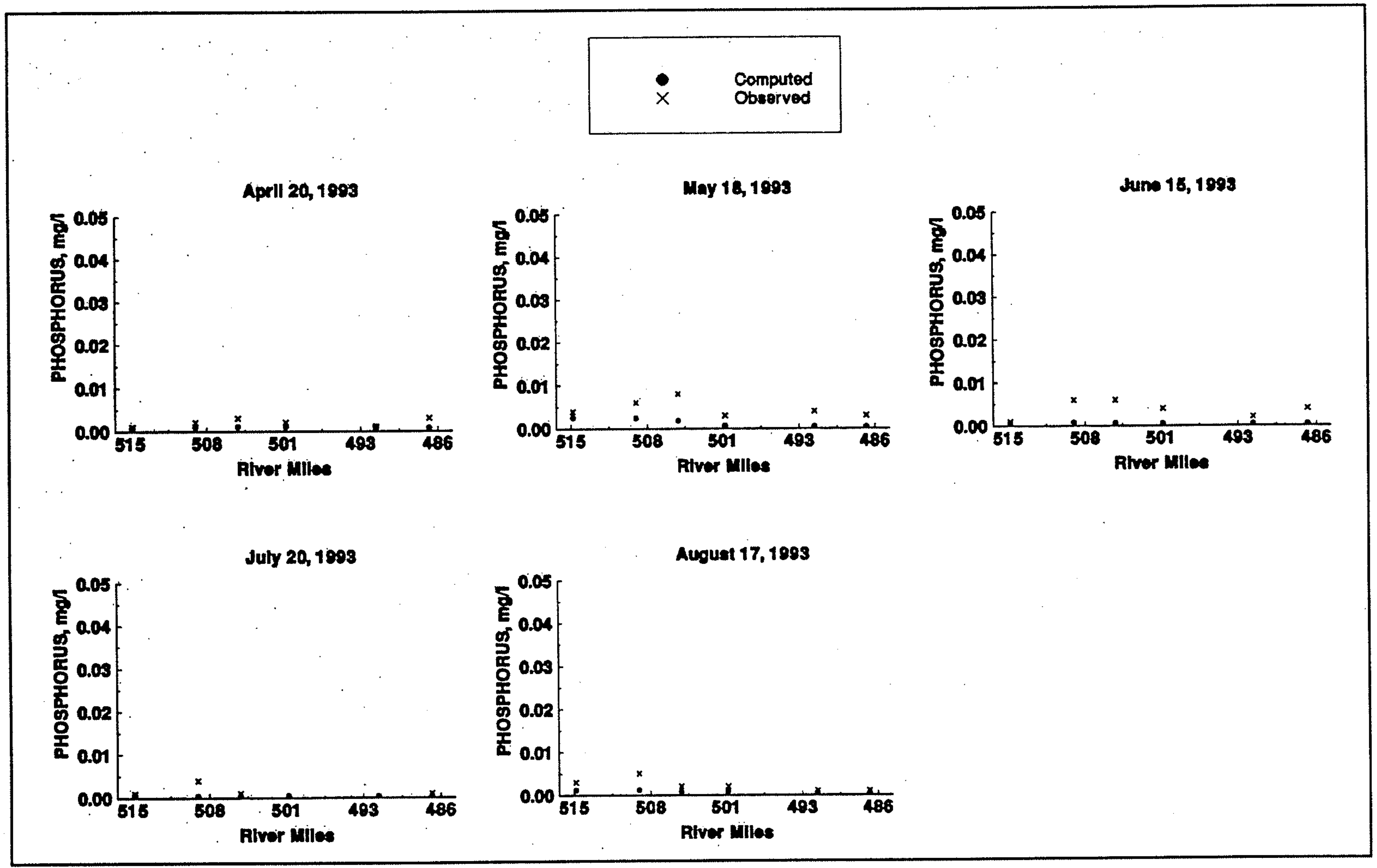


Figure 41. 1993 computed versus observed phosphorus at six longitudinal locations within Neely Henry

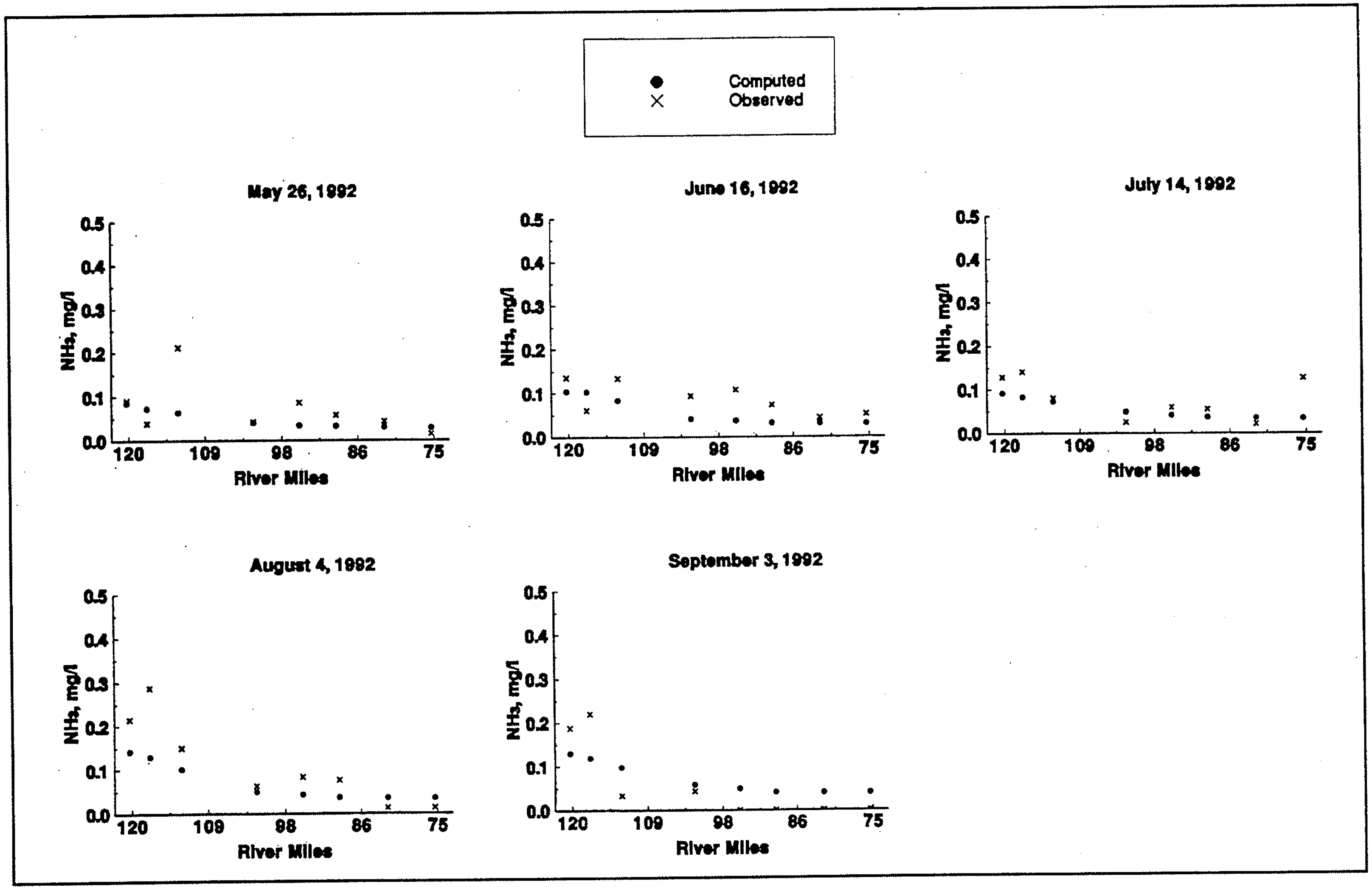


Figure 42. 1993 computed versus observed ammonium at six longitudinal stations within Neely Henry

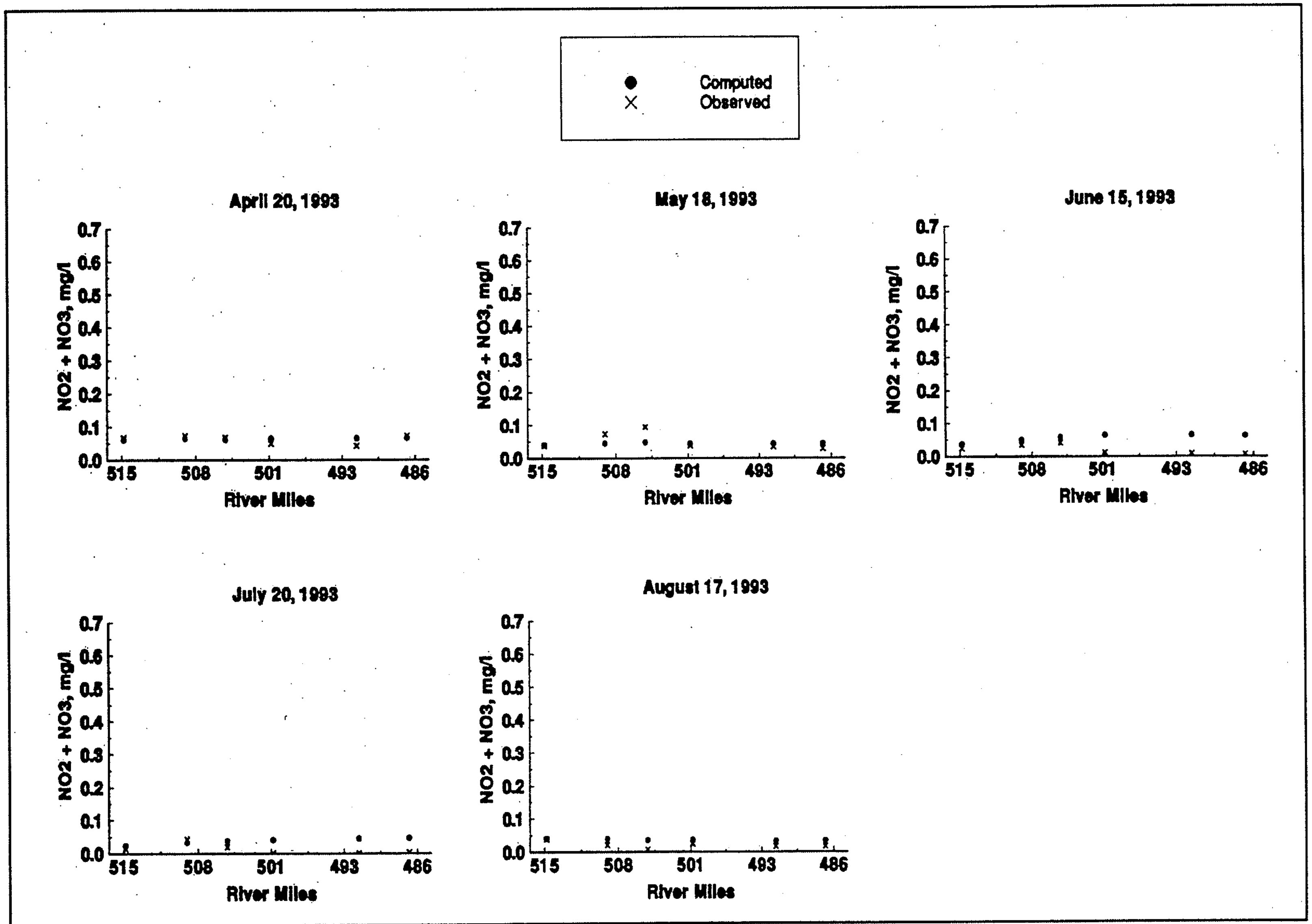


Figure 43. 1993 computed versus observed nitrate-nitrite at six longitudinal locations within Neely Henry

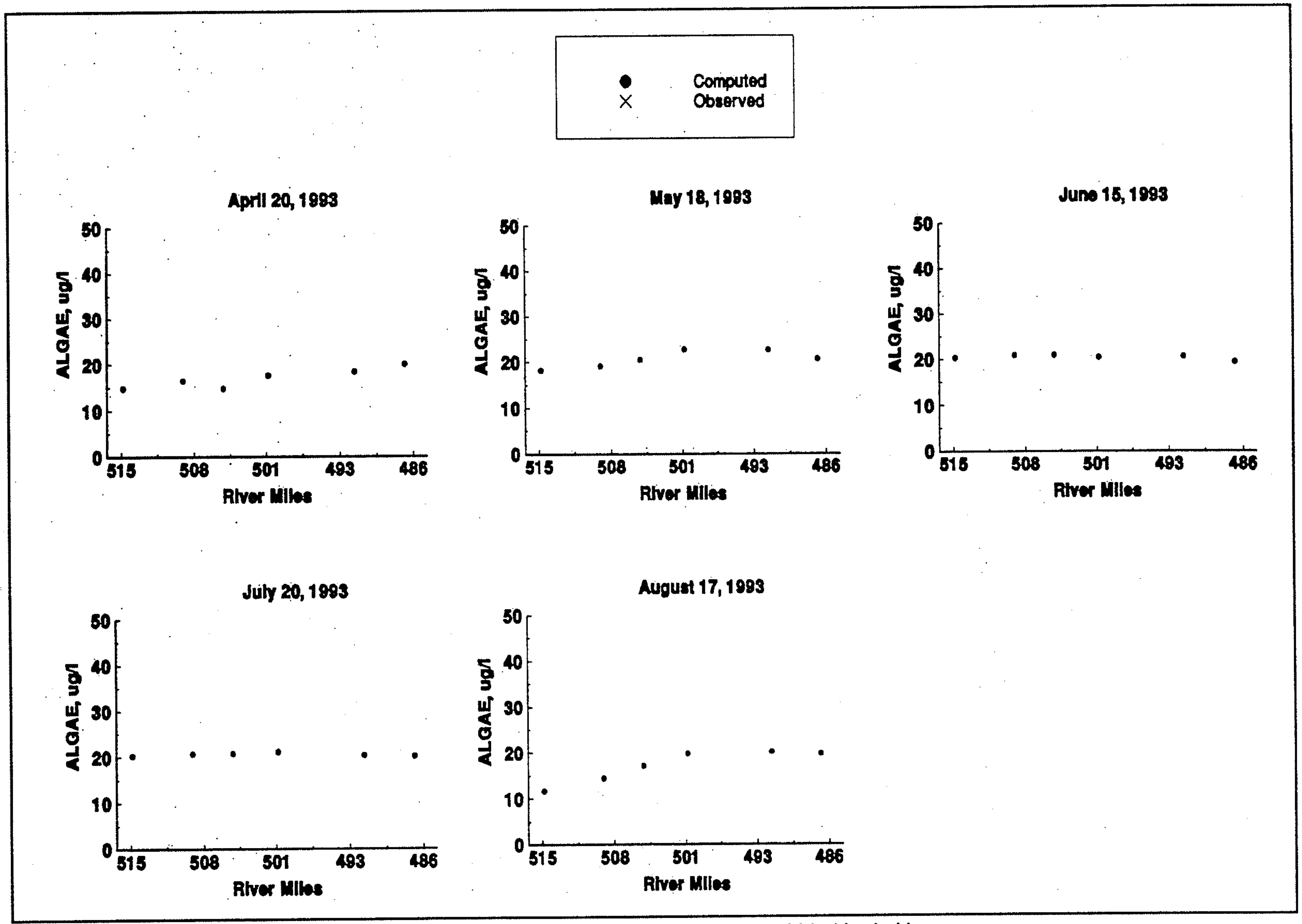


Figure 44. 1993 computed versus observed algae at six longitudinal locations within Neely Henry

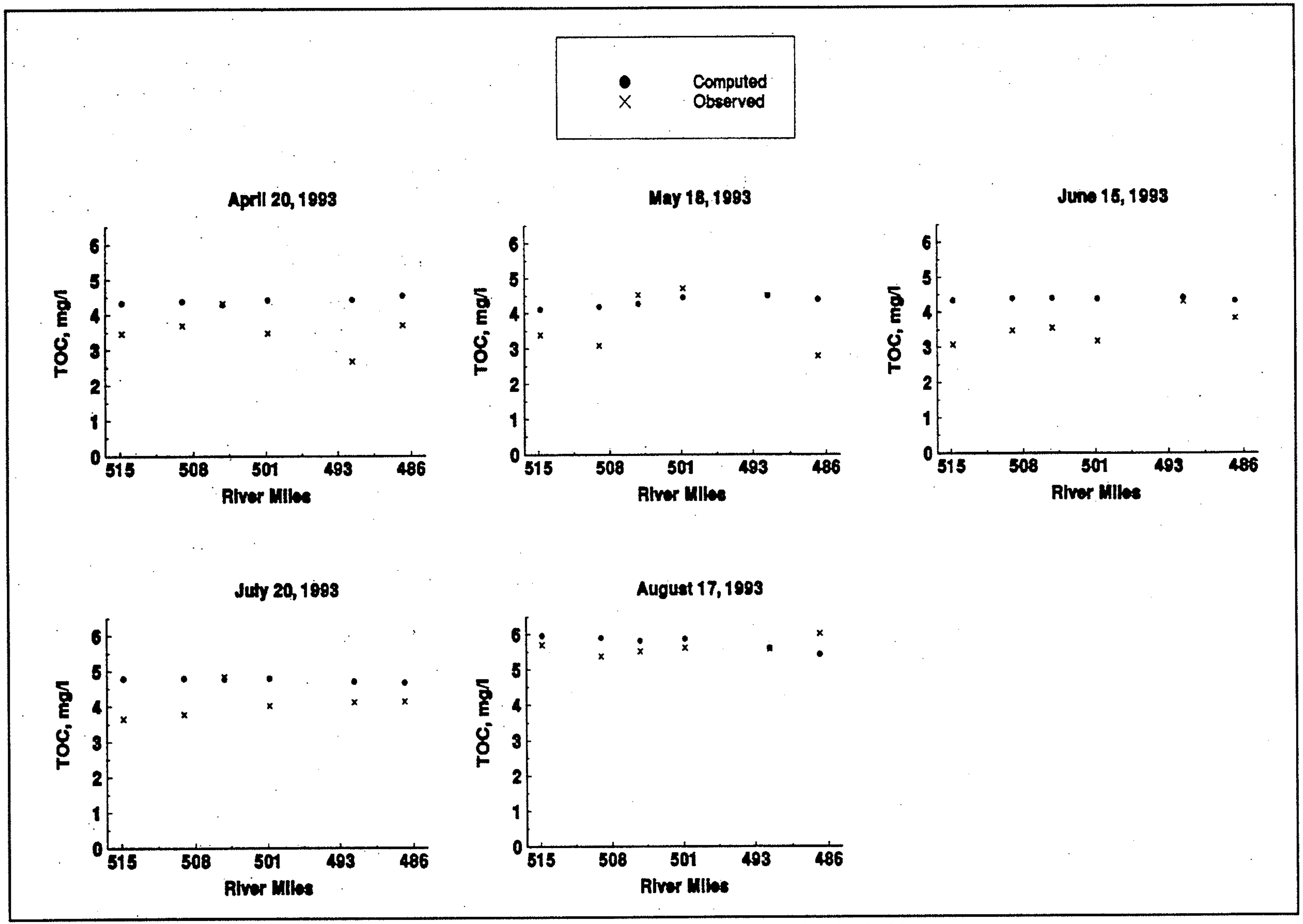


Figure 45. 1993 computed versus observed TOC at six longitudinal locations within Neely Henry

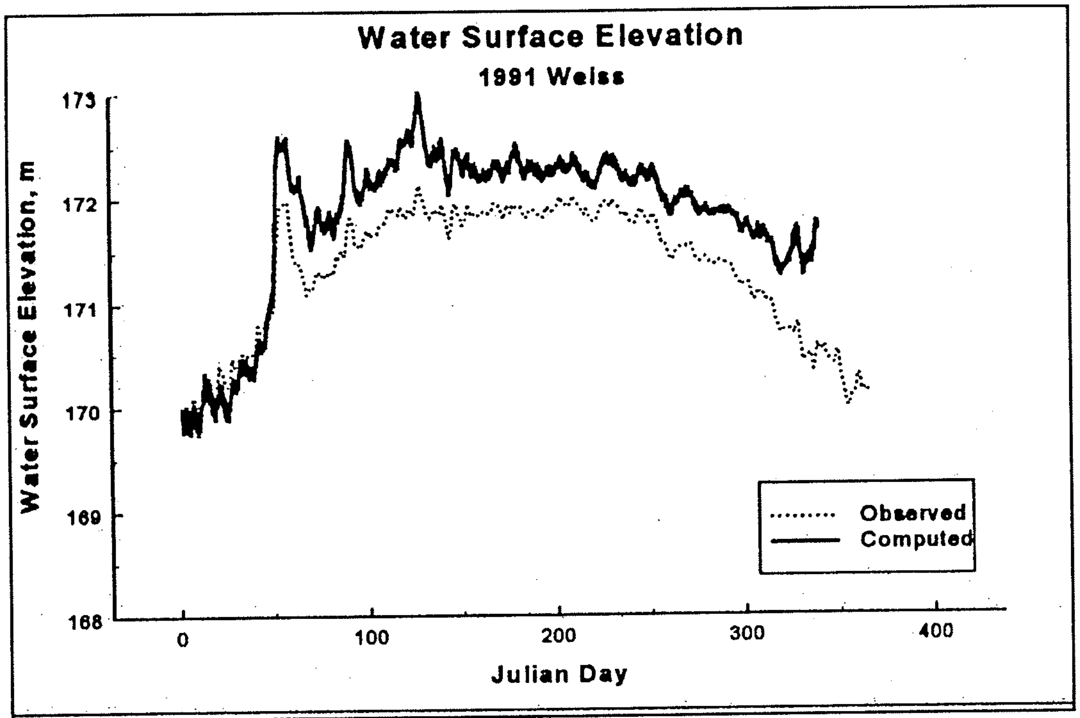


Figure 46. Weiss 1991 computed versus observed water surface elevations

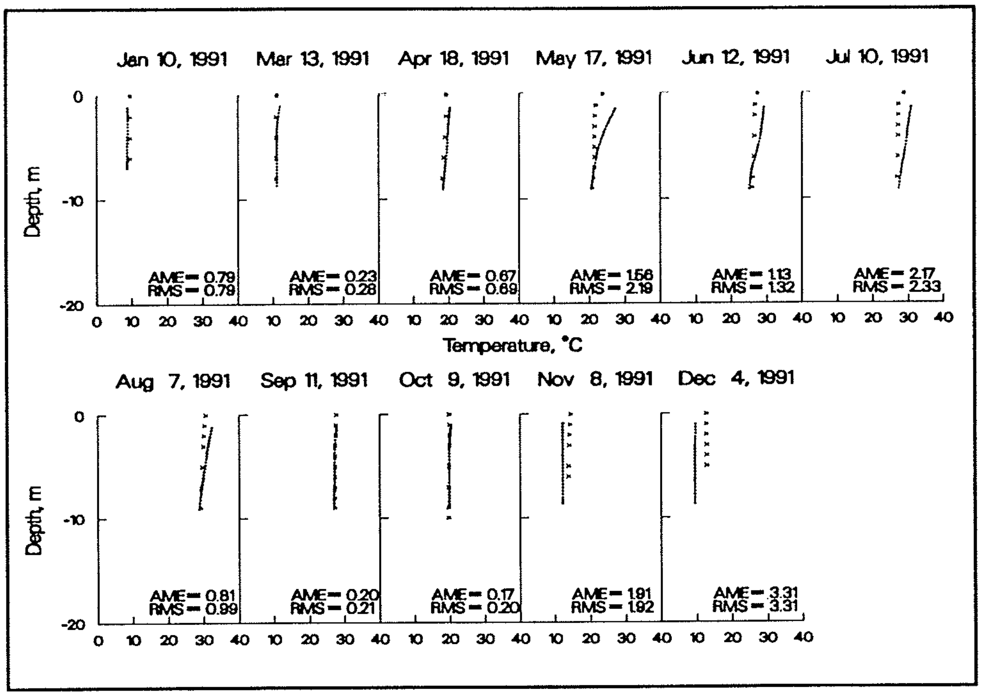


Figure 47. 1991 Weiss temperature results for station 1

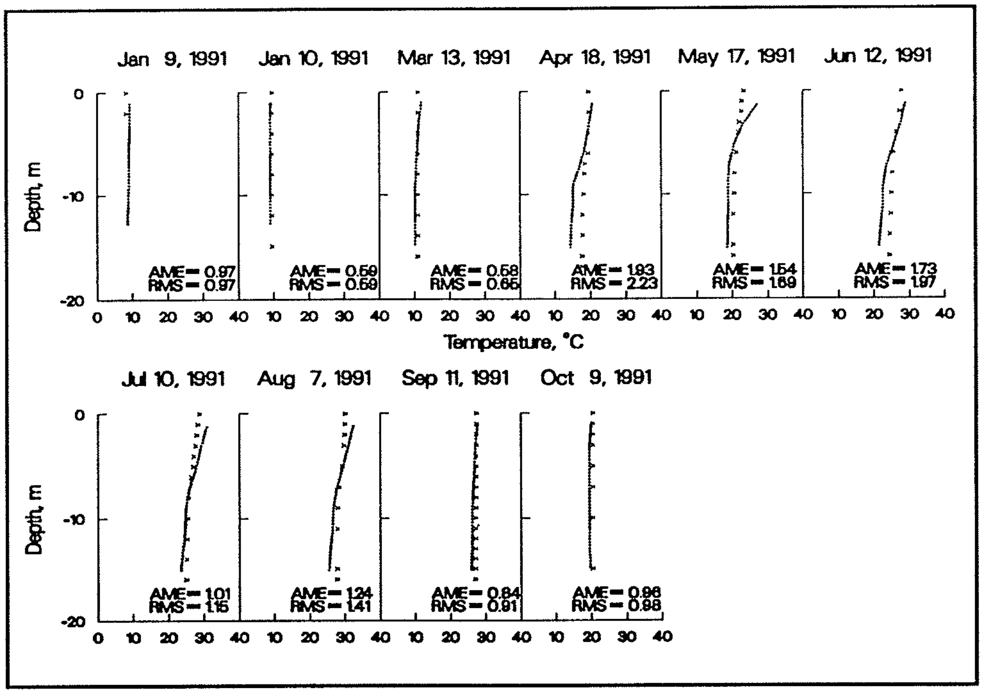


Figure 48. 1991 Weiss temperature results for station 2

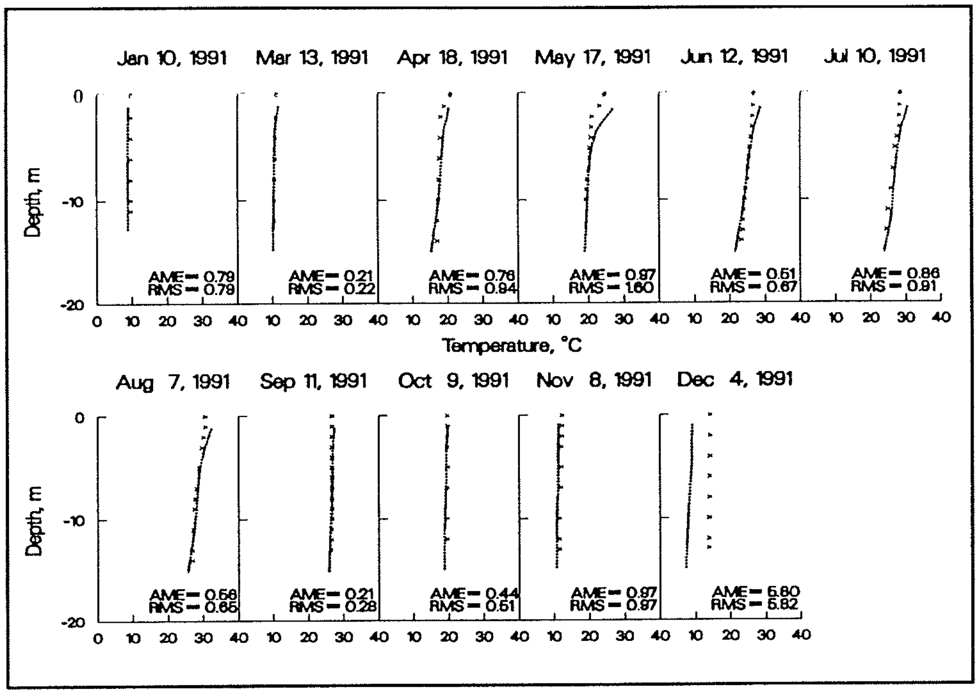


Figure 49. 1991 Weiss temperature results for station 3

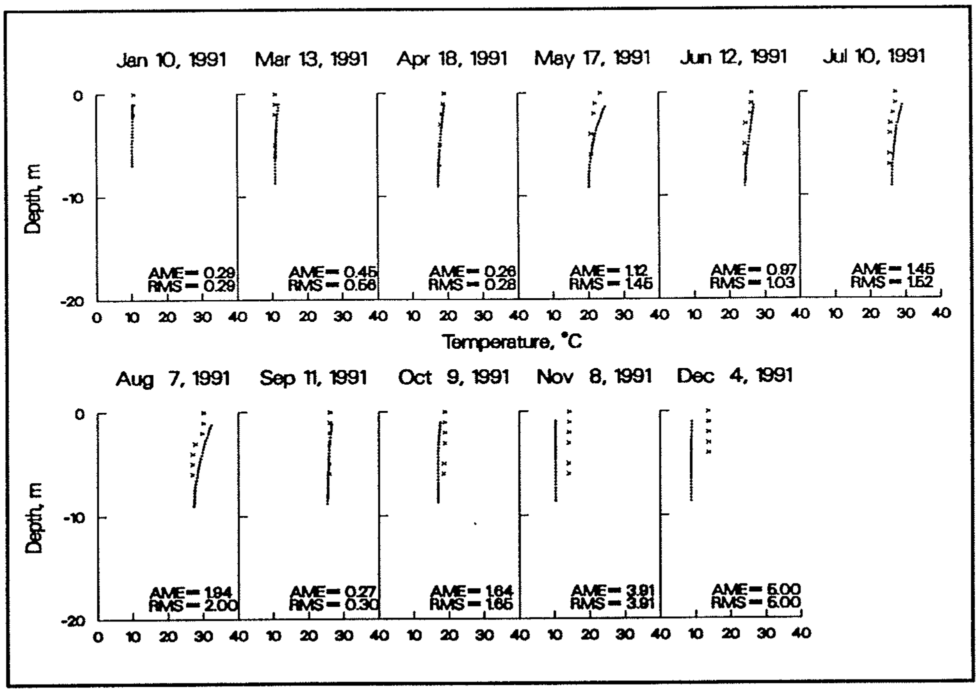


Figure 50. 1991 Weiss temperature results for station 11

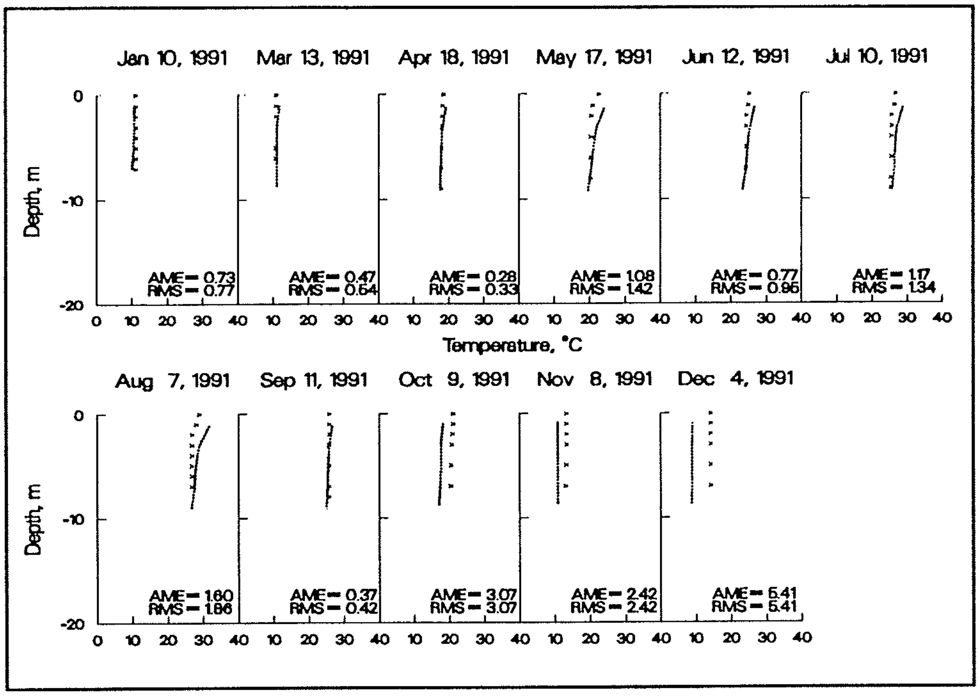


Figure 51. 1991 Weiss temperature results for station 12

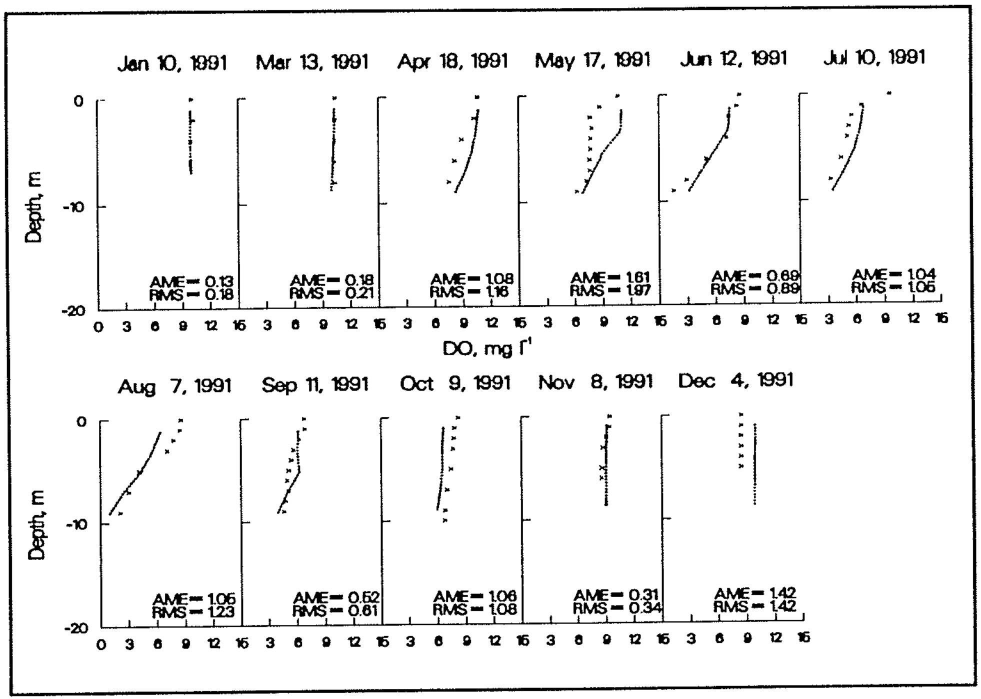


Figure 52. 1991 Weiss DO results for station 1

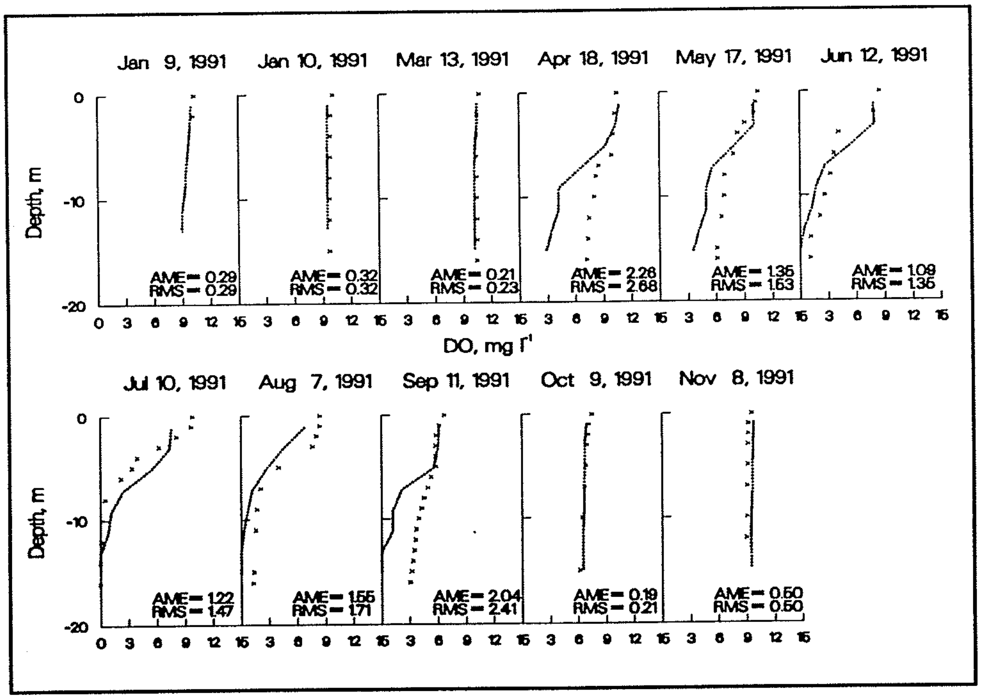


Figure 53. 1991 Weiss DO results for station 2

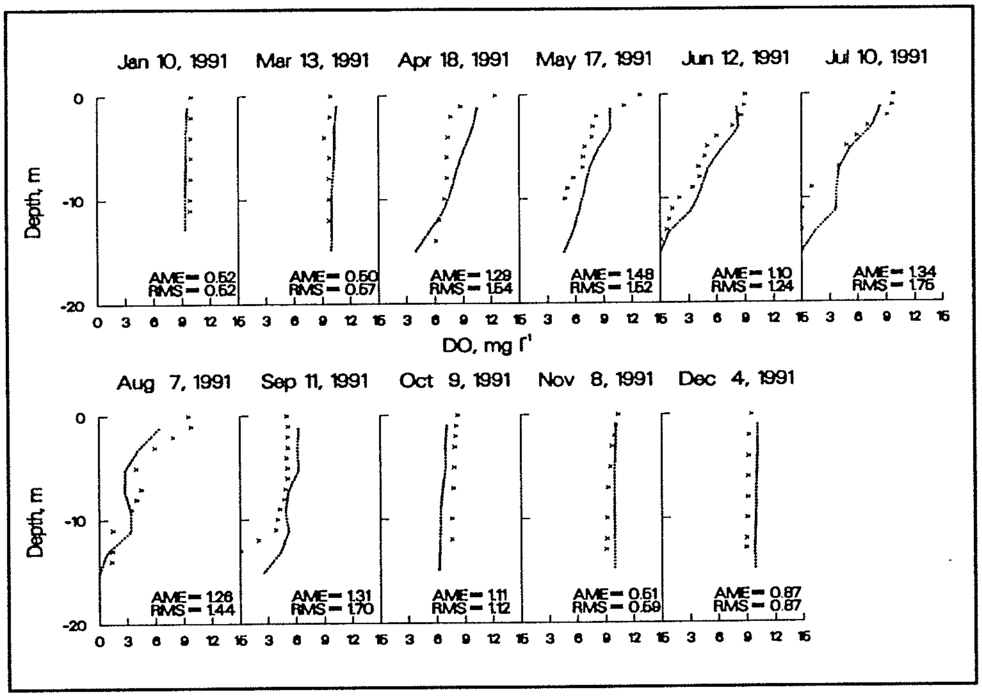


Figure 54. 1991 Weiss DO results for station 3

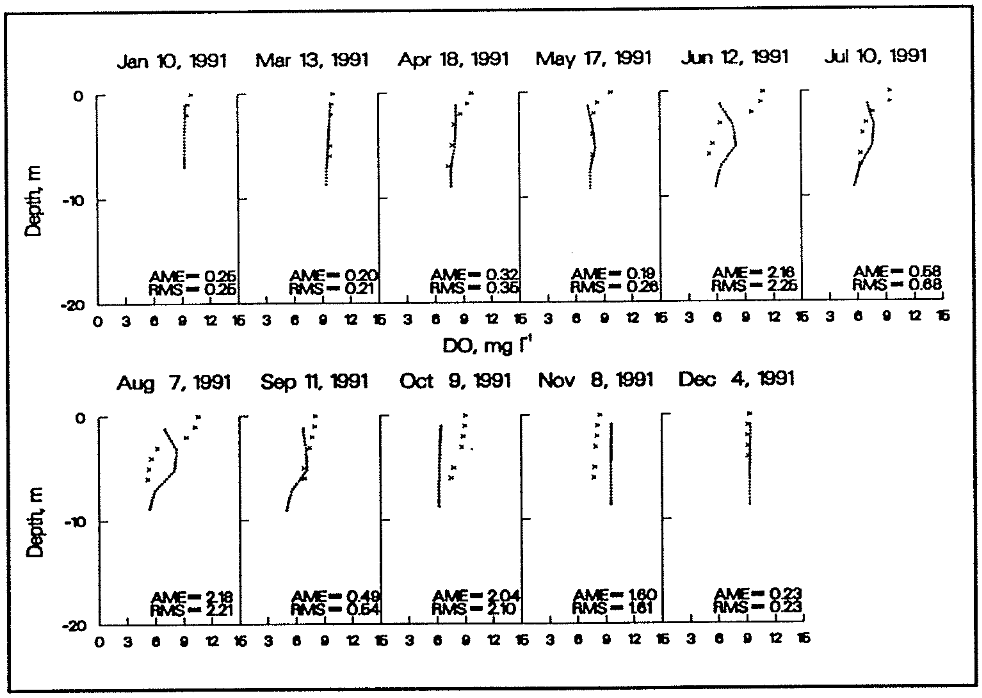


Figure 55. 1991 Weiss DO results for station 11

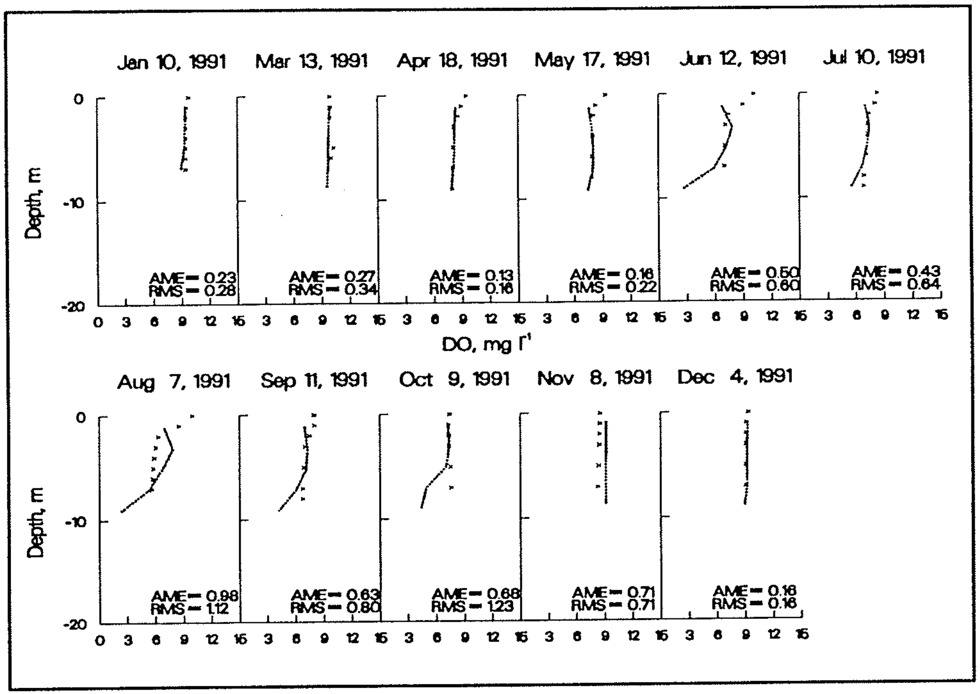


Figure 56. 1991 Weiss DO results for station 12

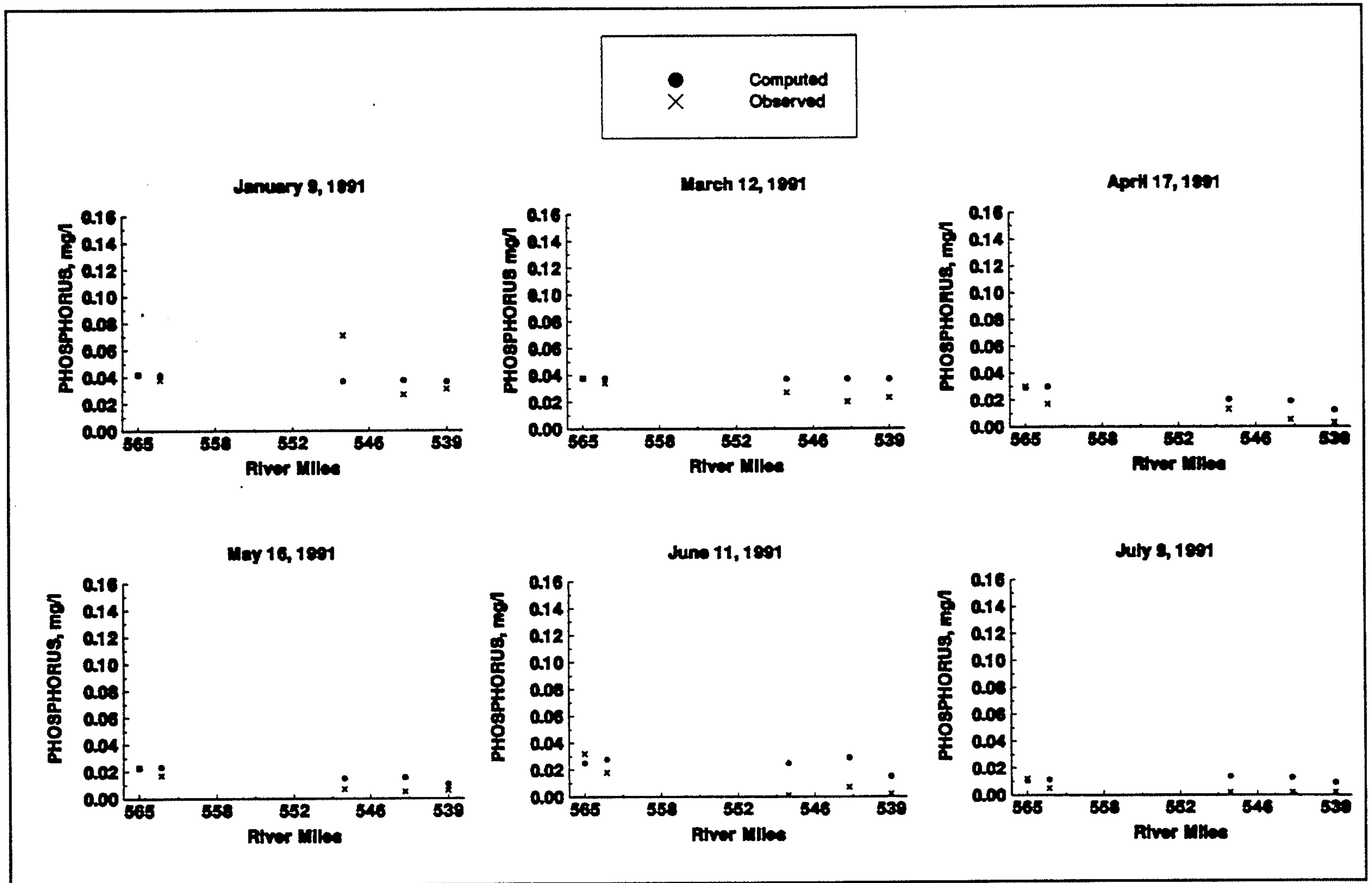


Figure 57. 1991 computed versus observed phosphorus at five longitudinal locations within Weiss (Continued)

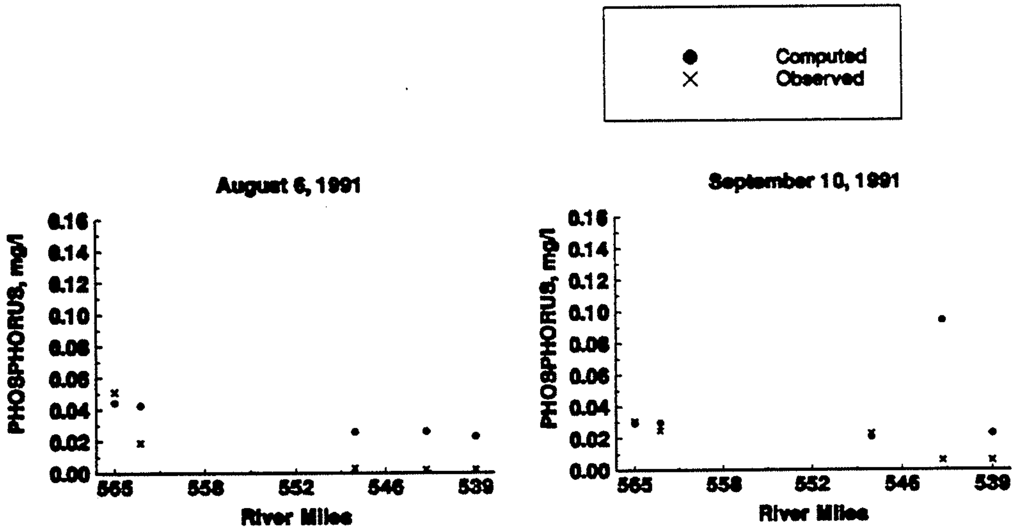


Figure 57. (Concluded)

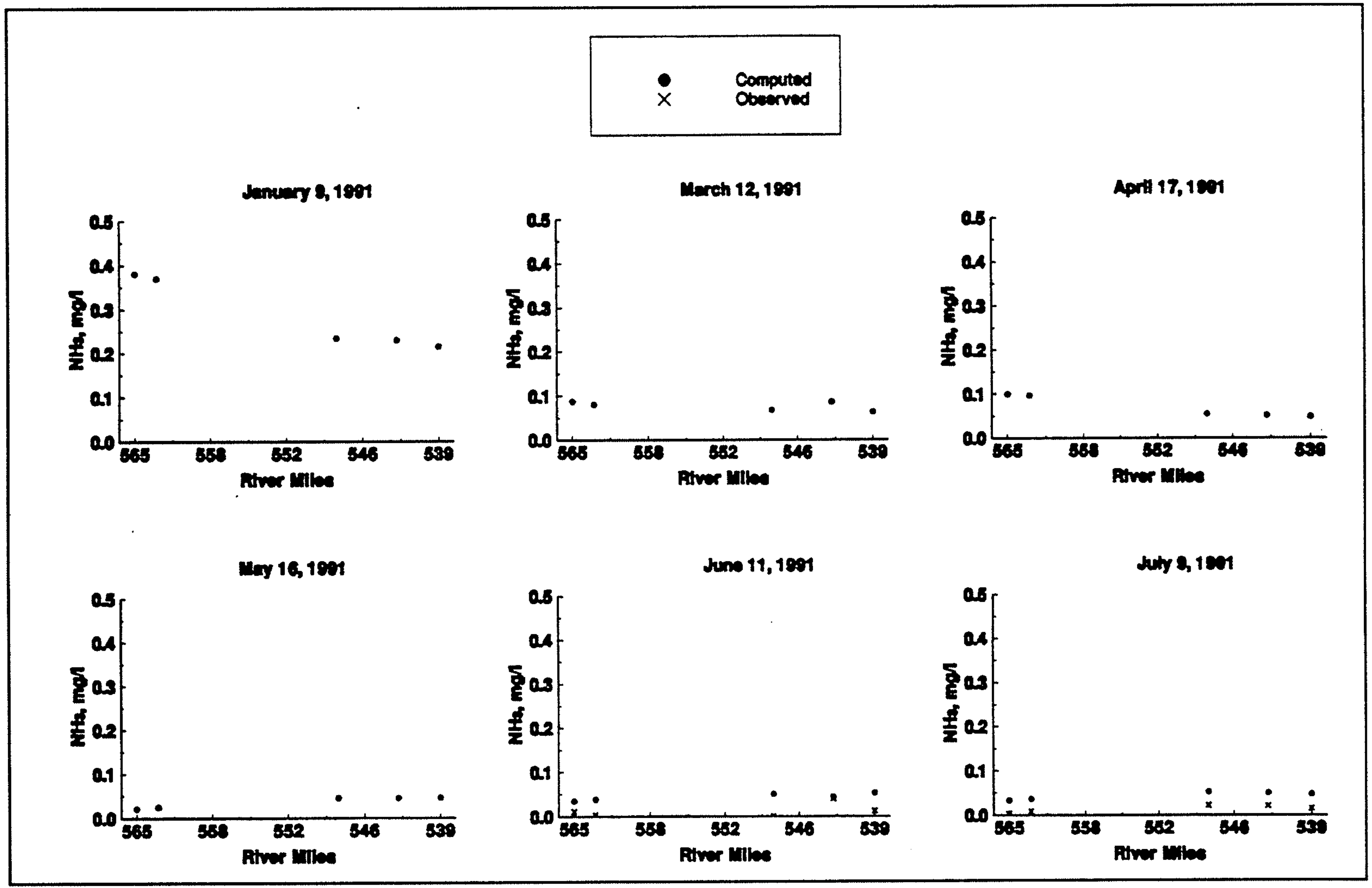


Figure 58. 1991 computed versus observed ammonium at five longitudinal locations within Weiss (Continued)

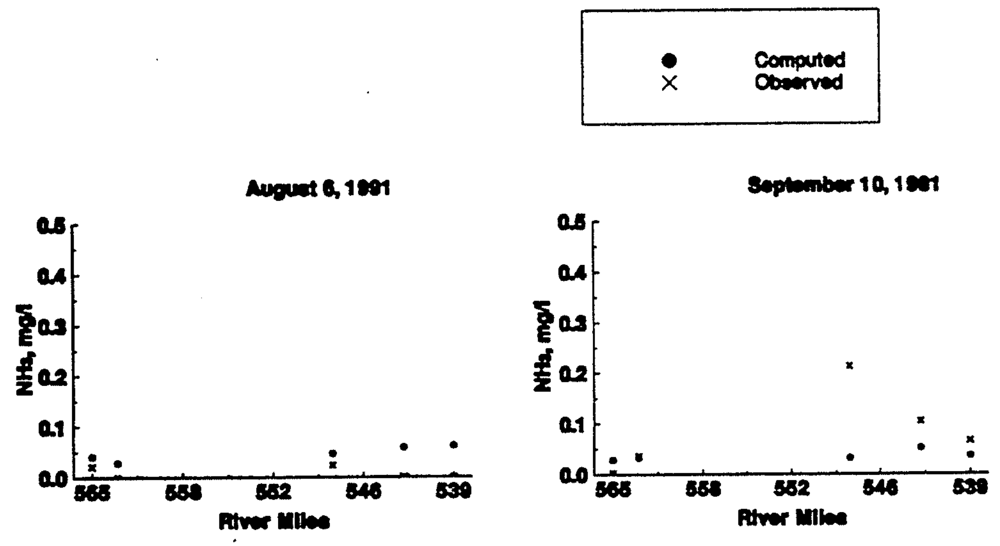


Figure 58. (Concluded)

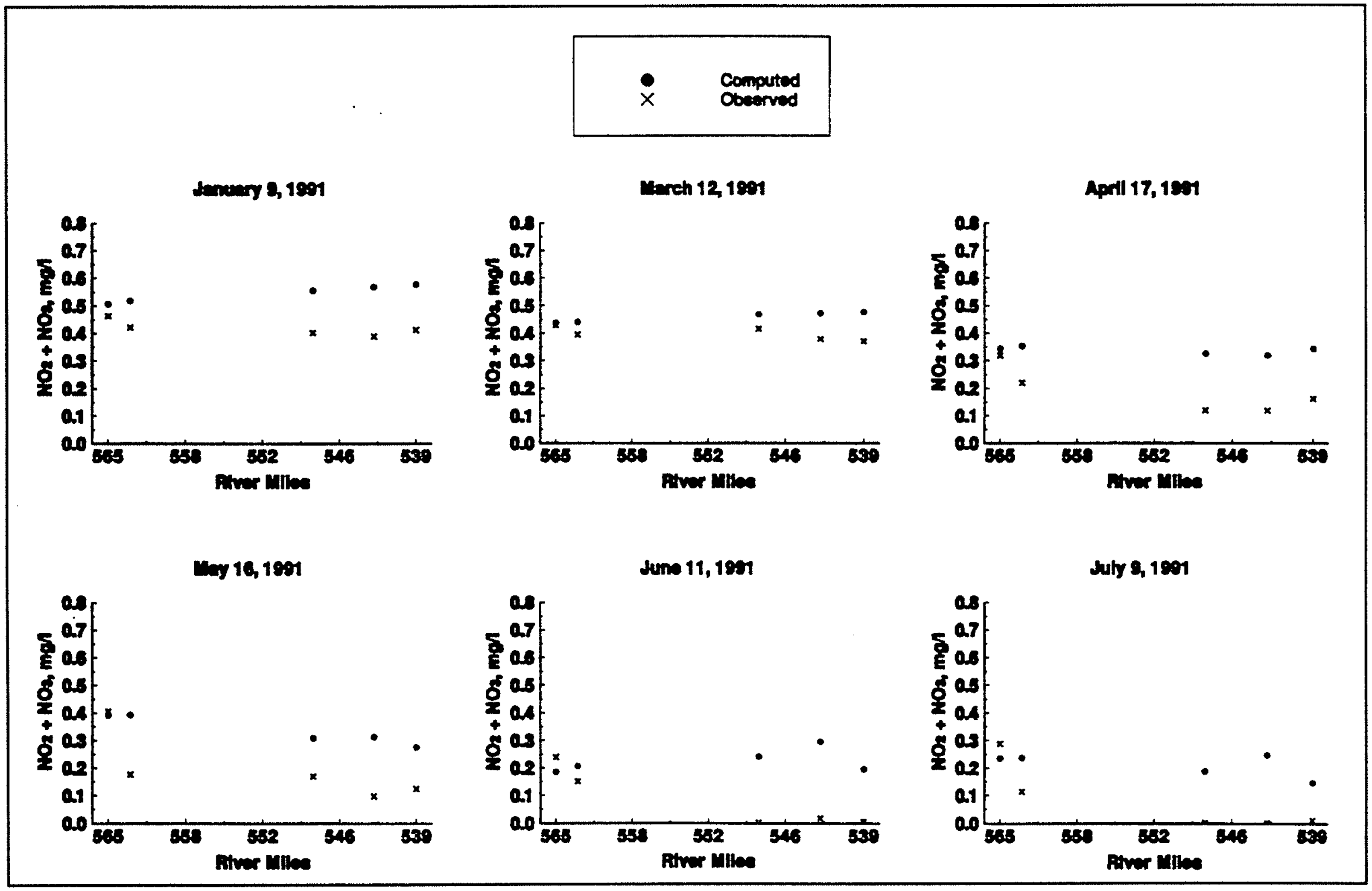


Figure 59. 1991 computed versus observed nitrate-nitrite at five longitudinal locations within Weiss (Continued)

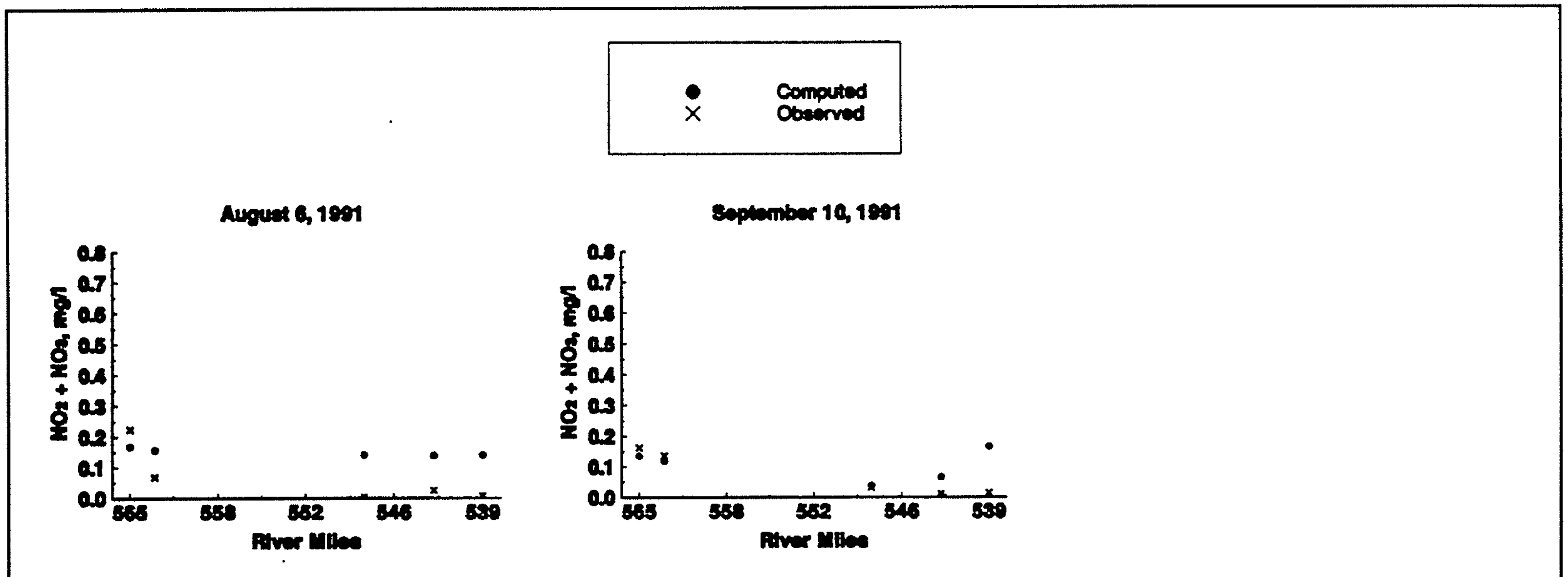


Figure 59. (Concluded)

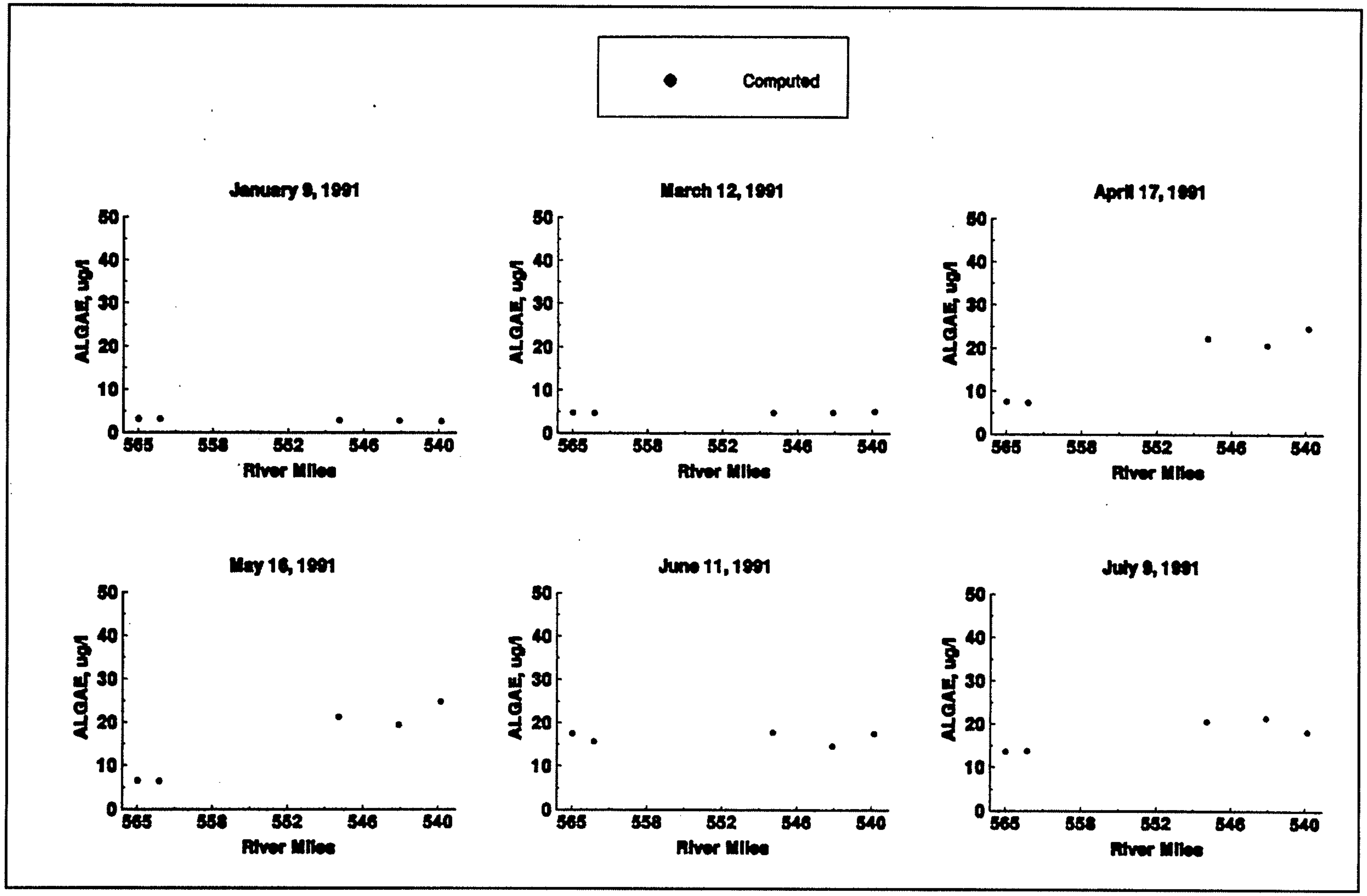


Figure 60. 1991 computed algae at five longitudinal locations within Weiss (Continued)

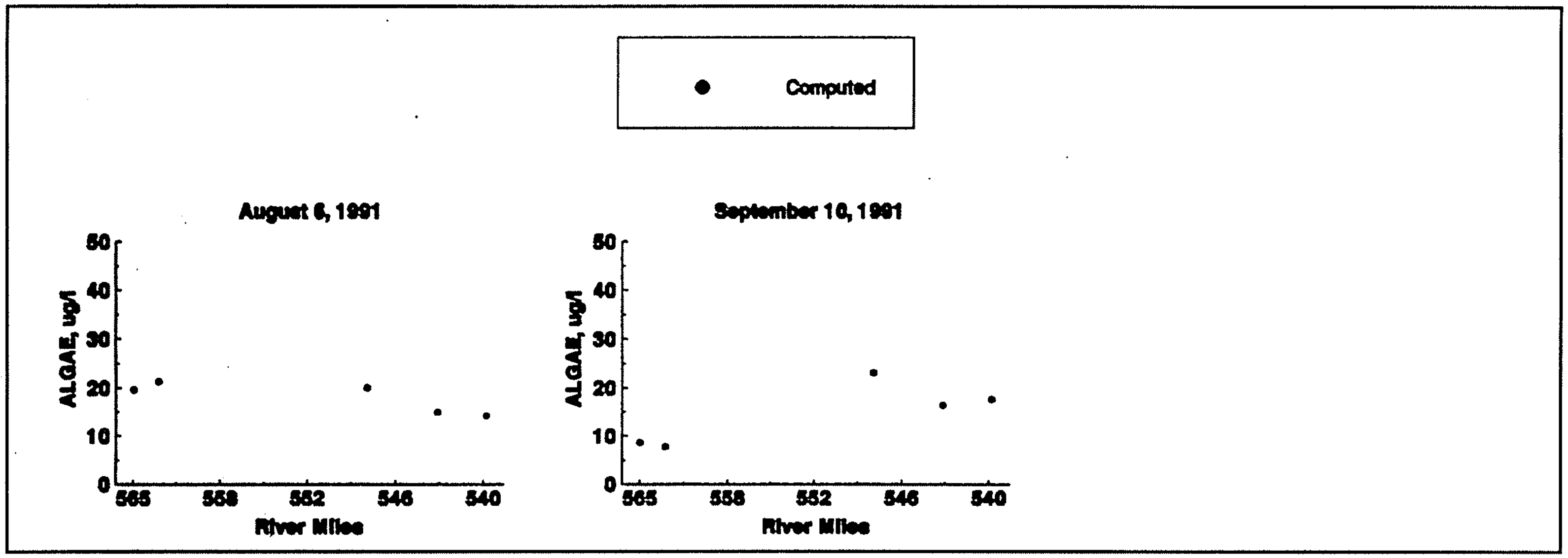


Figure 60. (Concluded)

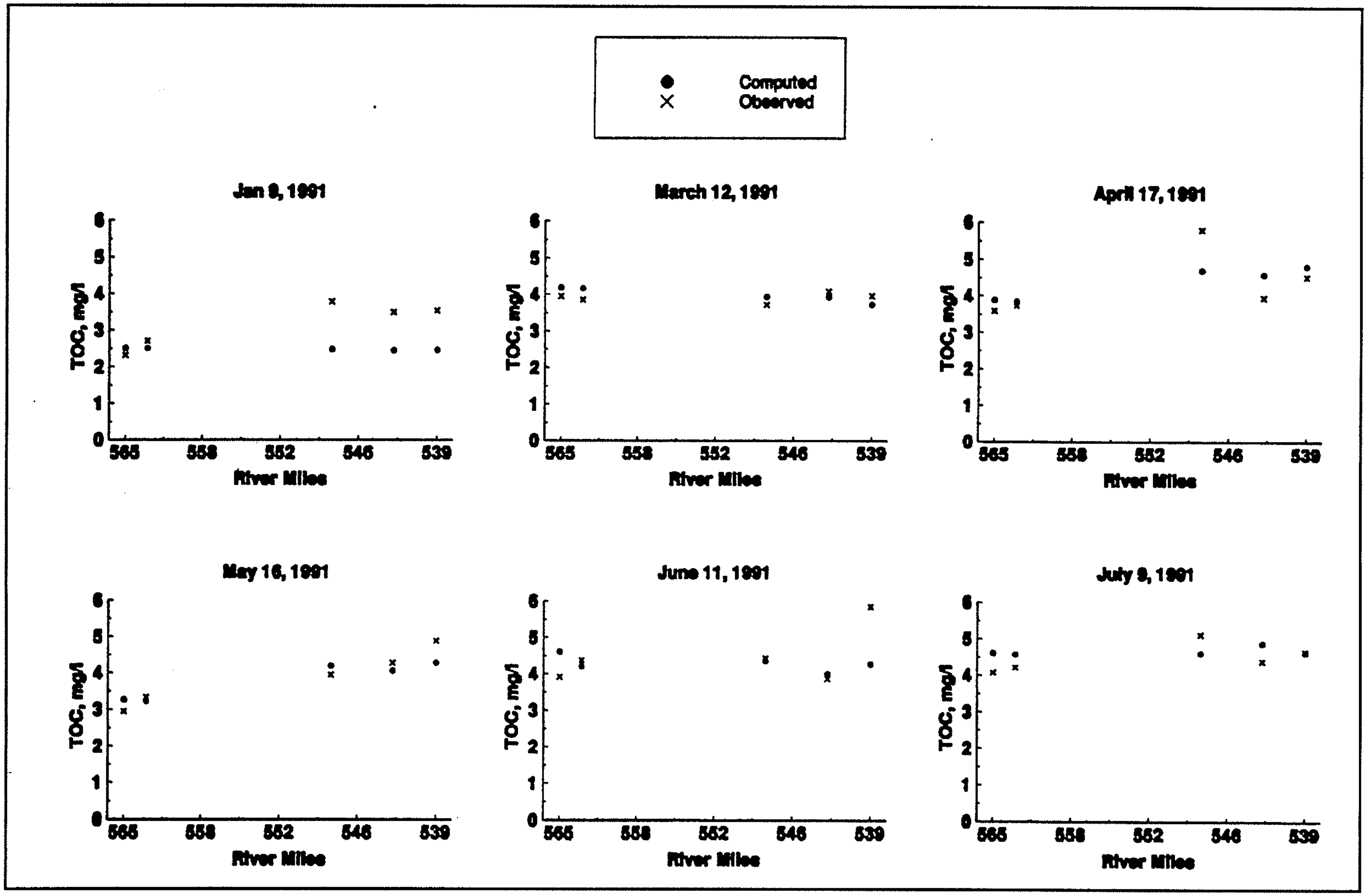


Figure 61. 1991 computed versus observed TOC at five longitudinal locations within Weiss (Continued)

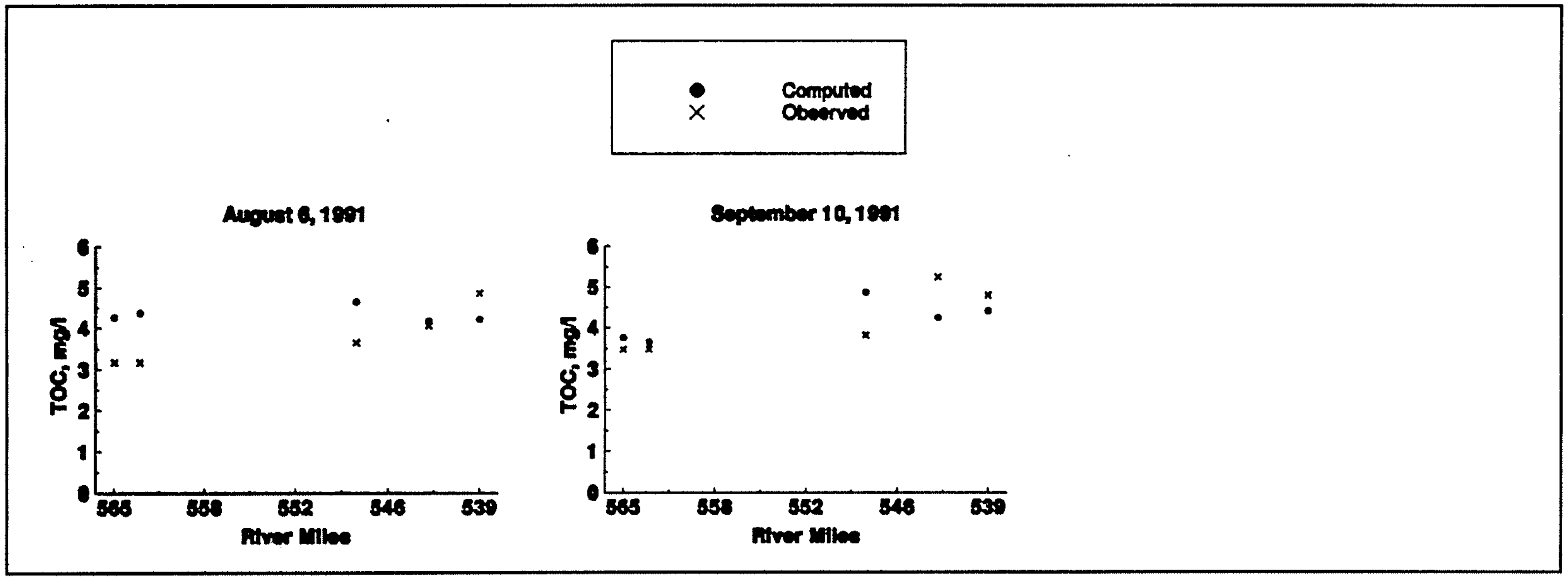


Figure 61. (Concluded)

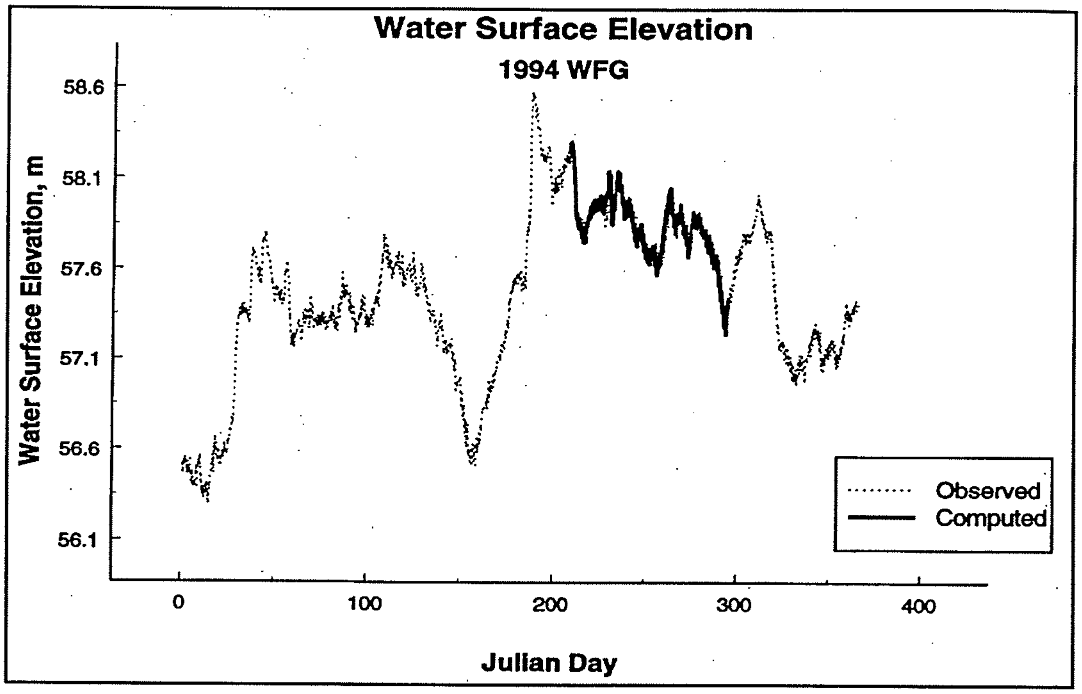


Figure 62. Walter F. George 1994 computed versus observed water surface elevations

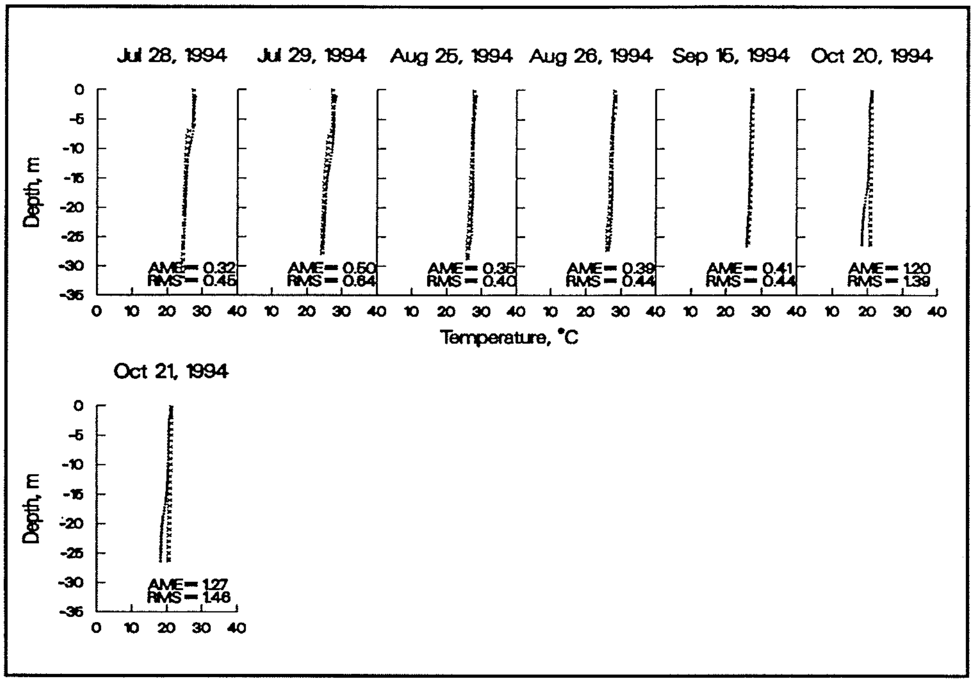


Figure 63. 1994 WFG temperature results for station 1

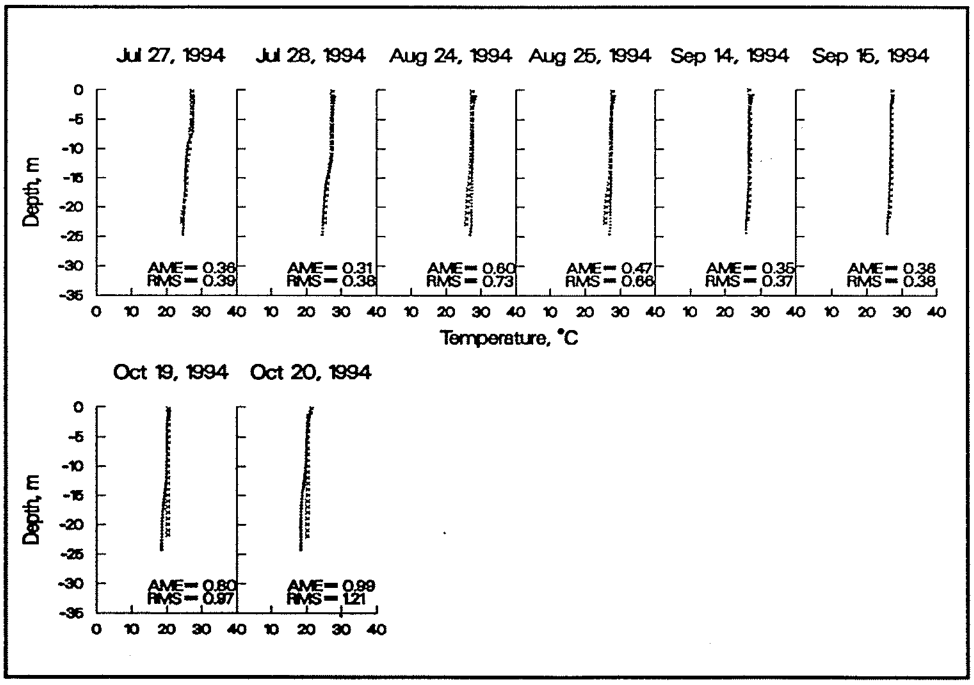


Figure 64. 1994 WFG temperature results for station 3

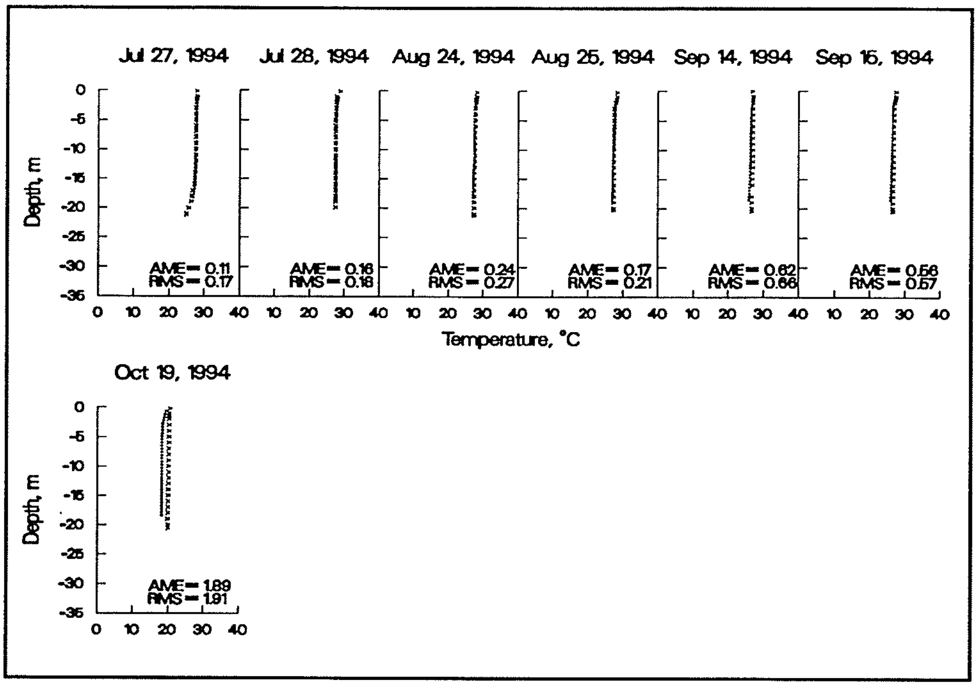


Figure 65. 1994 WFG temperature results for station 4

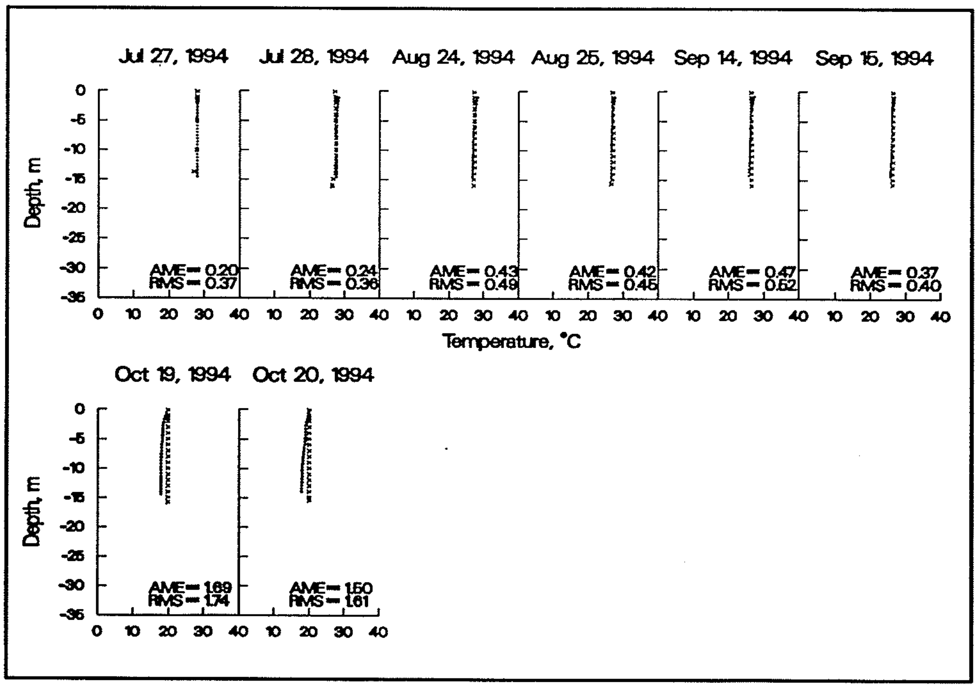


Figure 66. 1994 WFG temperature results for station 5

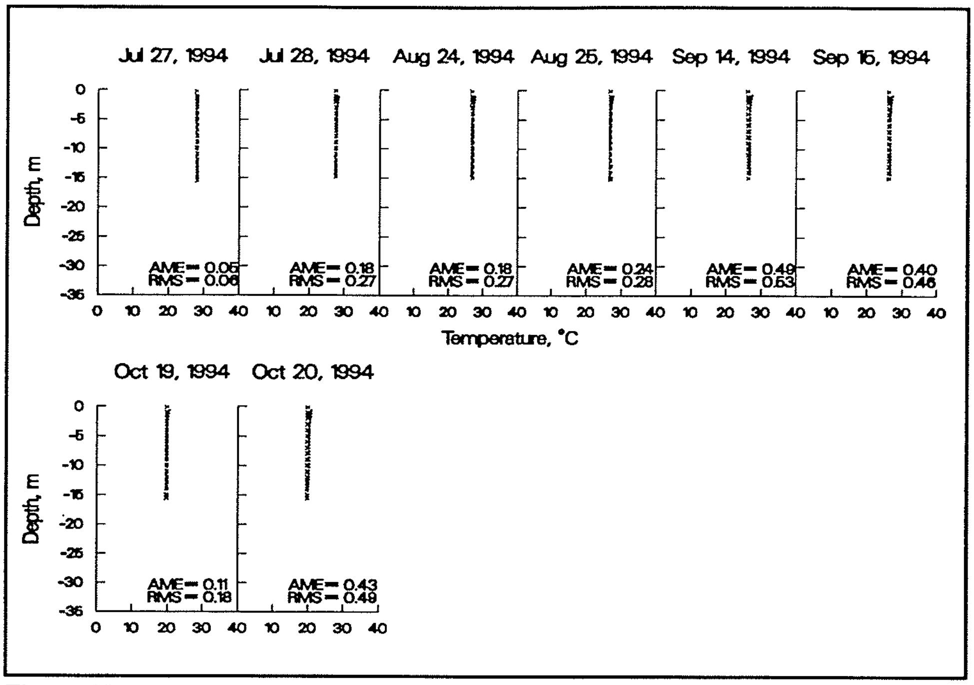


Figure 67. 1994 WFG temperature results for station 6

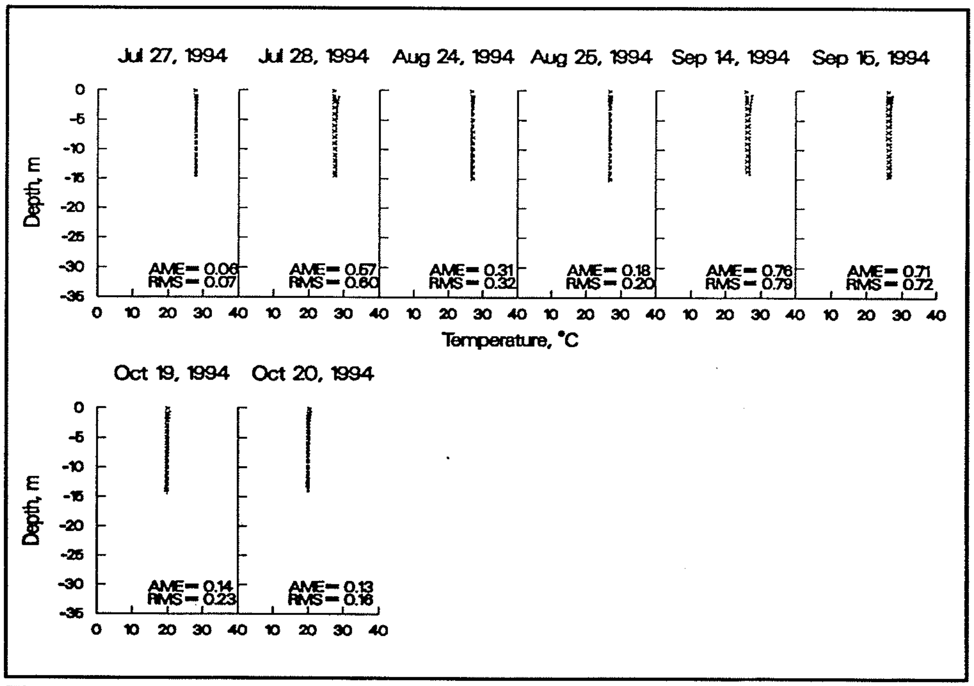


Figure 68. 1994 WFG temperature results for station 8

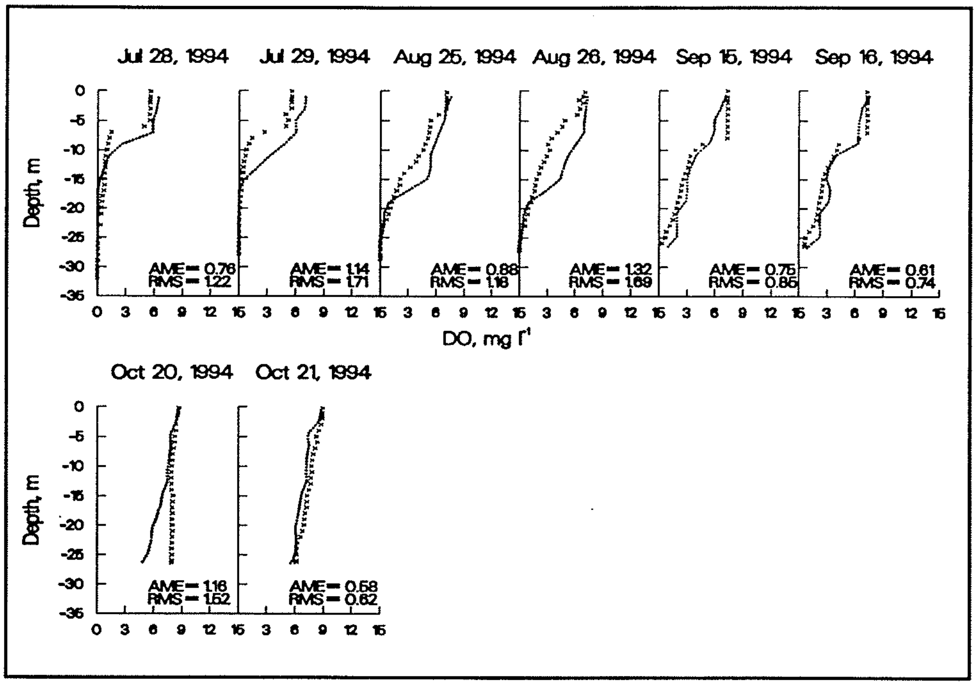


Figure 69. 1994 WFG DO results for station 1

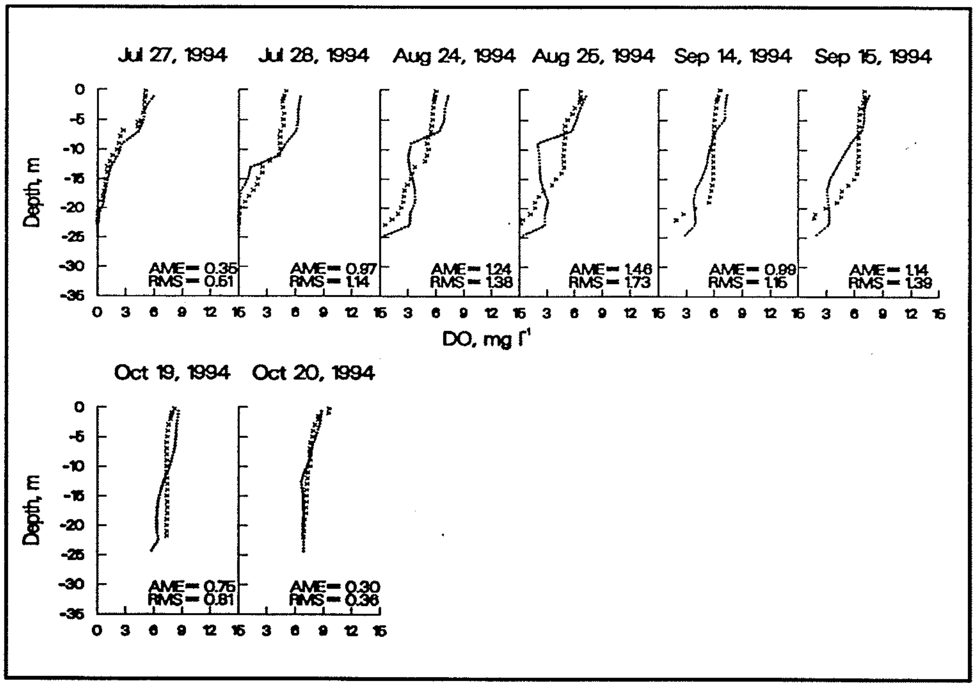


Figure 70. 1994 WFG DO results for station 3

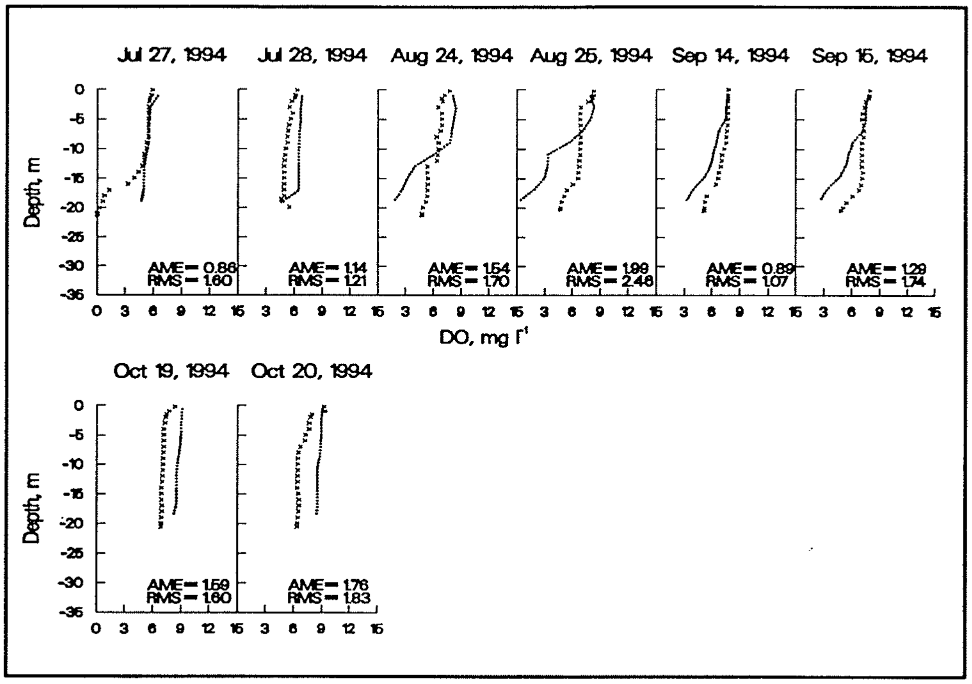


Figure 71. 1994 WFG DO results for station 4

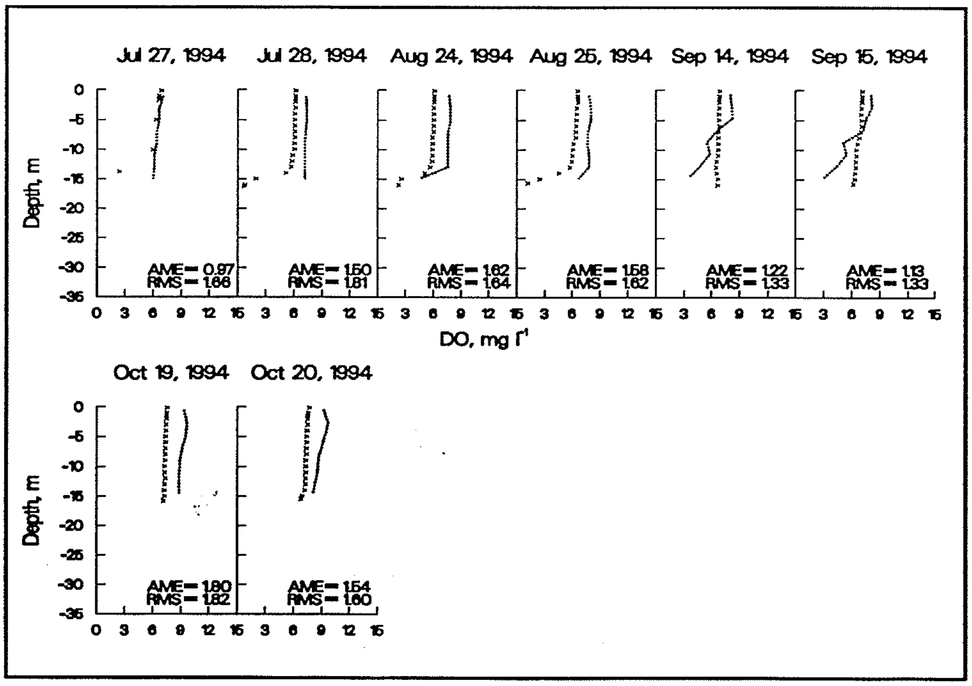


Figure 72. 1994 WFG DO results for station 5

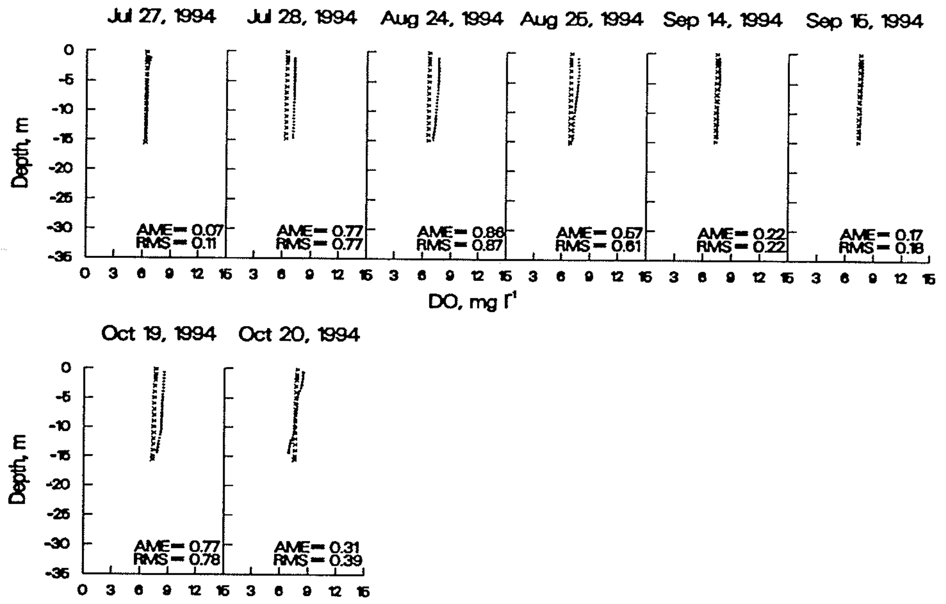


Figure 73. 1994 WFG DO results for station 6

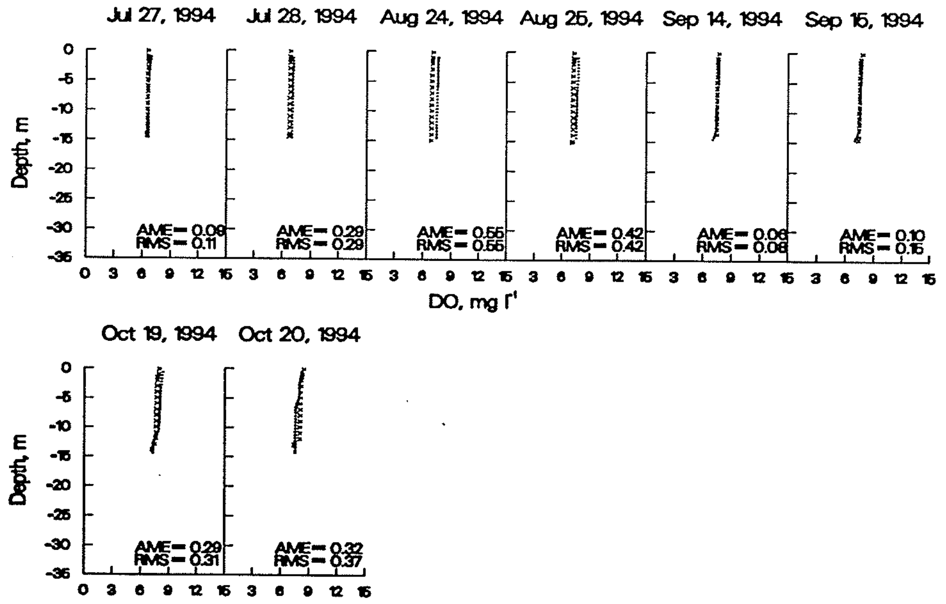


Figure 74. 1994 WFG DO results for station 8

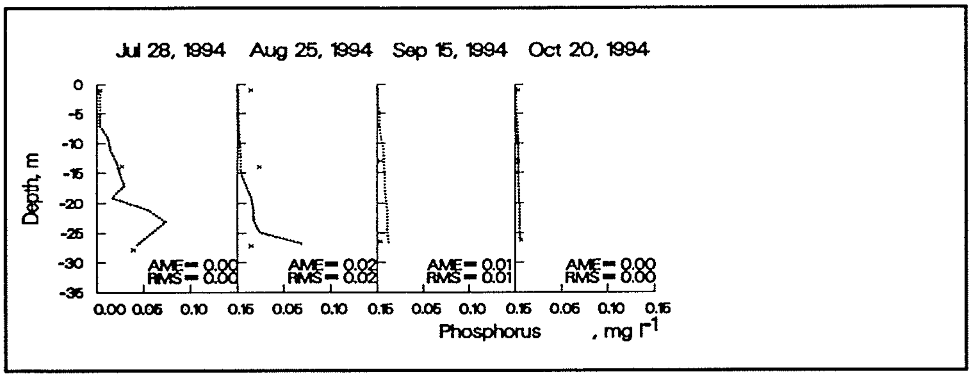


Figure 75. 1994 WFG phosphorus results for station 1

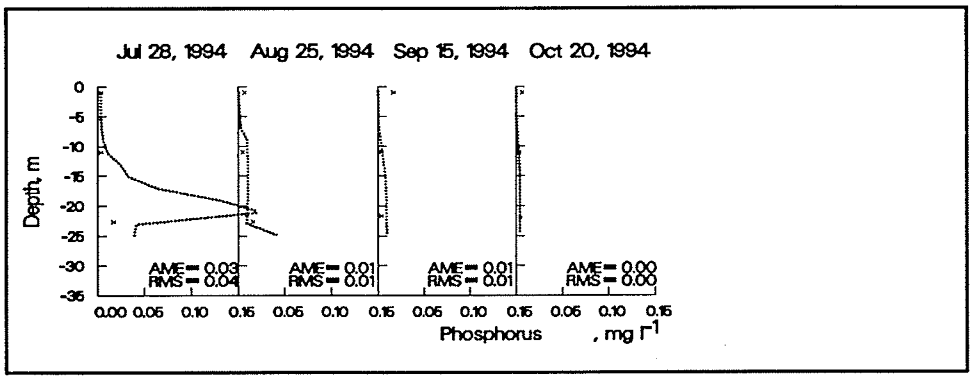


Figure 76. 1994 WFG phosphorus results for station 3

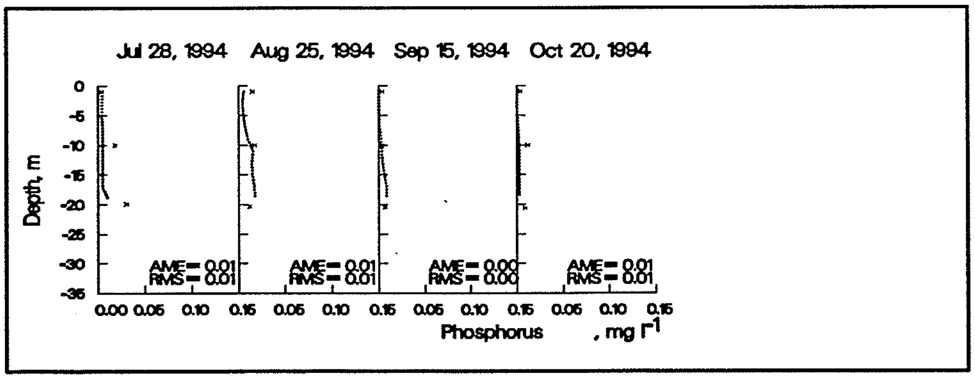


Figure 77. 1994 WFG phosphorus results for station 4

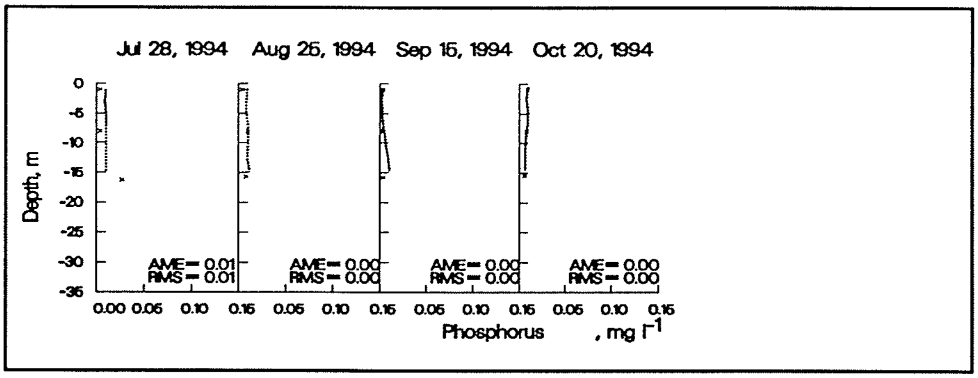


Figure 78. 1994 WFG phosphorus results for station 5

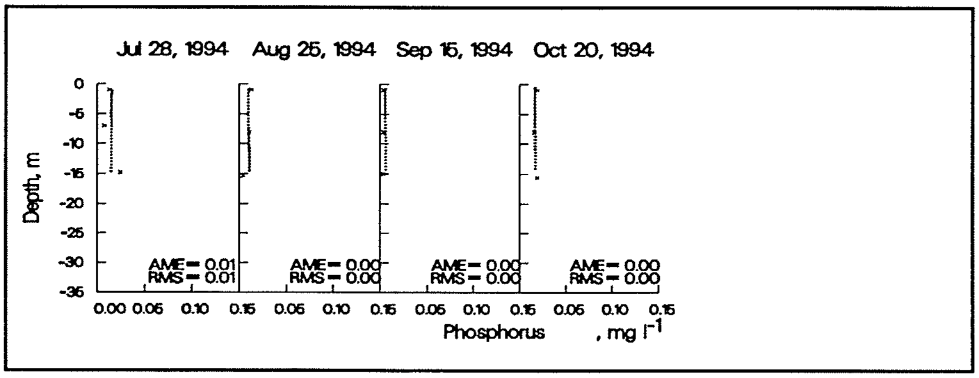


Figure 79. 1994 WFG phosphorus results for station 6

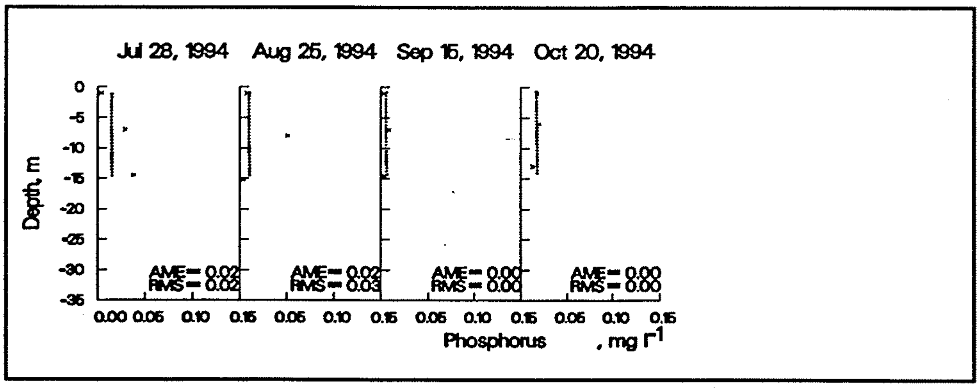


Figure 80. 1994 WFG phosphorus results for station 8

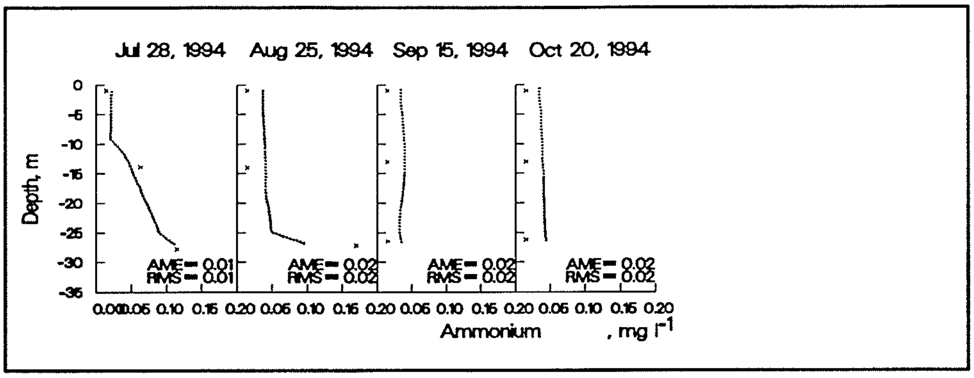


Figure 81. 1994 WFG ammonium results for station 1

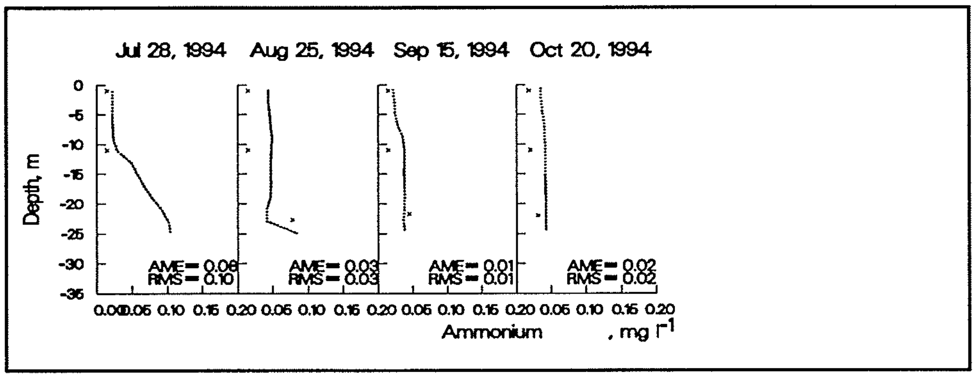


Figure 82. 1994 WFG ammonium results for station 3

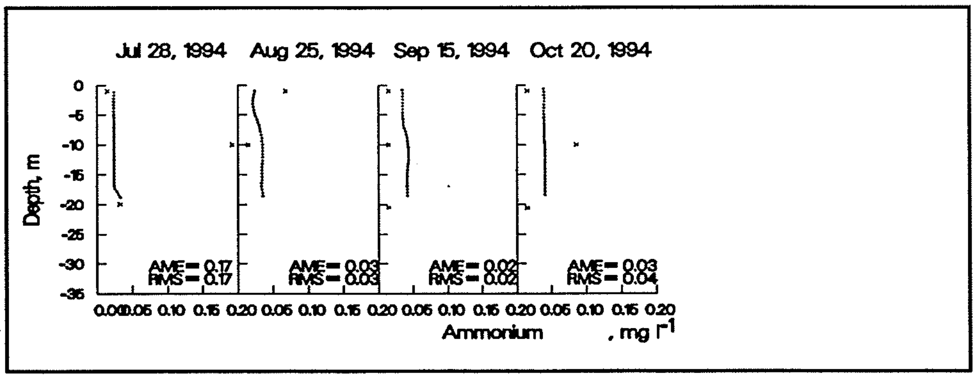


Figure 83. 1994 WFG ammonium results for station 4

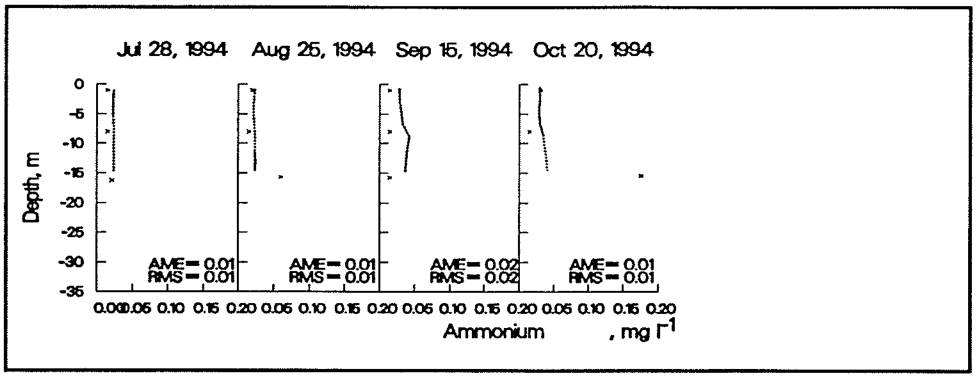


Figure 84. 1994 WFG ammonium results for station 5

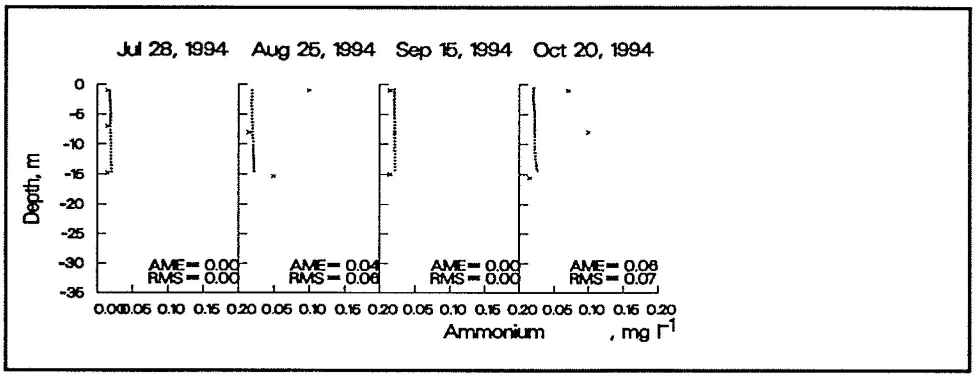


Figure 85. 1994 WFG ammonium results for station 6

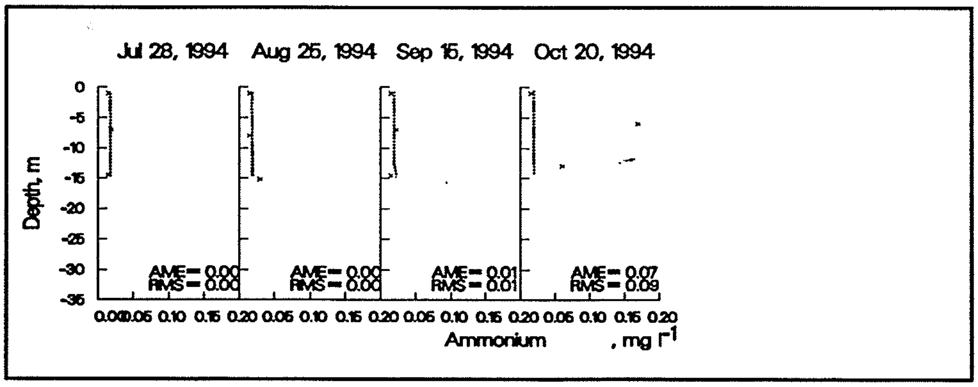


Figure 86. 1994 WFG ammonium results for station 8

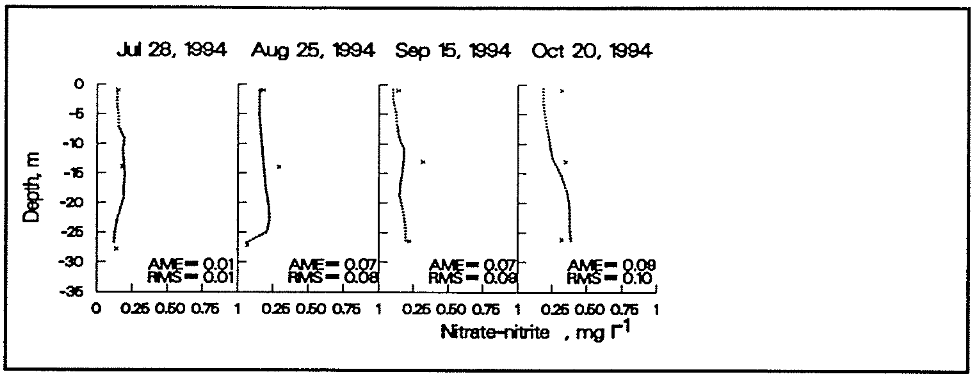


Figure 87. 1994 WFG nitrate-nitrite results for station 1

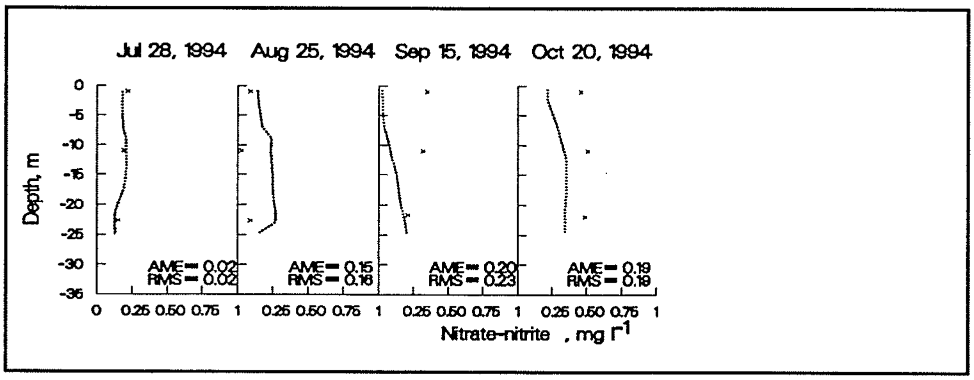


Figure 88. 1994 WFG nitrate-nitrite results for station 3

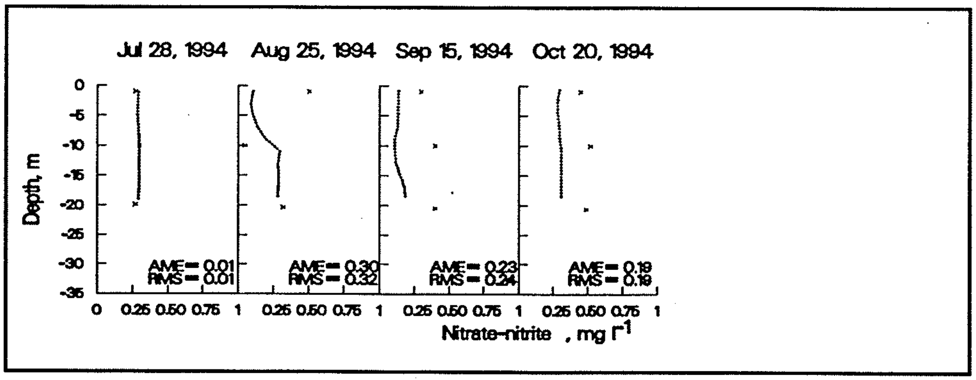


Figure 89. 1994 WFG nitrate-nitrite results for station 4

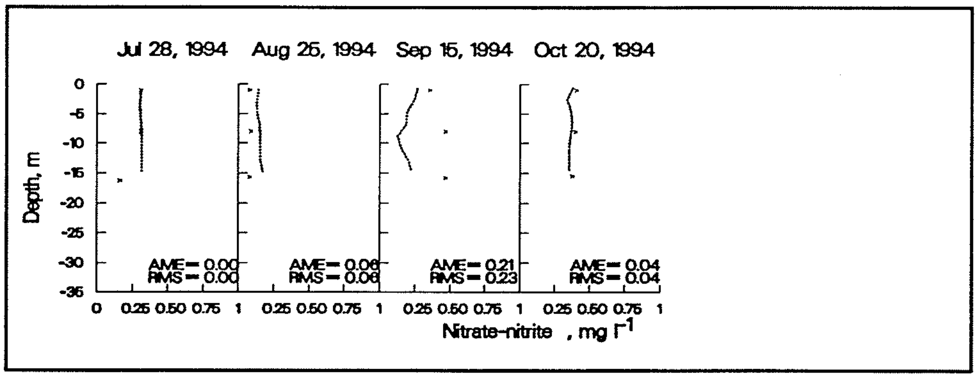


Figure 90. 1994 WFG nitrate-nitrite results for station 5

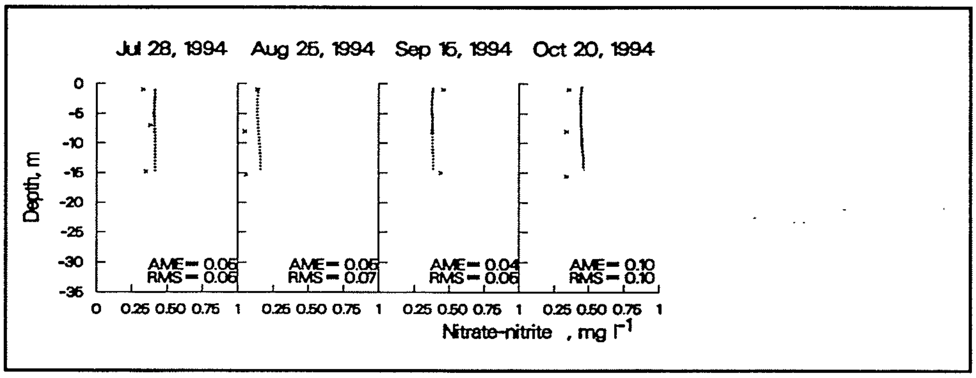


Figure 91. 1994 WFG nitrate-nitrite results for station 6

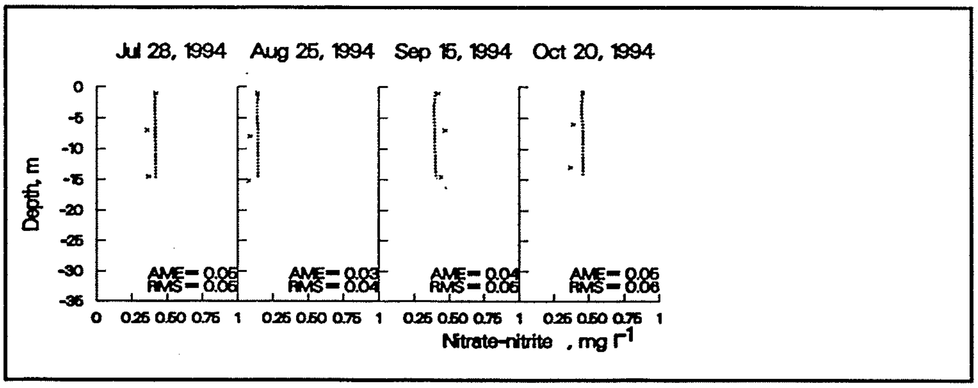


Figure 92. 1994 WFG nitrate-nitrite results for station 8

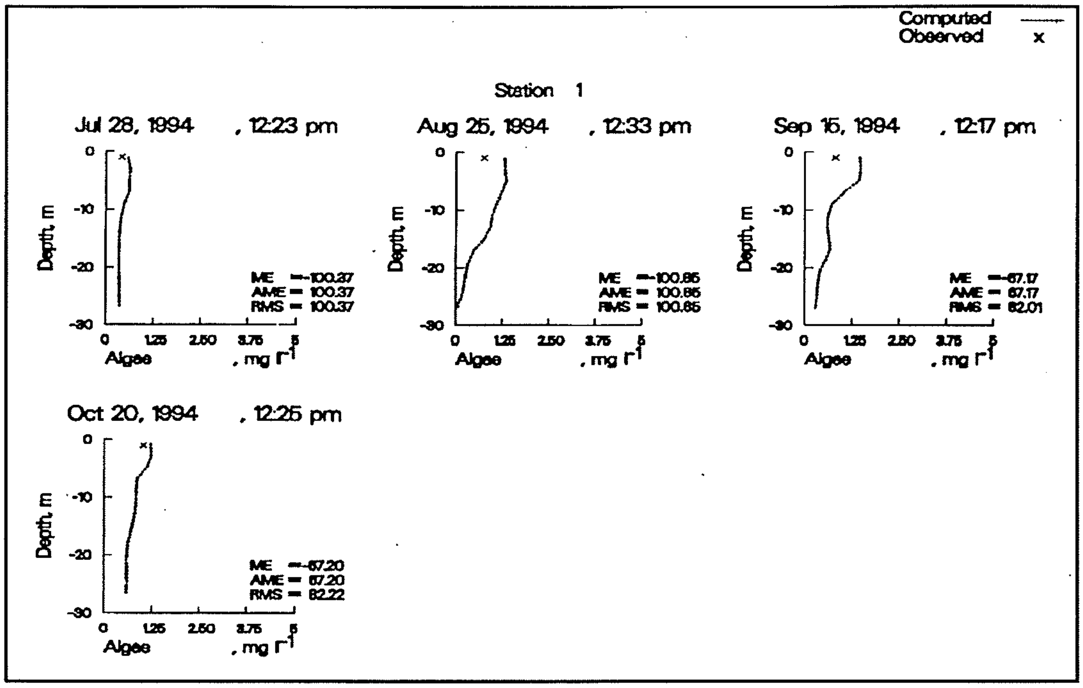


Figure 93. 1994 WFG algae results for station 1

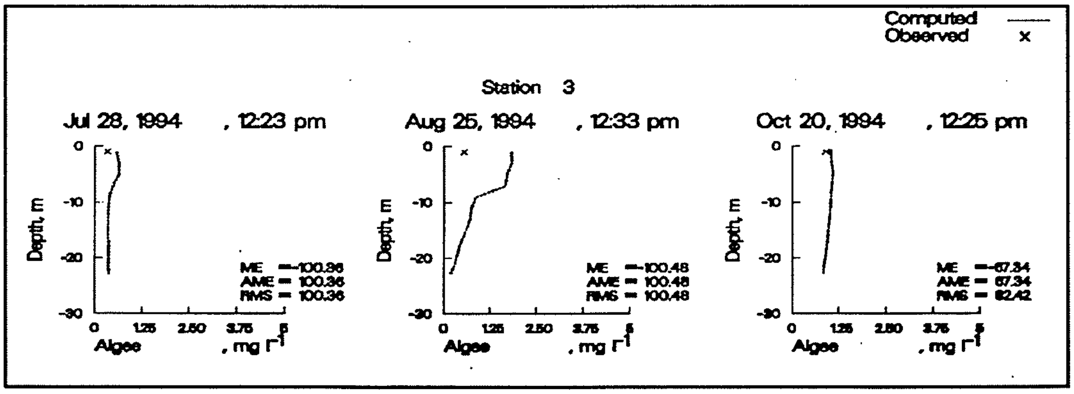


Figure 94. 1994 WFG algae results for station 3

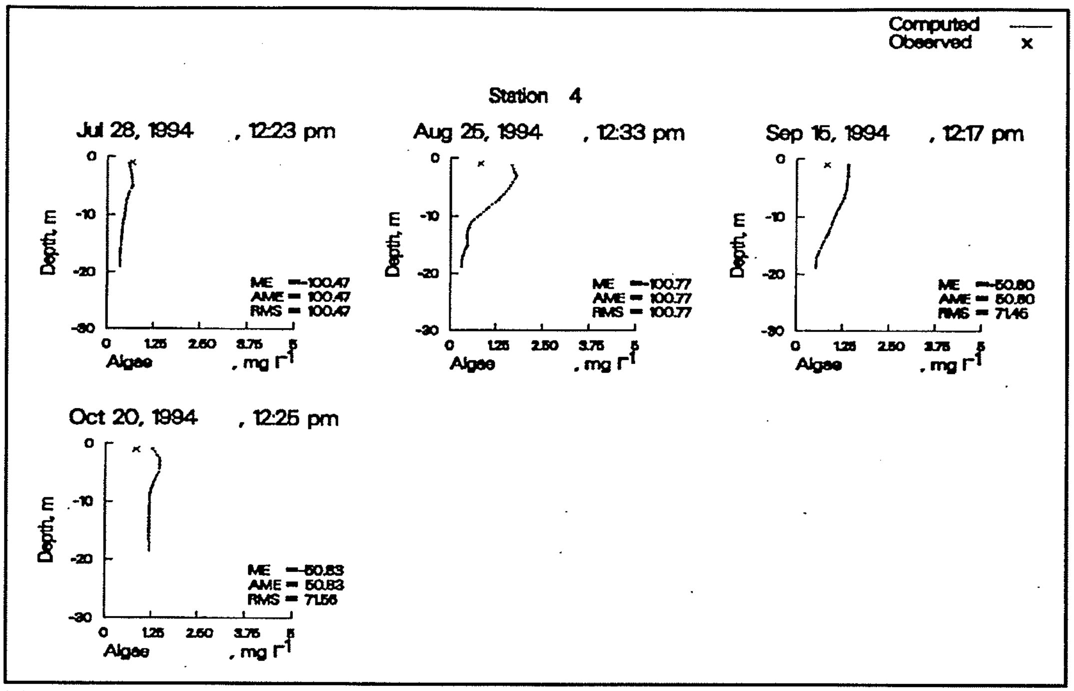


Figure 95. 1994 WFG algae results for station 4

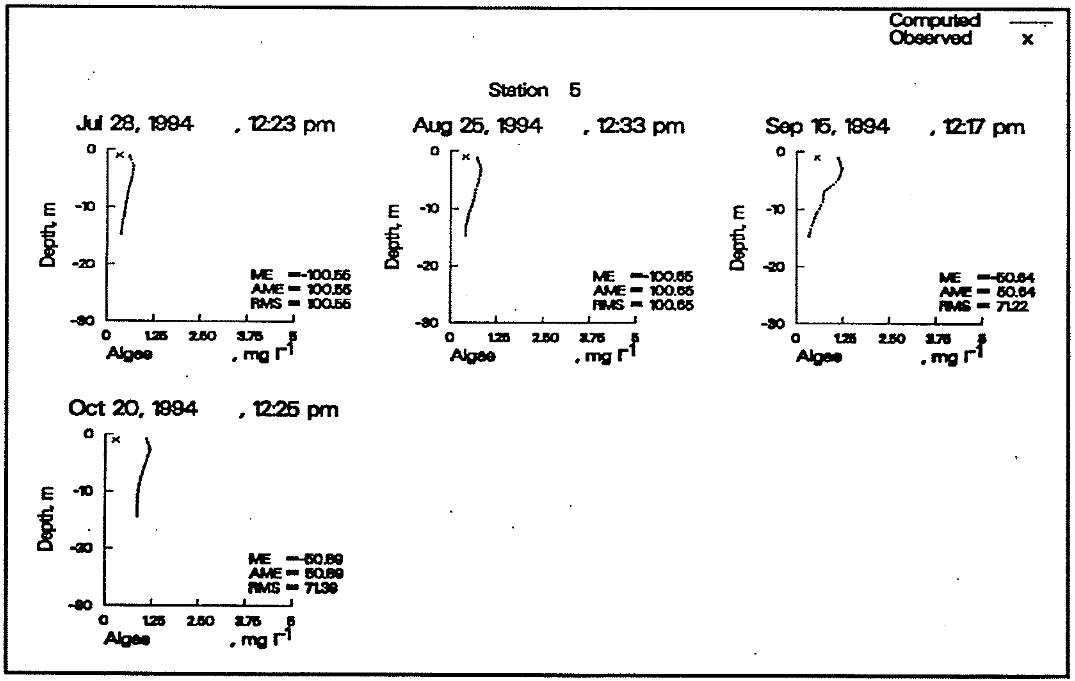


Figure 96. 1994 WFG algae results for station 5

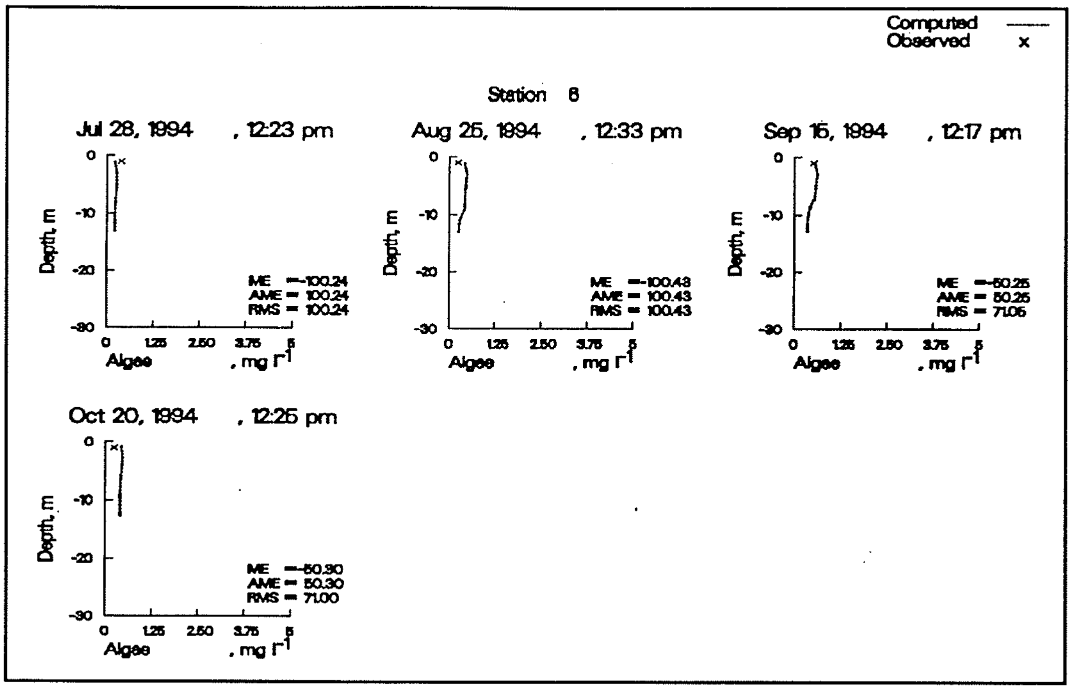


Figure 97. 1994 WFG algae results for station 6

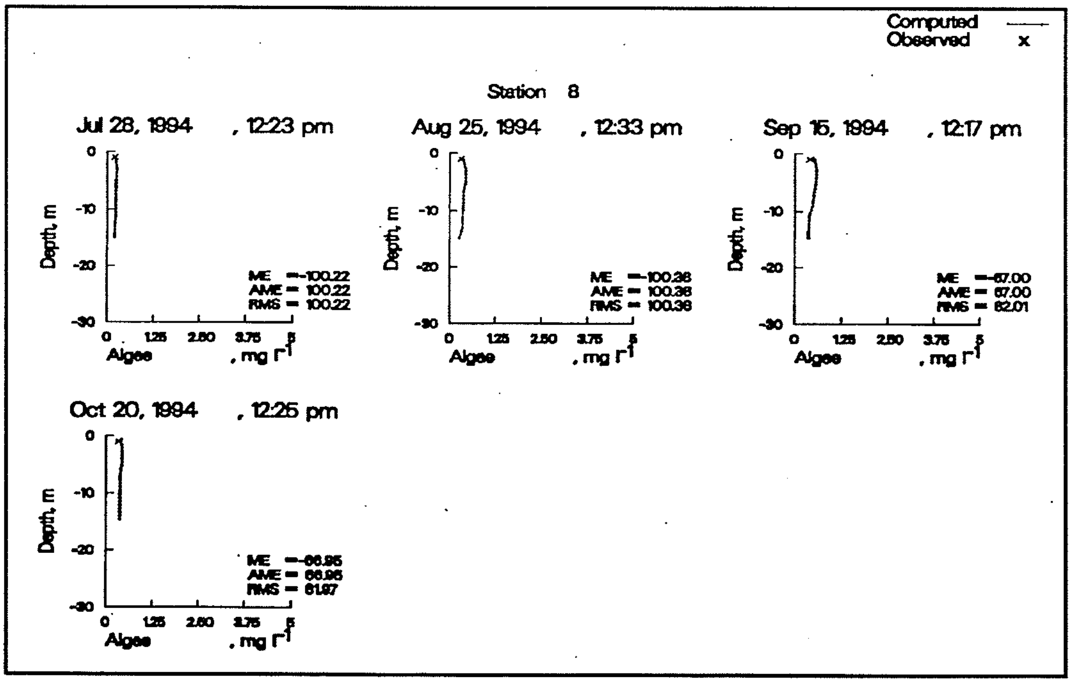


Figure 98. 1994 WFG algae results for station 8

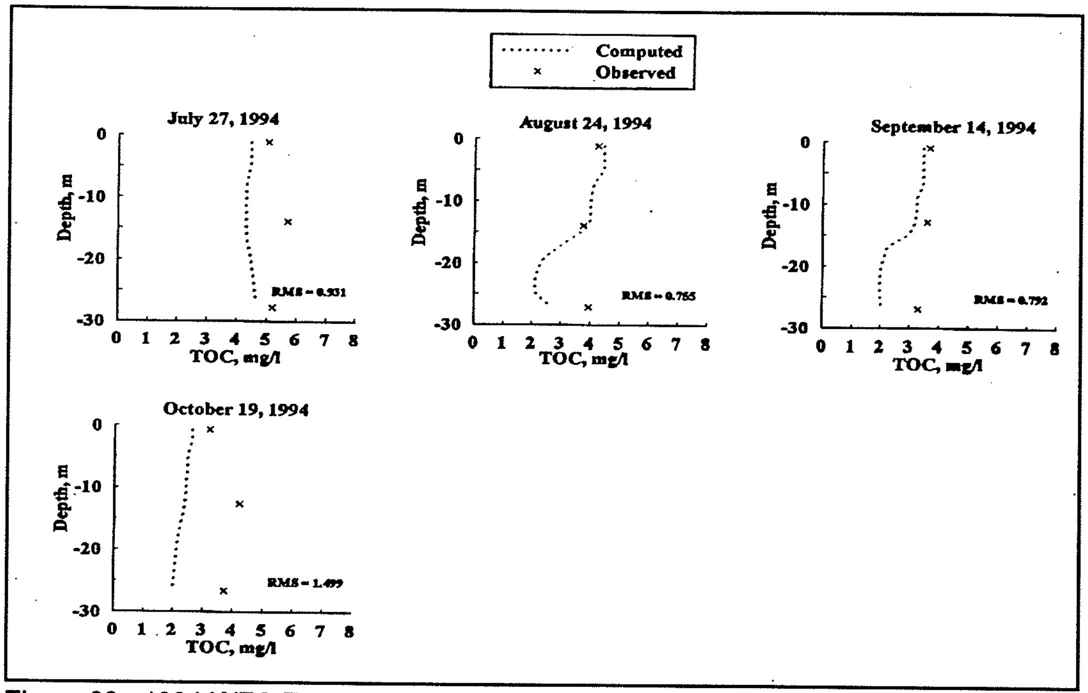


Figure 99. 1994 WFG TOC results for station 1

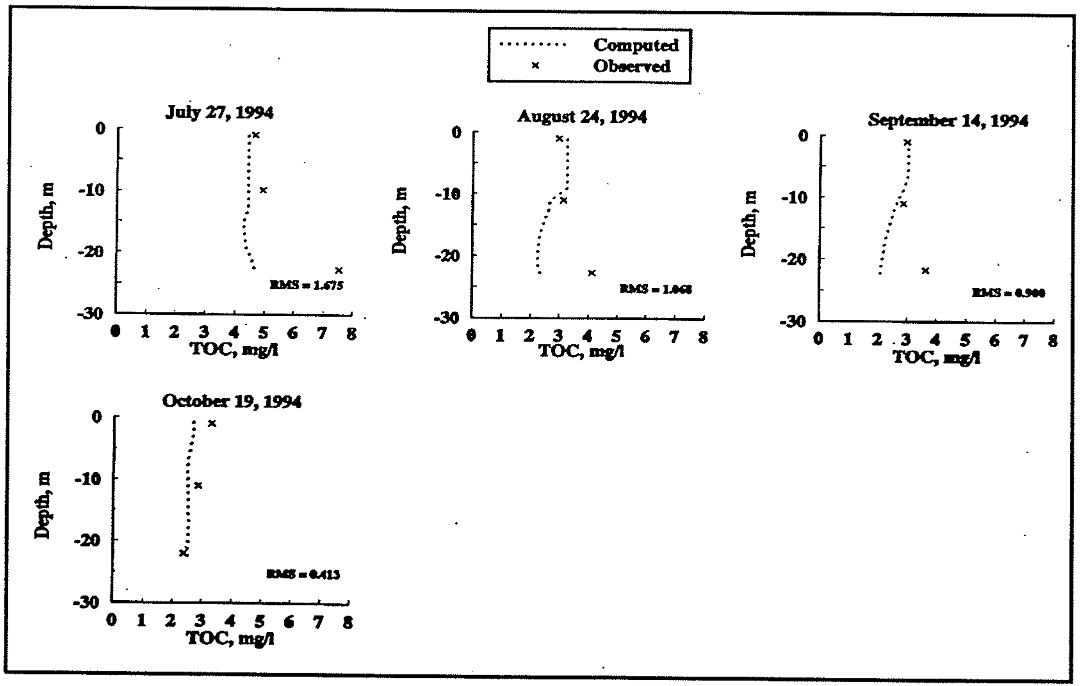


Figure 100. 1994 WFG TOC results for station 3

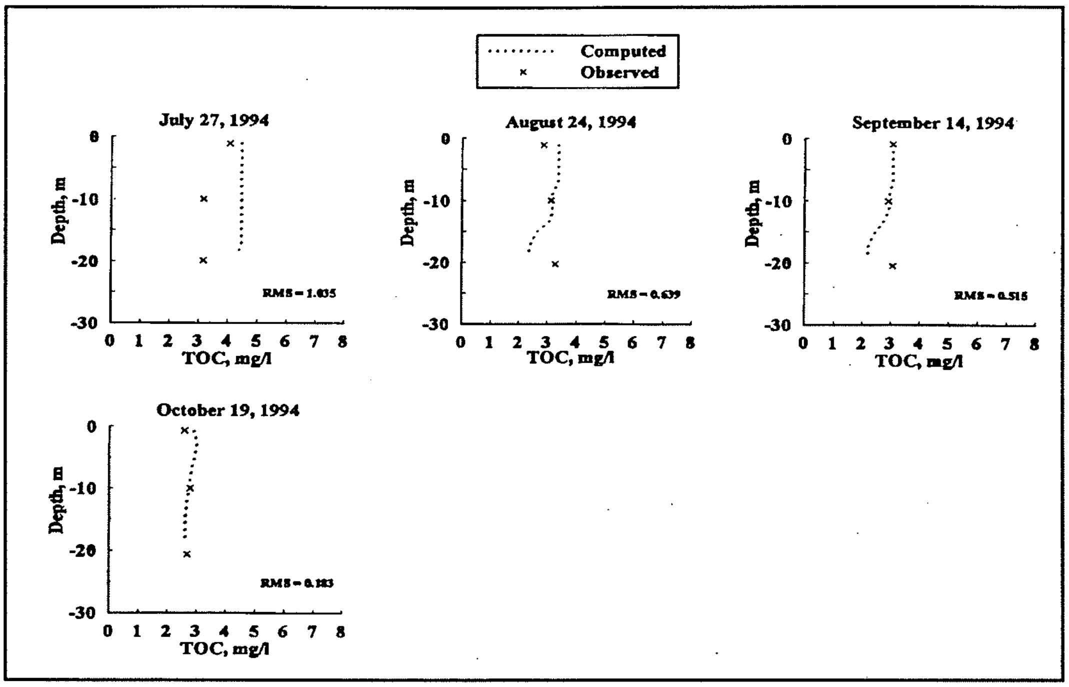


Figure 101. 1994 WFG TOC results for station 4

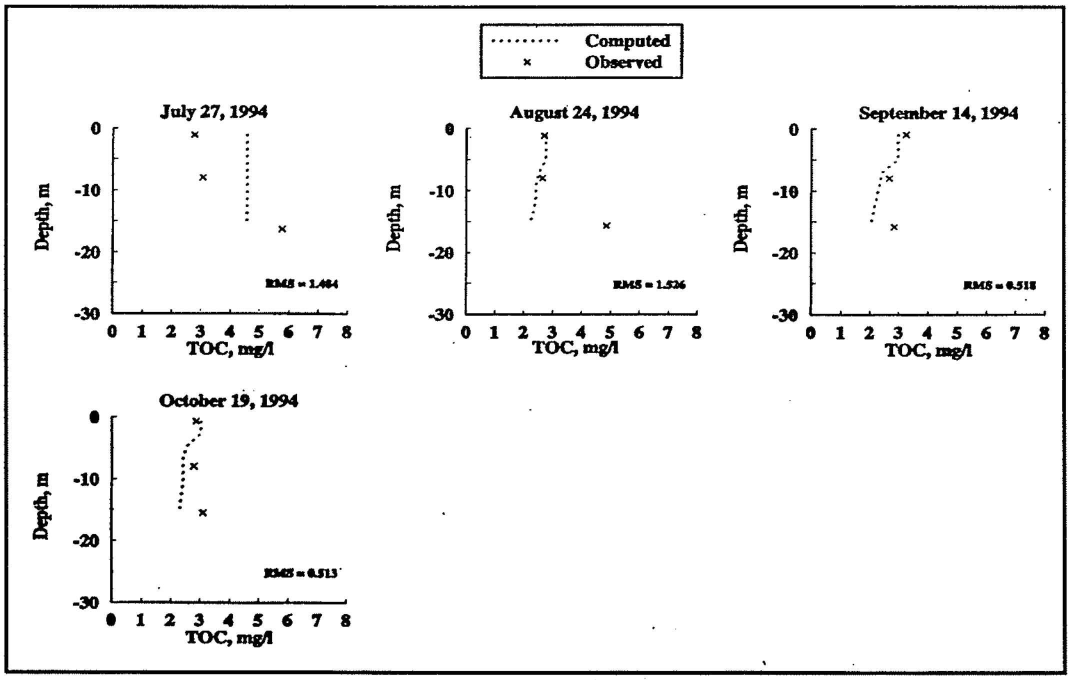


Figure 102. 1994 WFG TOC results for station 5

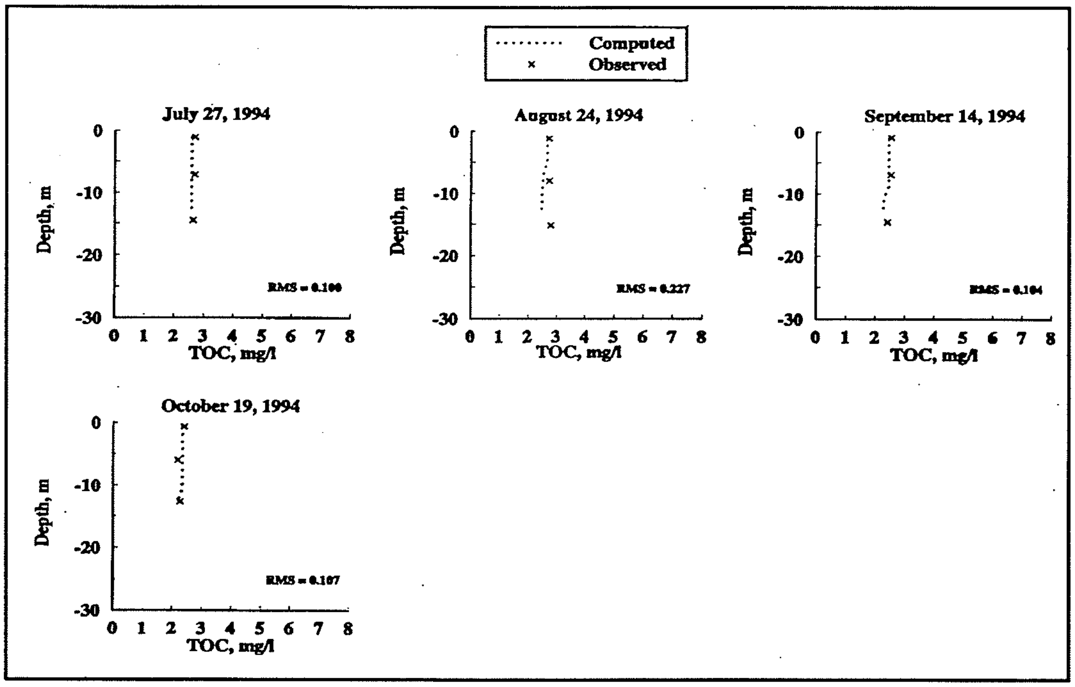


Figure 103. 1994 WFG TOC results for station 6

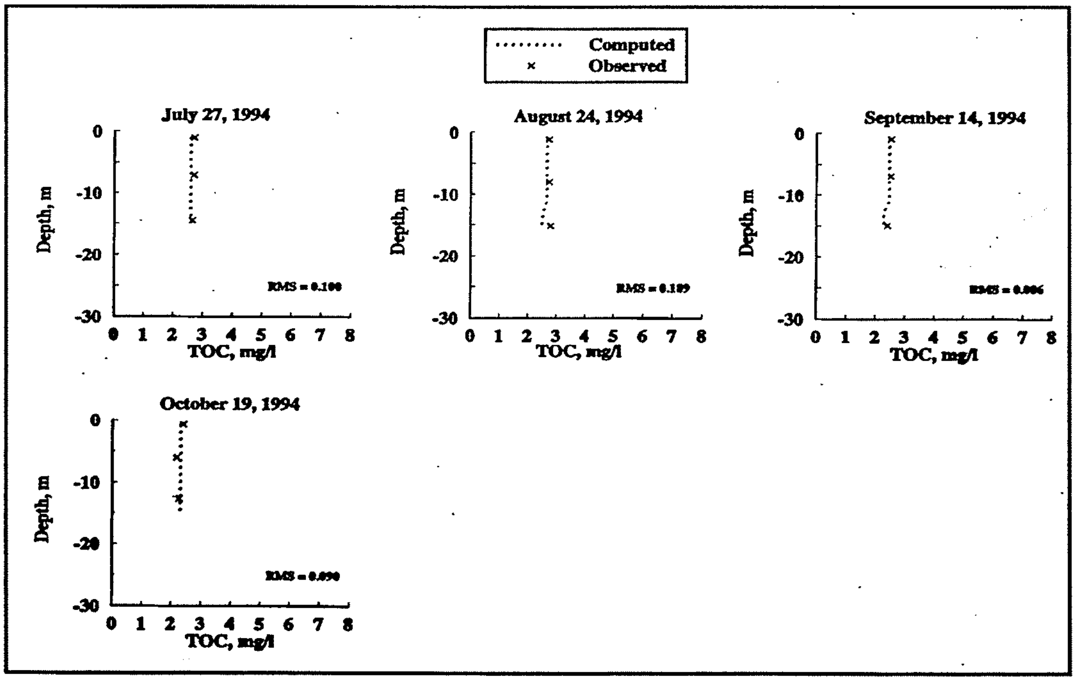


Figure 104. 1994 WFG TOC results for station 8

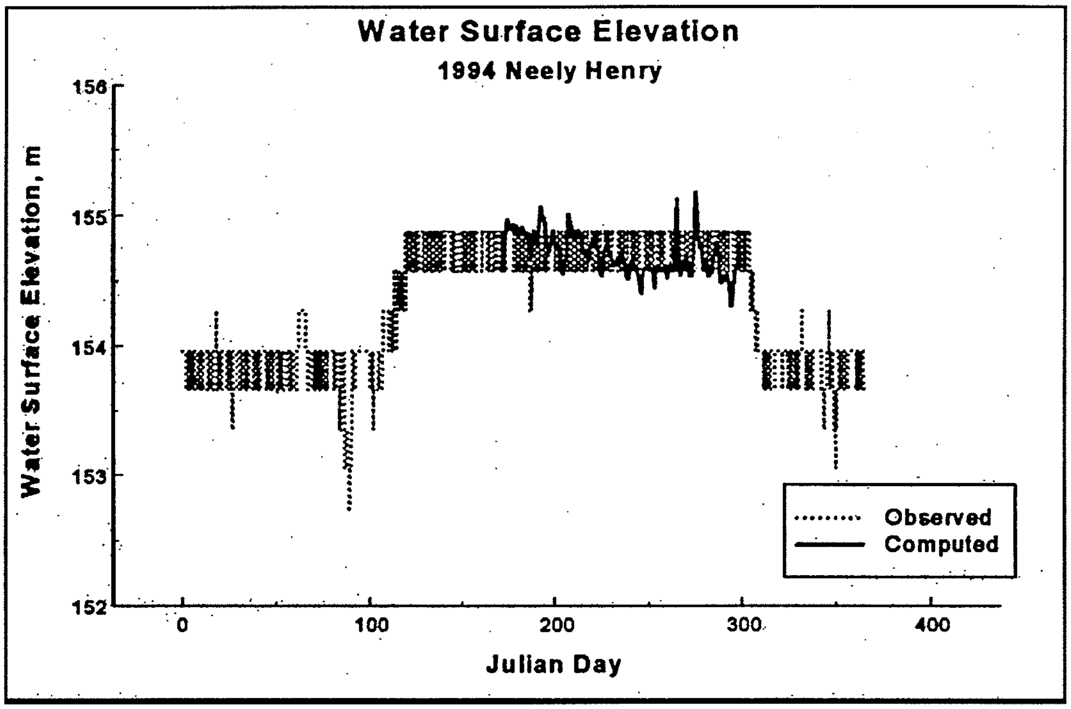


Figure 105. Neely Henry 1994 computed versus observed water surface elevations

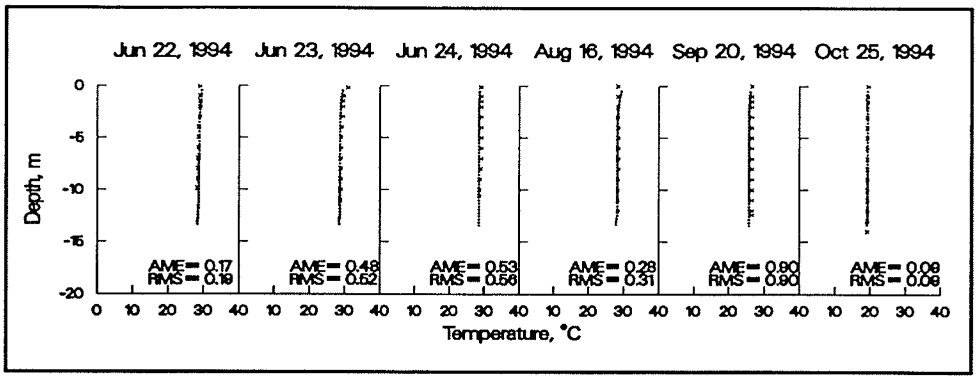


Figure 106. 1994 Neely Henry temperature results for station 1

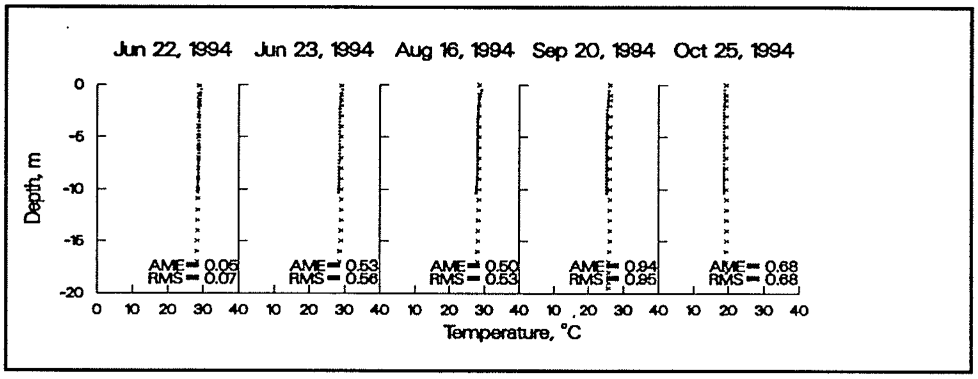


Figure 107. 1994 Neely Henry temperature results for station 2

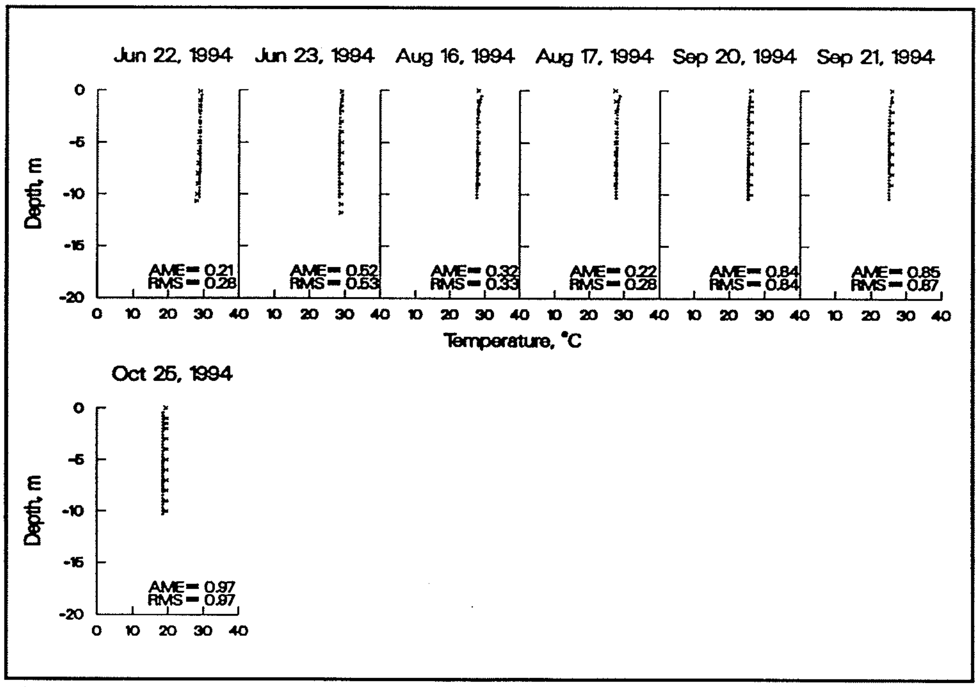


Figure 108. 1994 Neely Henry temperature results for station 4

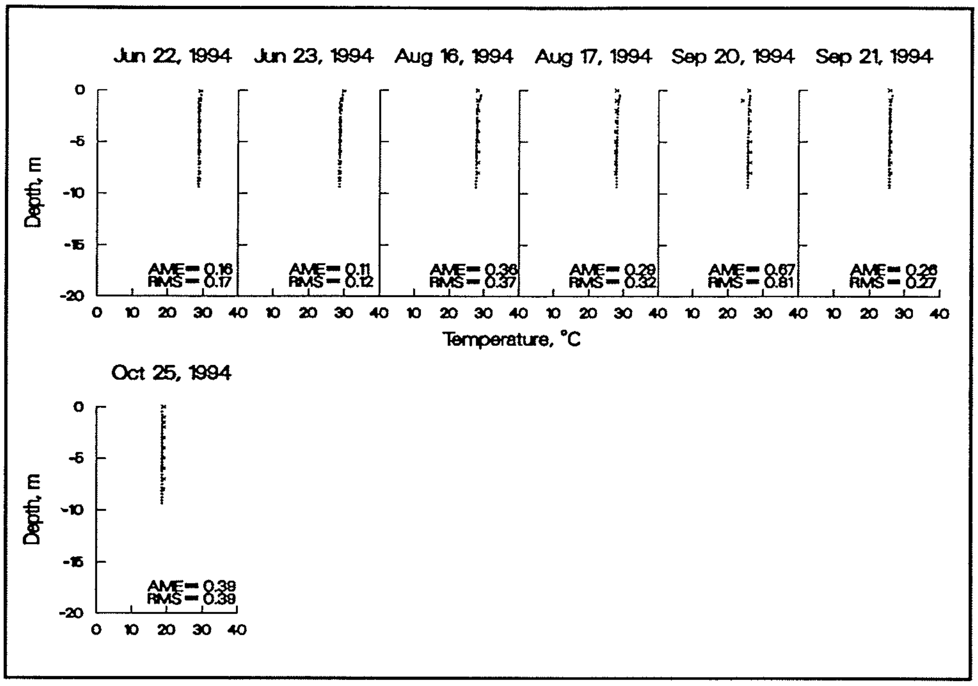


Figure 109. 1994 Neely Henry temperature results for station 6

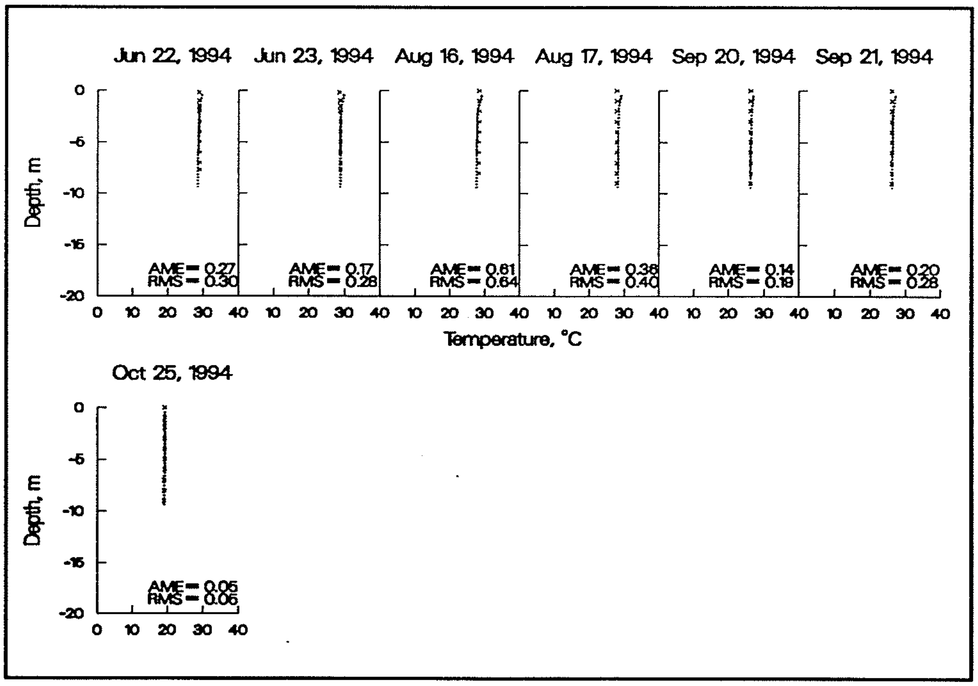


Figure 110. 1994 Neely Henry temperature results for station 8

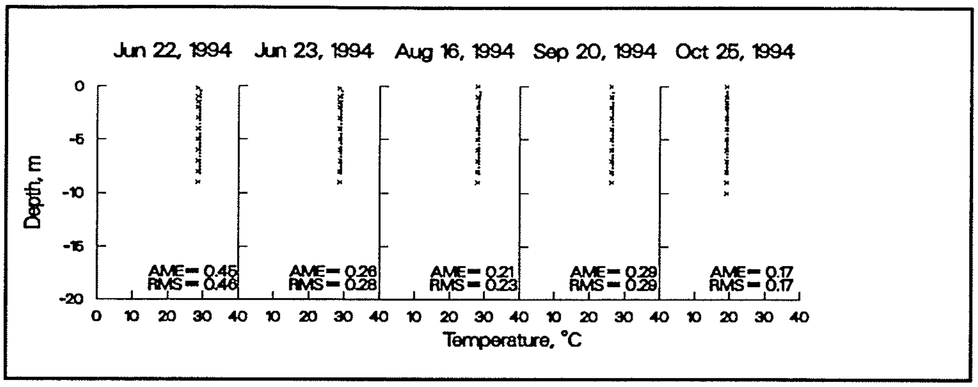


Figure 111. 1994 Neely Henry temperature results for station 10

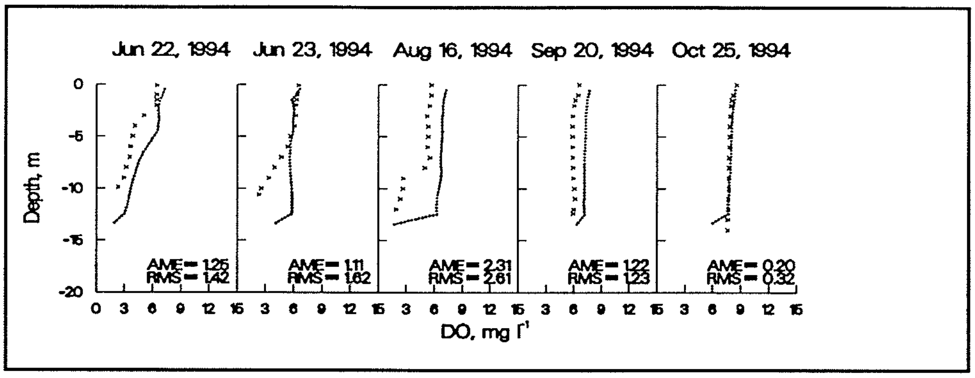


Figure 112. 1994 Neely Henry DO results for station 1

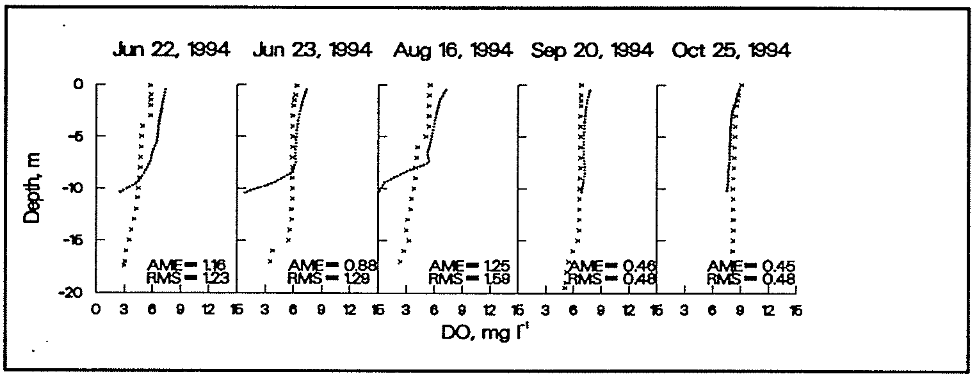


Figure 113. 1994 Neely Henry DO results for station 2

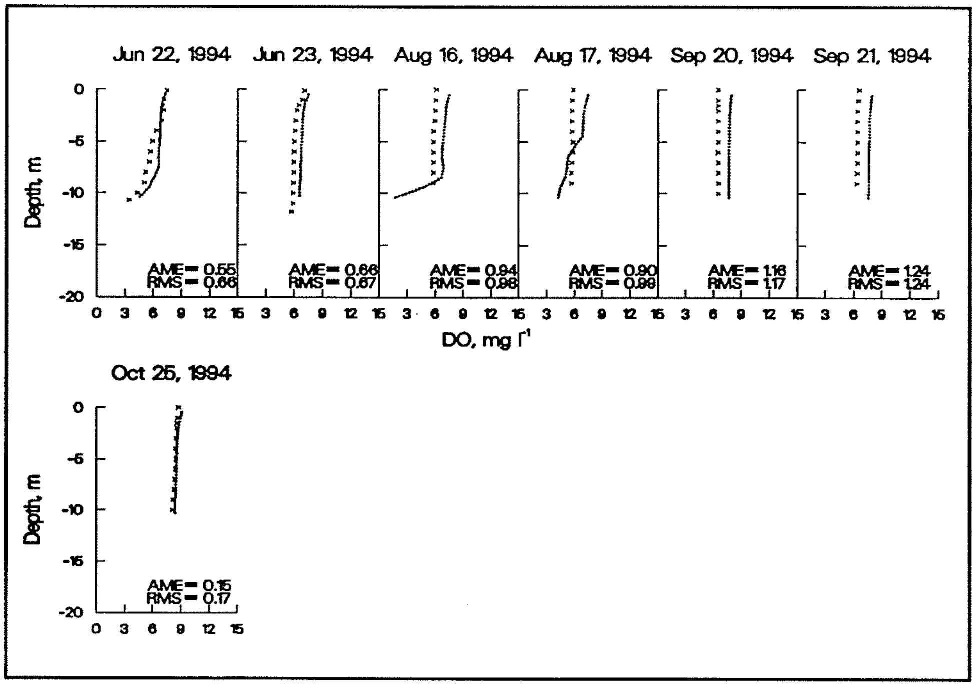


Figure 114. 1994 Neely Henry DO results for station 4

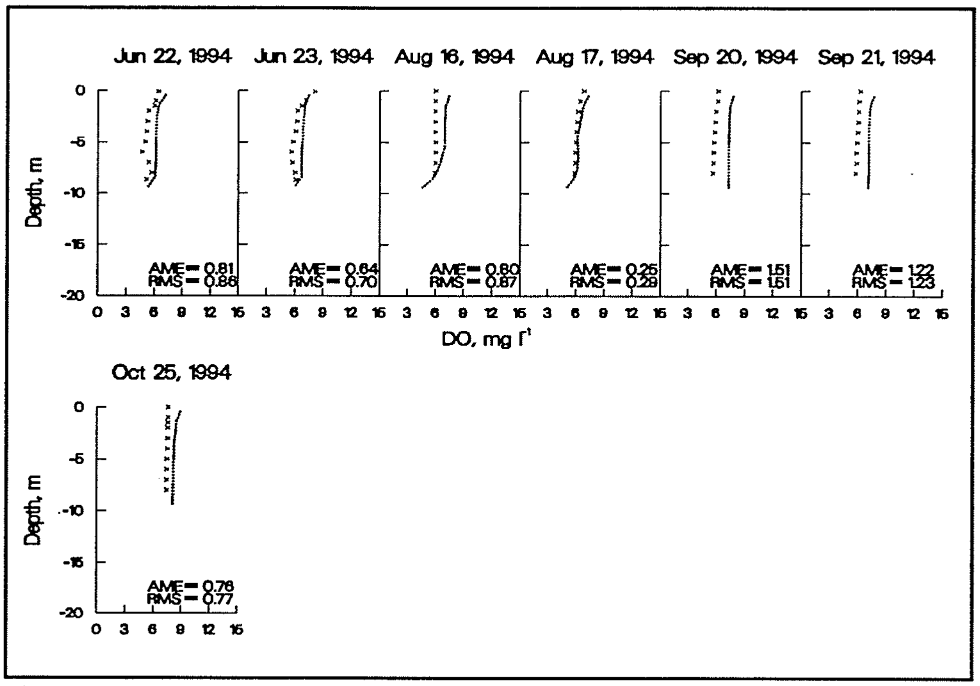


Figure 115. 1994 Neely Henry DO results for station 6

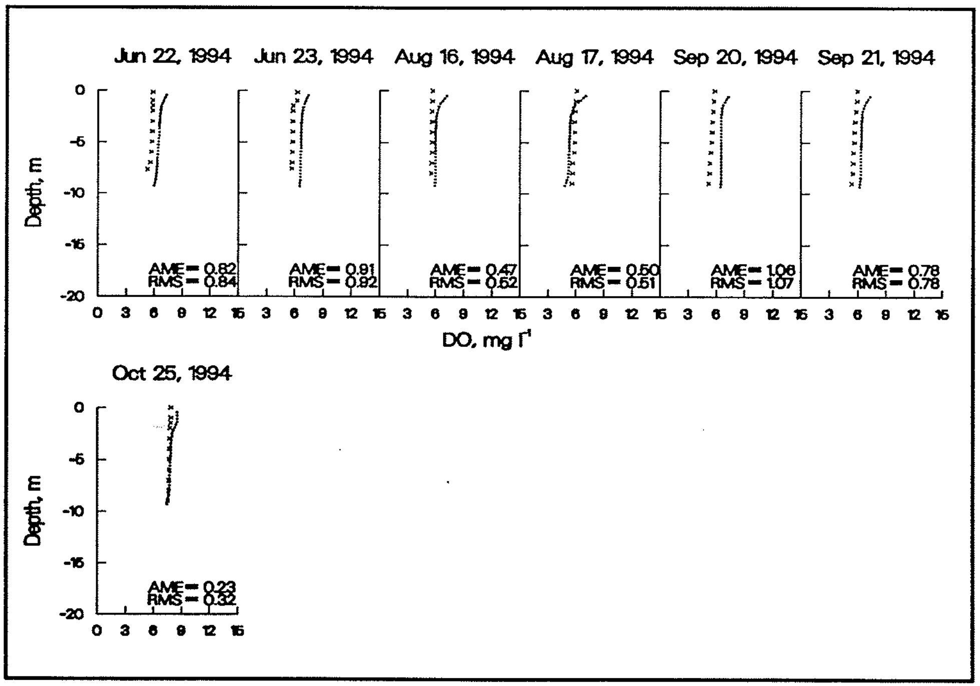


Figure 116. 1994 Neely Henry DO results for station 8

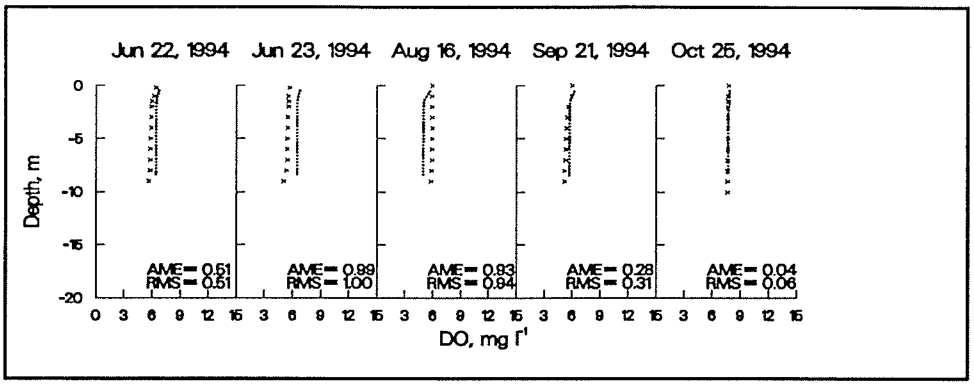


Figure 117. 1994 Neely Henry DO results for station 10

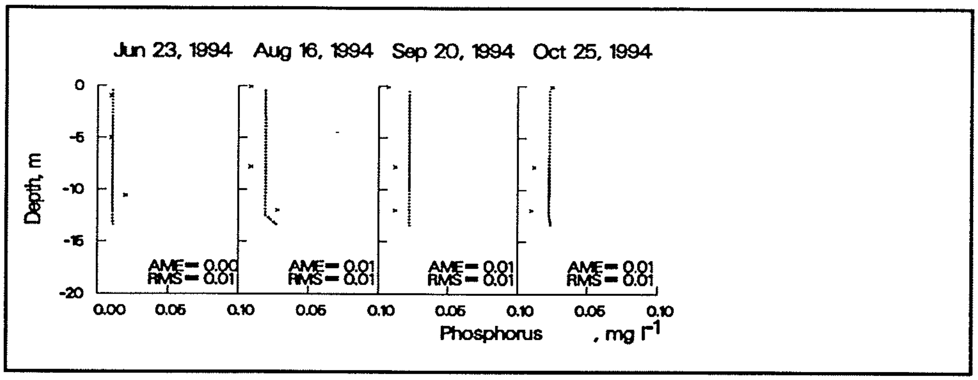


Figure 118. 1994 Neely Henry phosphorus results for station 1

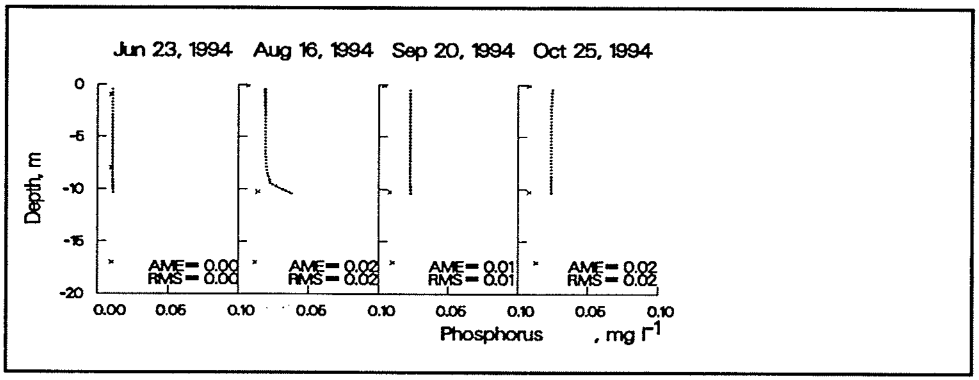


Figure 119. 1994 Neely Henry phosphorus results for station 2

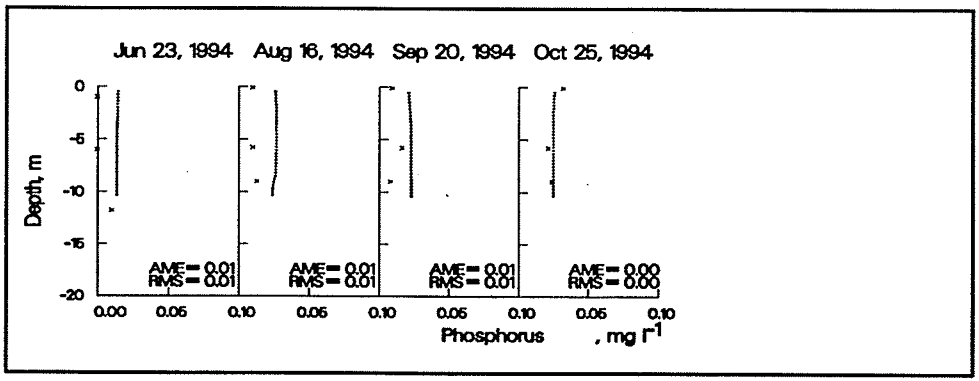


Figure 120. 1994 Neely Henry phosphorus results for station 4

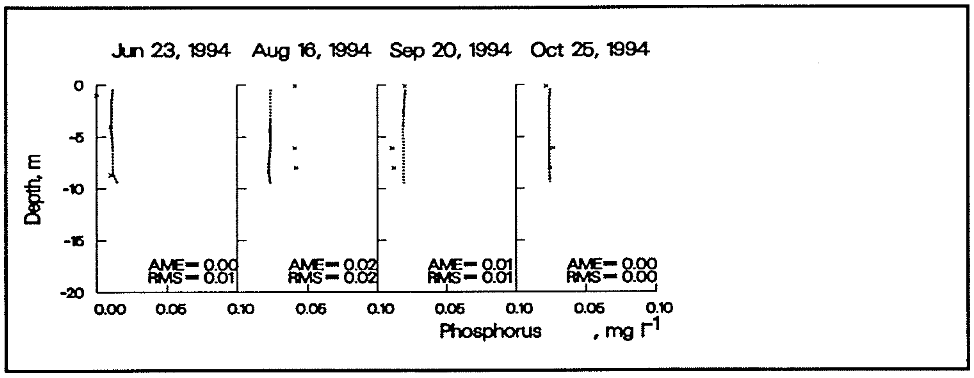


Figure 121. 1994 Neely Henry phosphorus results for station 6

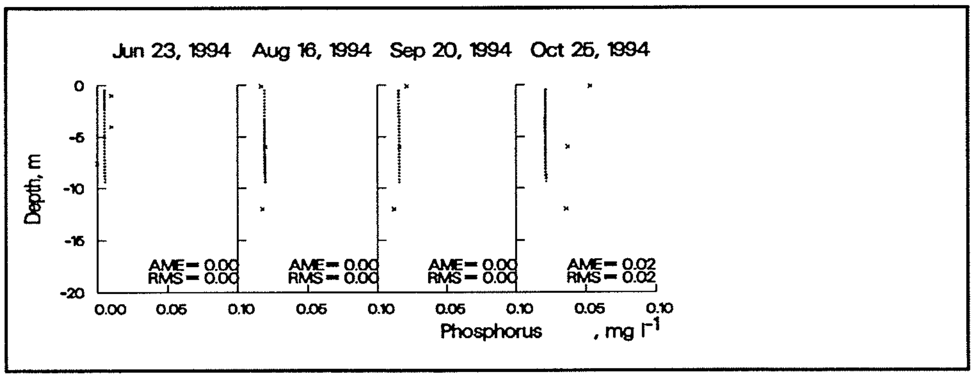


Figure 122. 1994 Neely Henry phosphorus results for station 8

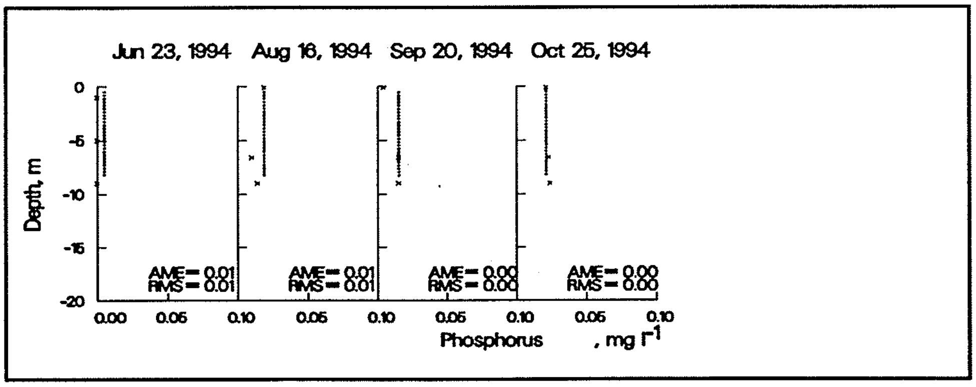


Figure 123. 1994 Neely Henry phosphorus results for station 10

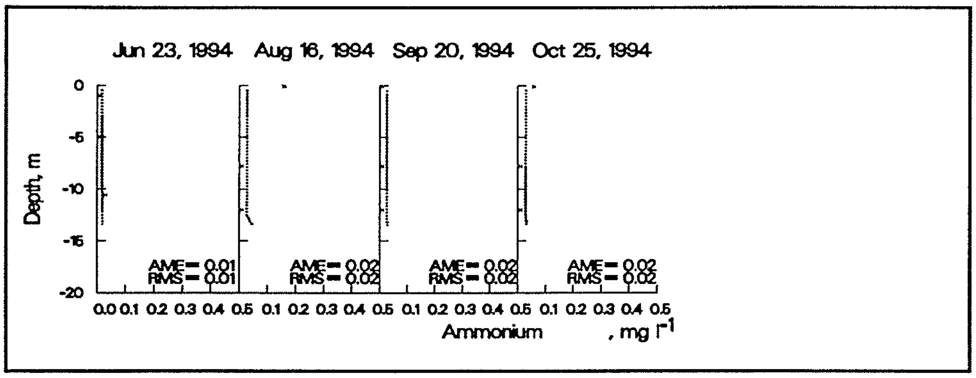


Figure 124. 1994 Neely Henry ammonium results for station 1

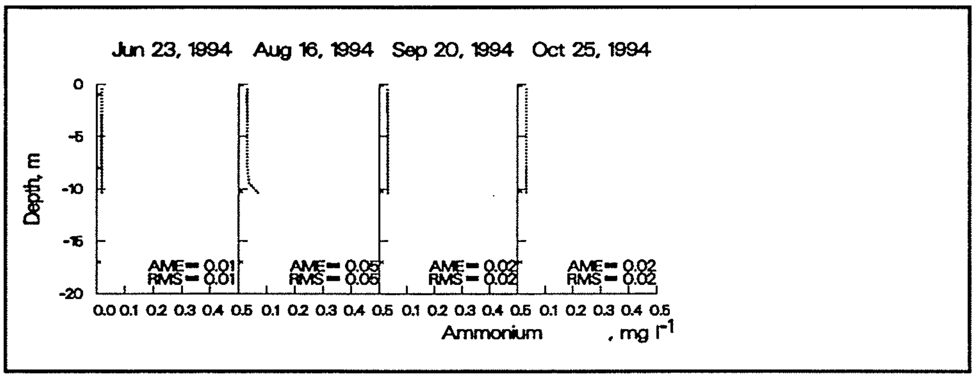


Figure 125. 1994 Neely Henry ammonium results for station 2

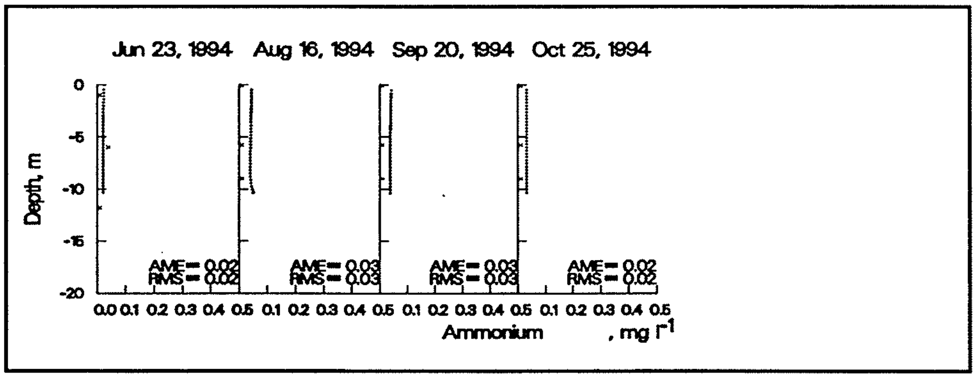


Figure 126. 1994 Neely Henry ammonium results for station 4

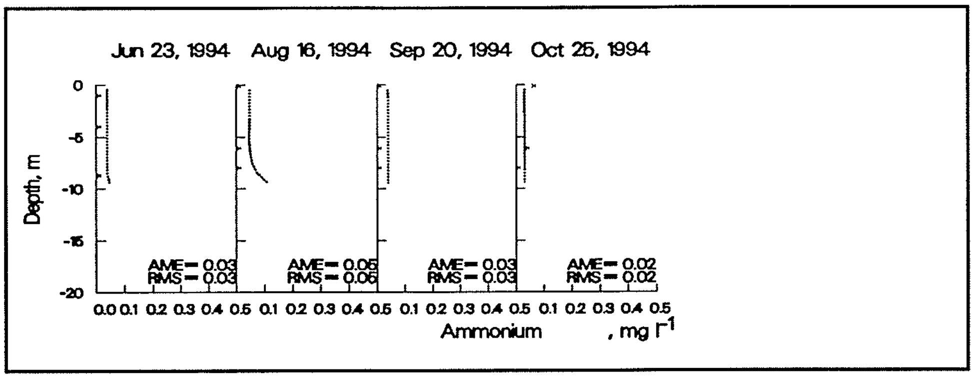


Figure 127. 1994 Neely Henry ammonium results for station 6

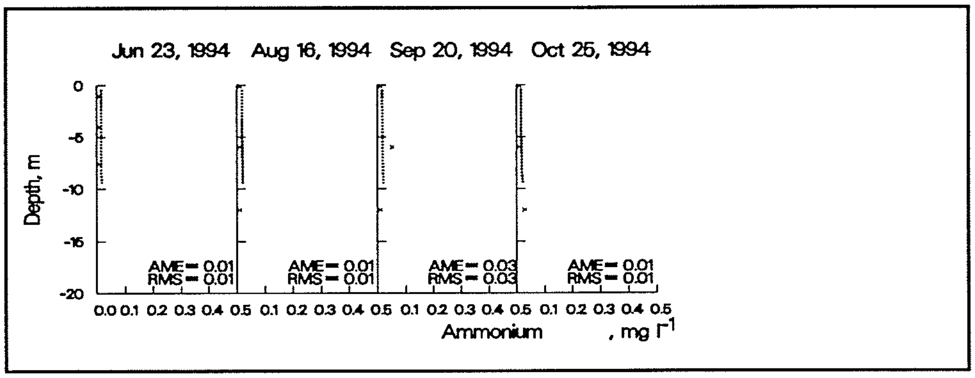


Figure 128. 1994 Neely Henry ammonium results for station 8

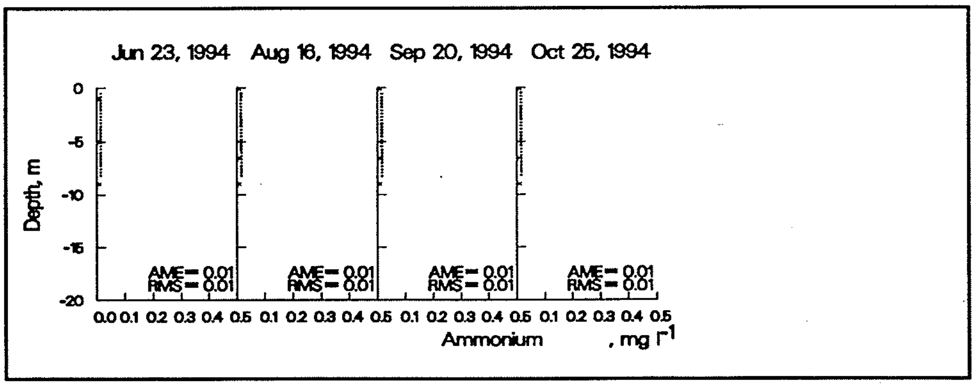


Figure 129. 1994 Neely Henry ammonium results for station 10

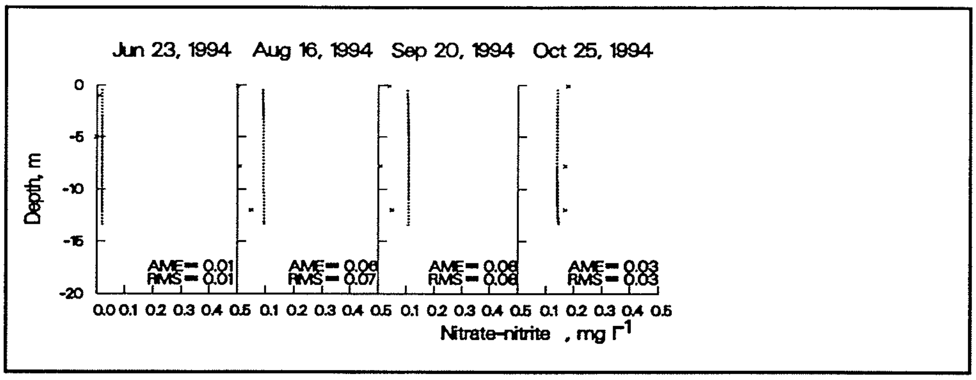


Figure 130. 1994 Neely Henry nitrate-nitrite results for station 1

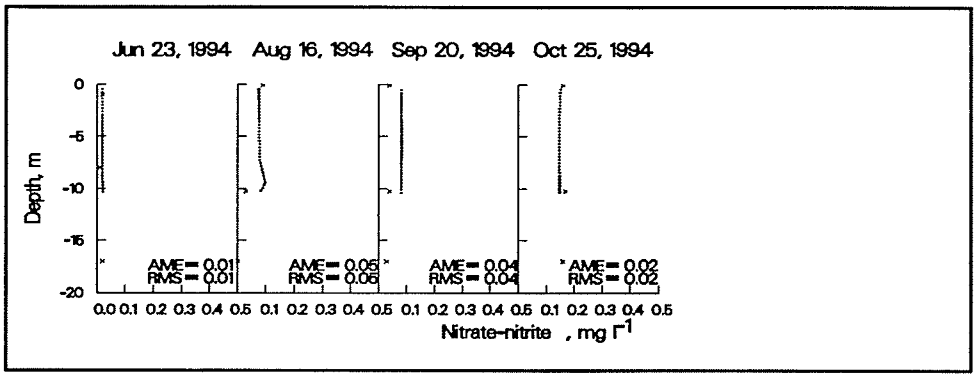


Figure 131. 1994 Neely Henry nitrate-nitrite results for station 2

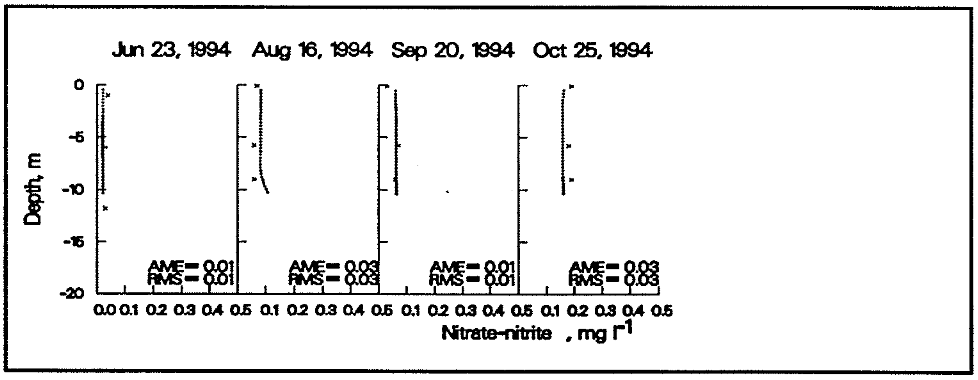


Figure 132. 1994 Neely Henry nitrate-nitrite results for station 4

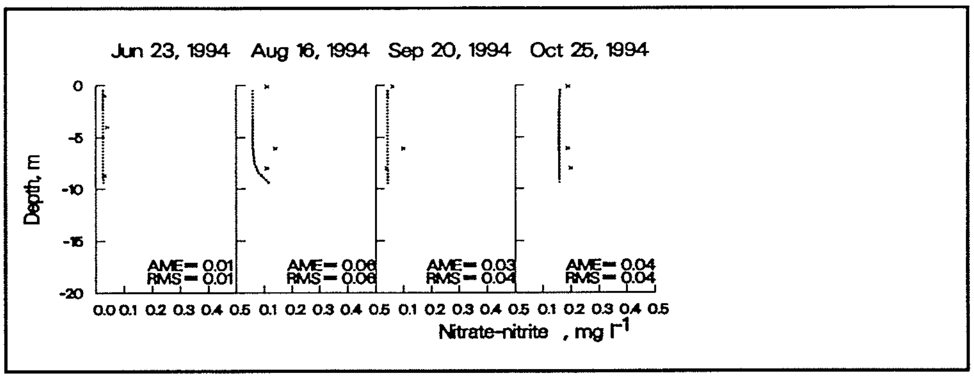


Figure 133. 1994 Neely Henry nitrate-nitrite results for station 6

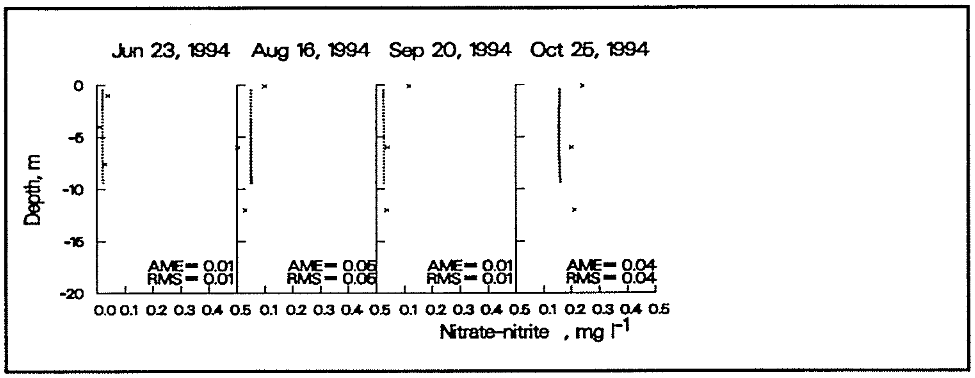


Figure 134. 1994 Neely Henry nitrate-nitrite results for station 8

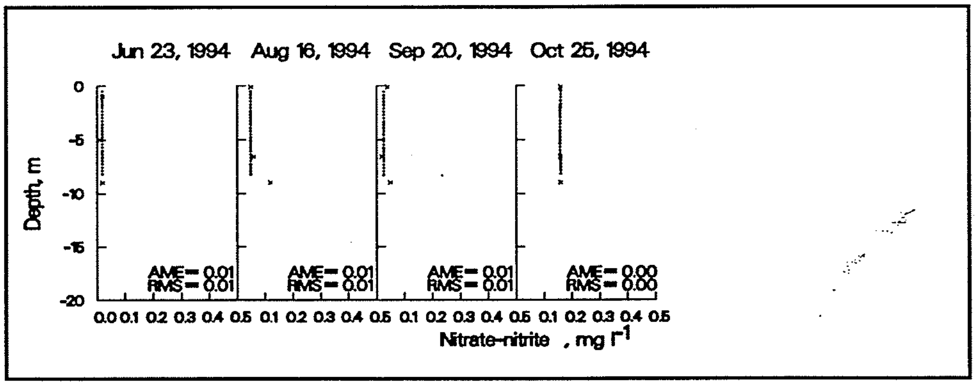


Figure 135. 1994 Neely Henry nitrate-nitrite results for station 10

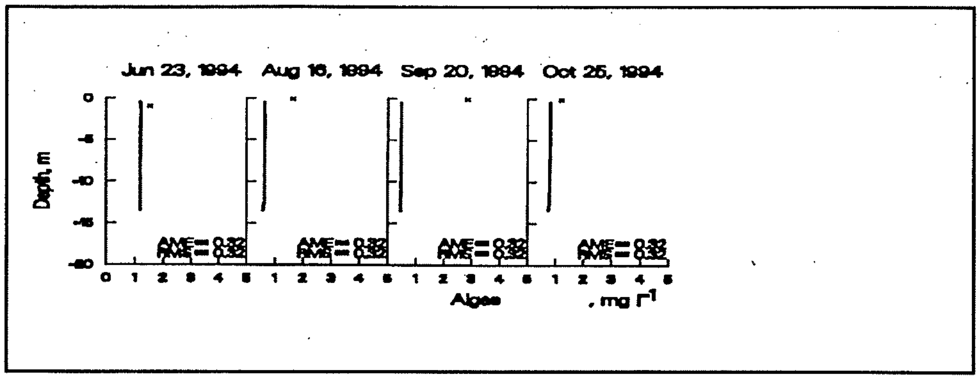


Figure 136. 1994 Neely Henry algae results for station 1

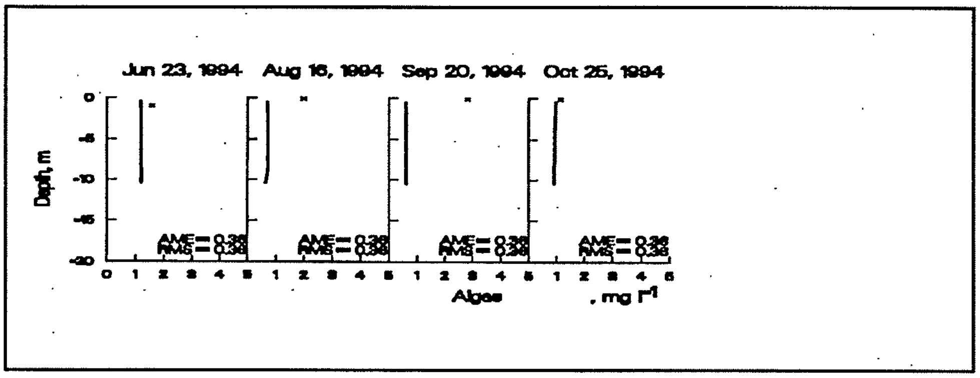


Figure 137. 1994 Neely Henry algae results for station 2

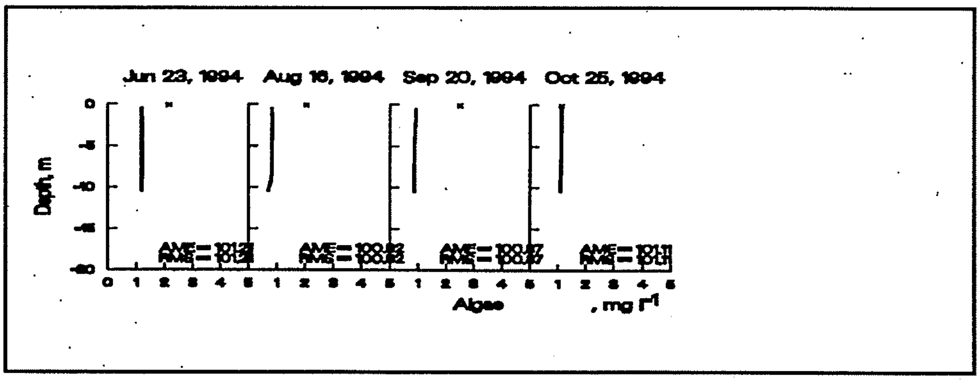


Figure 138. 1994 Neely Henry algae results for station 4

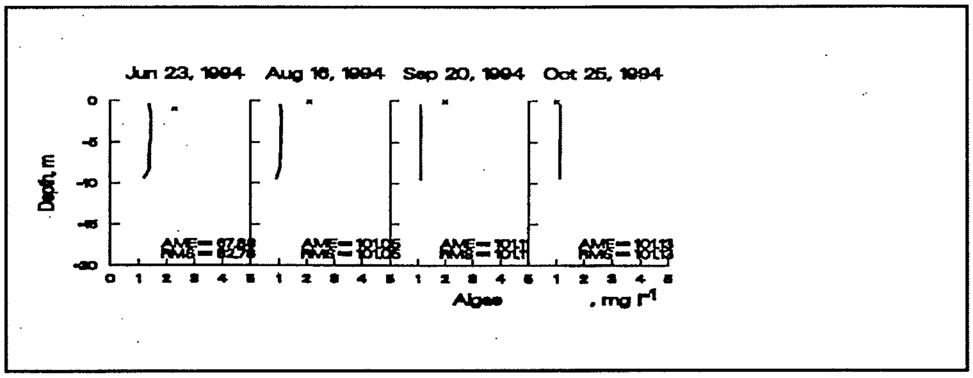


Figure 139. 1994 Neely Henry algae results for station 6

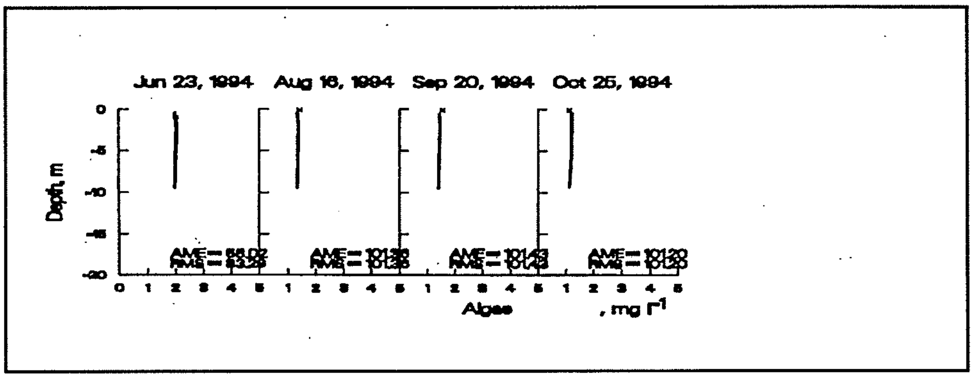


Figure 140. 1994 Neely Henry algae results for station 8

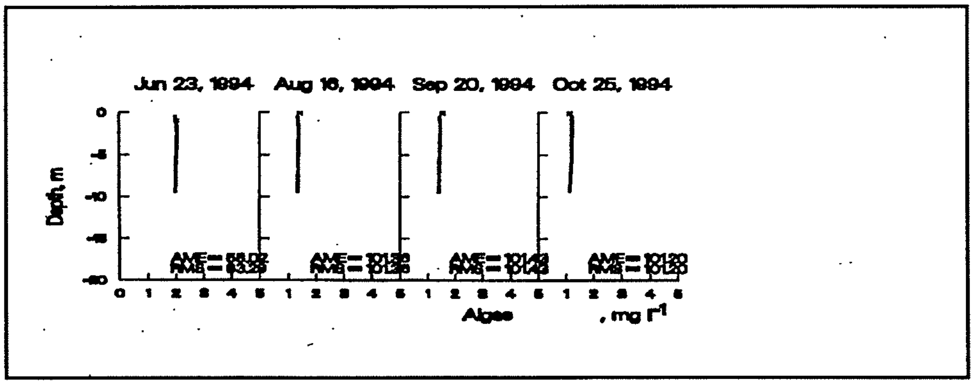


Figure 141. 1994 Neely Henry algae results for station 10

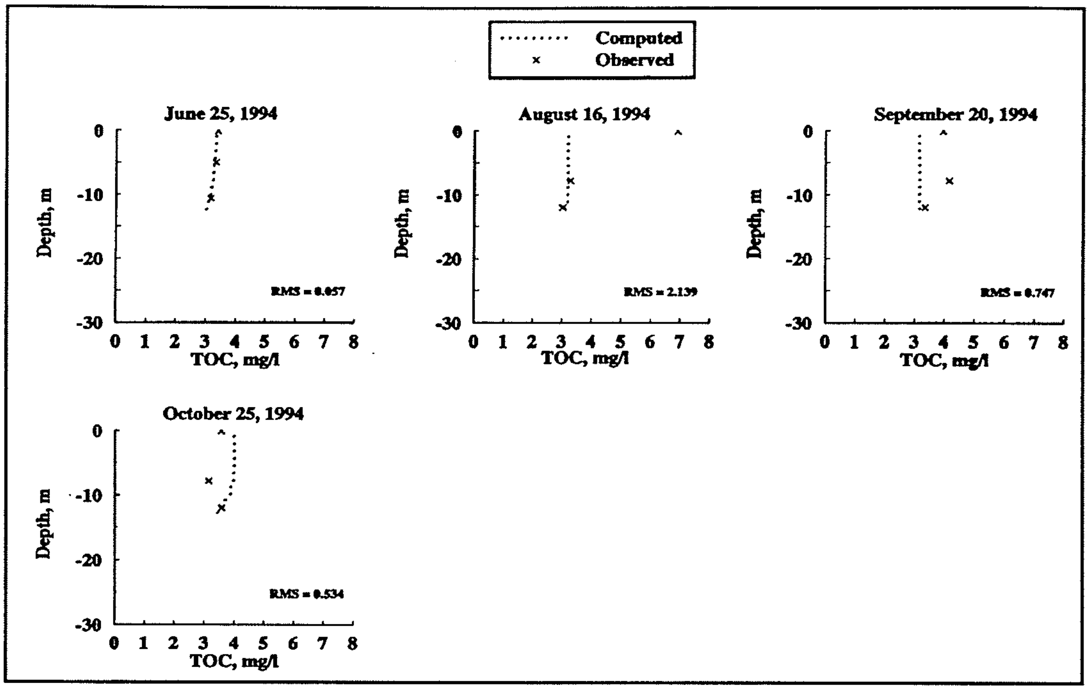


Figure 142. 1994 Neely Henry TOC results for station 1

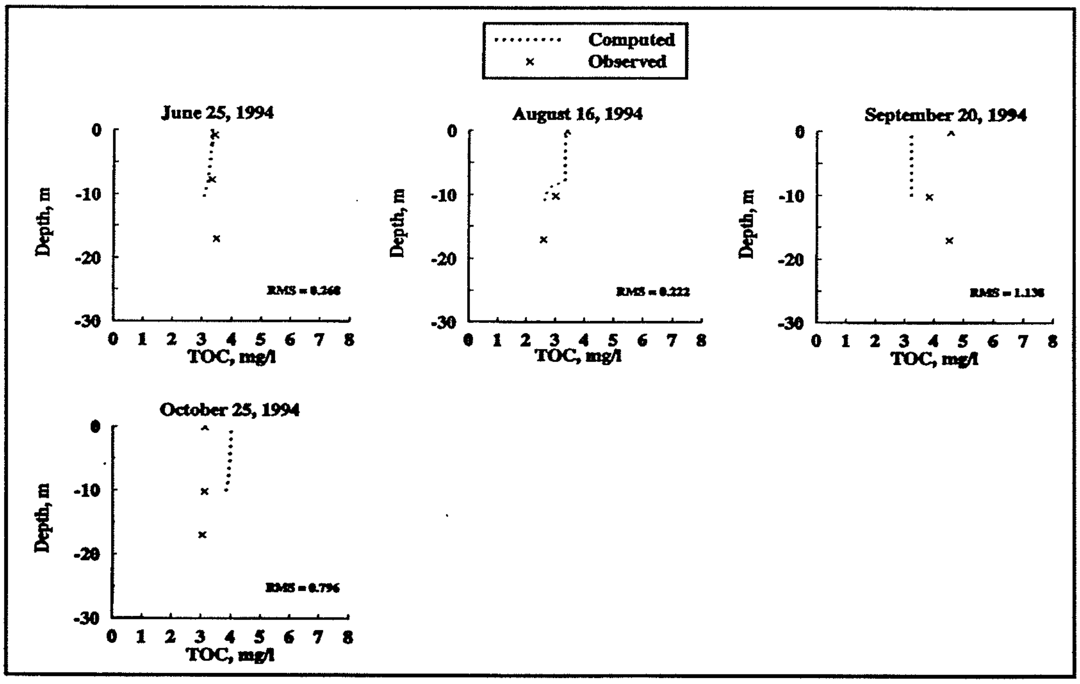


Figure 143. 1994 Neely Henry TOC results for station 2

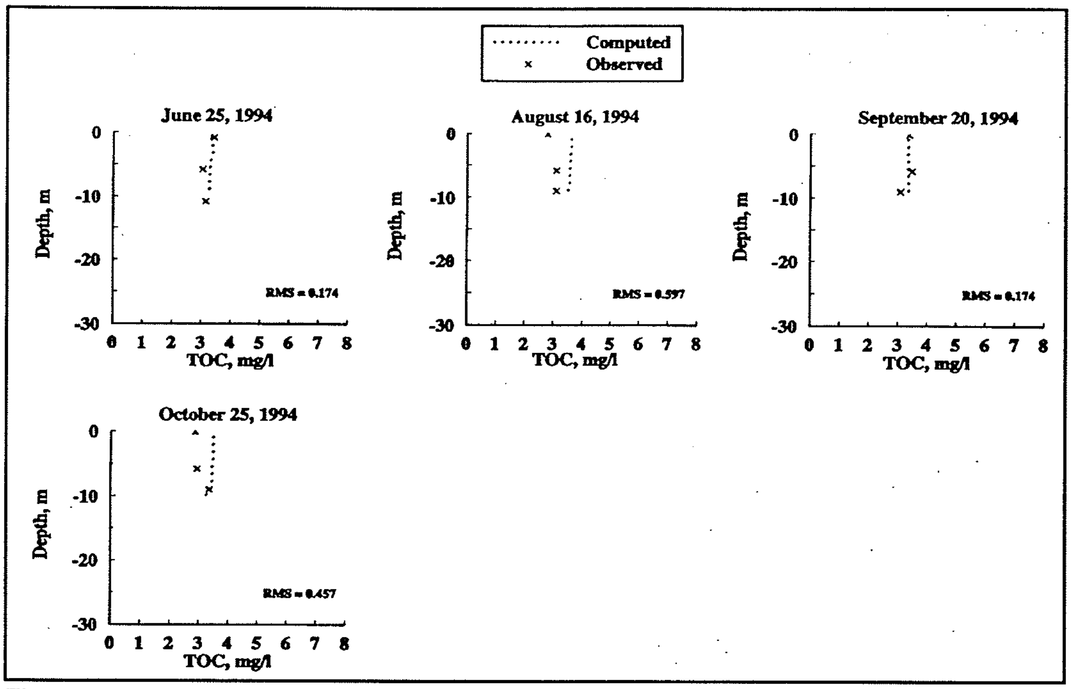


Figure 144. 1994 Neely Henry TOC results for station 4

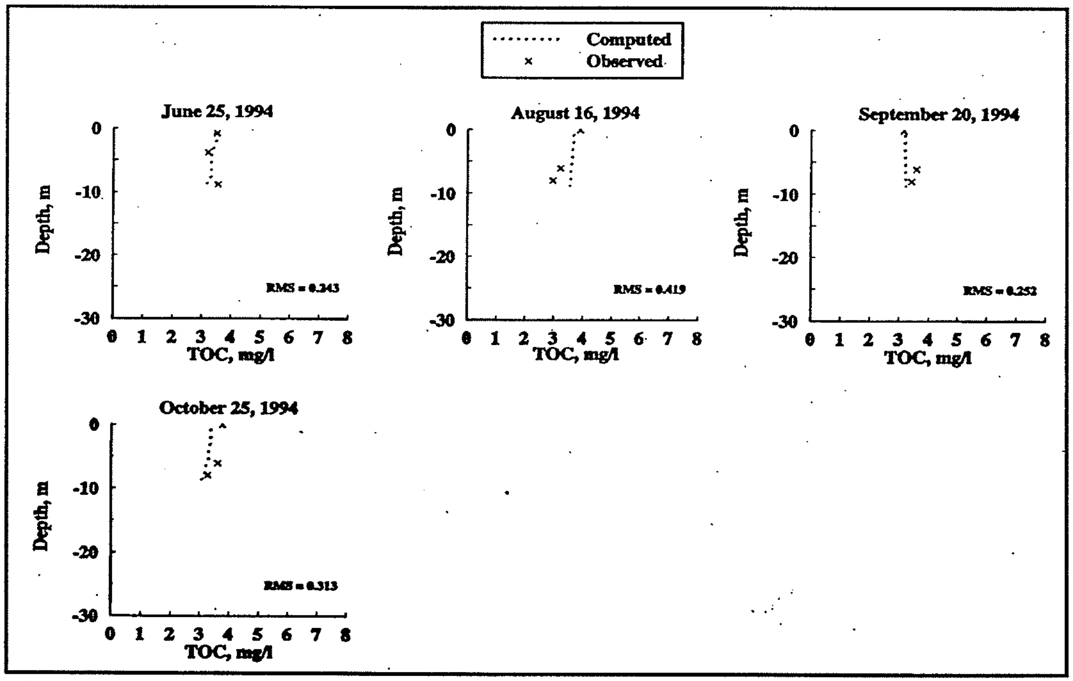


Figure 145. 1994 Neely Henry TOC results for station 6

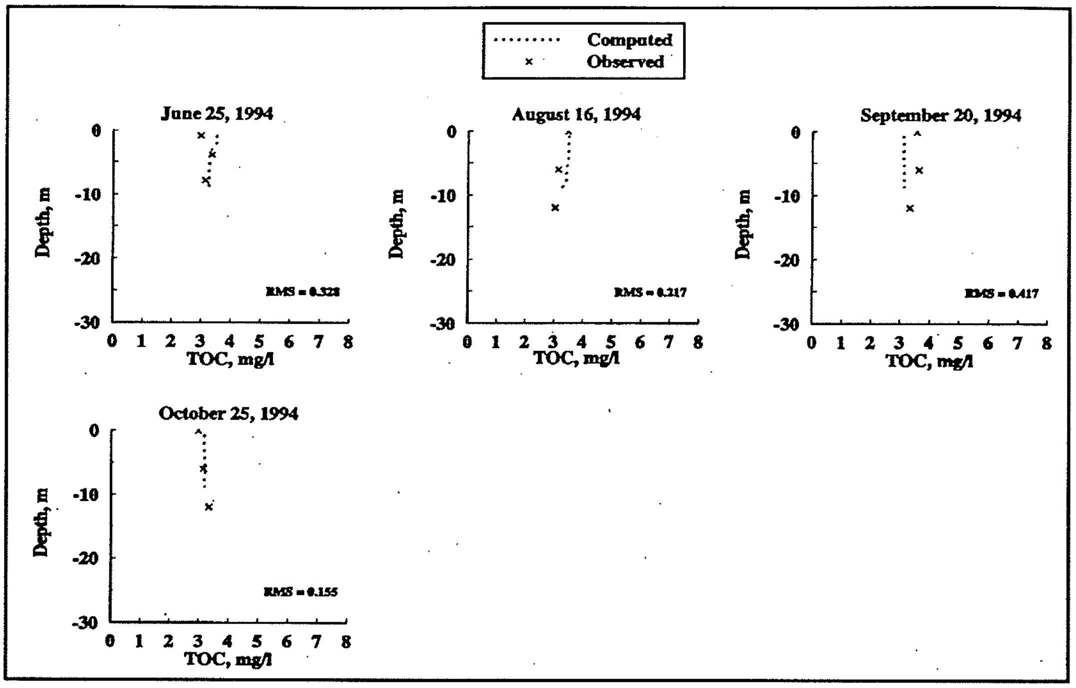


Figure 146. 1994 Neely Henry TOC results for station 8

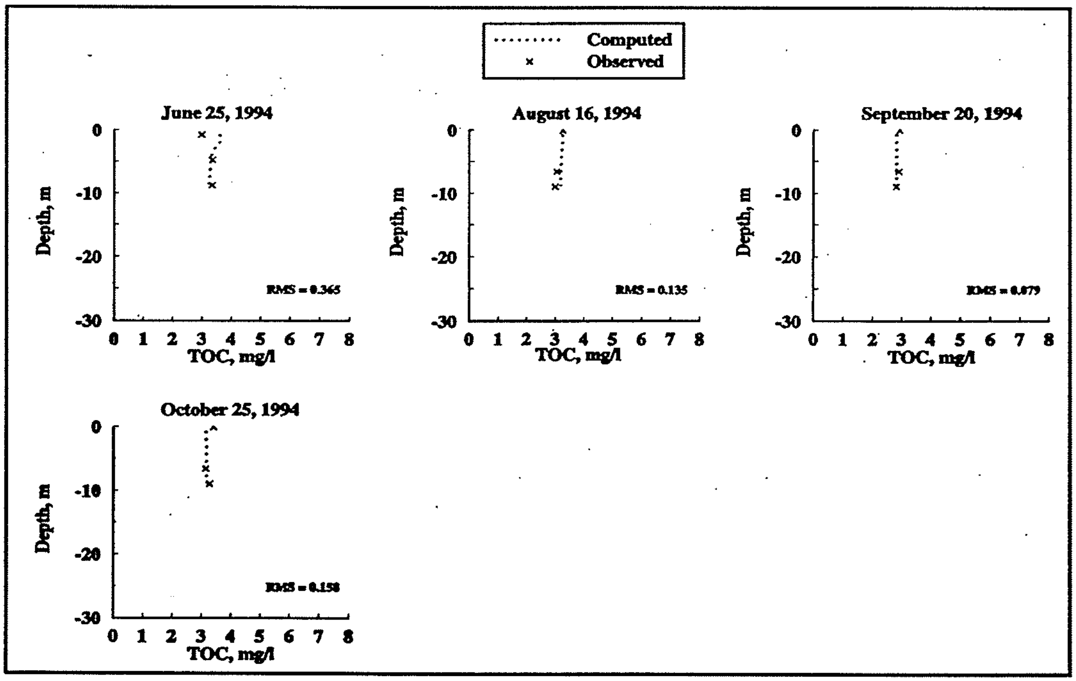


Figure 147. 1994 Neely Henry TOC results for station 10

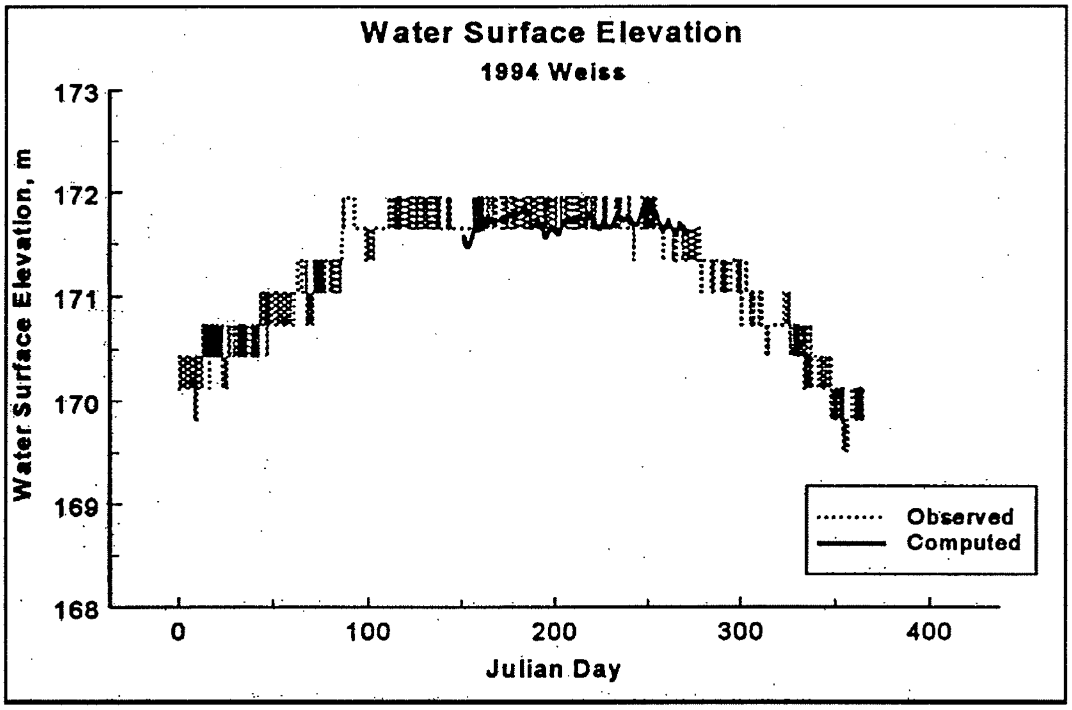


Figure 148. Weiss 1994 computed versus observed water surface elevations

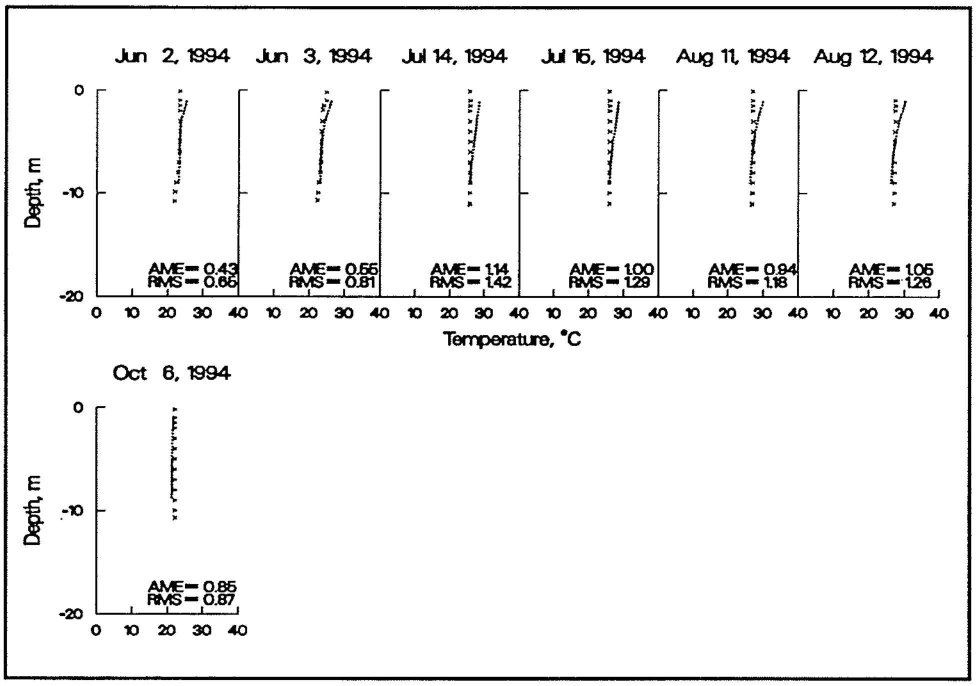


Figure 149. 1994 Weiss temperature results for station 1

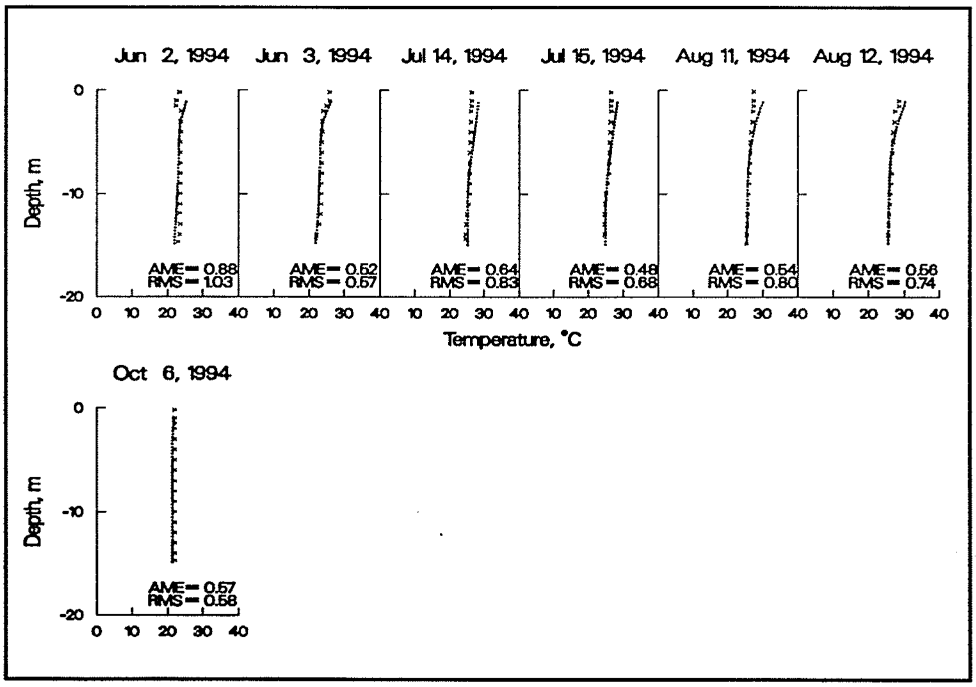


Figure 150. 1994 Weiss temperature results for station 2

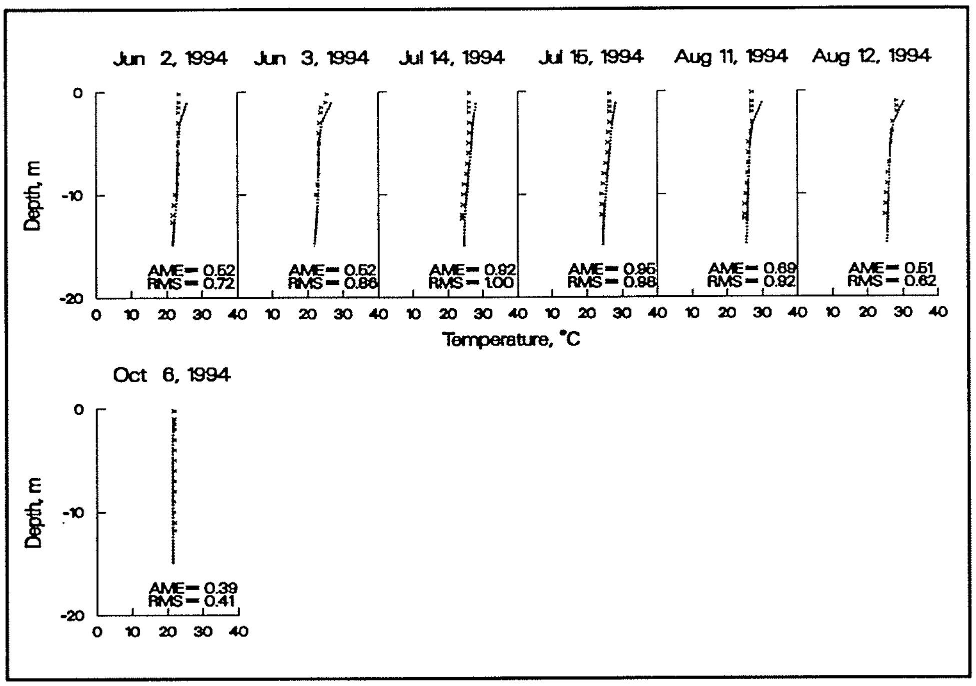


Figure 151. 1994 Weiss temperature results for station 3

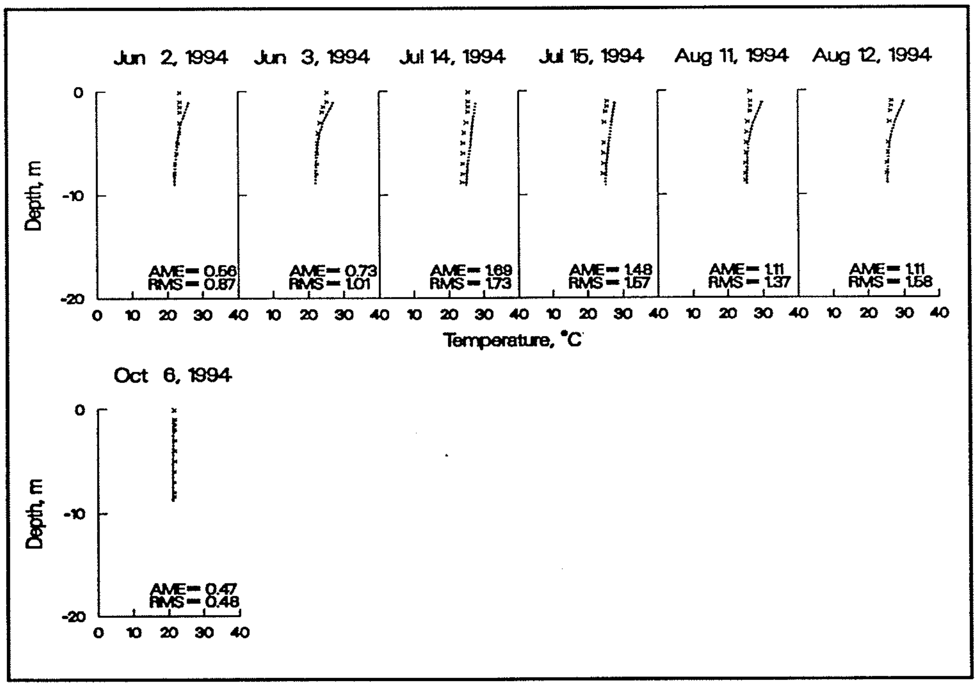


Figure 152. 1994 Weiss temperature results for station 5

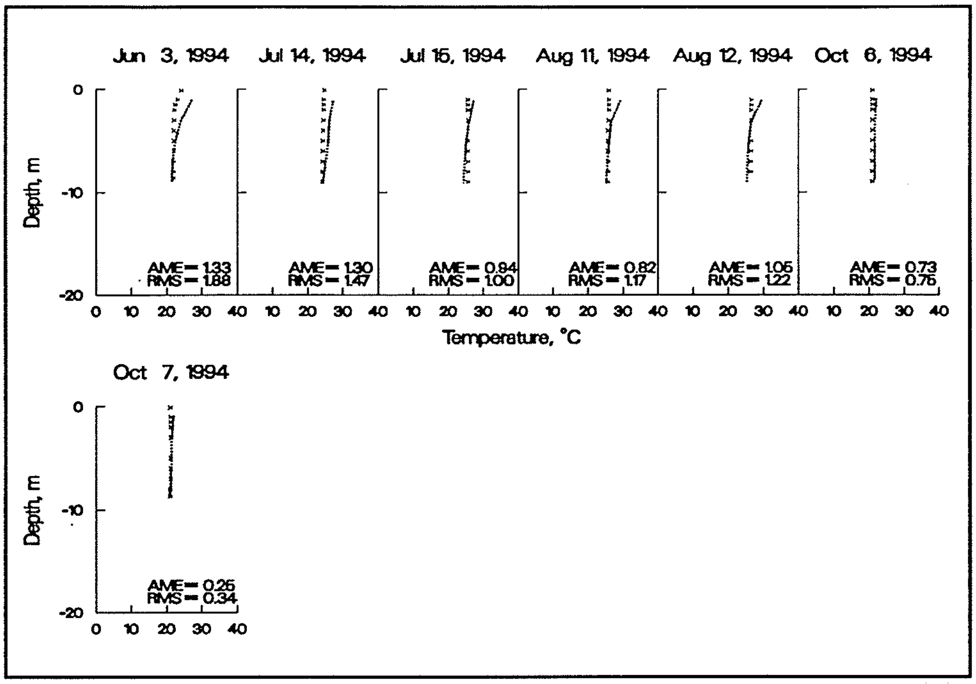


Figure 153. 1994 Weiss temperature results for station 6

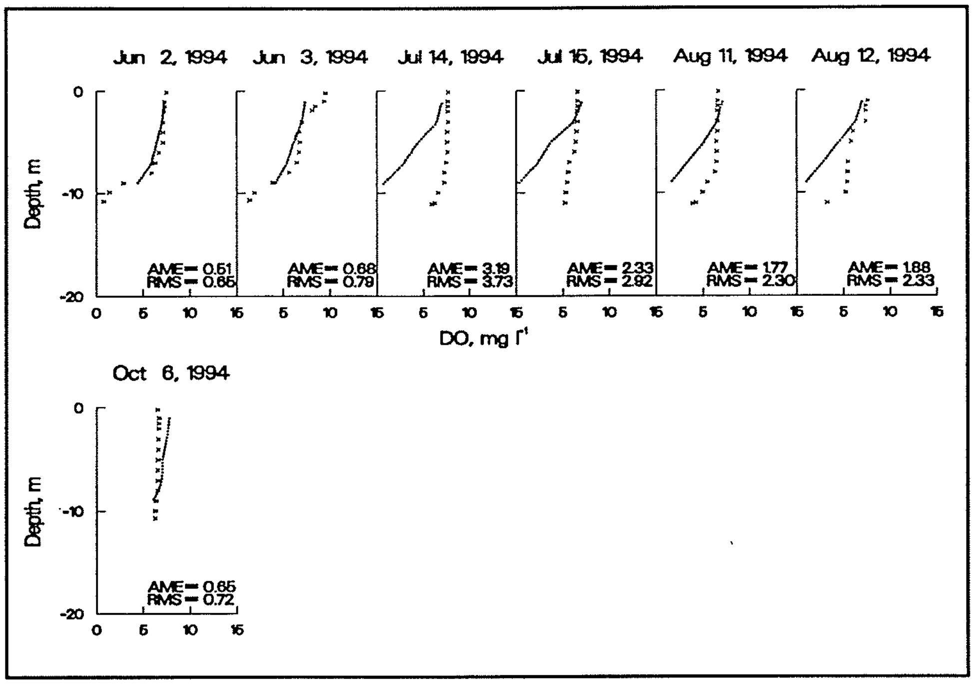


Figure 154. 1994 Weiss DO results for station 1

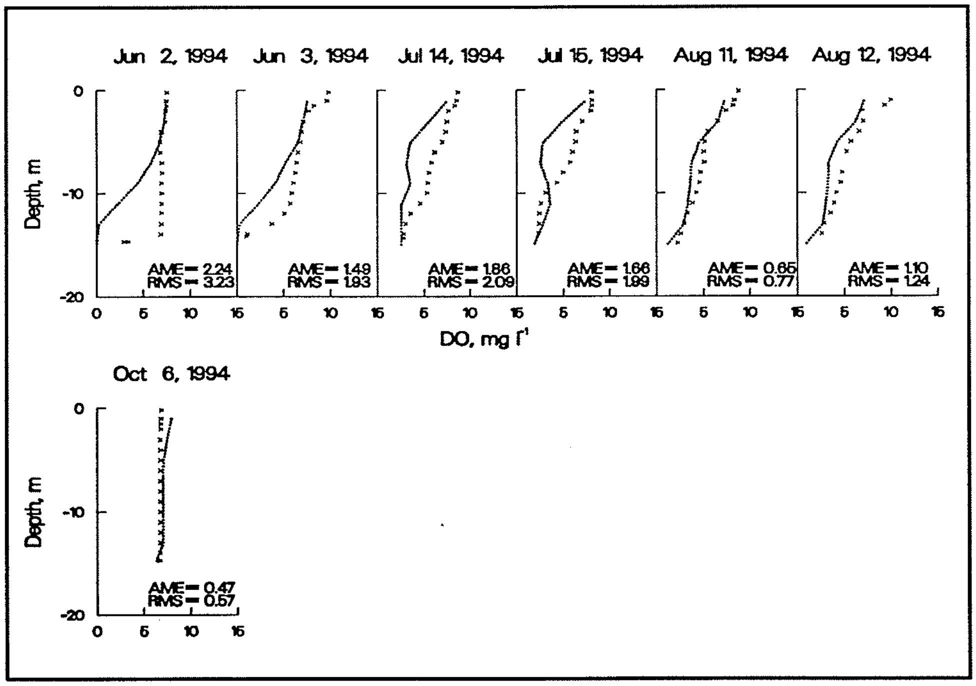


Figure 155. 1994 Weiss DO results for station 2

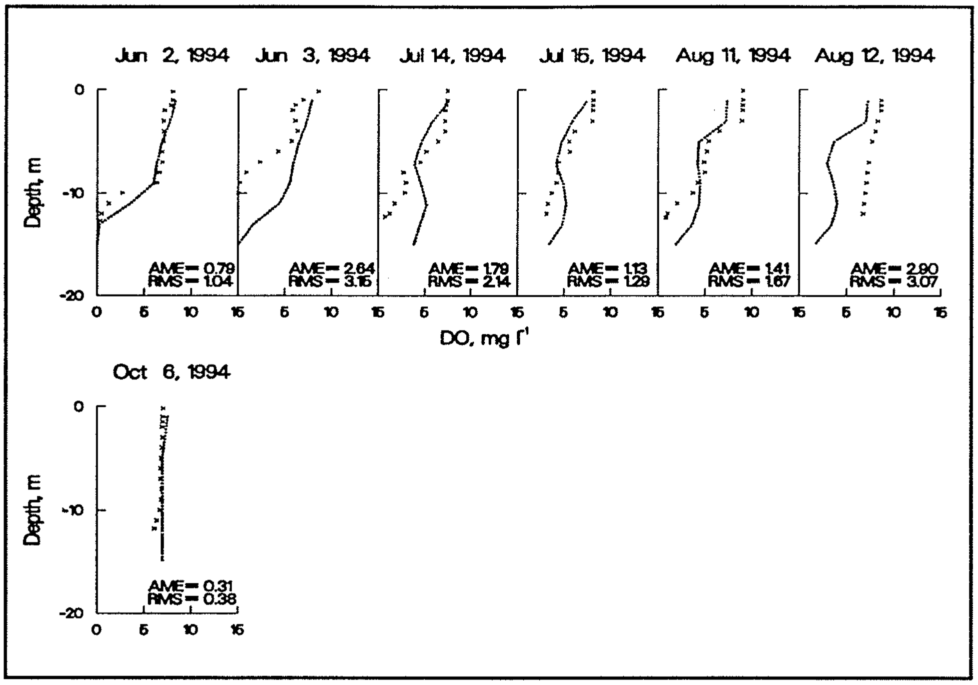


Figure 156. 1994 Weiss DO results for station 3

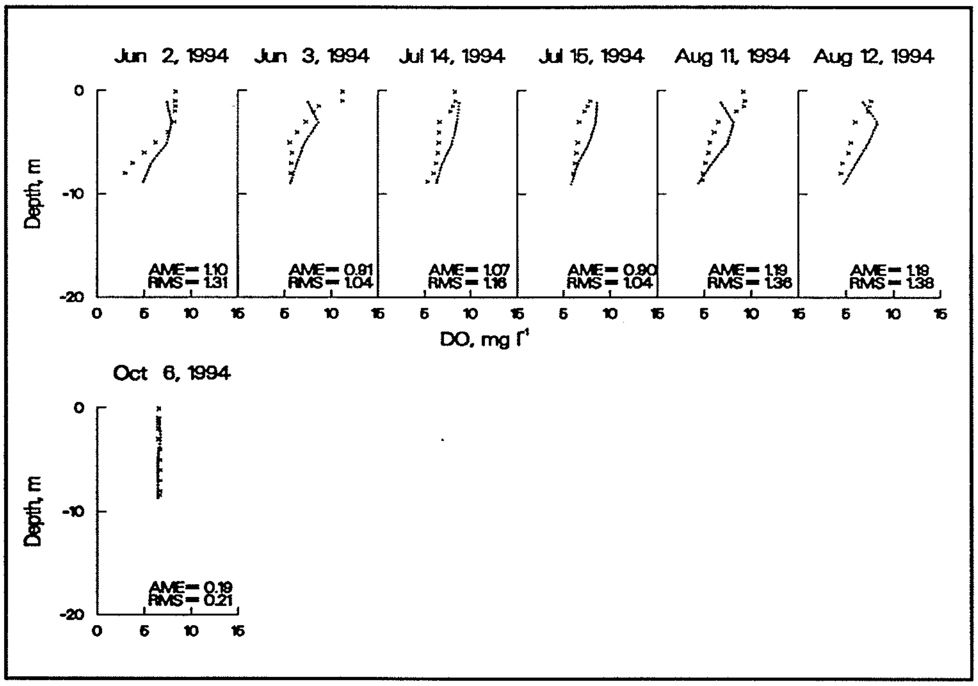


Figure 157. 1994 Weiss DO results for station 5

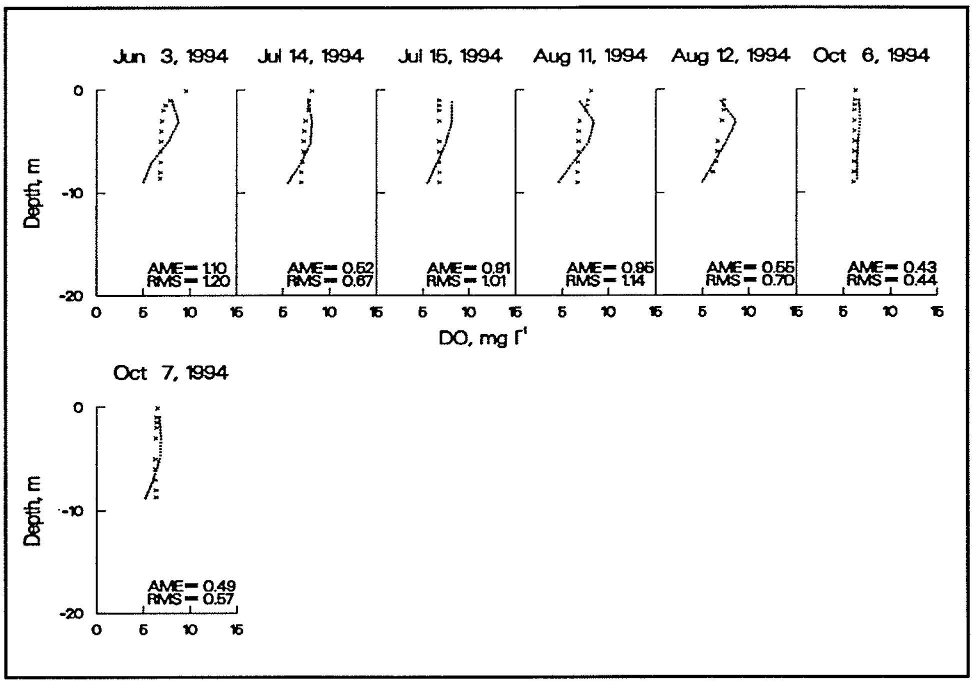


Figure 158. 1994 Weiss DO results for station 6

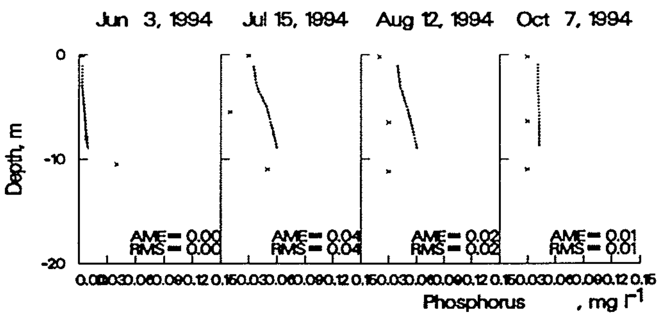


Figure 159. 1994 Weiss phosphorus results for station 1

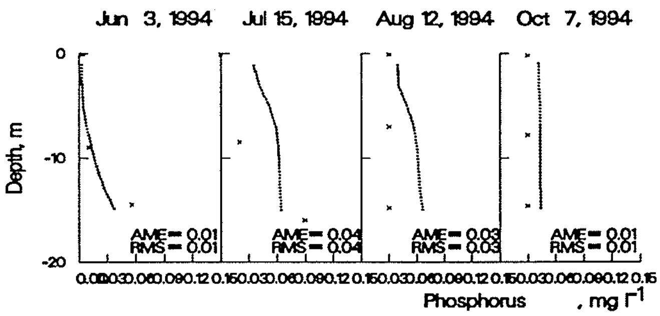


Figure 160. 1994 Weiss phosphorus results for station 2

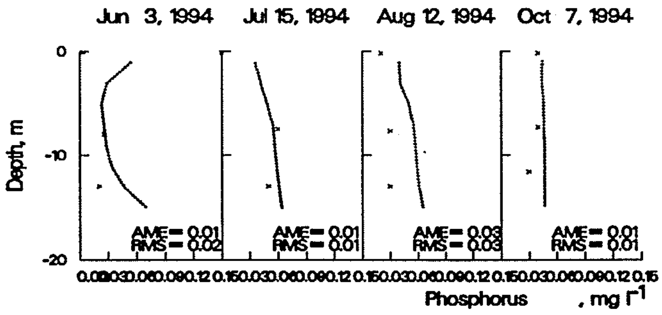


Figure 161. 1994 Weiss phosphorus results for station 3

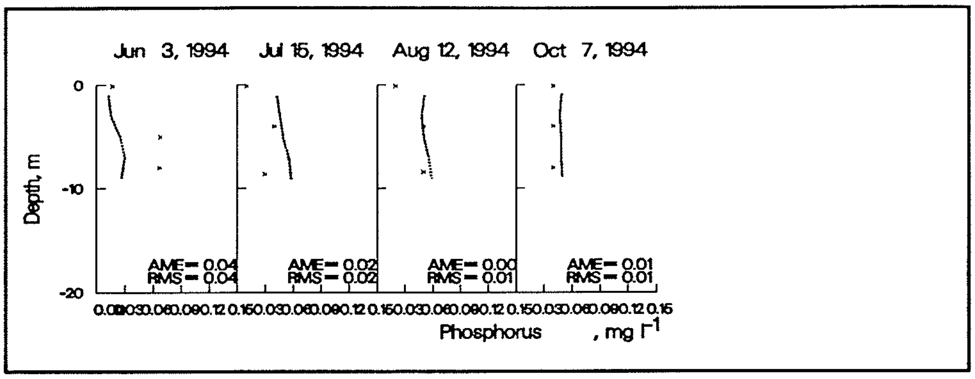


Figure 162. 1994 Weiss phosphorus results for station 5

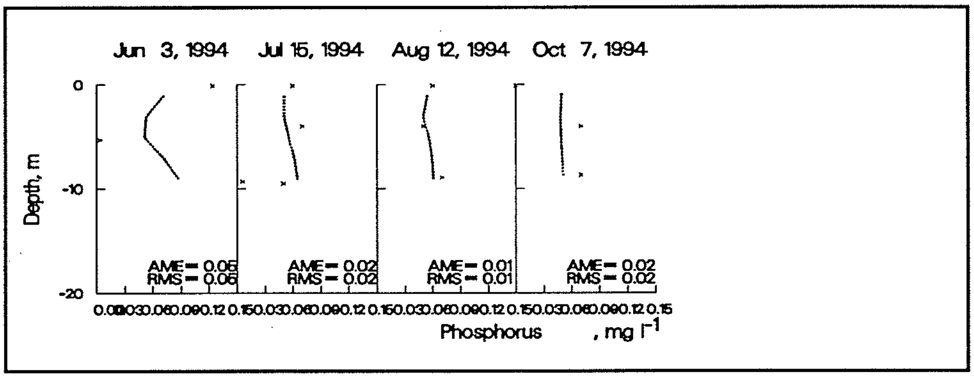


Figure 163. 1994 Weiss phosphorus results for station 6

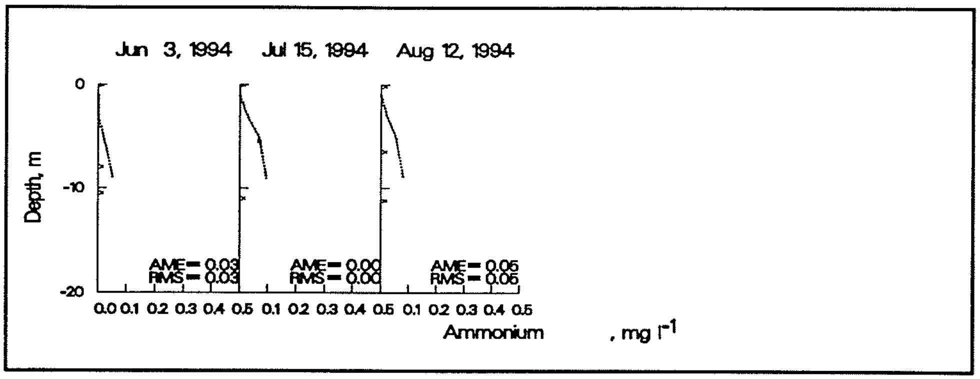


Figure 164. 1994 Weiss ammonium results for station 1

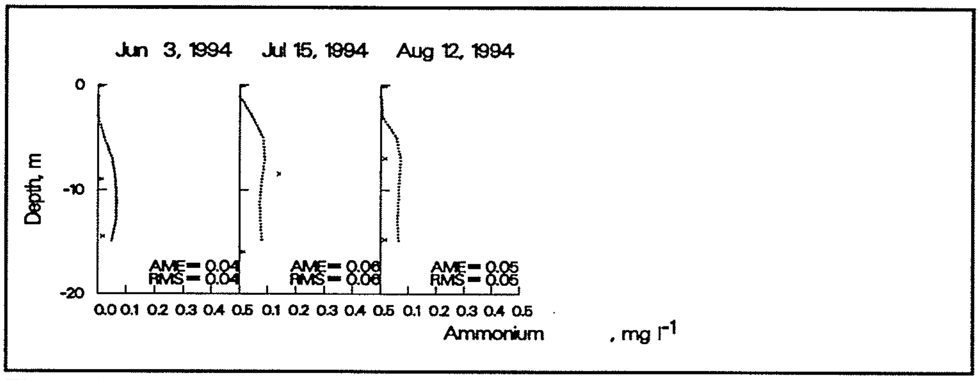


Figure 165. 1994 Weiss ammonium results for station 2

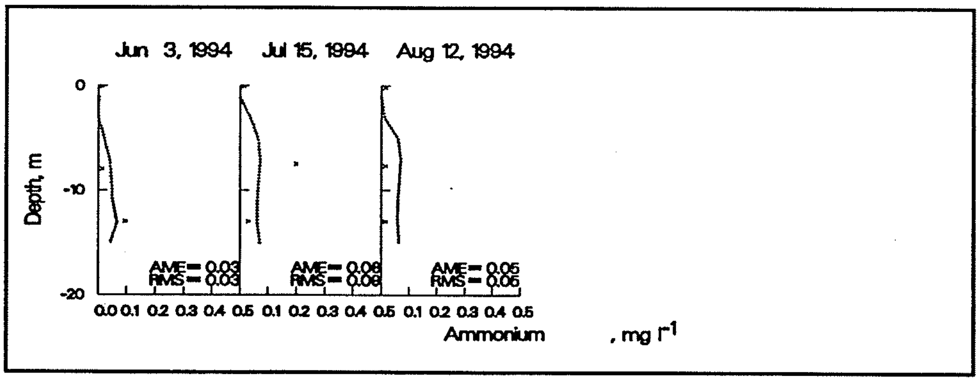


Figure 166. 1994 Weiss ammonium results for station 3

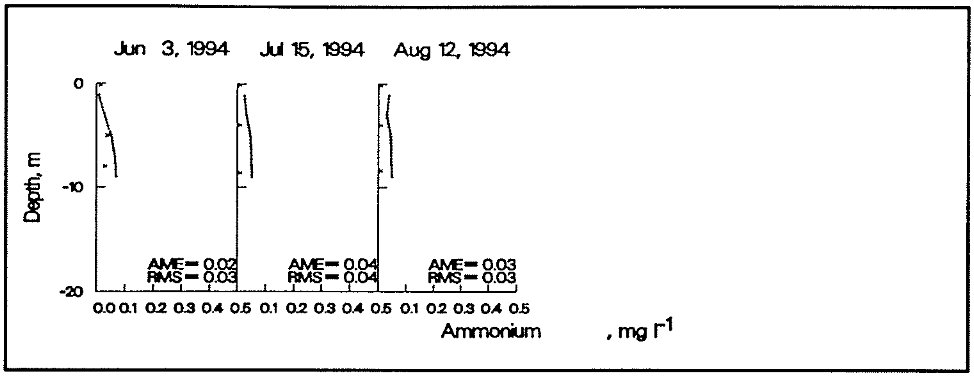


Figure 167. 1994 Weiss ammonium results for station 5

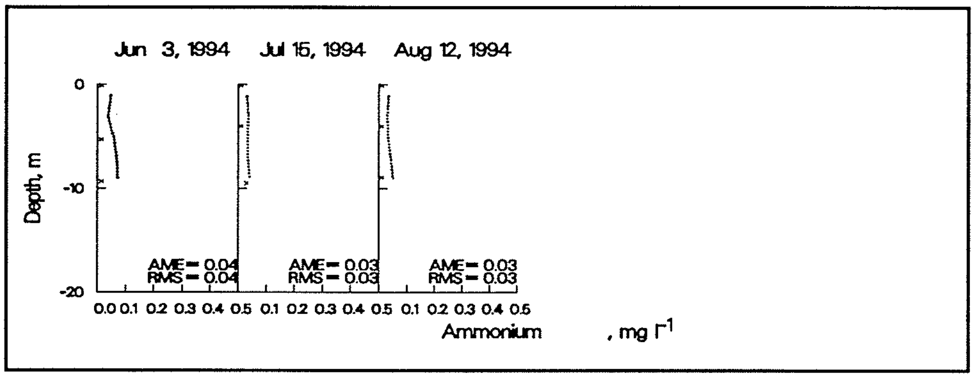


Figure 168. 1994 Weiss ammonium results for station 6

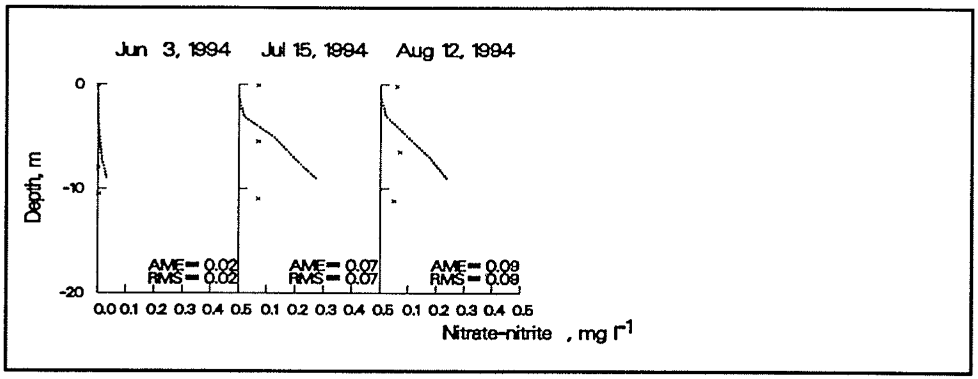


Figure 169. 1994 Weiss nitrate-nitrite results for station 1

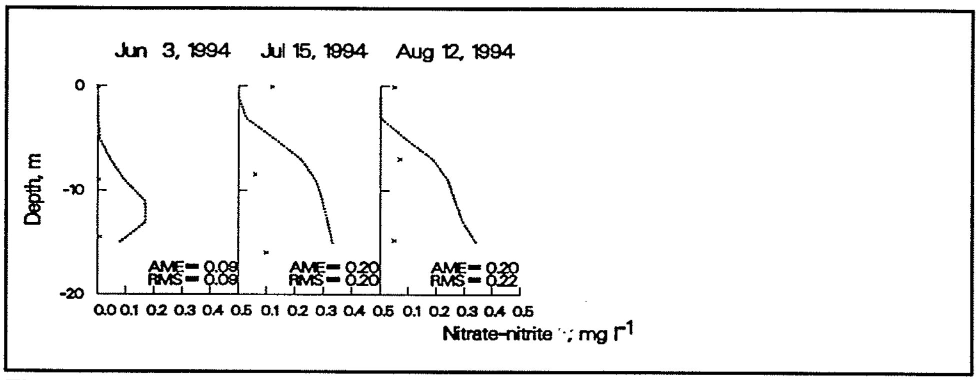


Figure 170. 1994 Weiss nitrate-nitrite results for station 2

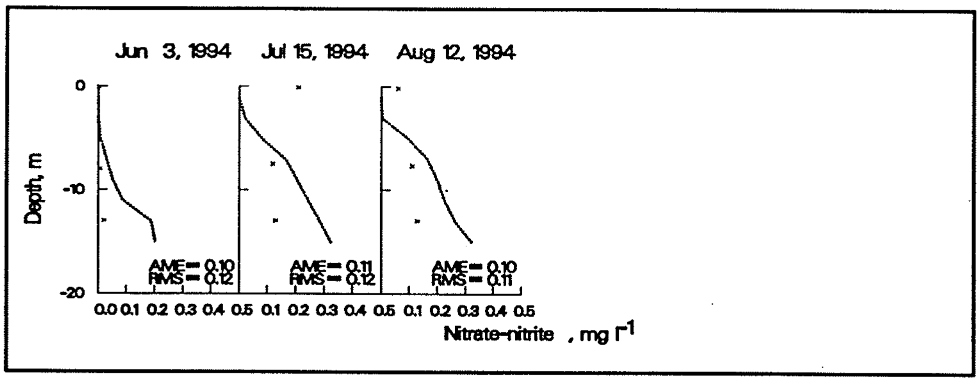


Figure 171. 1994 Weiss nitrate-nitrite results for station 3

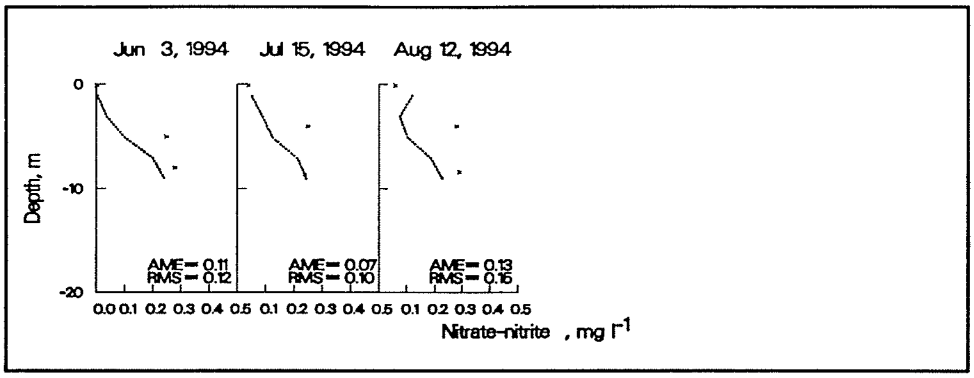


Figure 172. 1994 Weiss nitrate-nitrite results for station 5

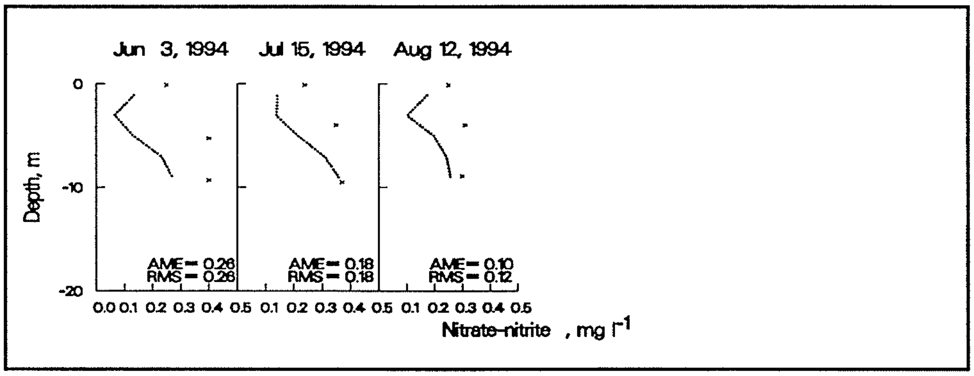


Figure 173. 1994 Weiss nitrate-nitrite results for station 6

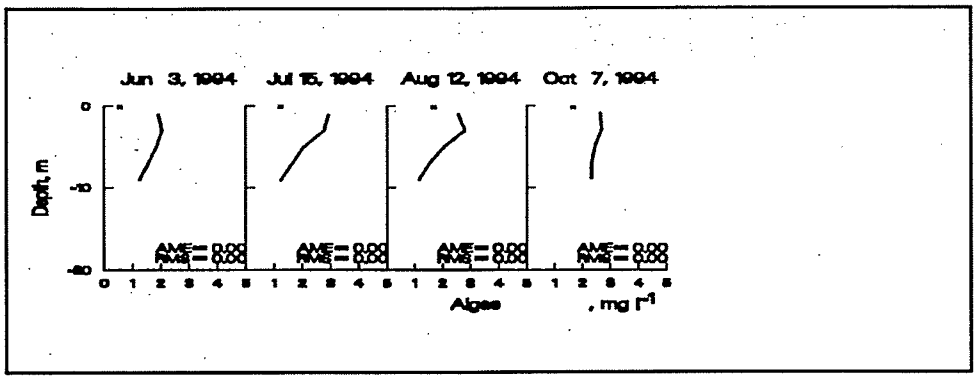


Figure 174. 1994 Weiss algae results for station 1

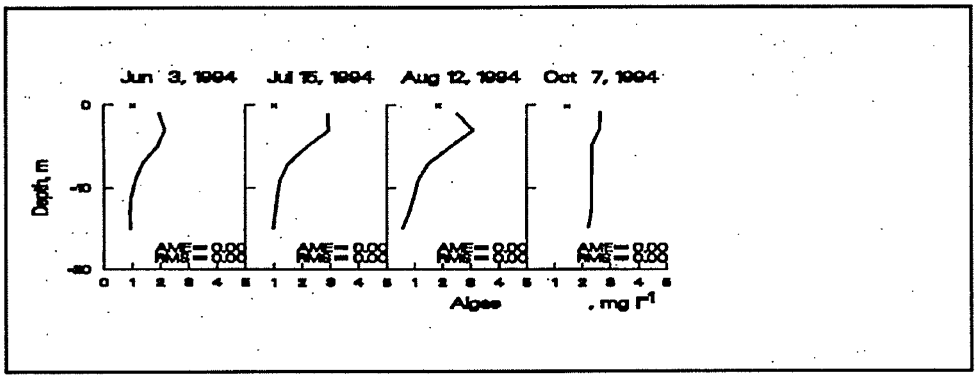


Figure 175. 1994 Weiss algae results for station 2

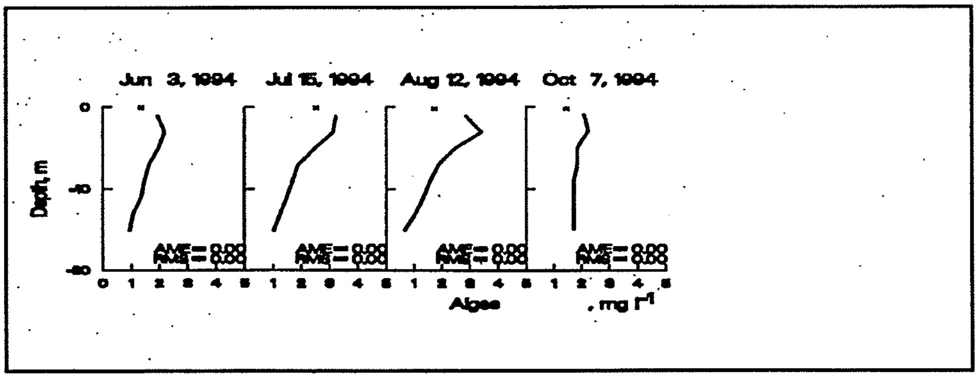


Figure 176. 1994 Weiss algae results for station 3

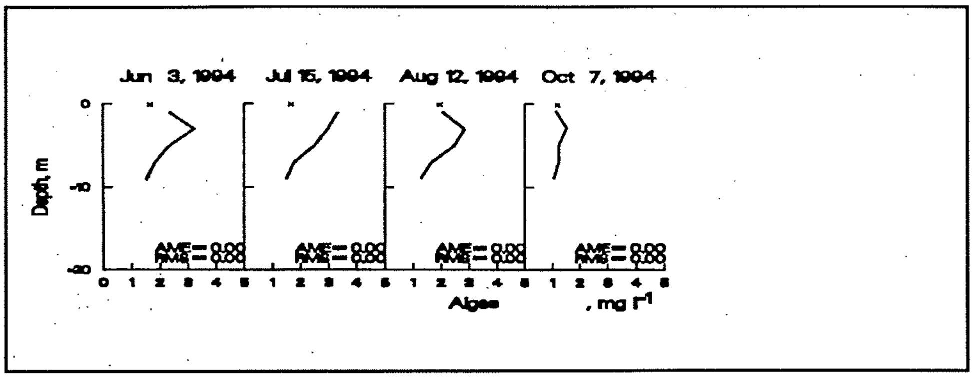


Figure 177. 1994 Weiss algae results for station 5

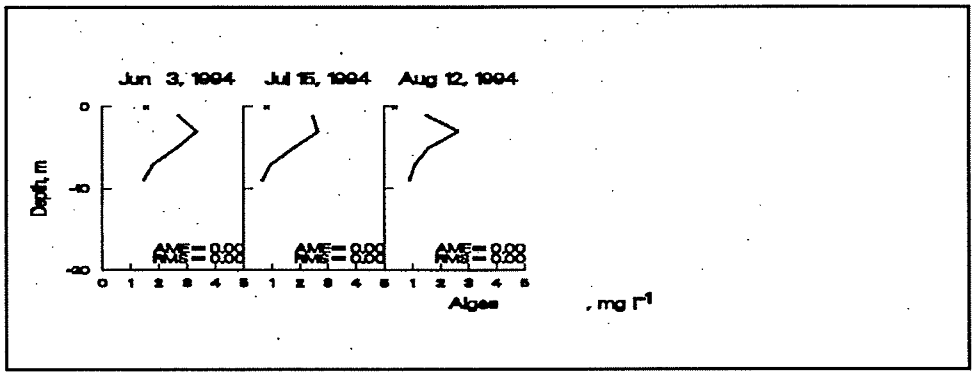


Figure 178. 1994 Weiss algae results for station 6

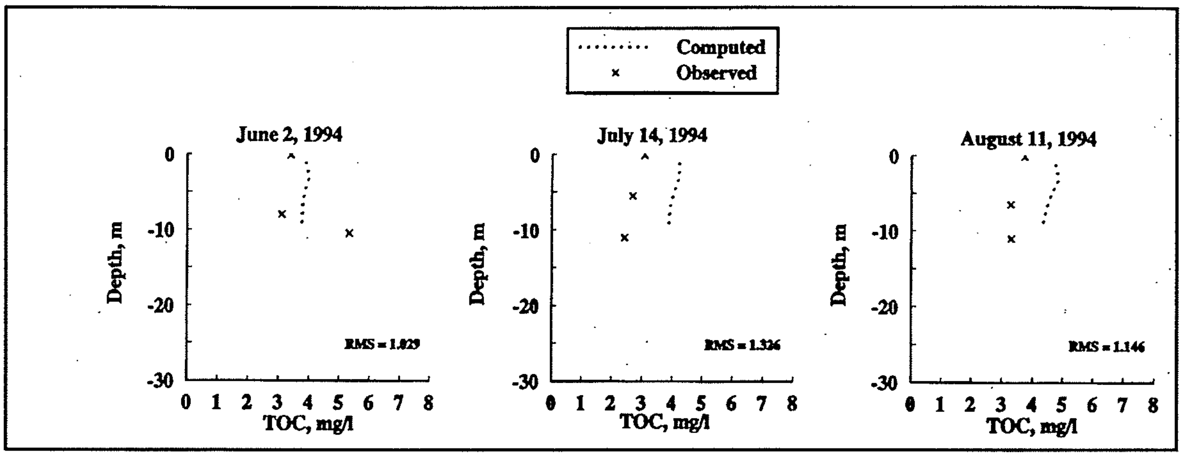


Figure 179. 1994 TOC results for Weiss station 1

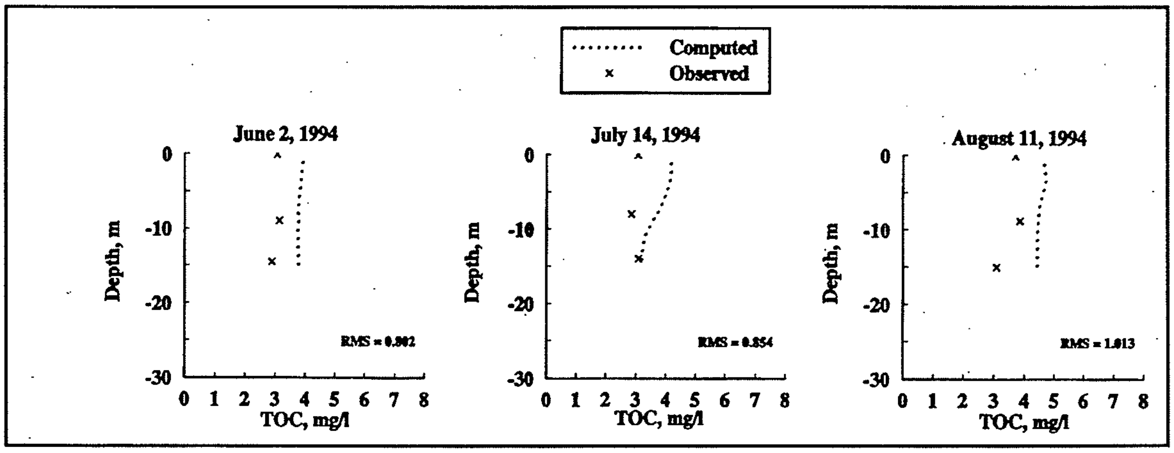


Figure 180. 1994 TOC results for Weiss station 2

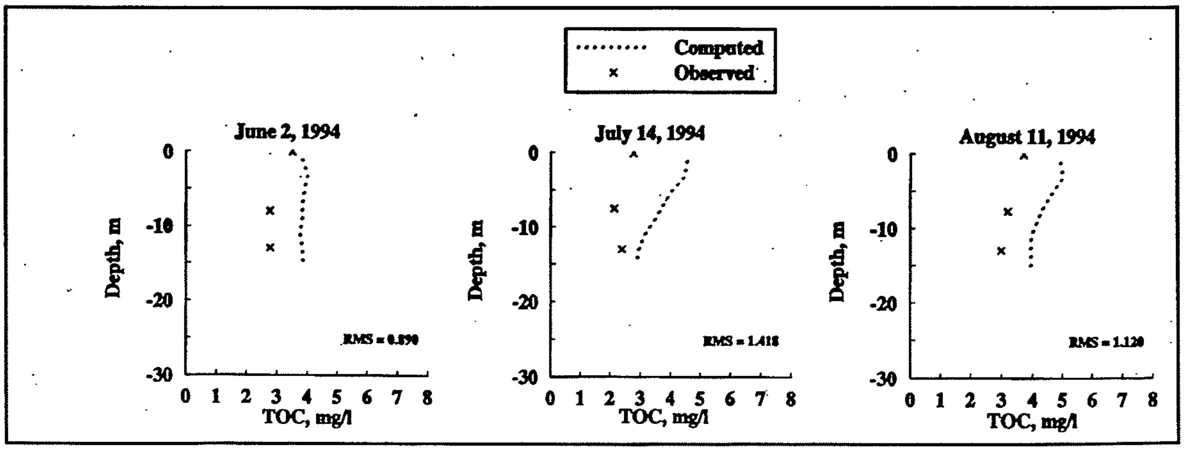


Figure 181. 1994 TOC results for Weiss station 3

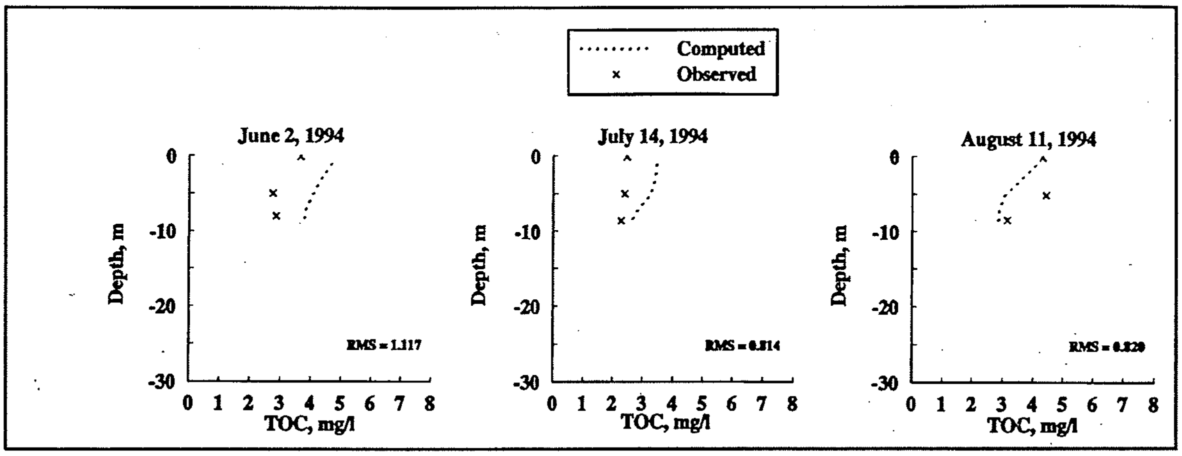


Figure 182. 1994 TOC results for Weiss station 5

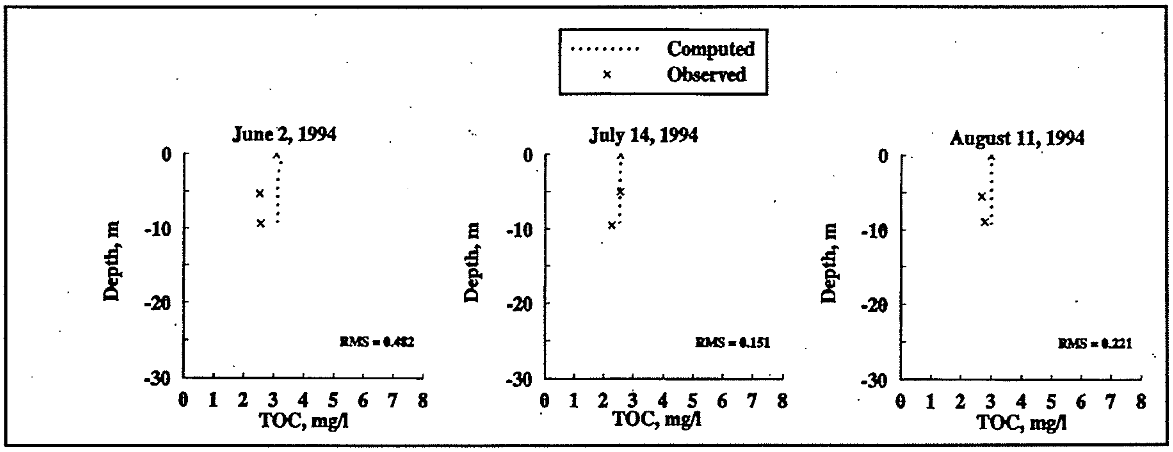


Figure 183. 1994 TOC results for Weiss station 6

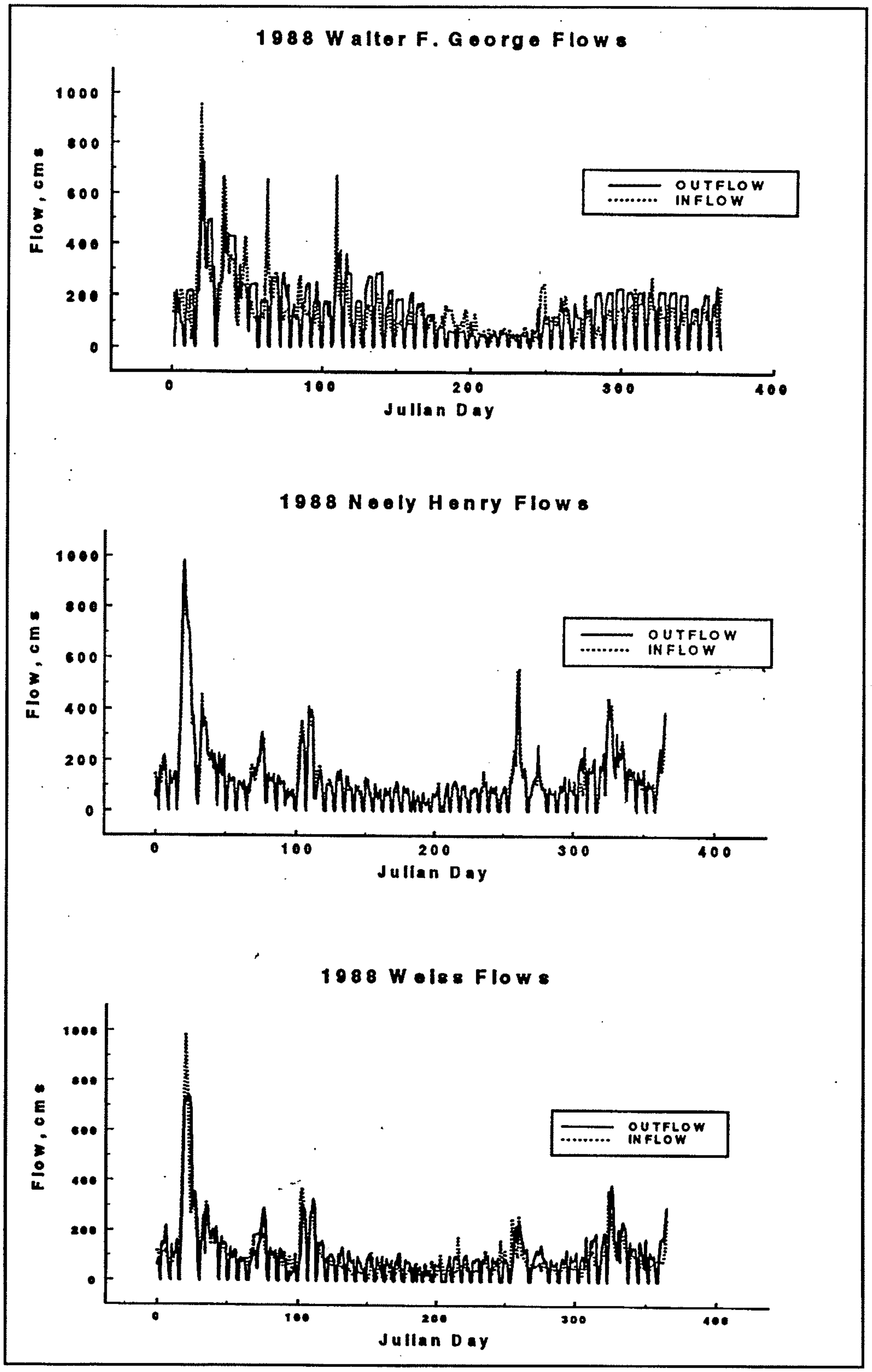


Figure 184. Inflows and outflows for Walter F. George, Neely Henry, and Weiss

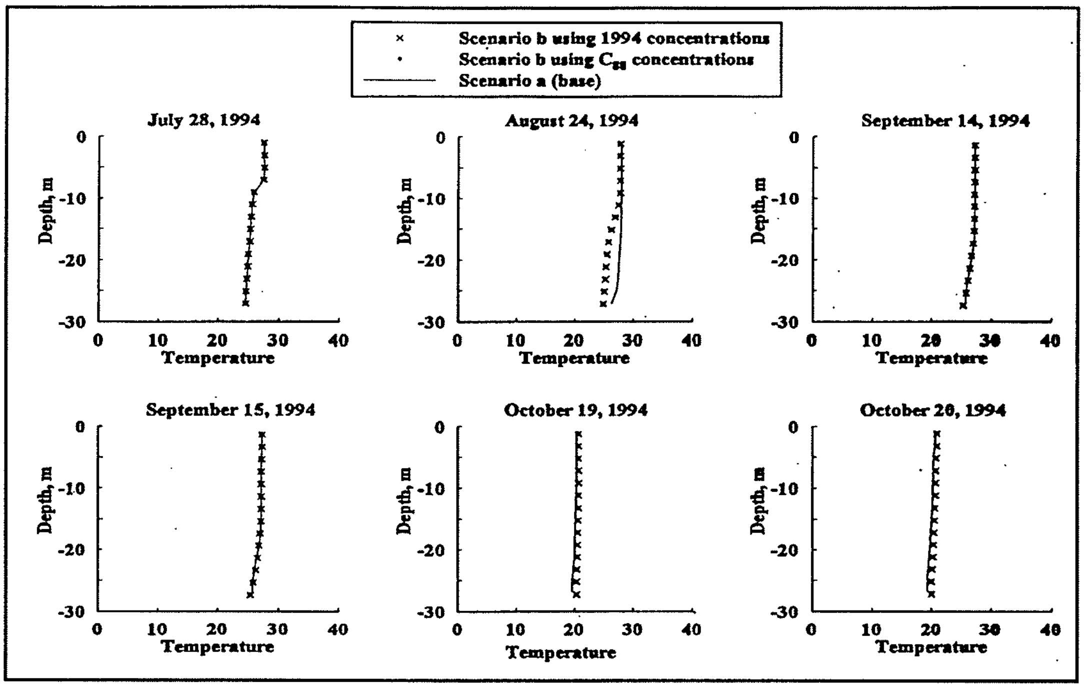


Figure 185. 1994 WFG scenario temperature results for station 1

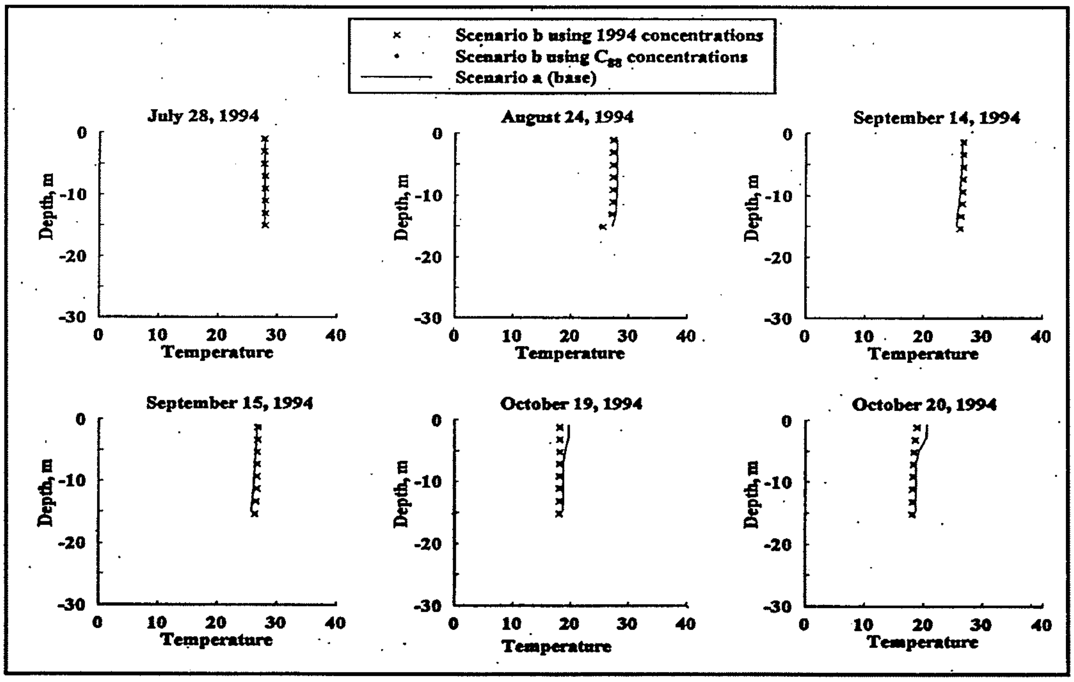


Figure 186. 1994 WFG scenario temperature results for station 5

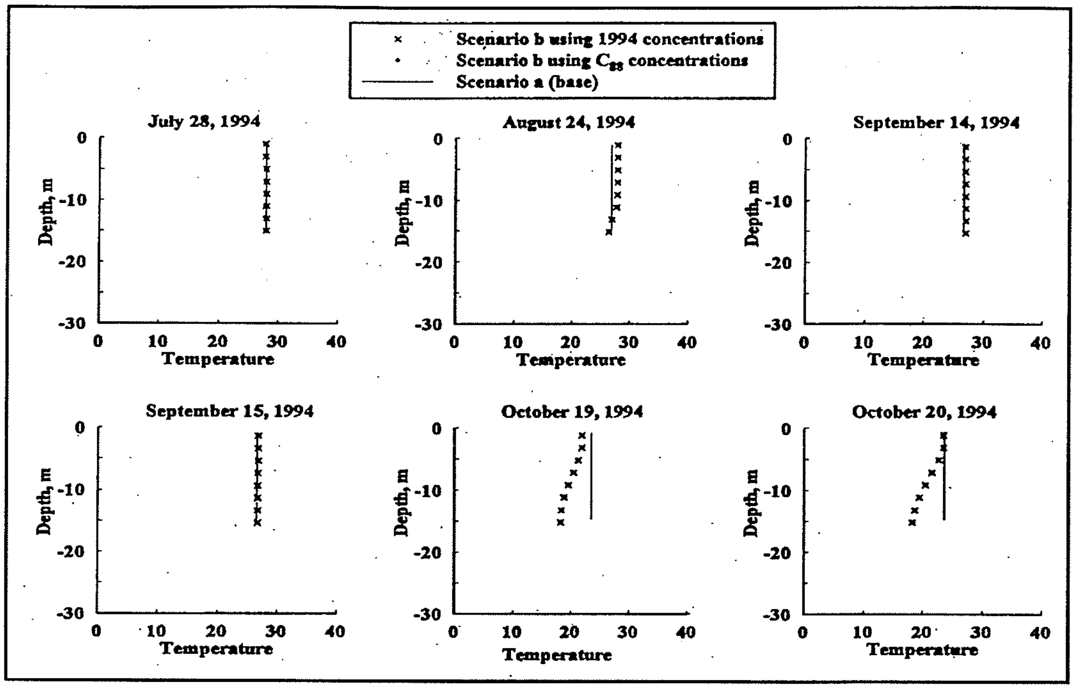


Figure 187. 1994 WFG scenario temperature results for station 8

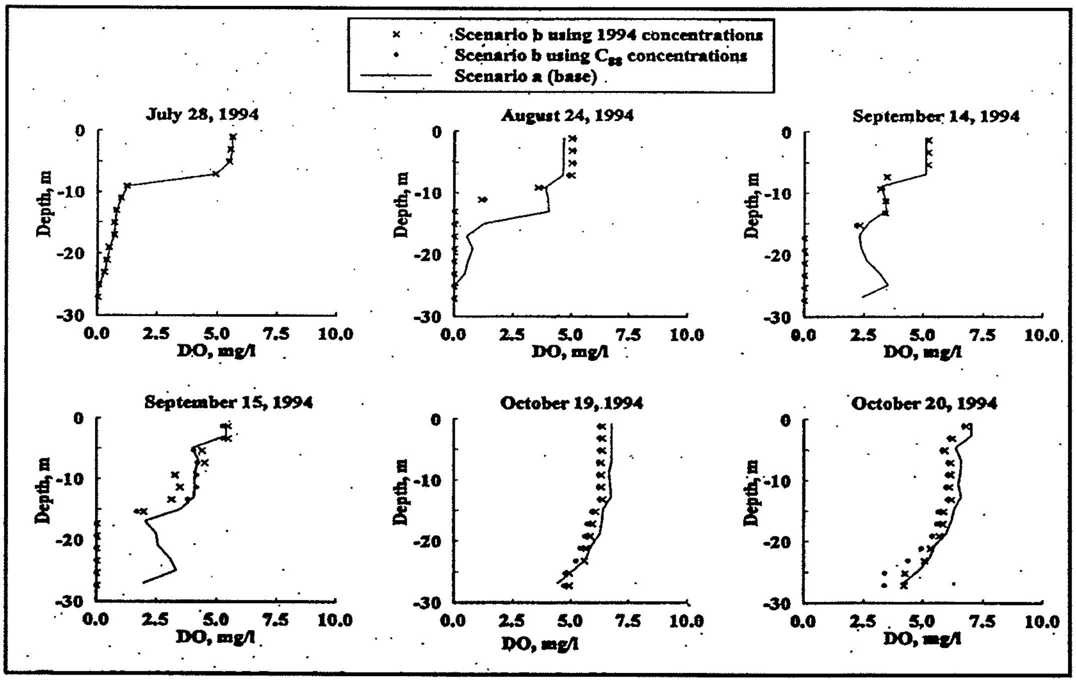


Figure 188. 1994 WFG scenario DO results for station 1

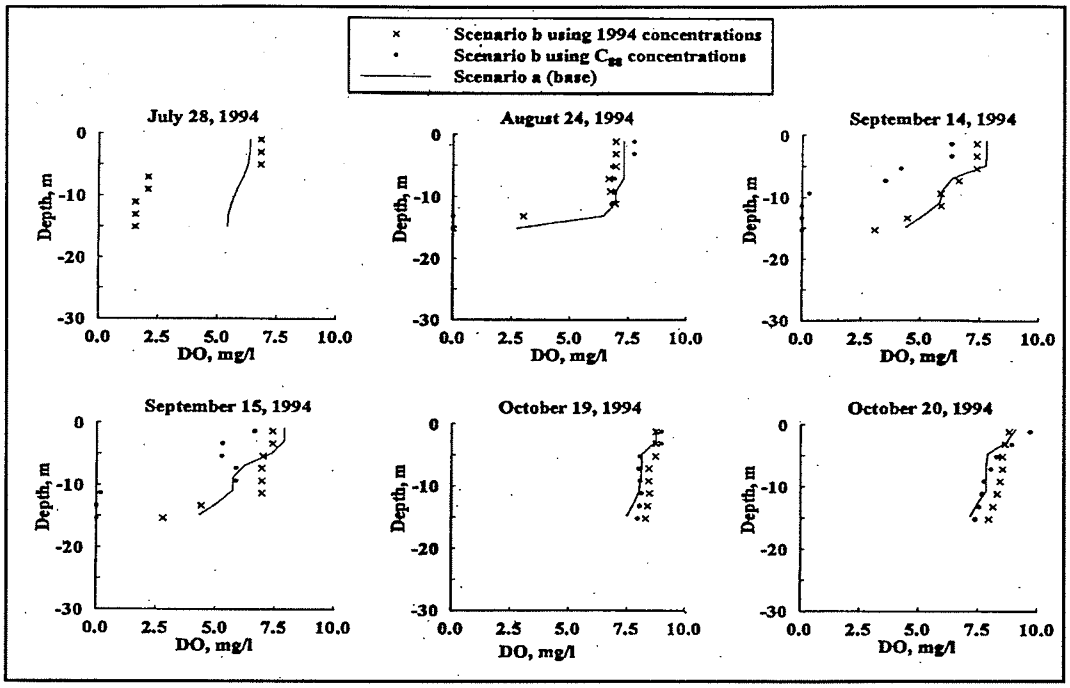


Figure 189. 1994 WFG scenario DO results for station 5

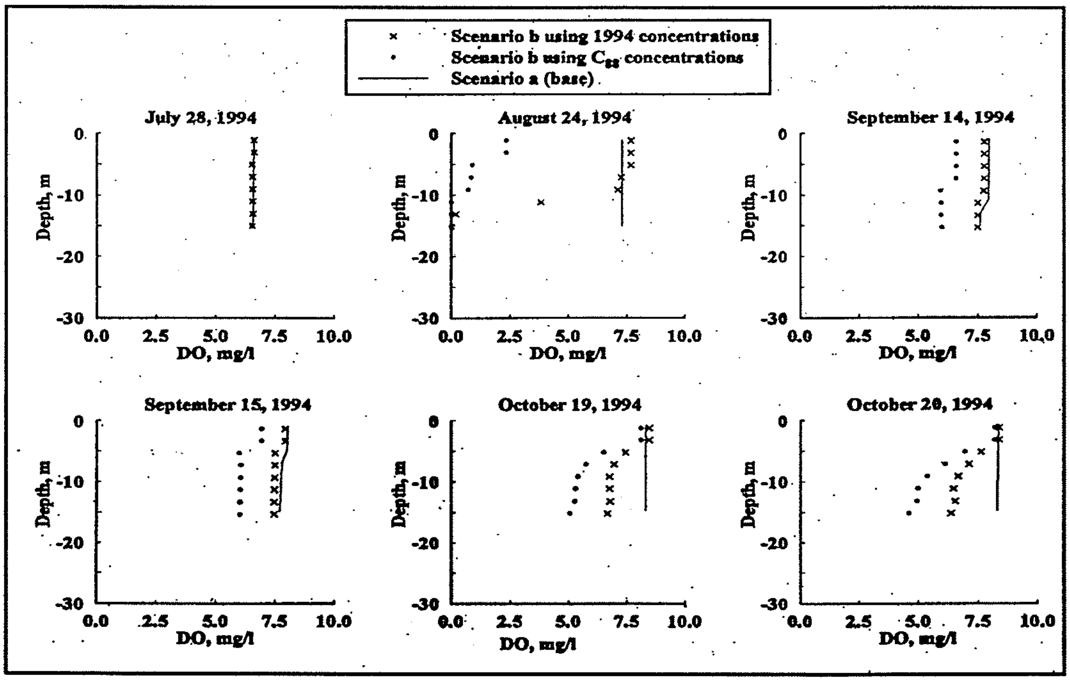


Figure 190. 1994 WFG scenario results for station 8

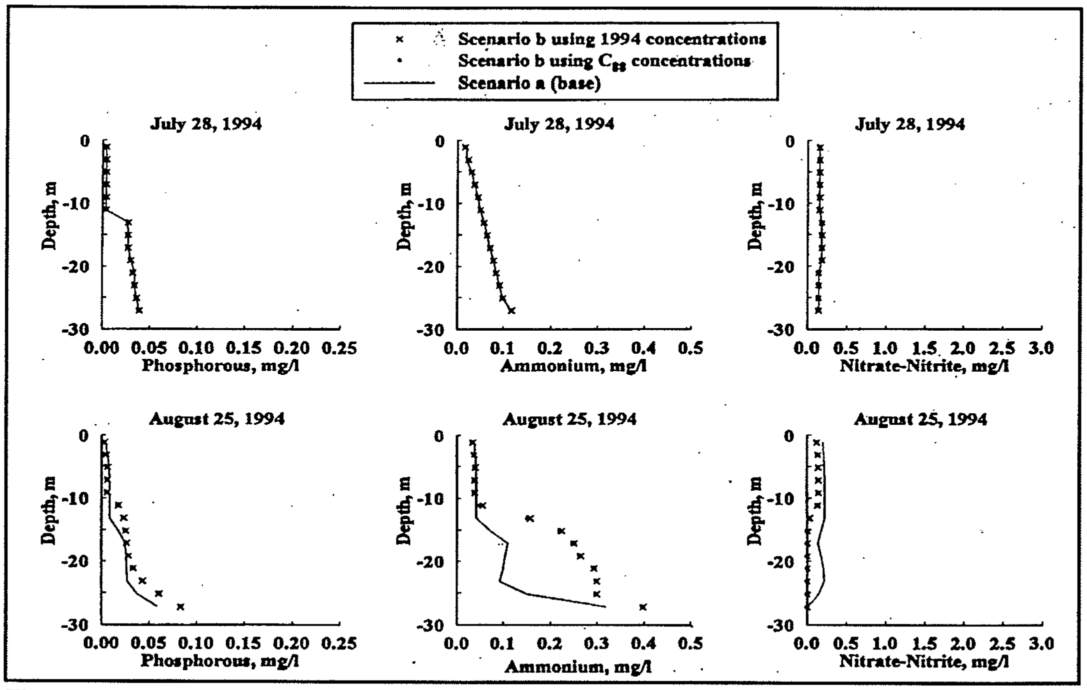


Figure 191. 1994 WFG scenario phosphorus, ammonium, and nitrate-nitrite results for station 1 (Continued)

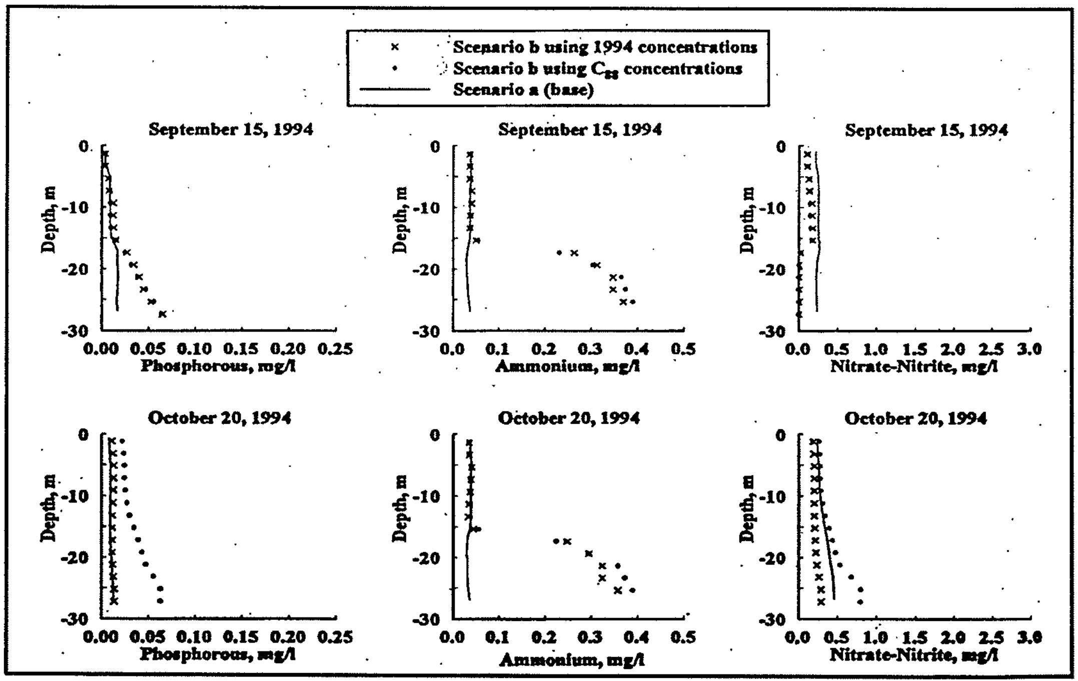


Figure 191. (Concluded)

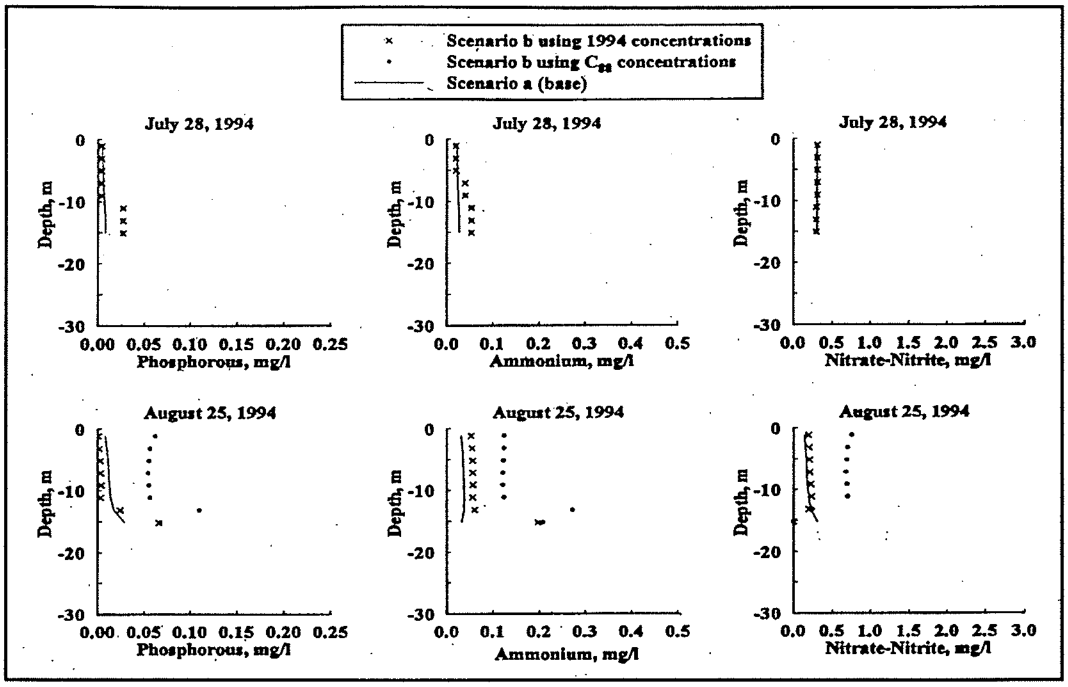


Figure 192. 1994 WFG scenario phosphorus, ammonium, and nitrate-nitrite results for station 5 (Continued)

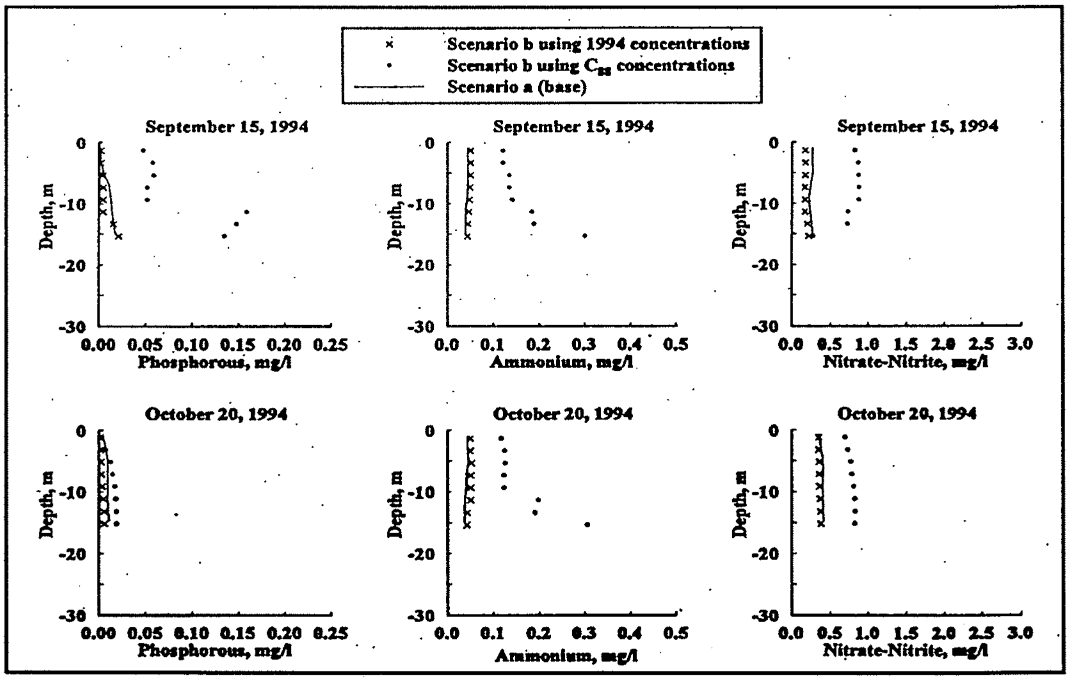


Figure 192. (Concluded)

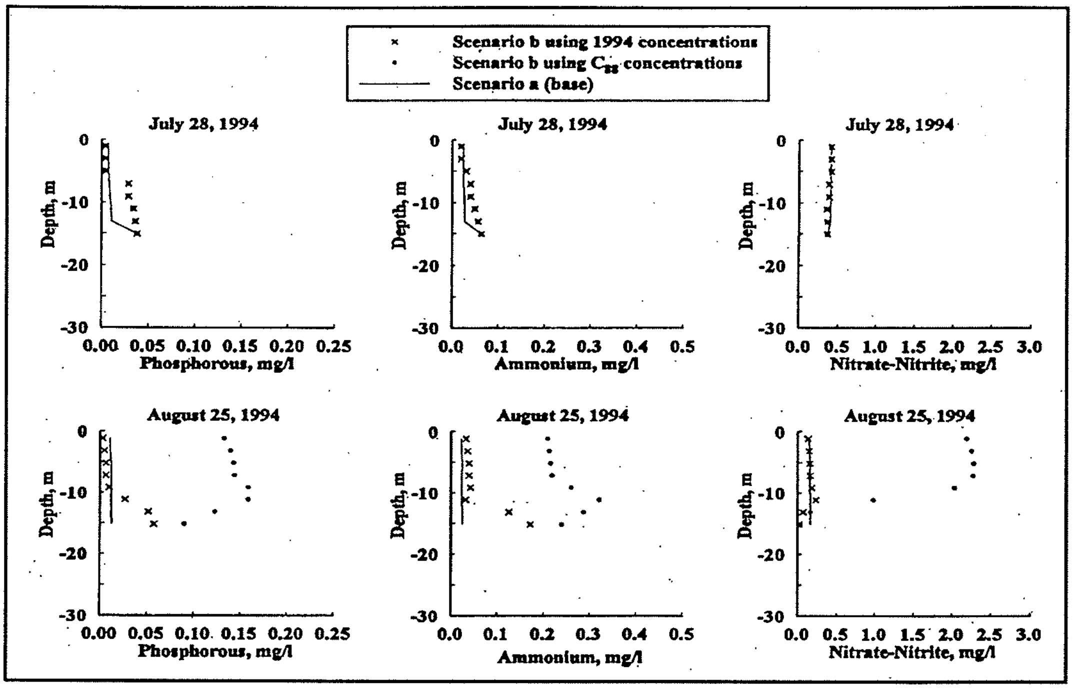


Figure 193. 1994 WFG scenario phosphorus, ammonium, and nitrate-nitrite results for station 8 (Continued)

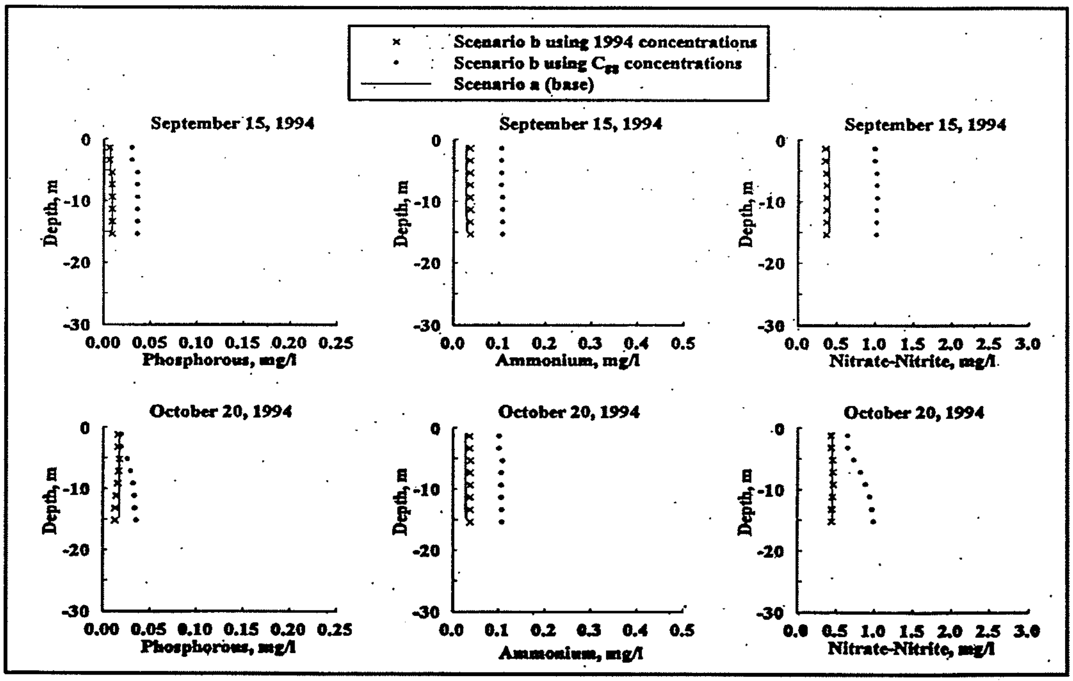


Figure 193. (Concluded)

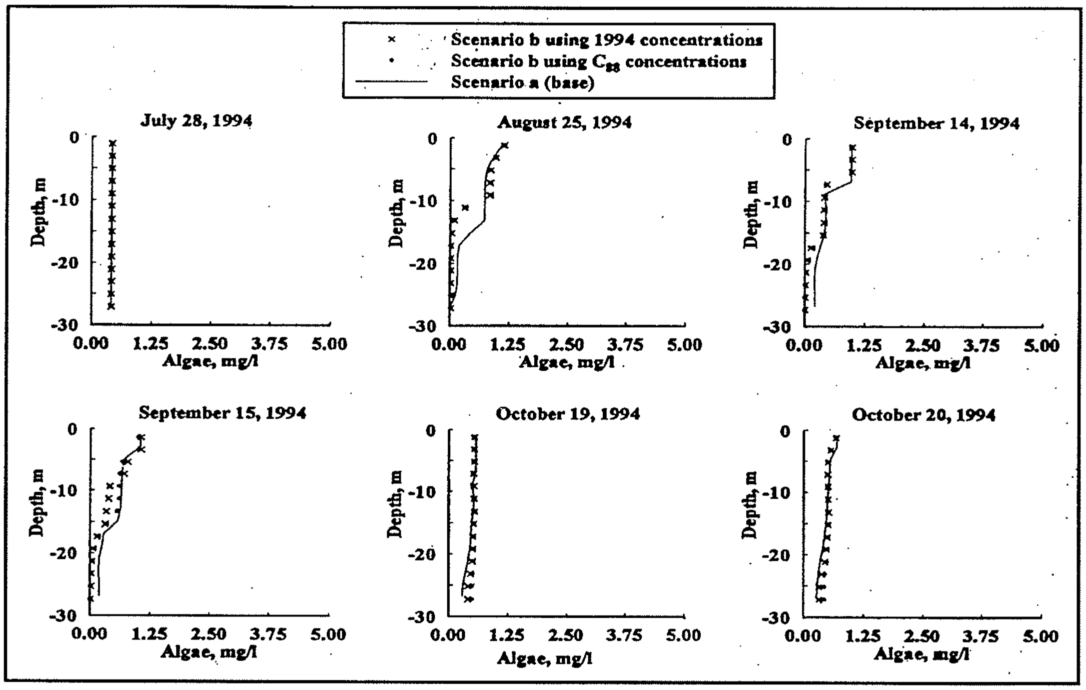


Figure 194. 1994 WFG scenario algae results for station 1

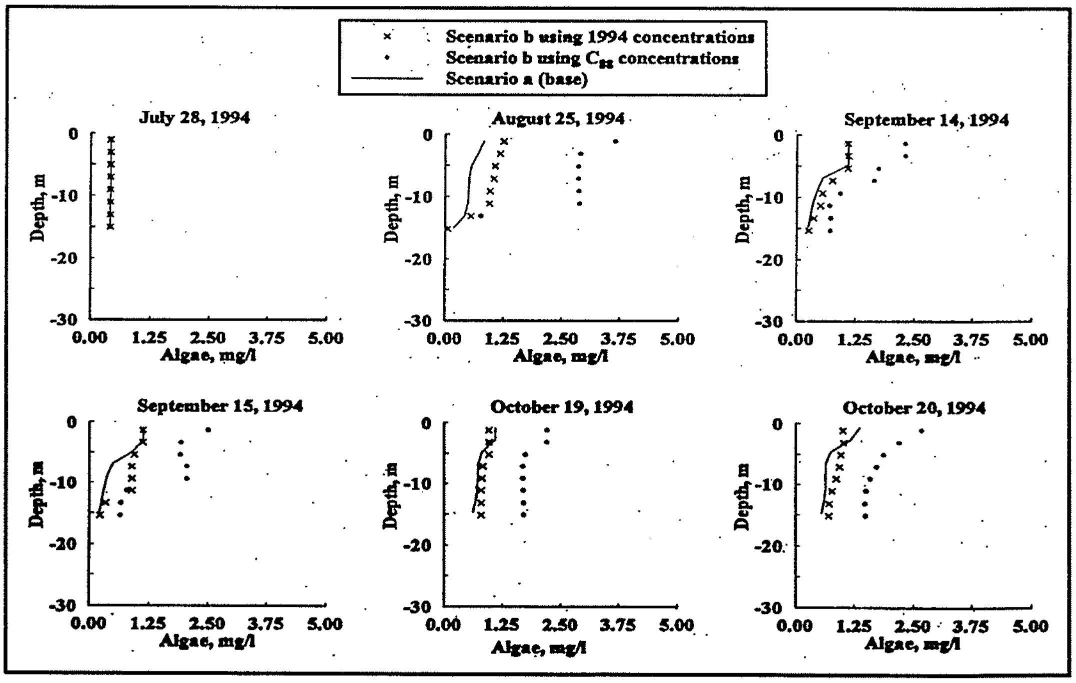


Figure 195. 1994 WFG scenario algae results for station 5

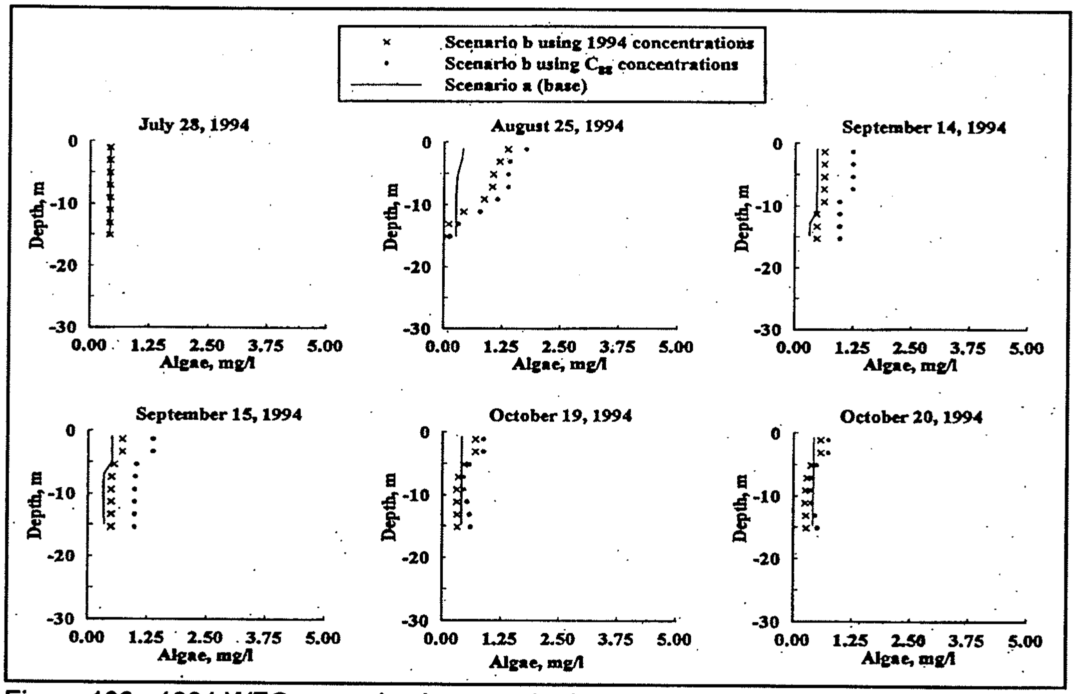


Figure 196. 1994 WFG scenario algae results for station 8

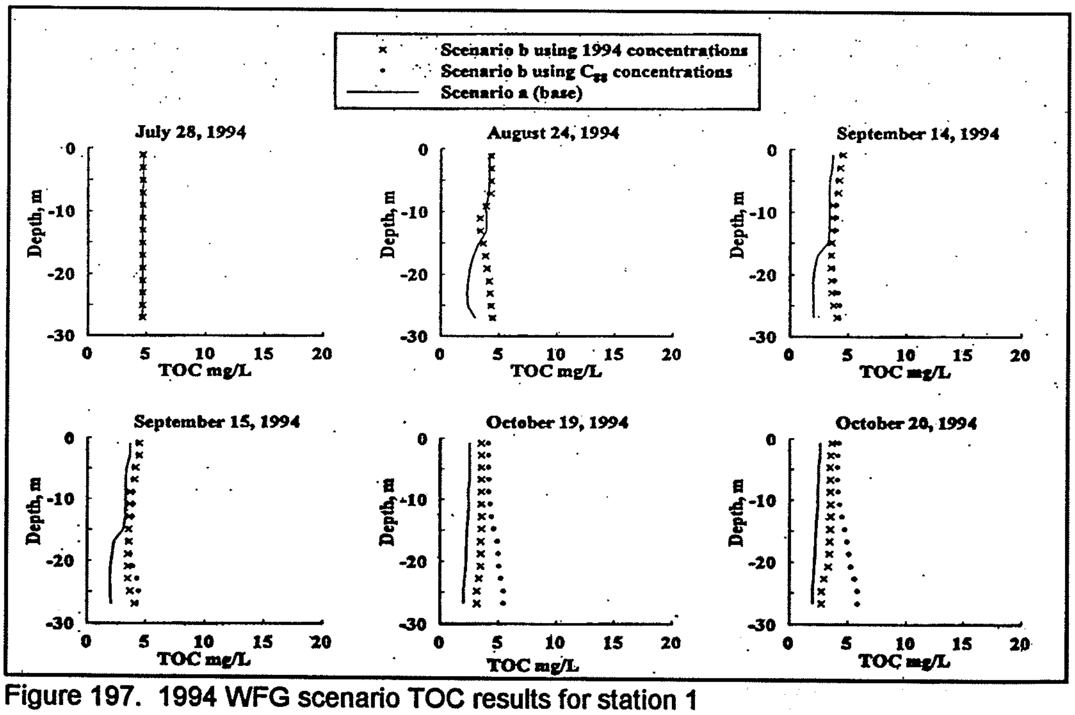


Figure 197. 1994 WFG scenario TOC results for station 1

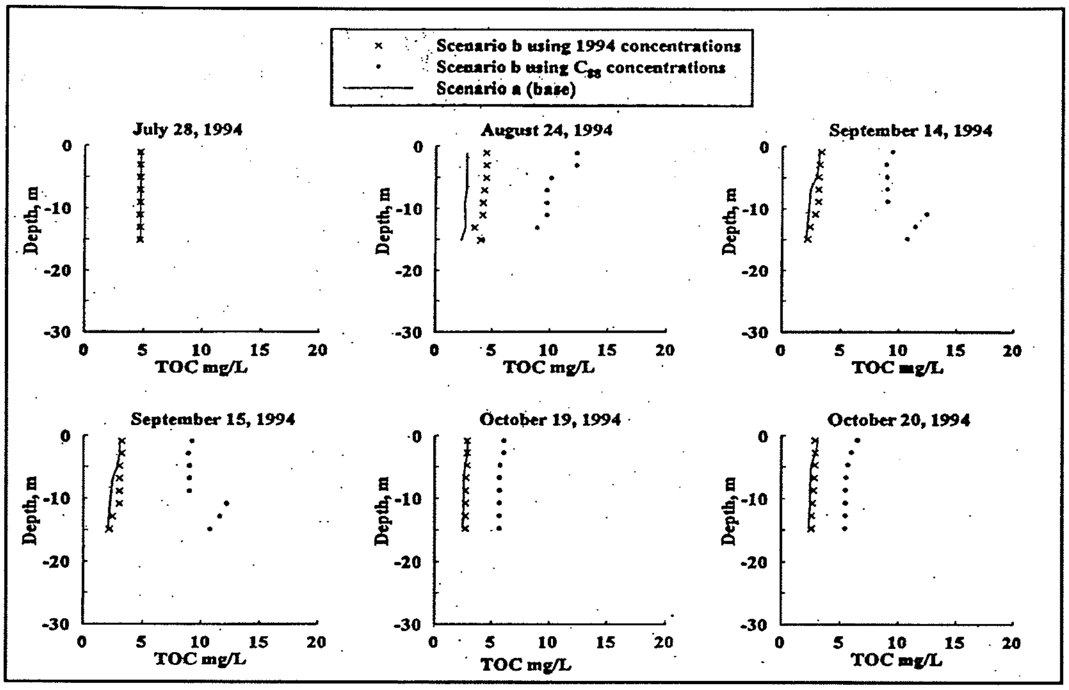


Figure 198. 1994 WFG scenario TOC results for station 5

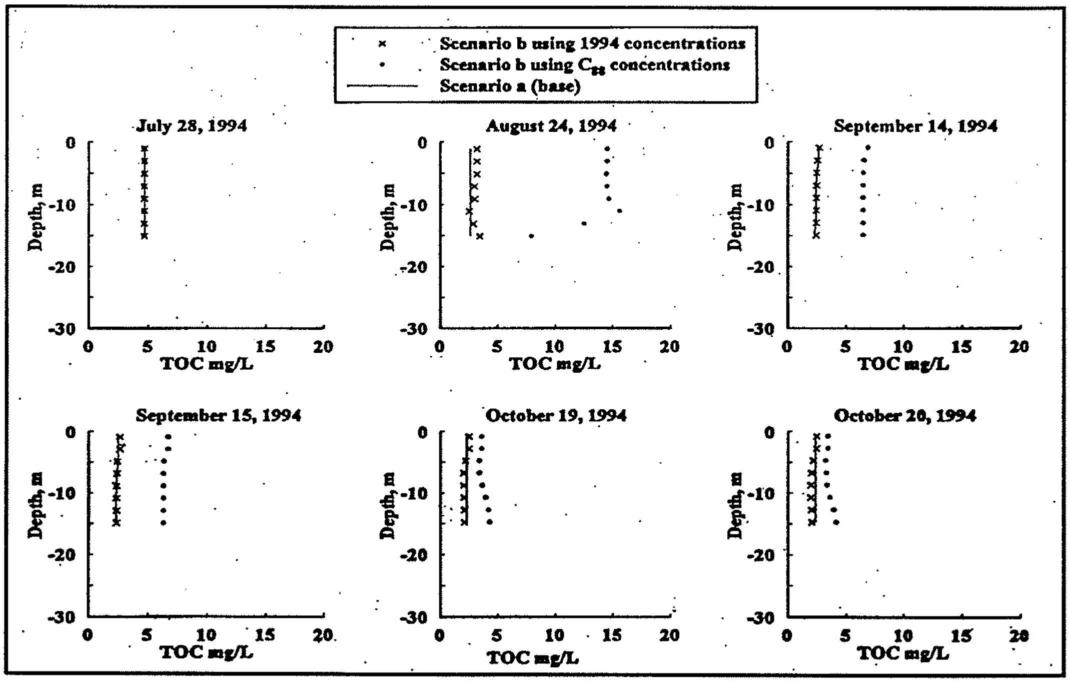


Figure 199. 1994 WFG scenario TOC results for station 8

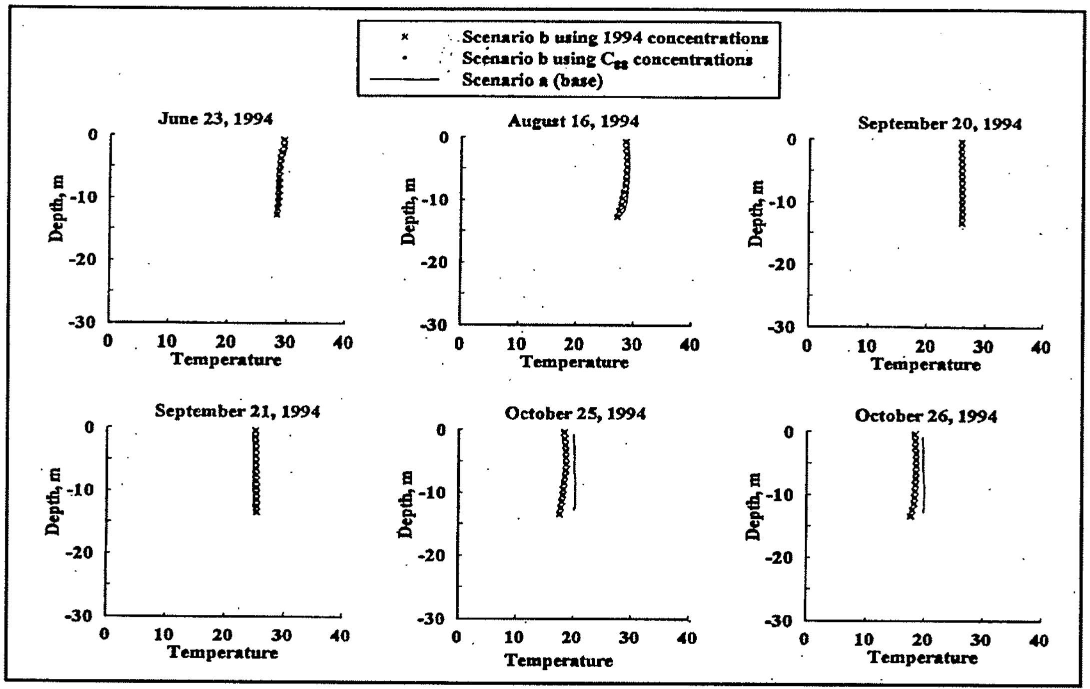


Figure 200. 1994 Neely Henry scenario temperature results for station 1

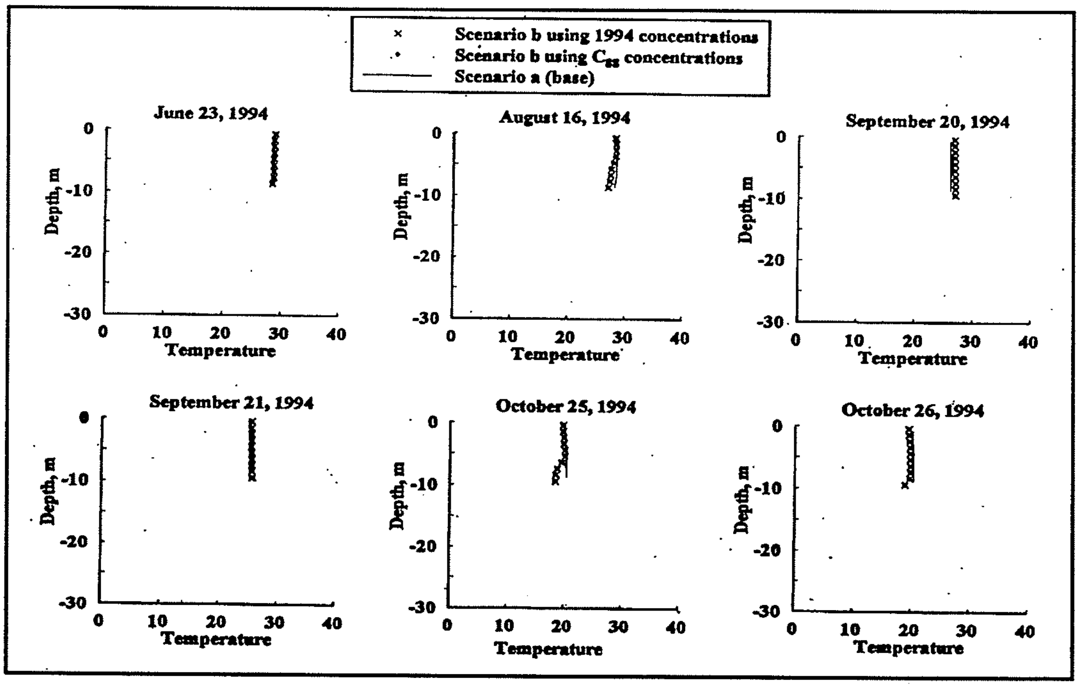


Figure 201. 1994 Neely Henry scenario temperature results for station 6

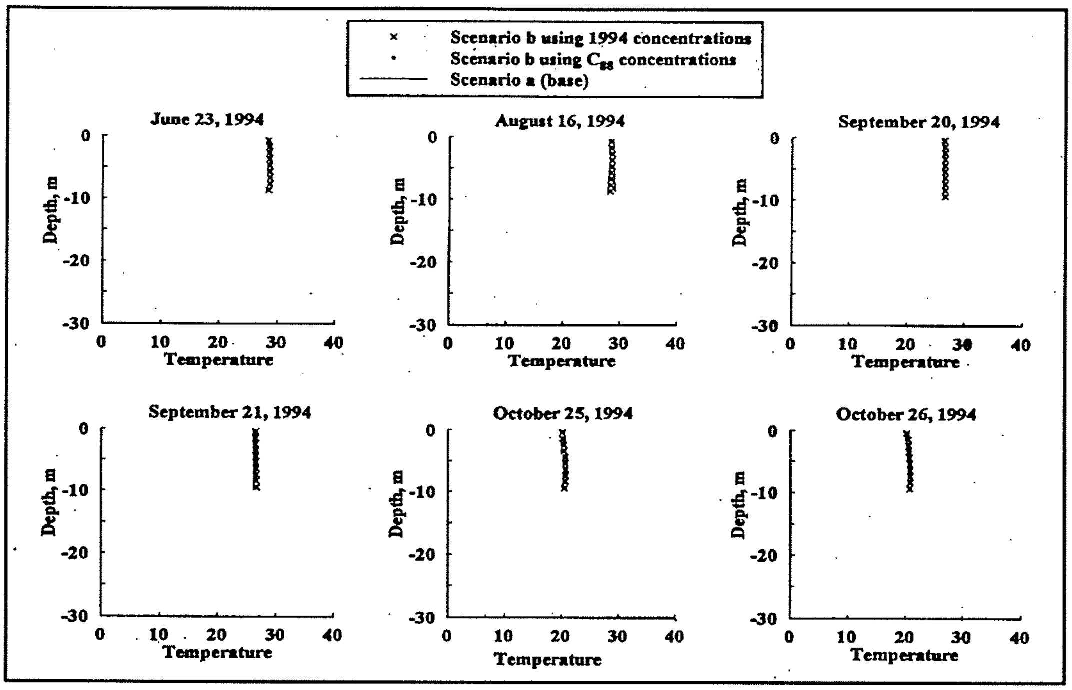


Figure 202. 1994 Neely Henry scenario temperature results for station 10

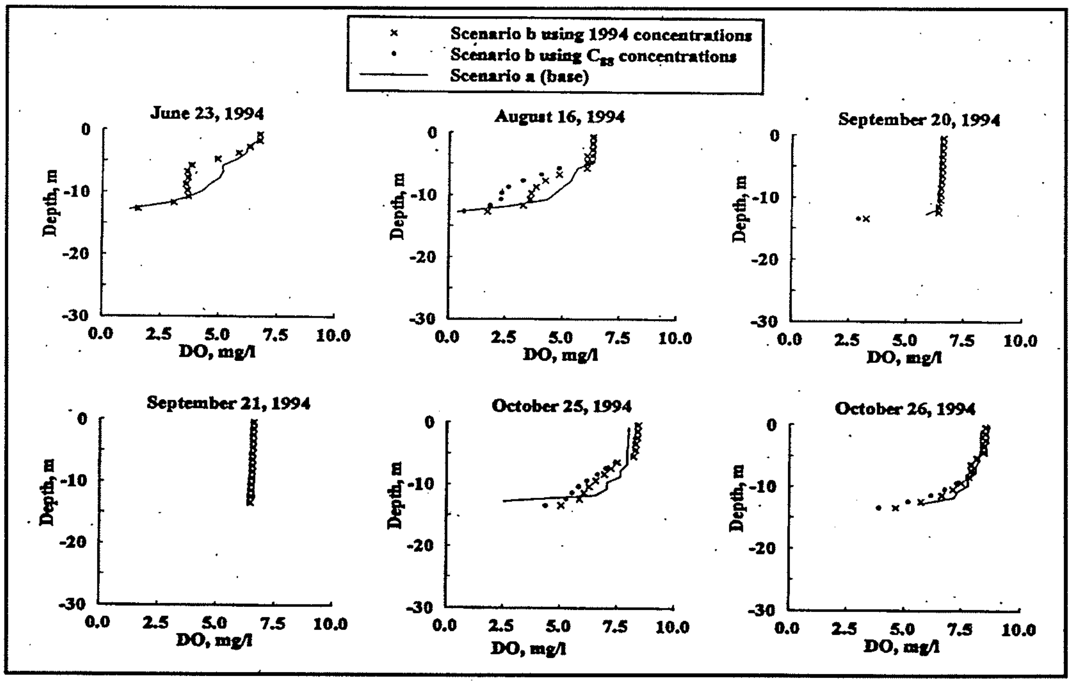


Figure 203. 1994 Neely Henry scenario DO results for station 1

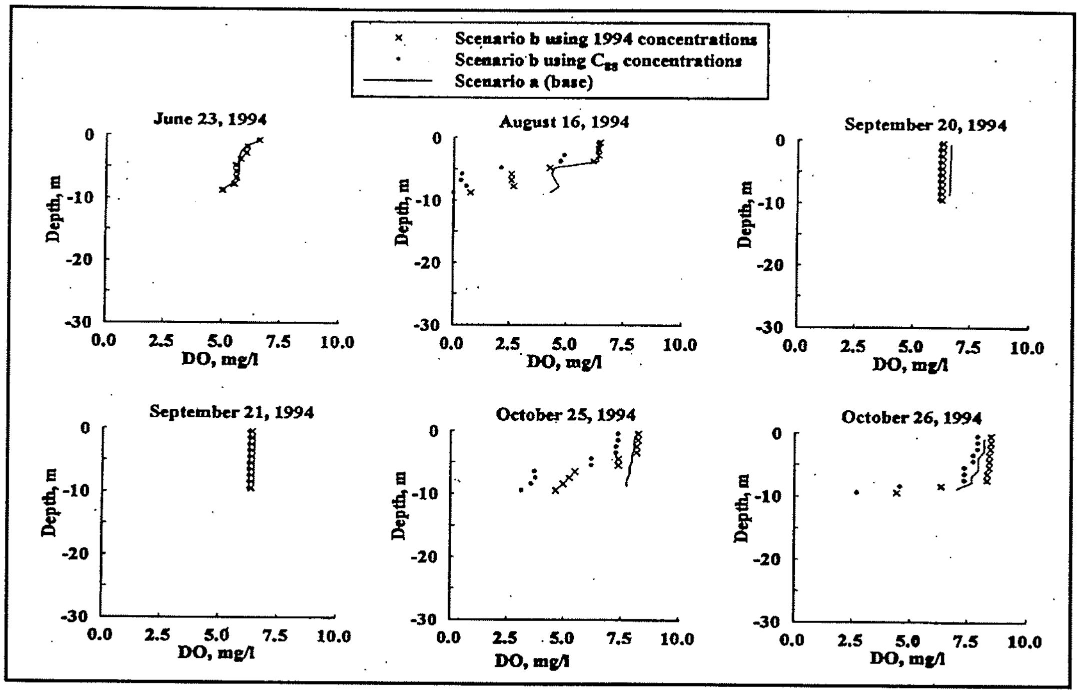


Figure 204. 1994 Neely Henry scenario DO results for station 6

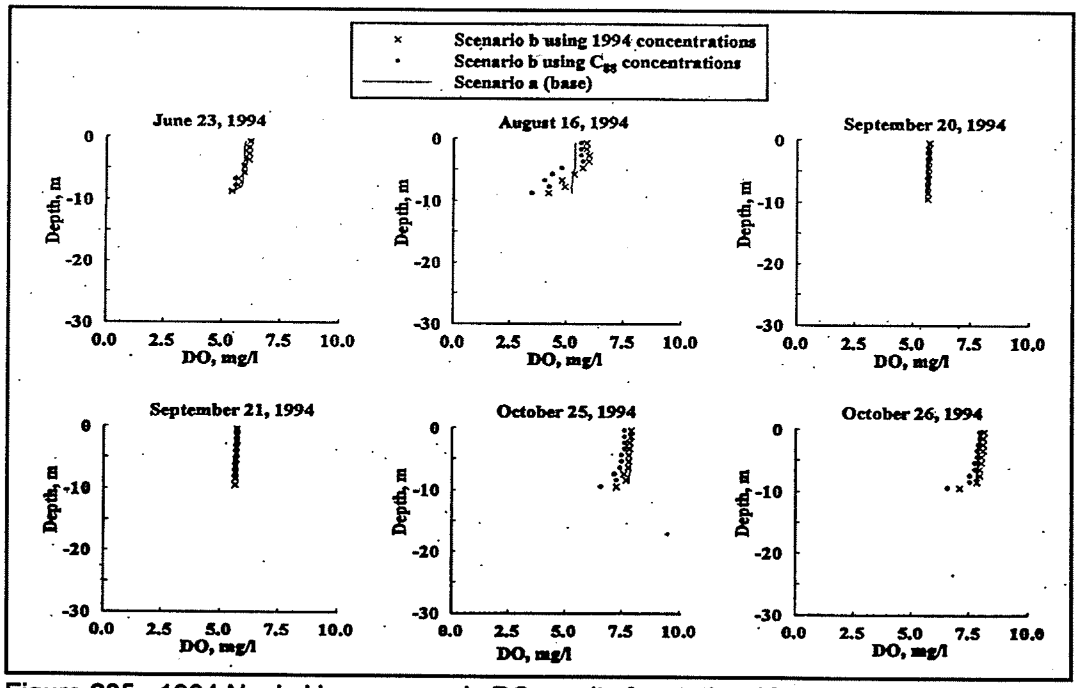


Figure 205. 1994 Neely Henry scenario DO results for station 10

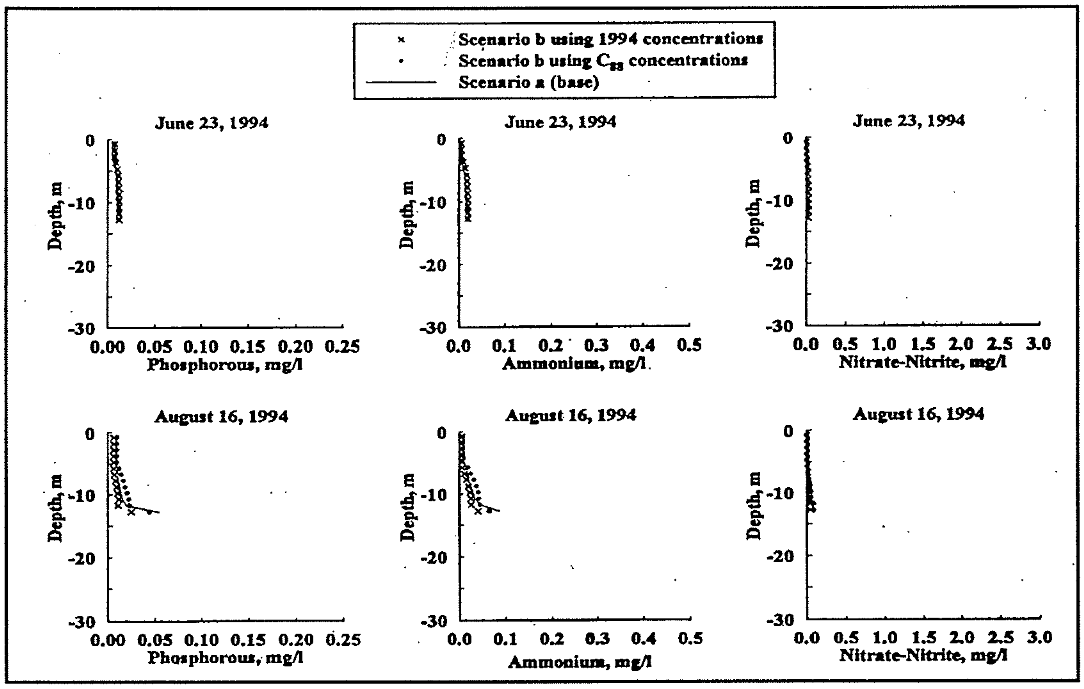


Figure 206. 1994 Neely Henry scenario phosphorus, ammonium, and nitrate-nitrite results for station 1 (Continued)

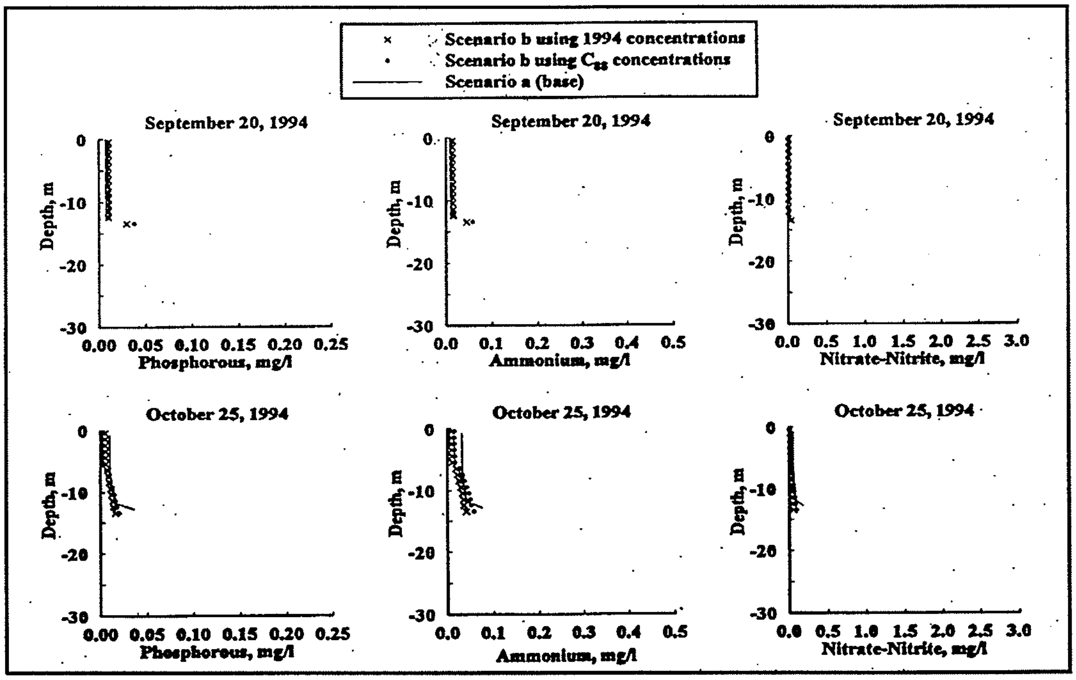


Figure 206. (Concluded)

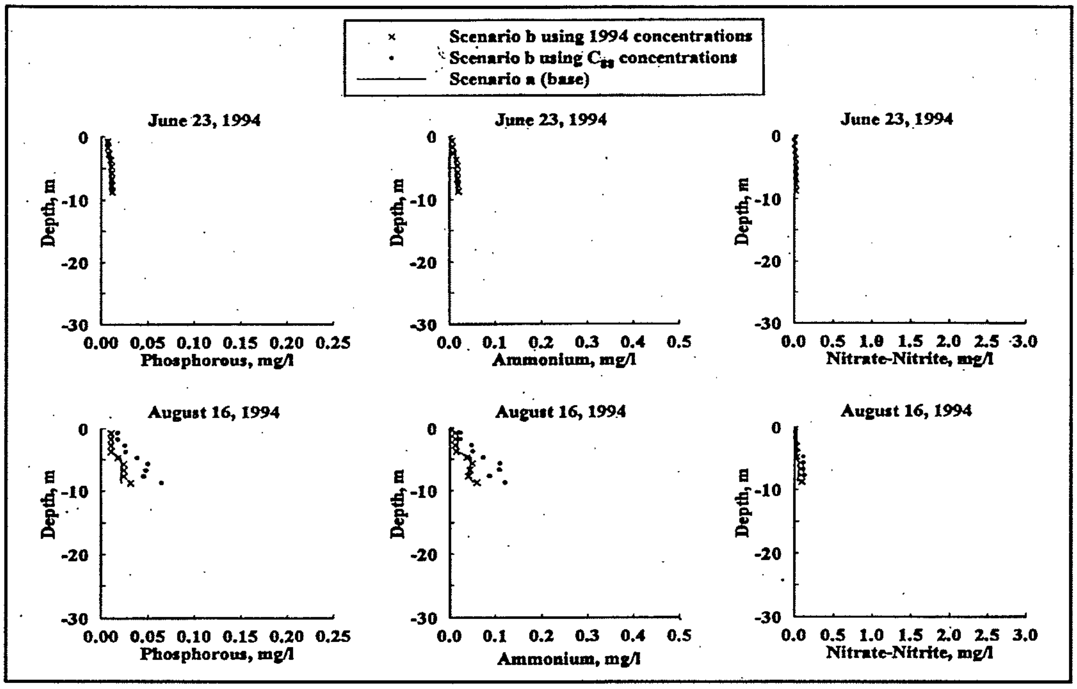


Figure 207. 1994 Neely Henry scenario phosphorus, ammonium, and nitrate-nitrite results for station 6 (Continued)

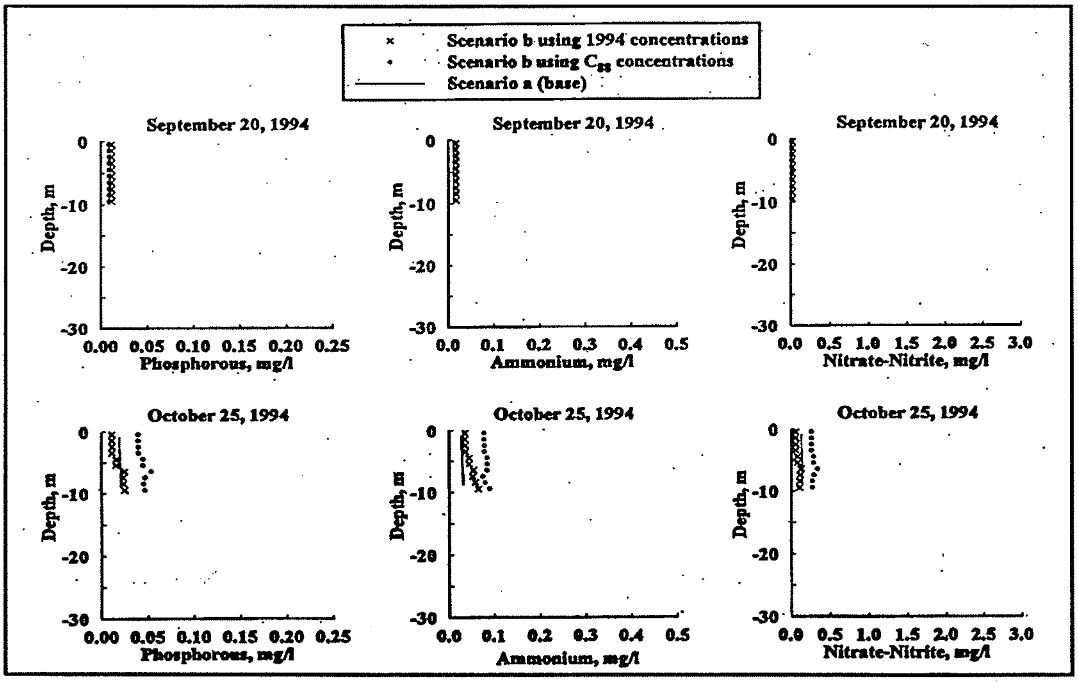


Figure 207. (Concluded)

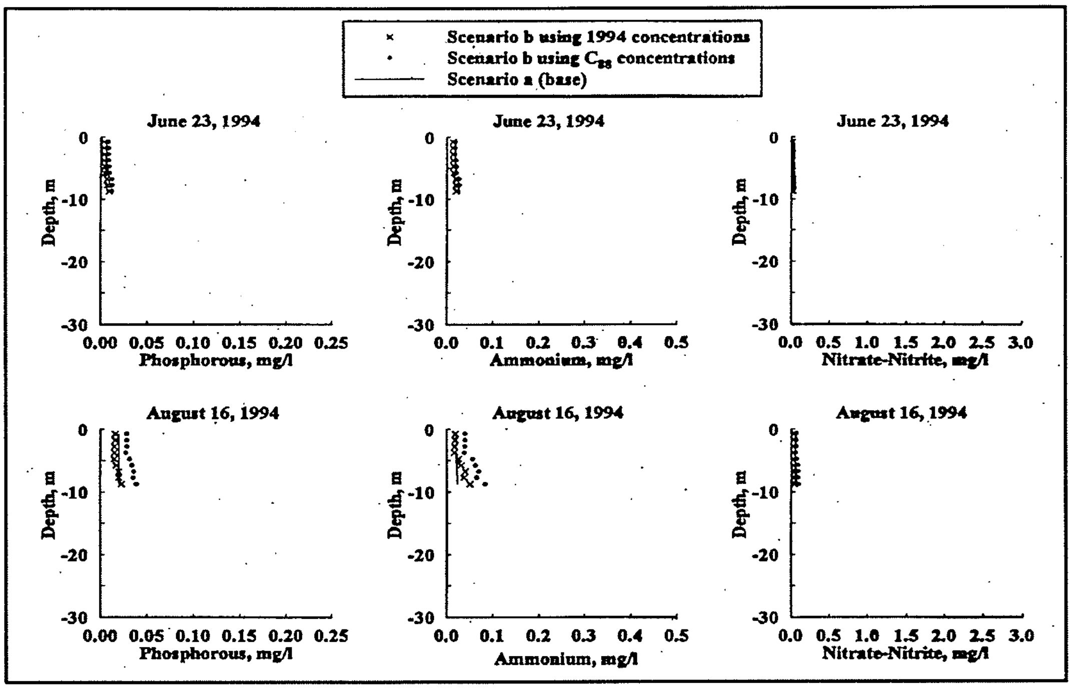


Figure 208. 1994 Neely Henry scenario phosphorus, ammonium, and nitrate-nitrite results for station 10 (Continued)

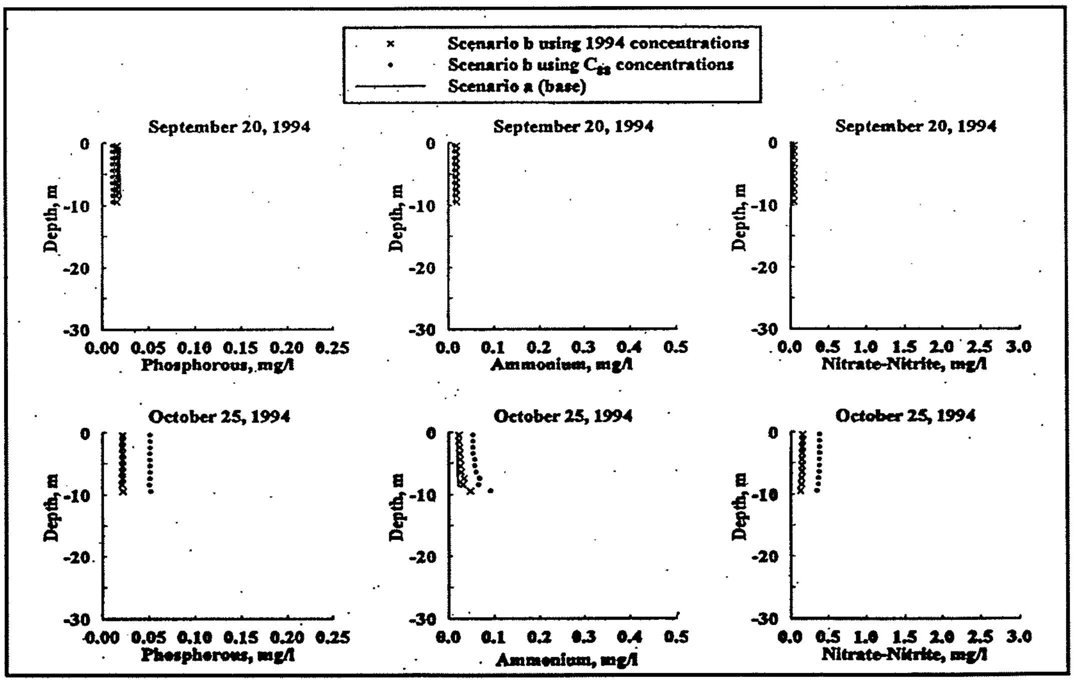


Figure 208. (Concluded)

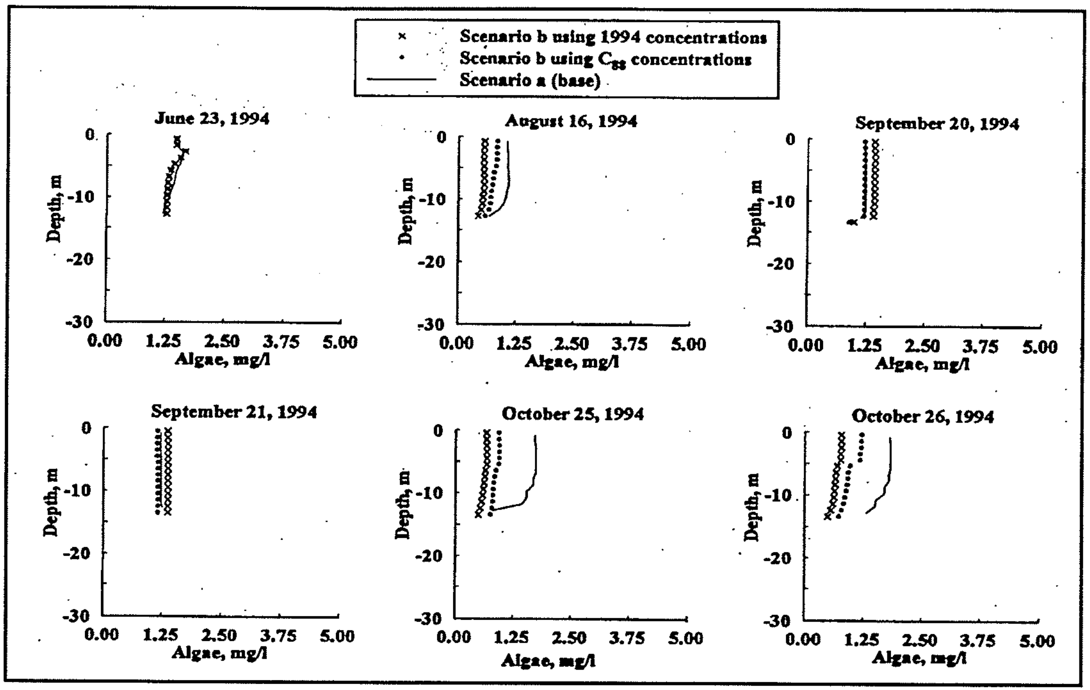


Figure 209. 1994 Neely Henry scenario algae results for station 1

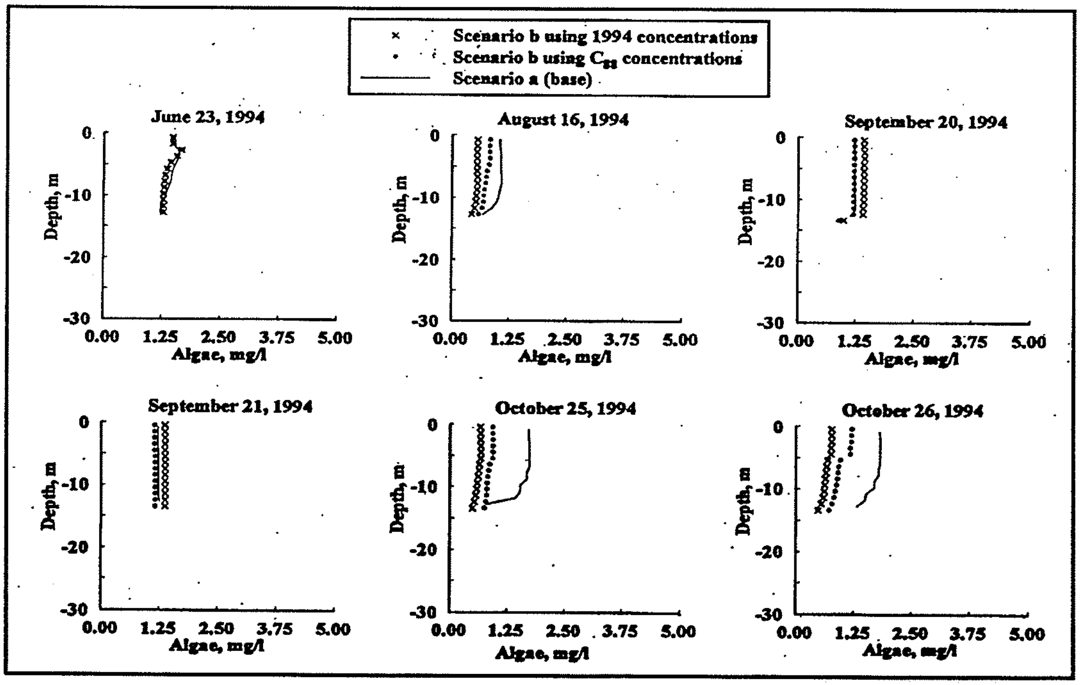


Figure 210. 1994 Neely Henry scenario algae results for station 6

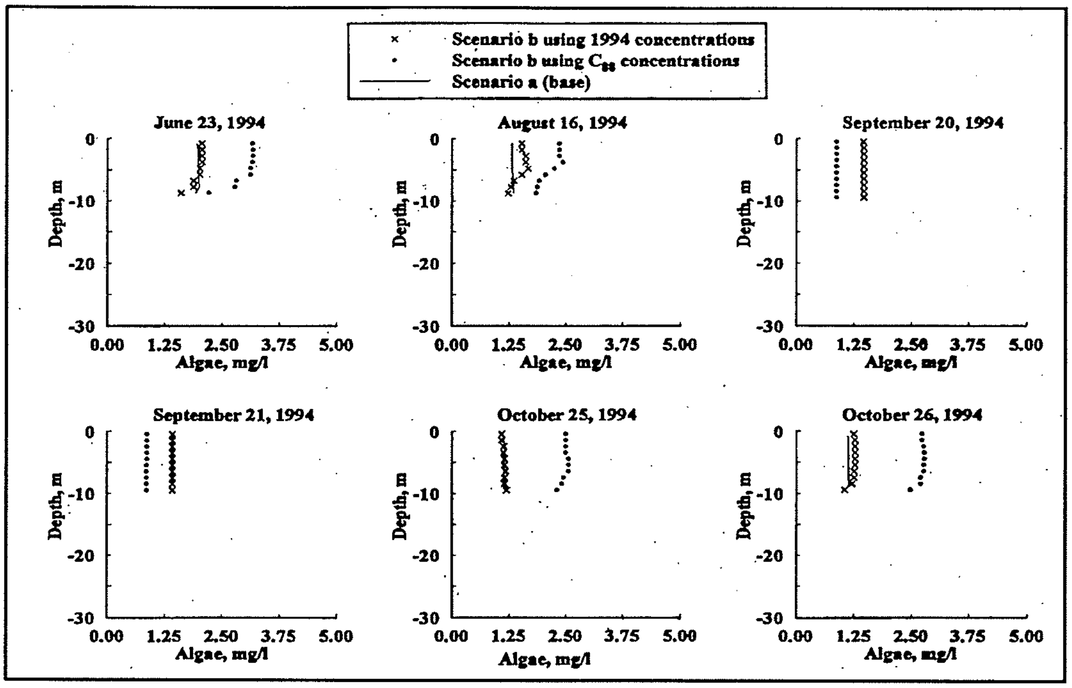


Figure 211. 1994 Neely Henry scenario algae results for station 10

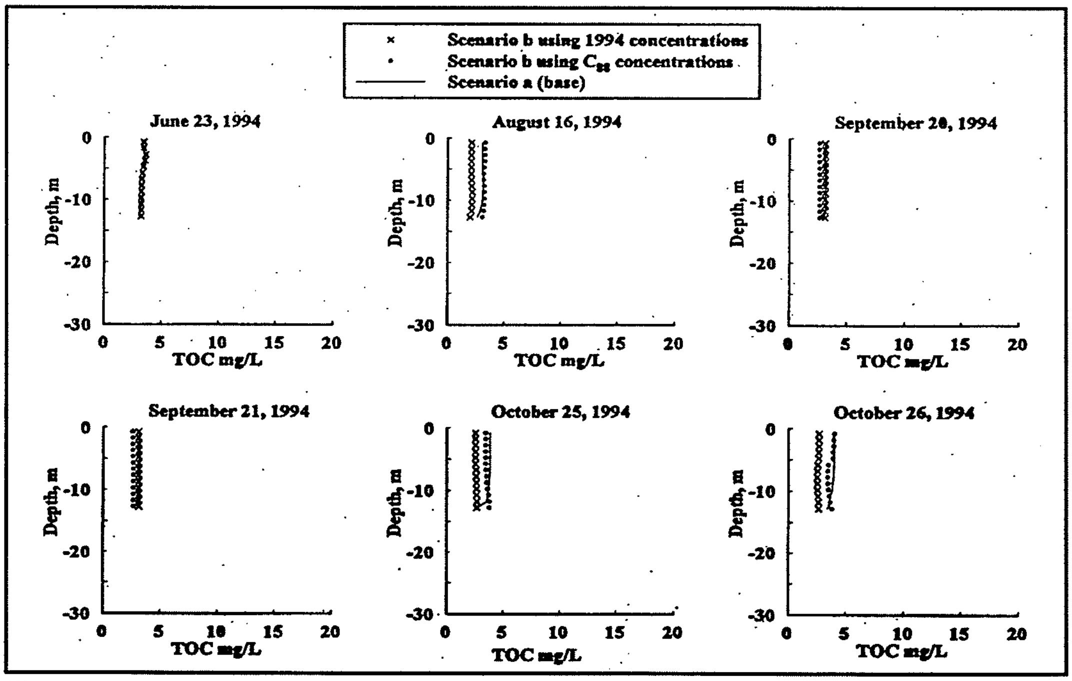


Figure 212. 1994 Neely Henry scenario TOC results for station 1

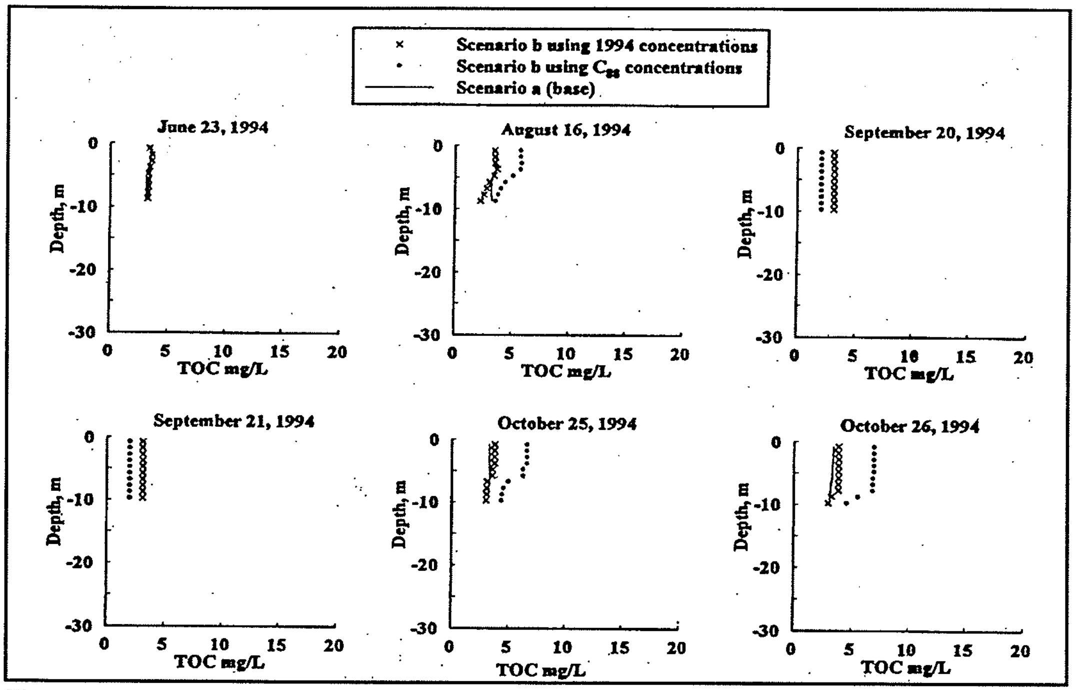


Figure 213. 1994 Neely Henry scenario algae results for station 6

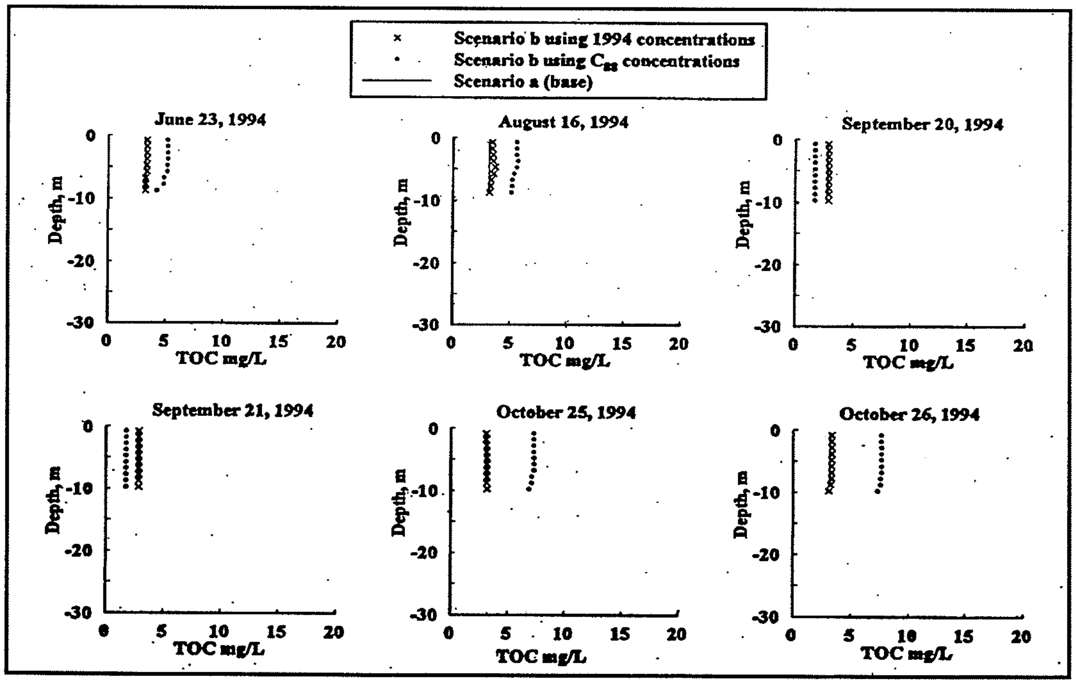


Figure 214. 1994 Neely Henry scenario TOC results for station 10

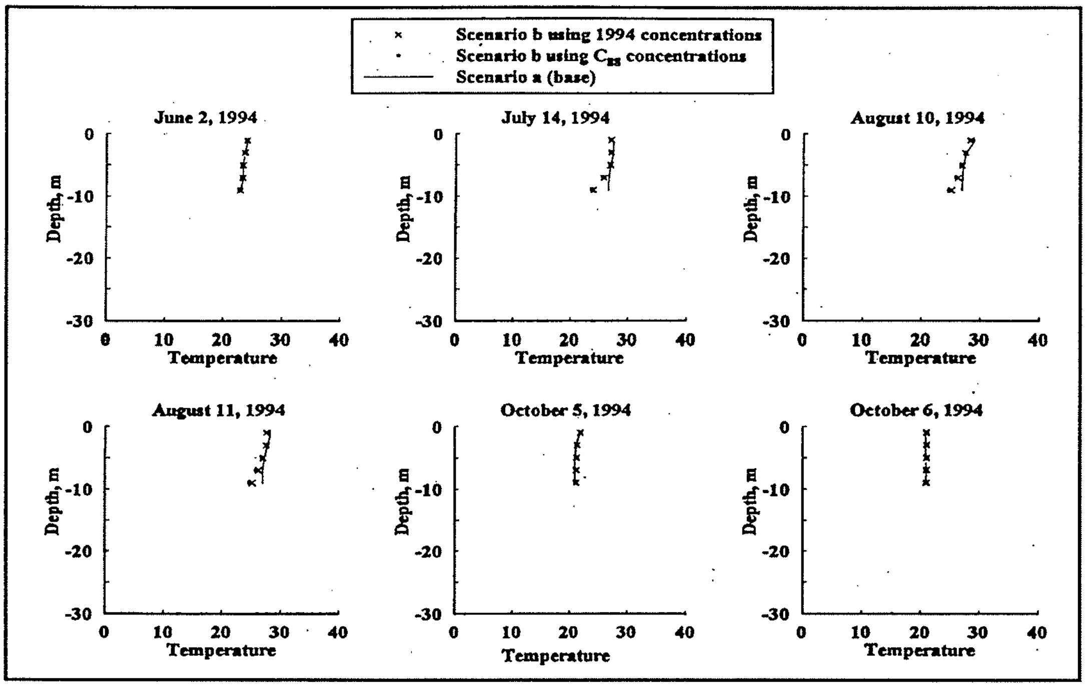


Figure 215. 1994 Weiss scenario temperature results for station 1

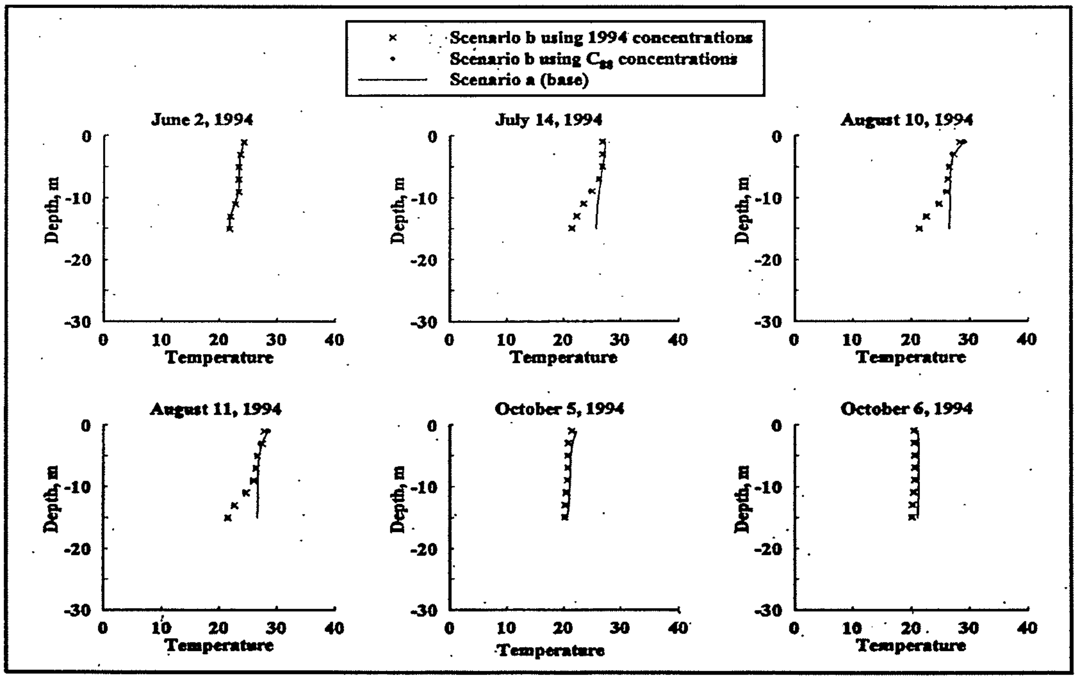


Figure 216. 1994 Weiss scenario temperature results for station 3

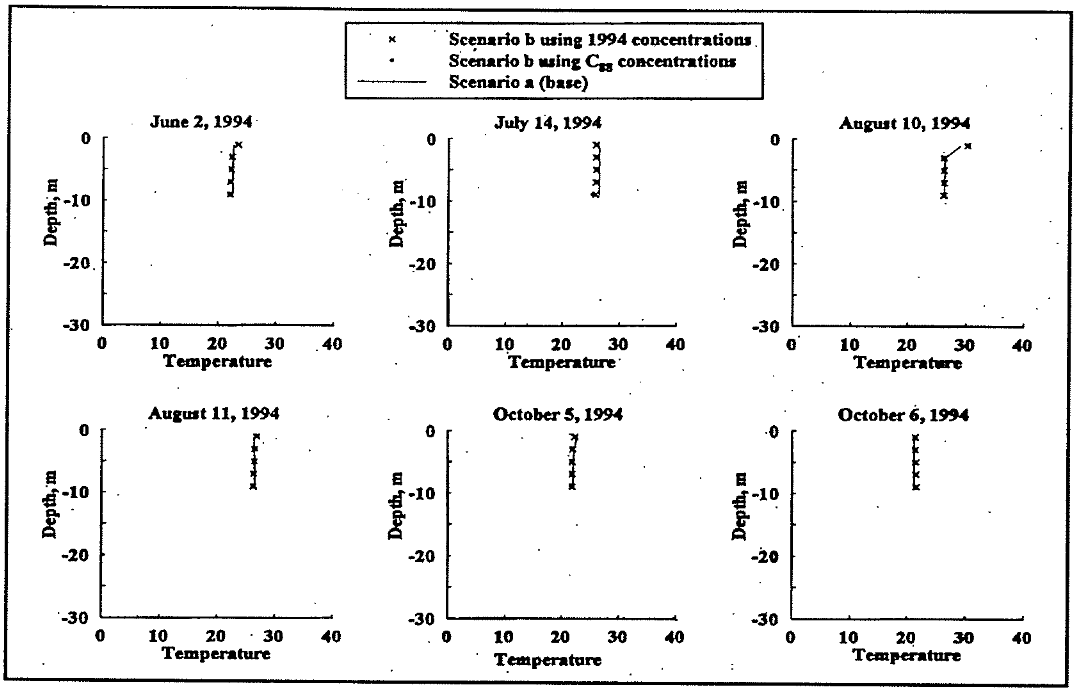


Figure 217. 1994 Weiss scenario temperature results for station 6

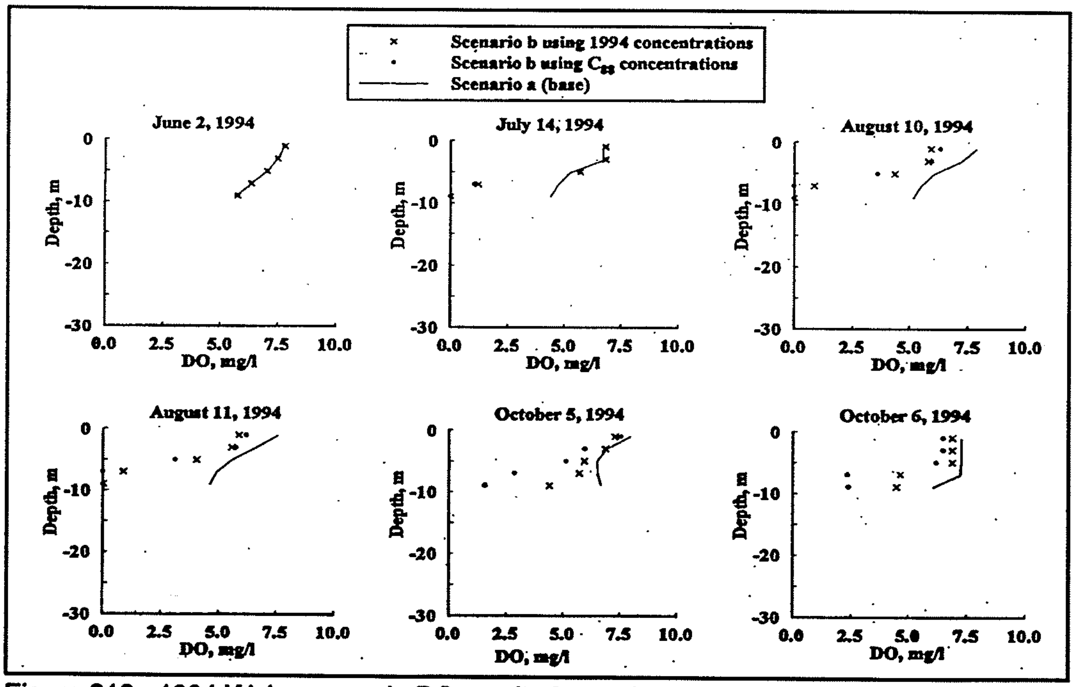


Figure 218. 1994 Weiss scenario DO results for station 1

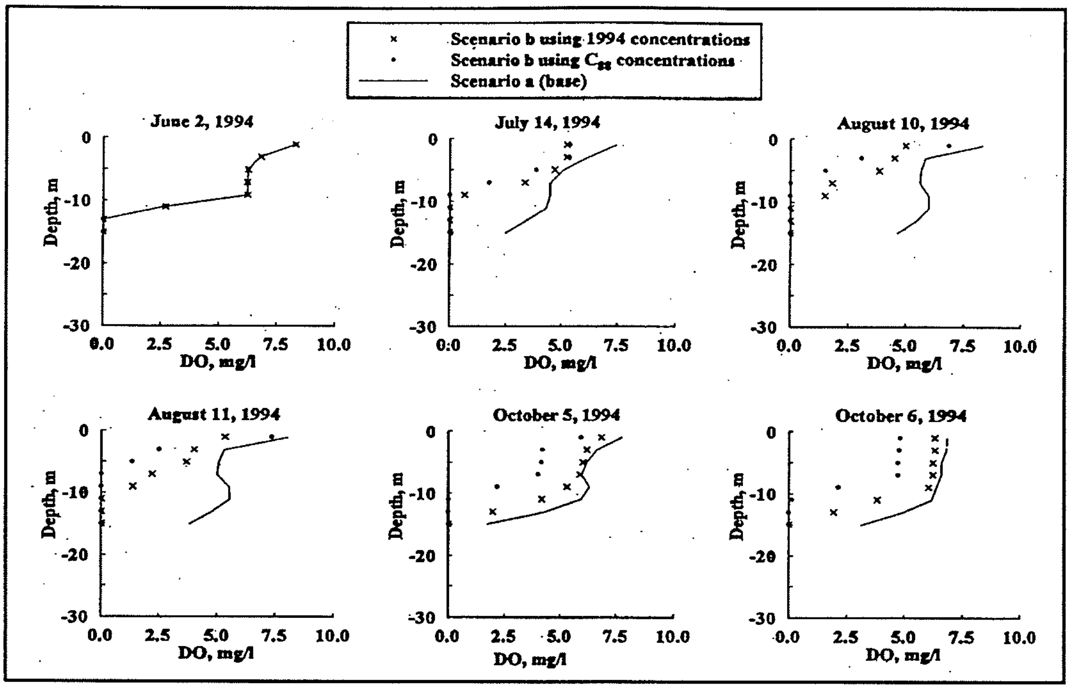


Figure 219. 1994 Weiss scenario DO results for station 3

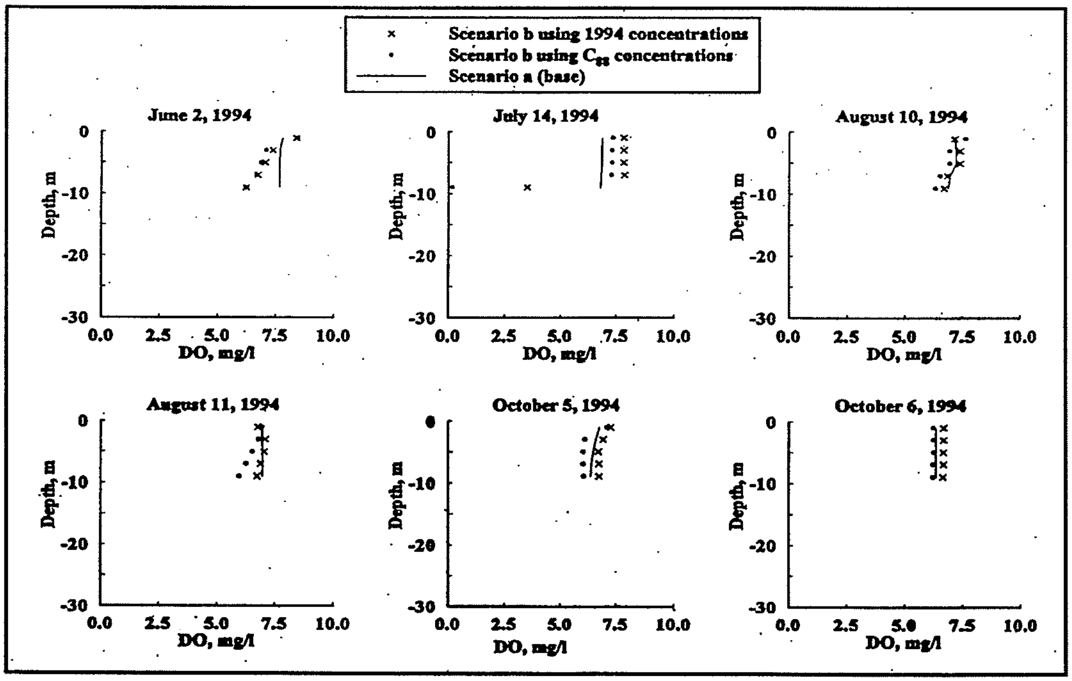


Figure 220. 1994 Weiss scenario DO results for station 6

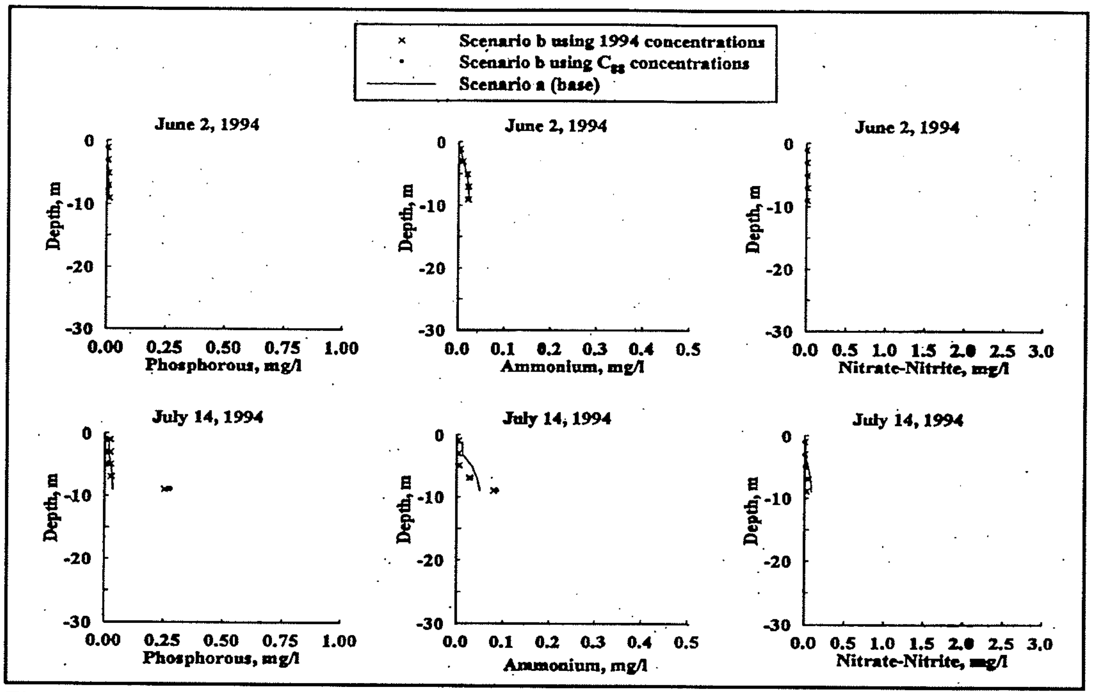


Figure 221. 1994 Weiss scenario phosphorus, ammonium, and nitrate-nitrite results for station 1 (Continued)

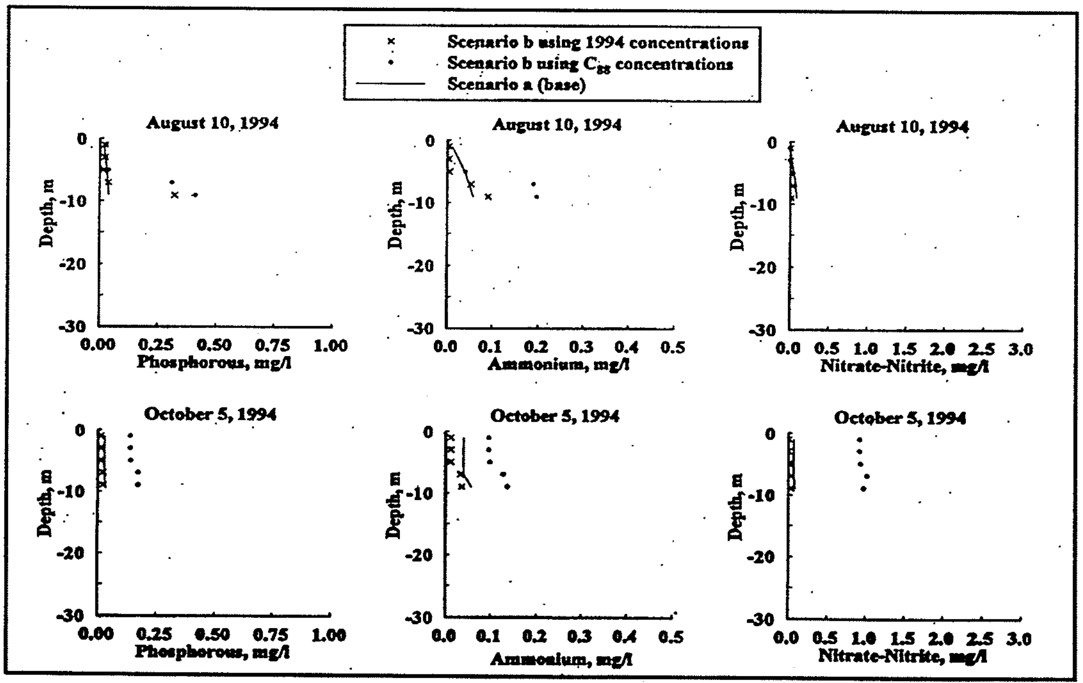


Figure 221. (Concluded)

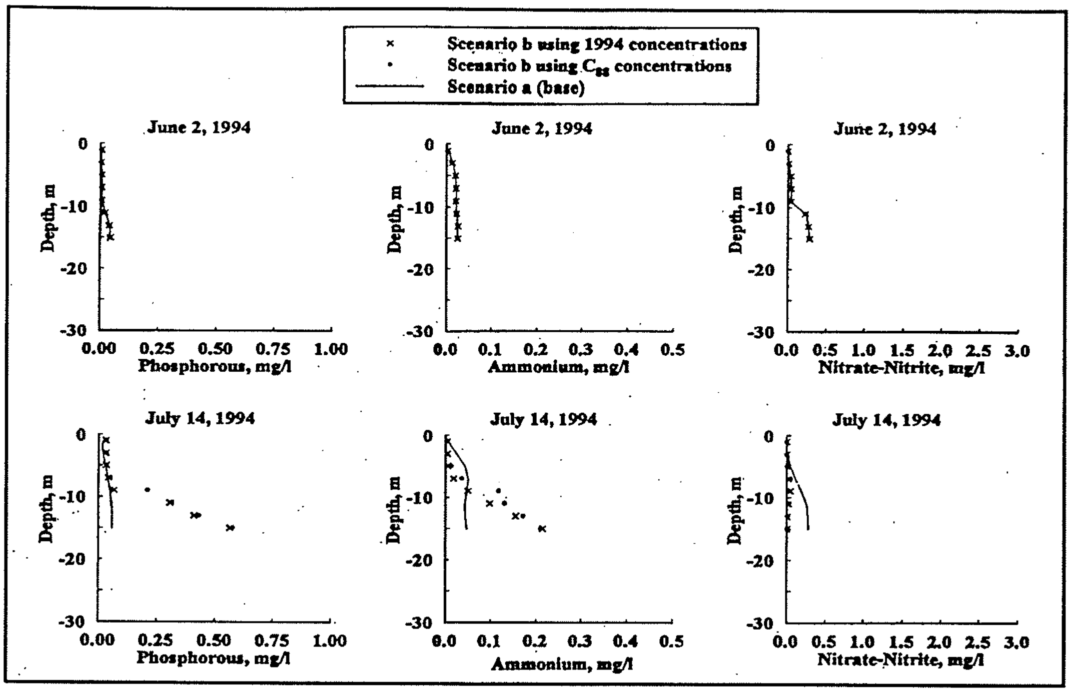
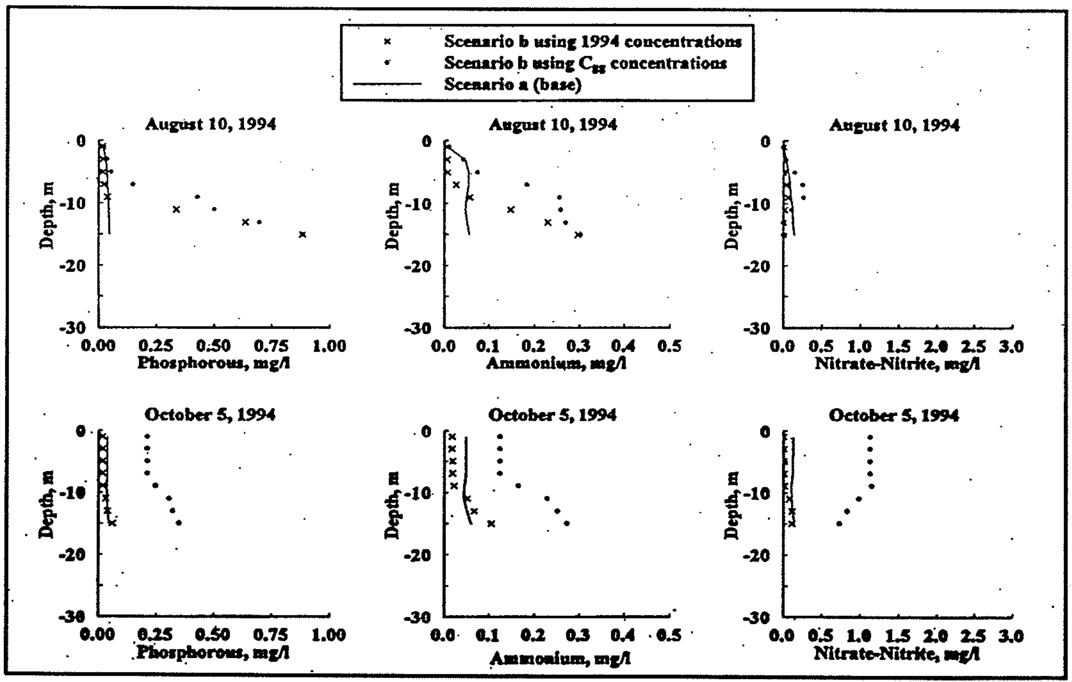


Figure 222. 1994 Weiss scenario phosphorus, ammonium, and nitrate-nitrite results for station 3 (Continued)



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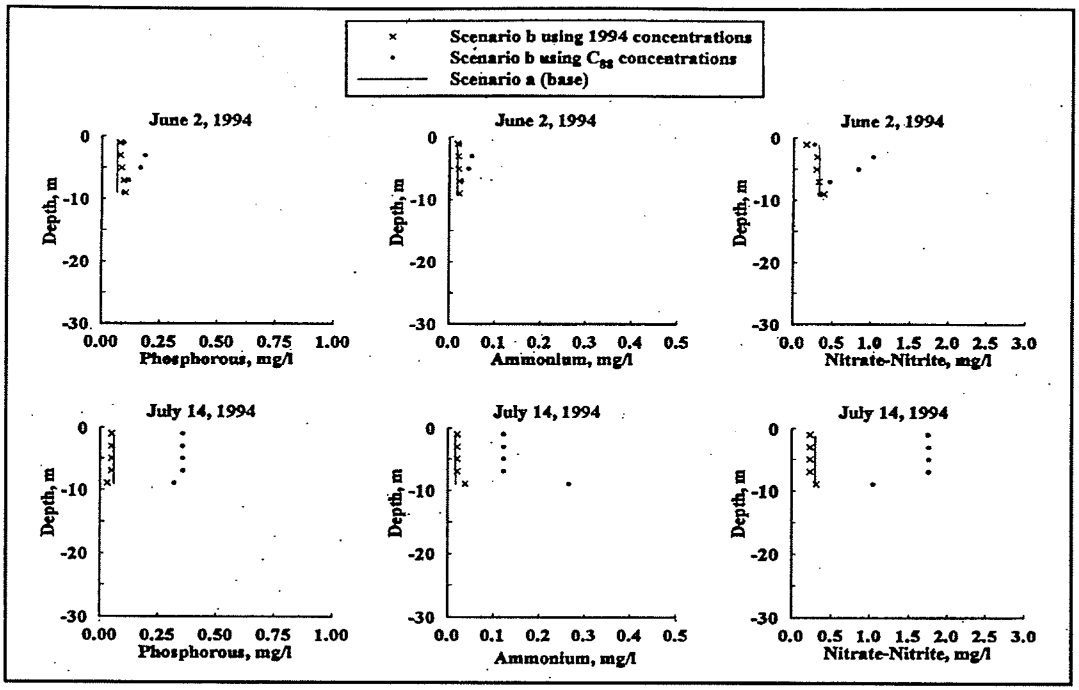
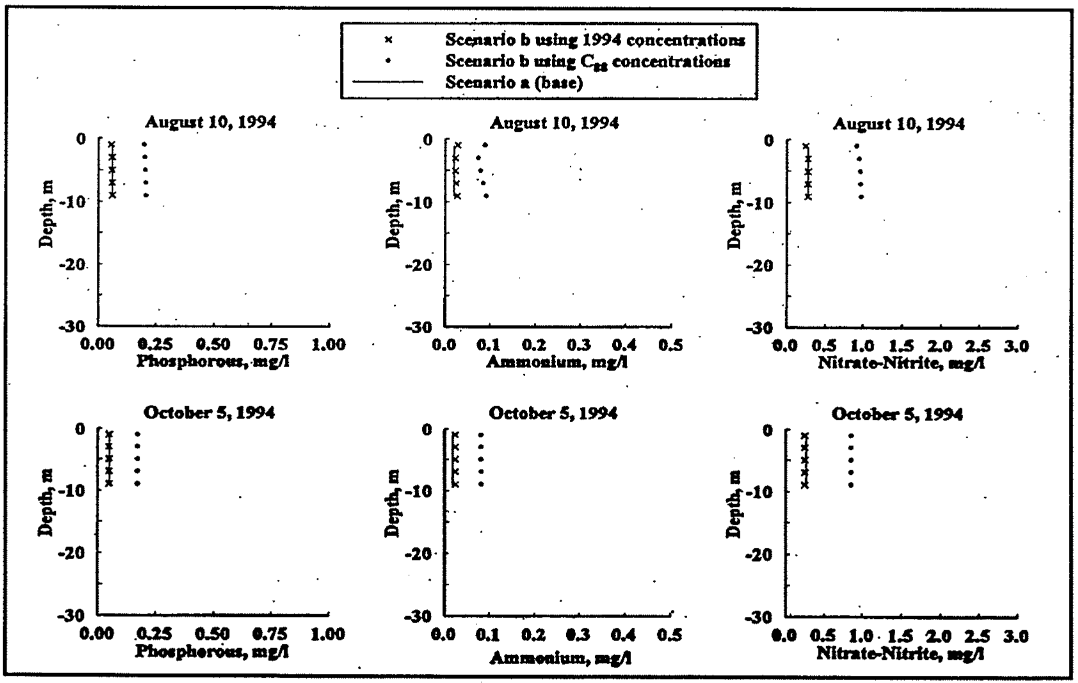


Figure 223. 1994 Weiss scenario phosphorus, ammonium, and nitrate-nitrite results for station 6 (Continued)



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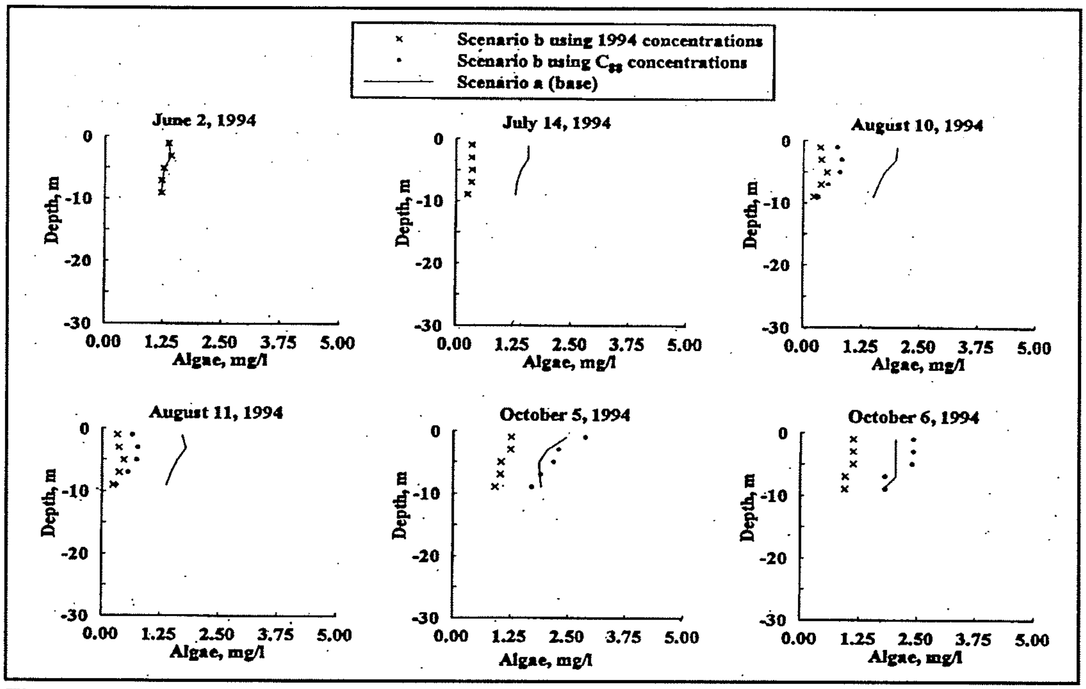
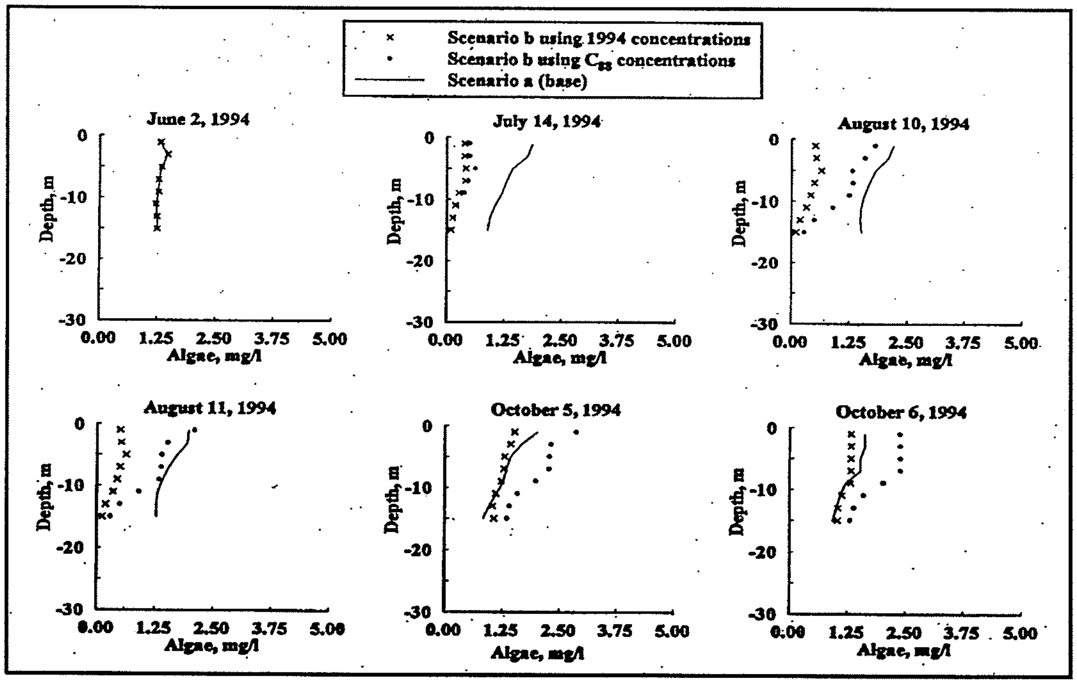


Figure 224. 1994 Weiss scenario algae results for station 1



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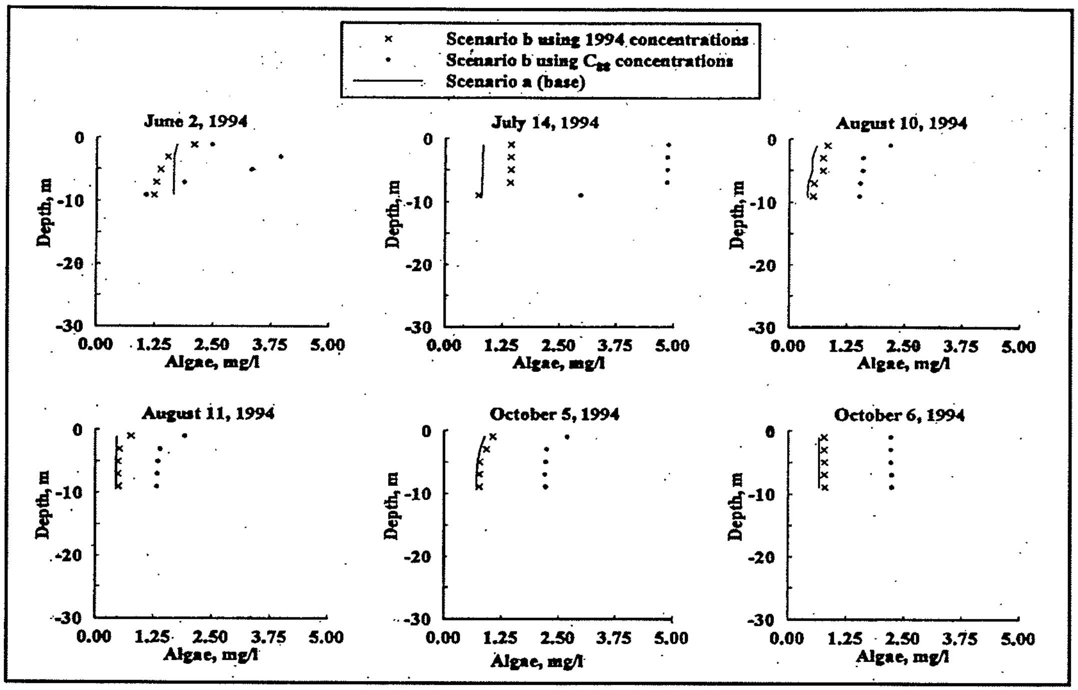


Figure 226. 1994 Weiss scenario algae results for station 6

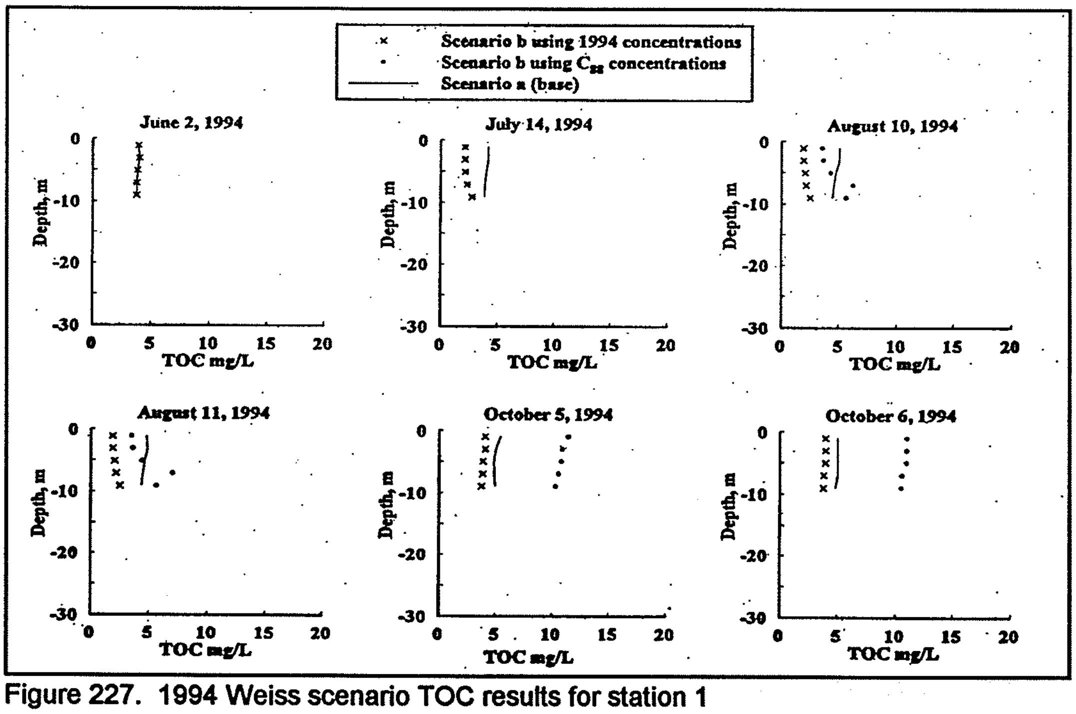
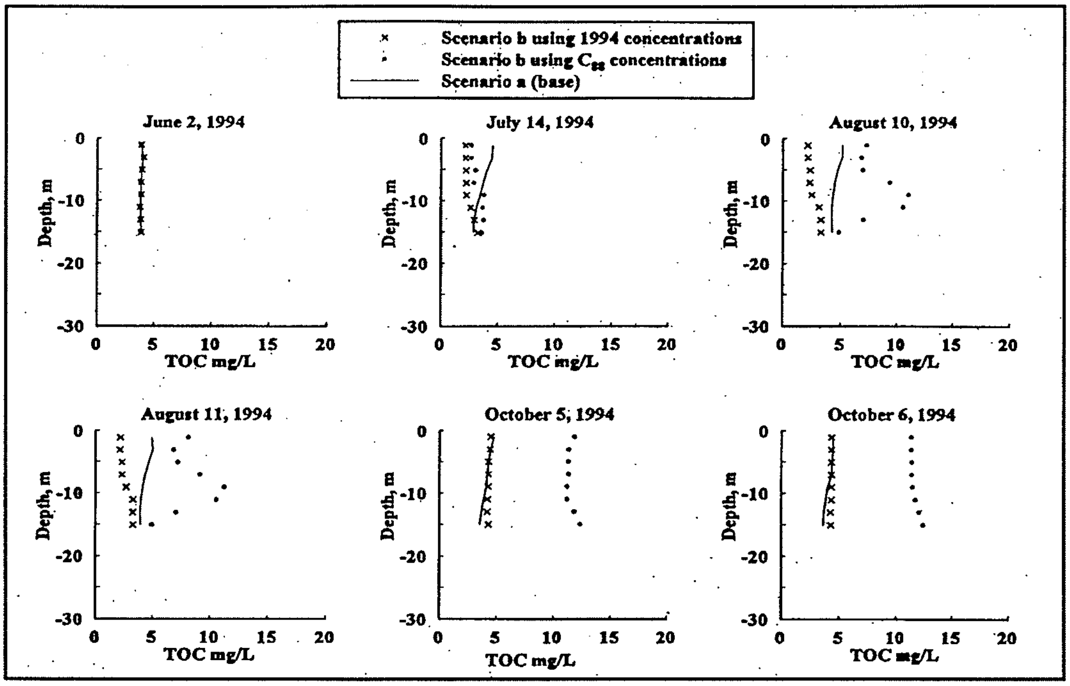


Figure 227. 1994 Weiss scenario TOC results for station 1



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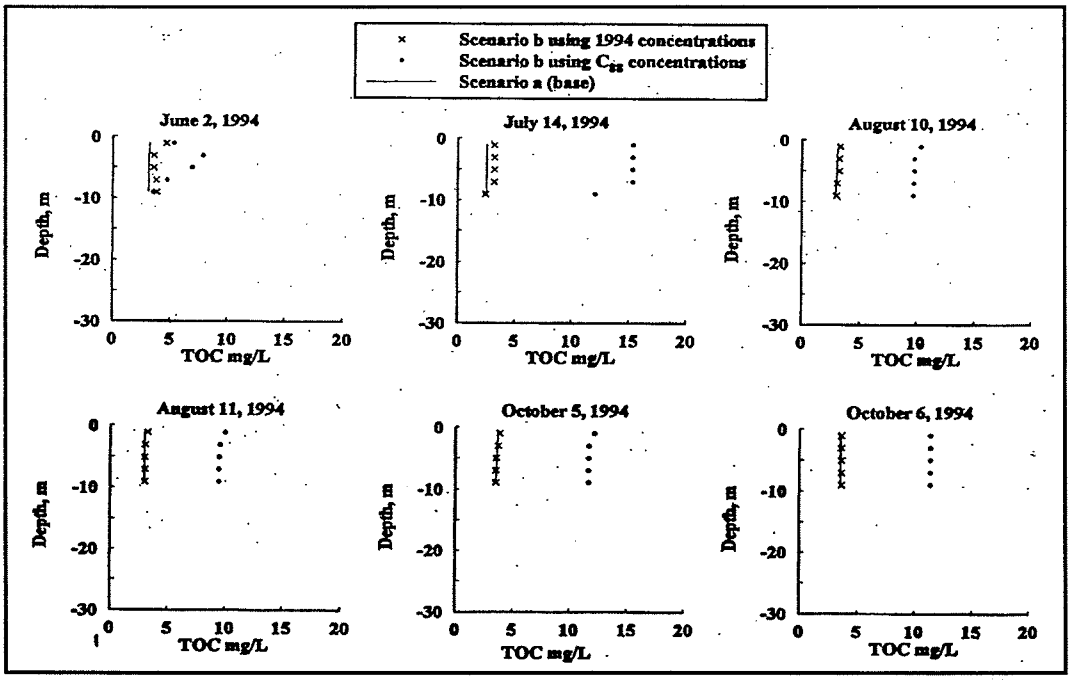


Figure 229. 1994 Weiss scenario TOC results for station 6

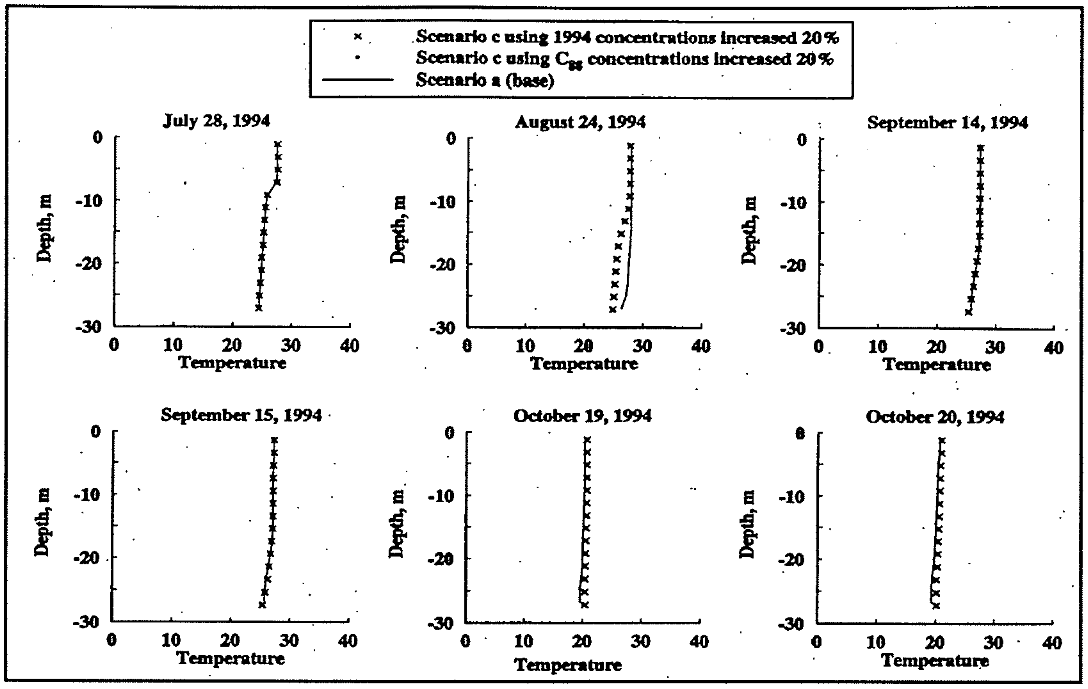


Figure 230. 1994 WFG scenario temperature results for station 1

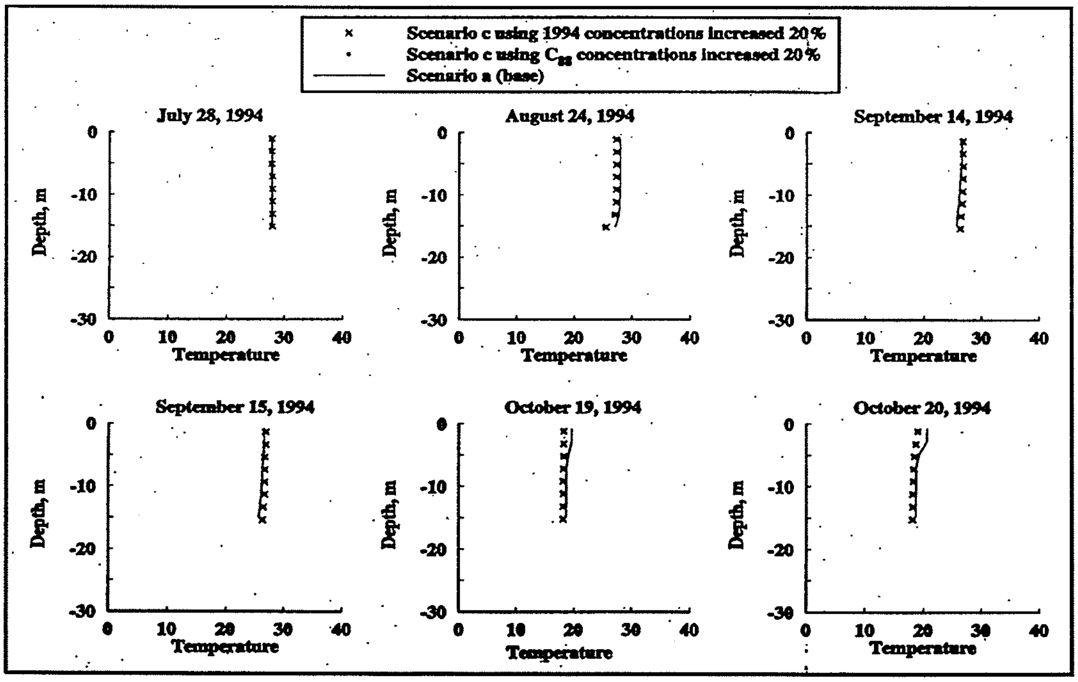


Figure 231. 1994 WFG scenario temperature results for station 5

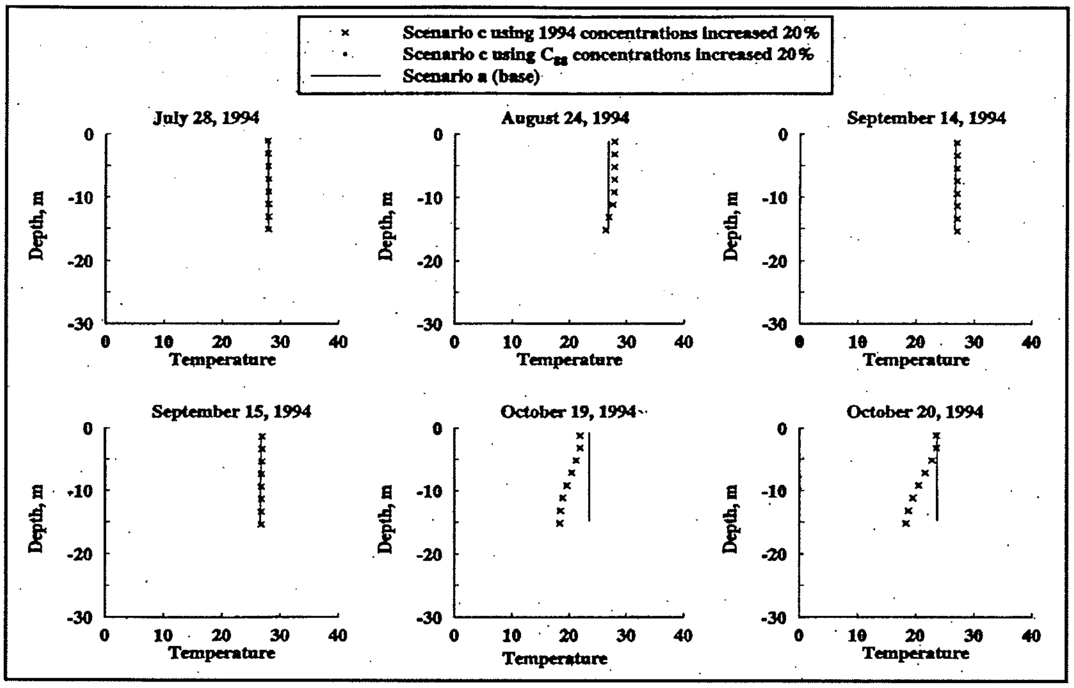
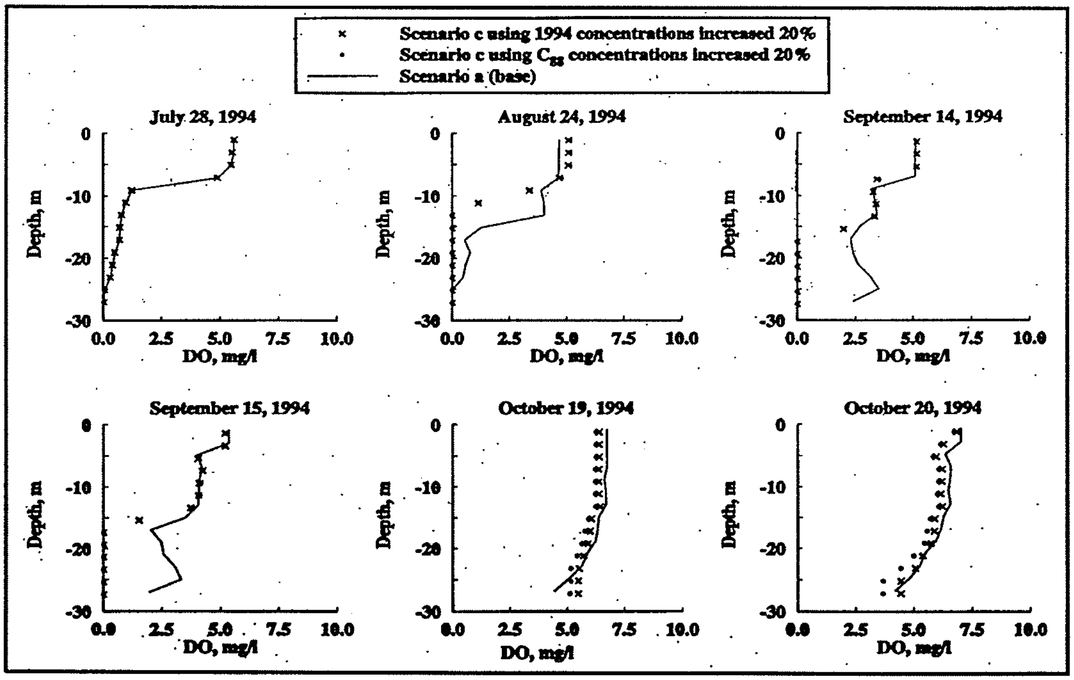


Figure 232. 1994 WFG scenario temperature results for station 8



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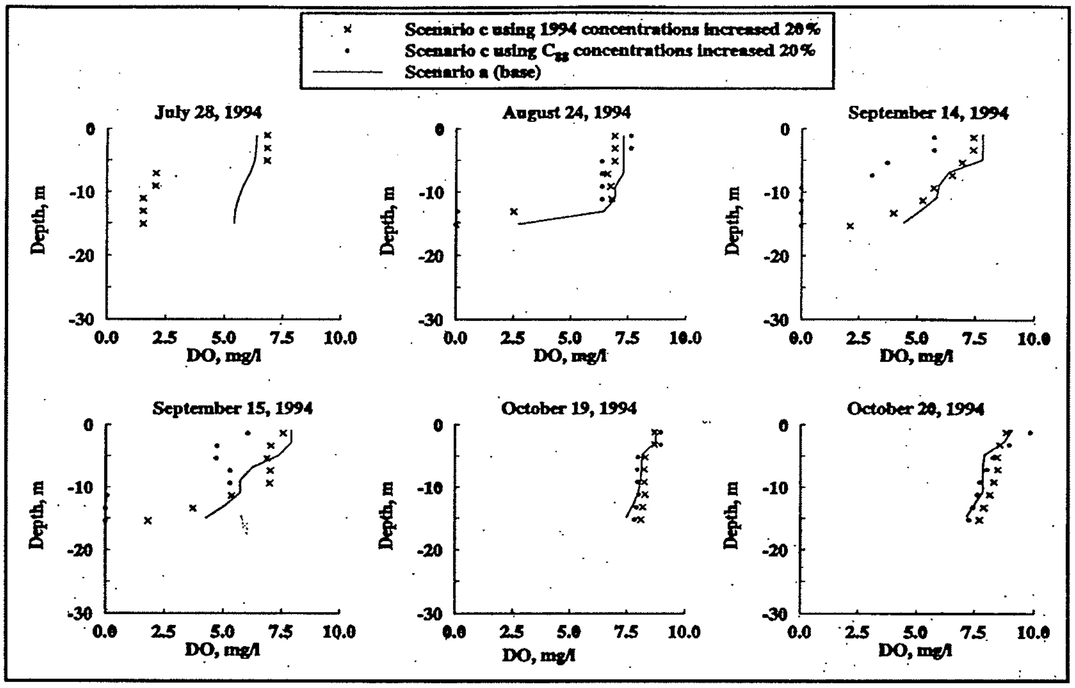

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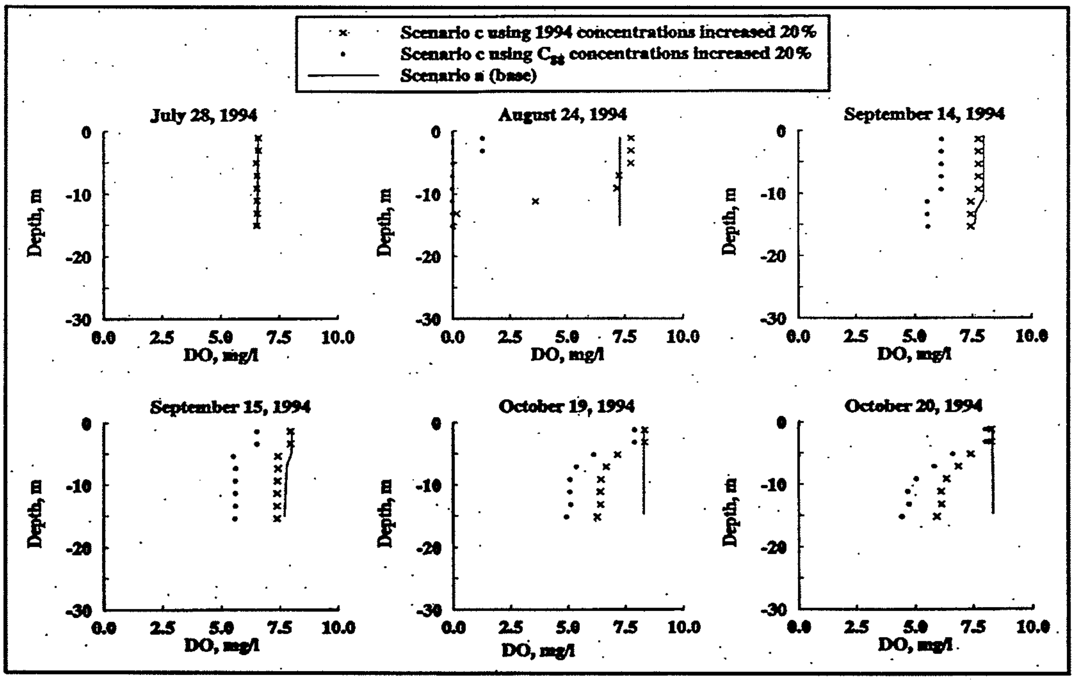

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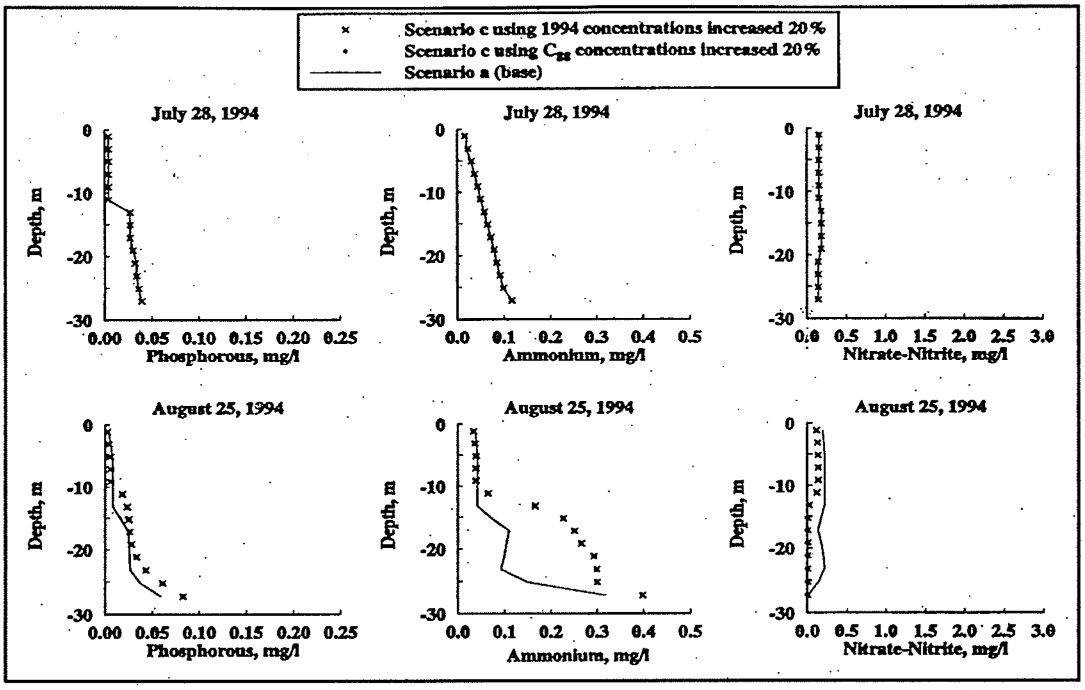
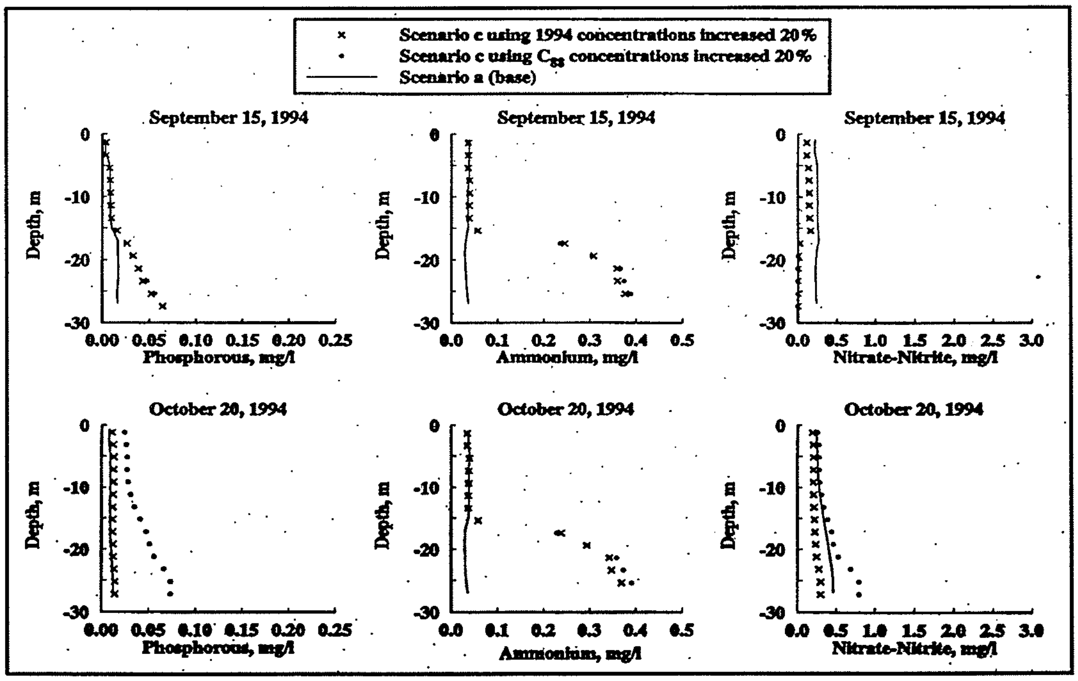


Figure 236. 1994 WFG phosphorus, ammonium, and nitrate-nitrite scenario results for station 1 (Continued)



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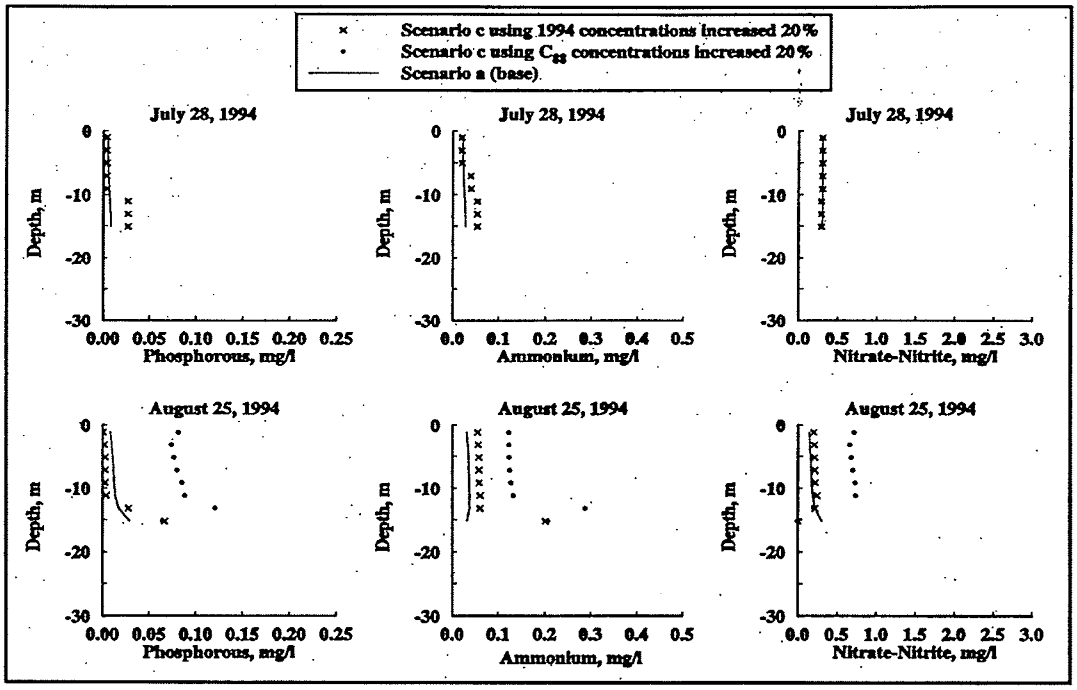
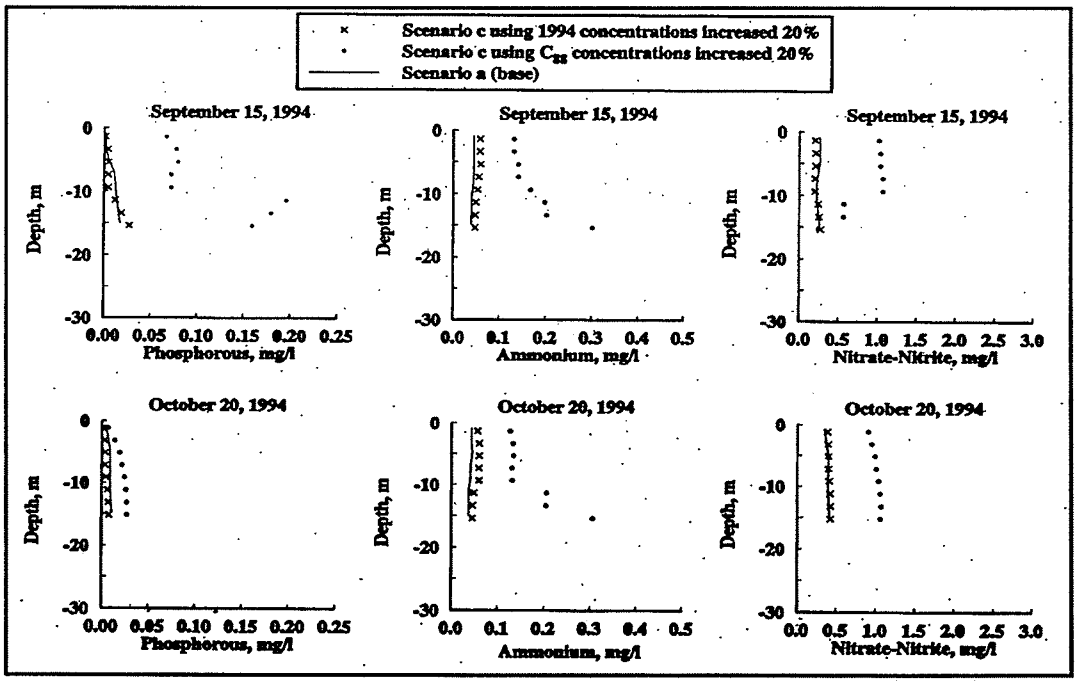


Figure 237. 1994 WFG phosphorus, ammonium, and nitrate-nitrite scenario results for station 5 (Continued)



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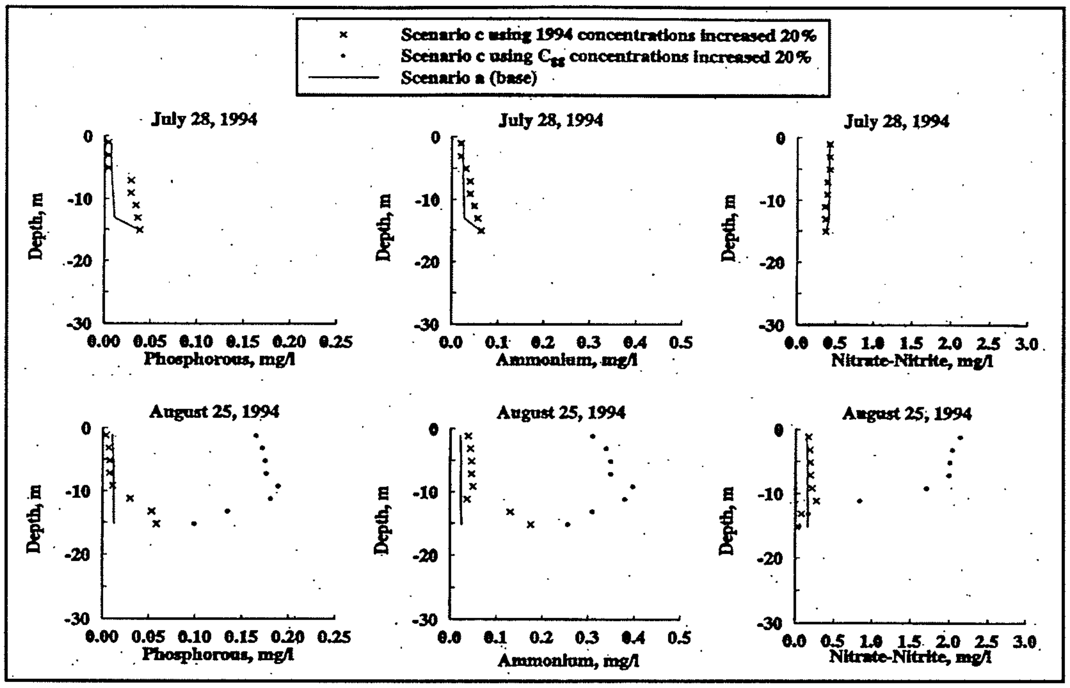
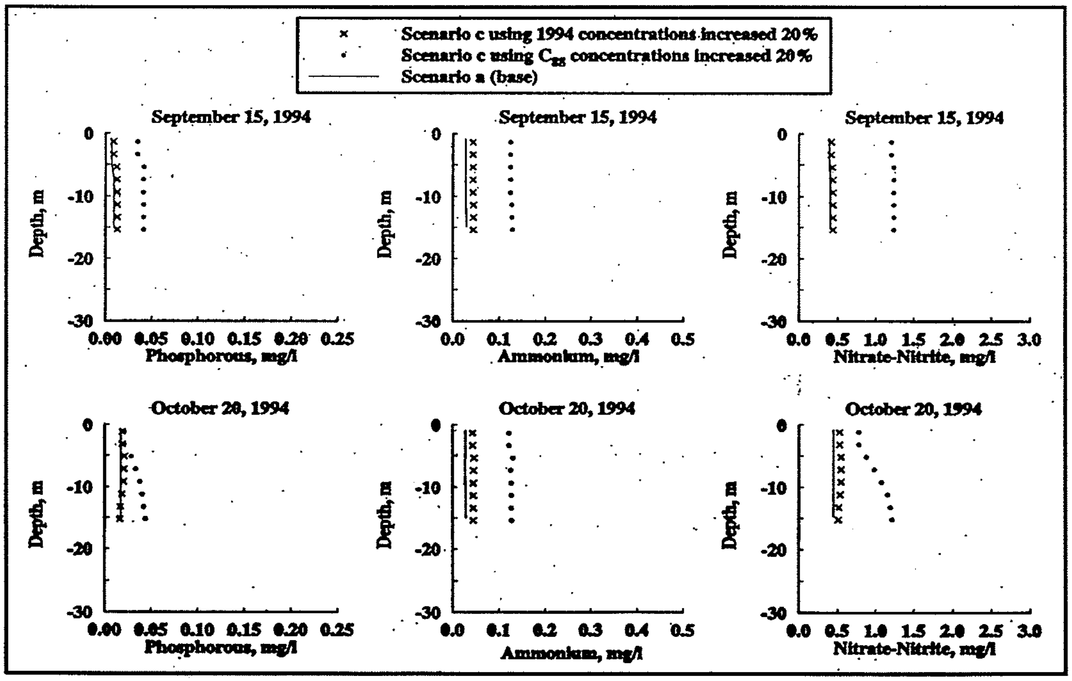


Figure 238. 1994 WFG phosphorus, ammonium, nitrate-nitrite scenario DO results for station 8 (Continued)



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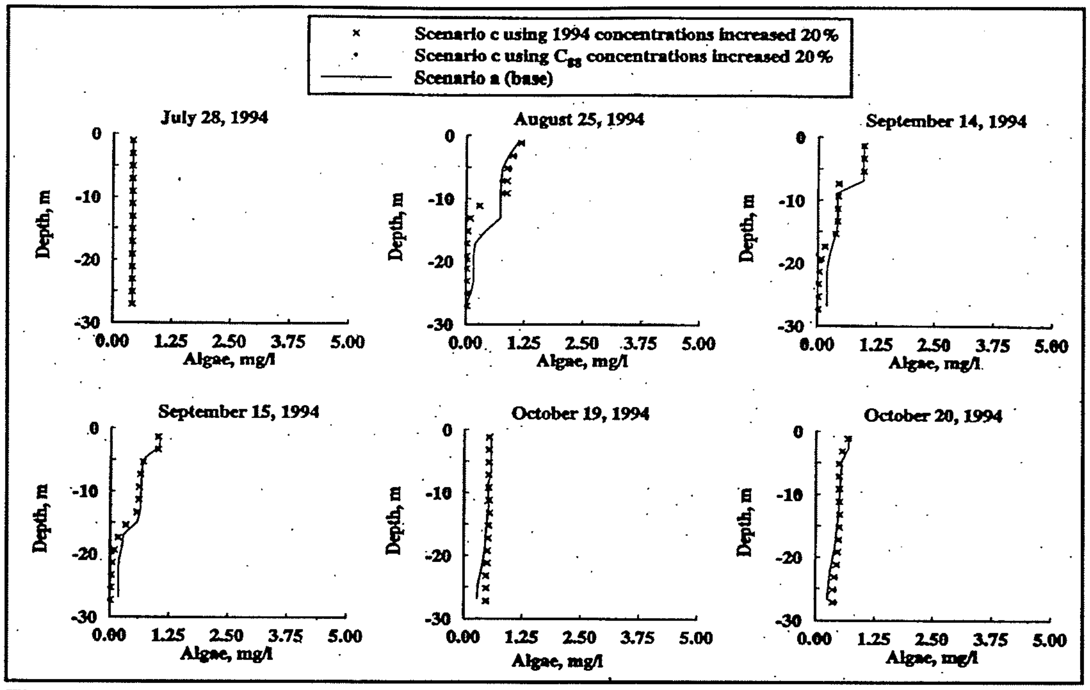

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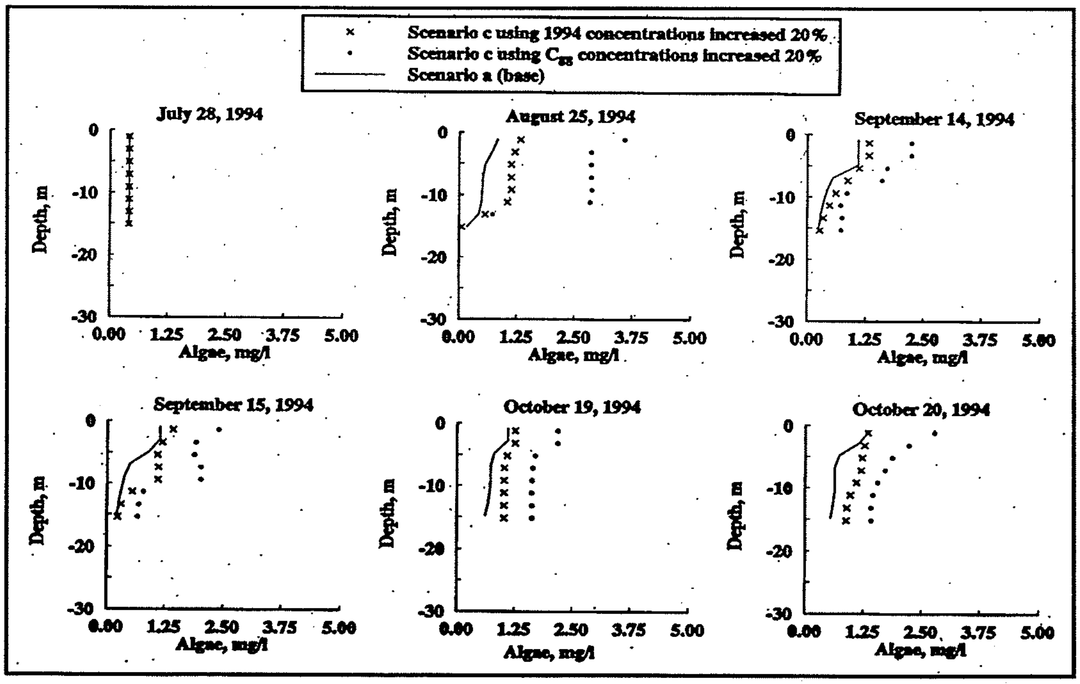

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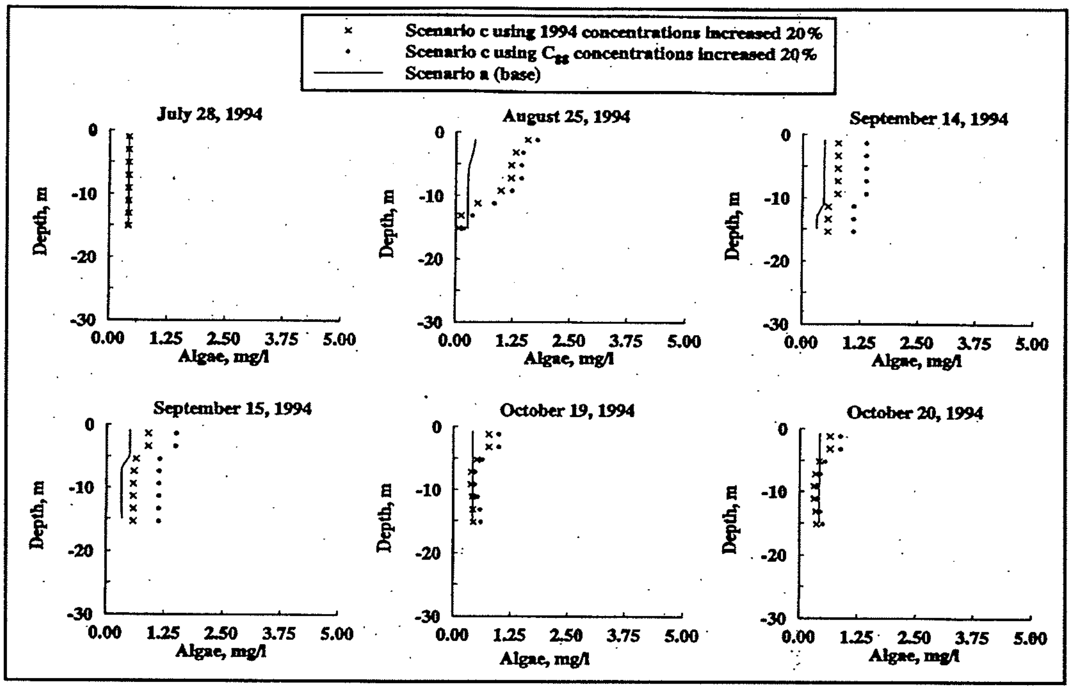


Figure 241. 1994 WFG algae scenario results for station 8

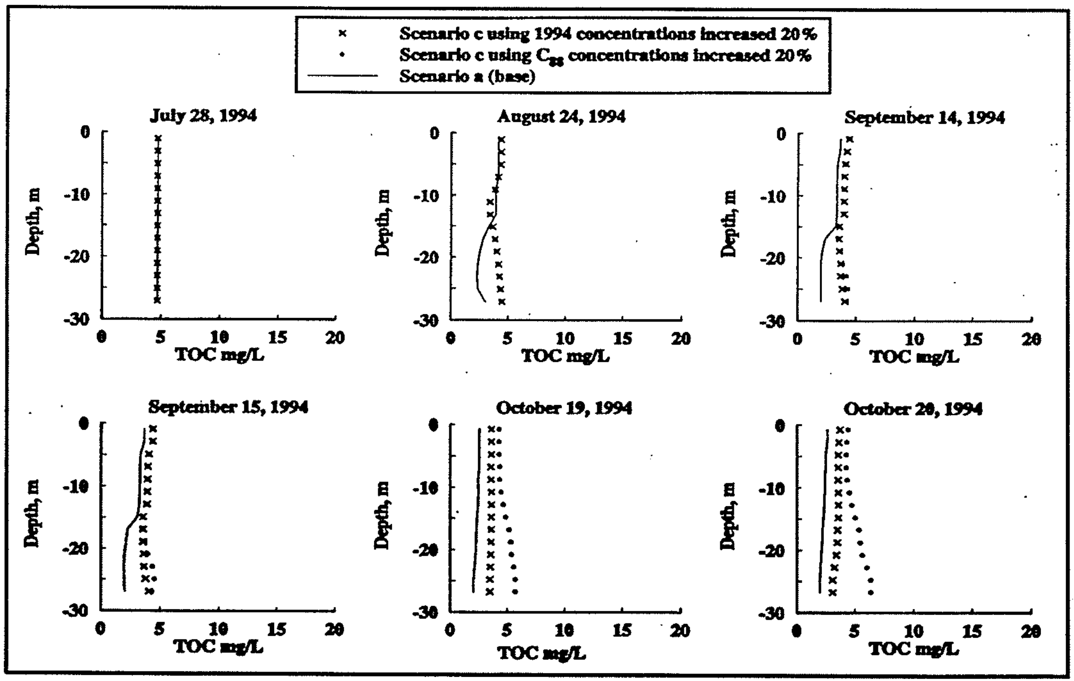
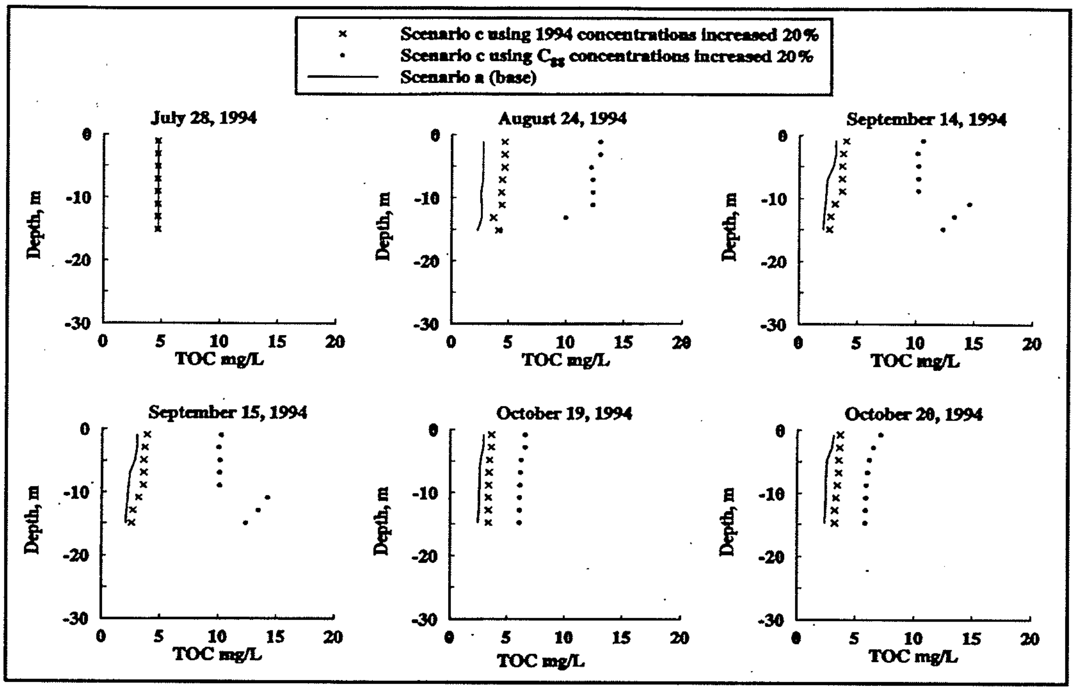


Figure 242. 1994 WFG TOC scenario results for station 1



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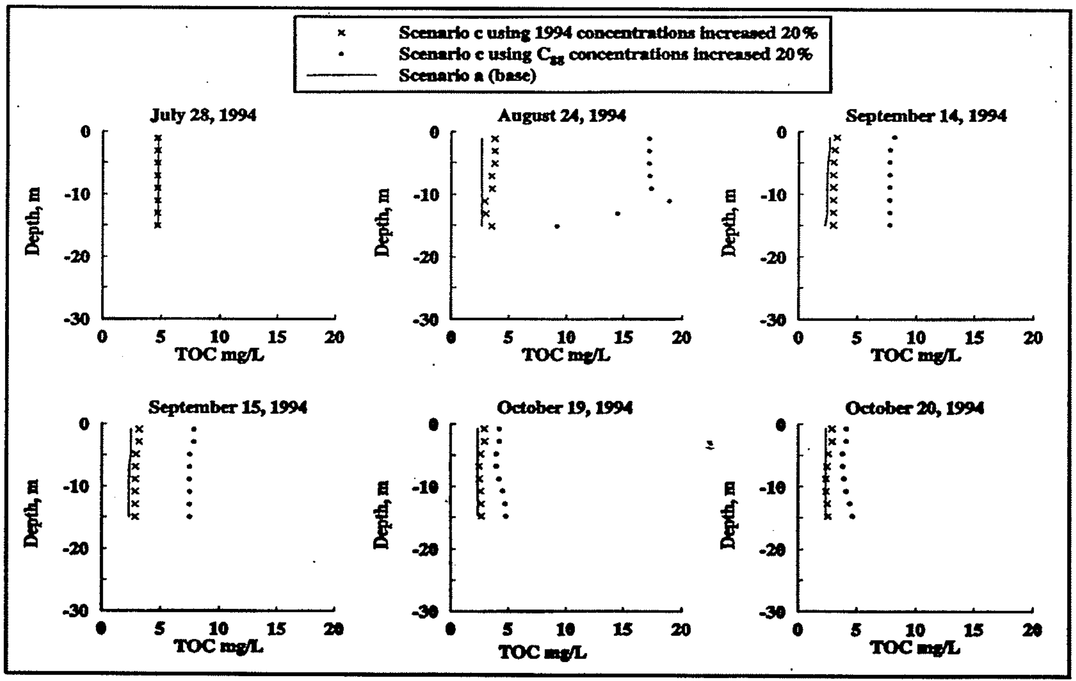


Figure 244. 1994 WFG TOC scenario results for station 8

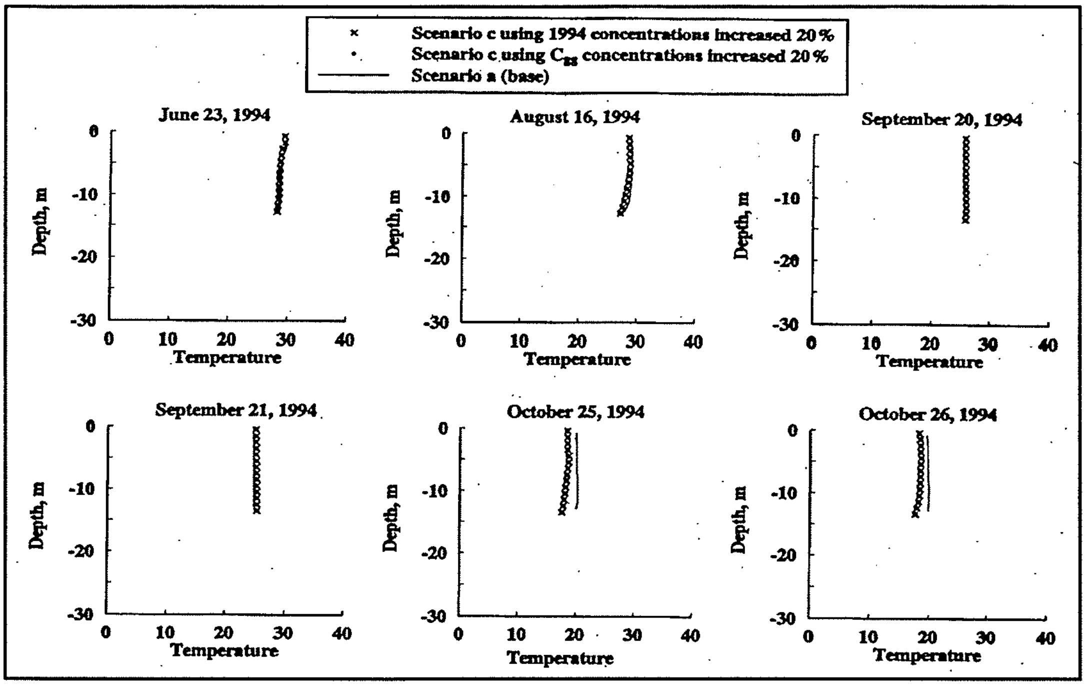


Figure 245. 1994 Neely Henry temperature scenario results for station 1

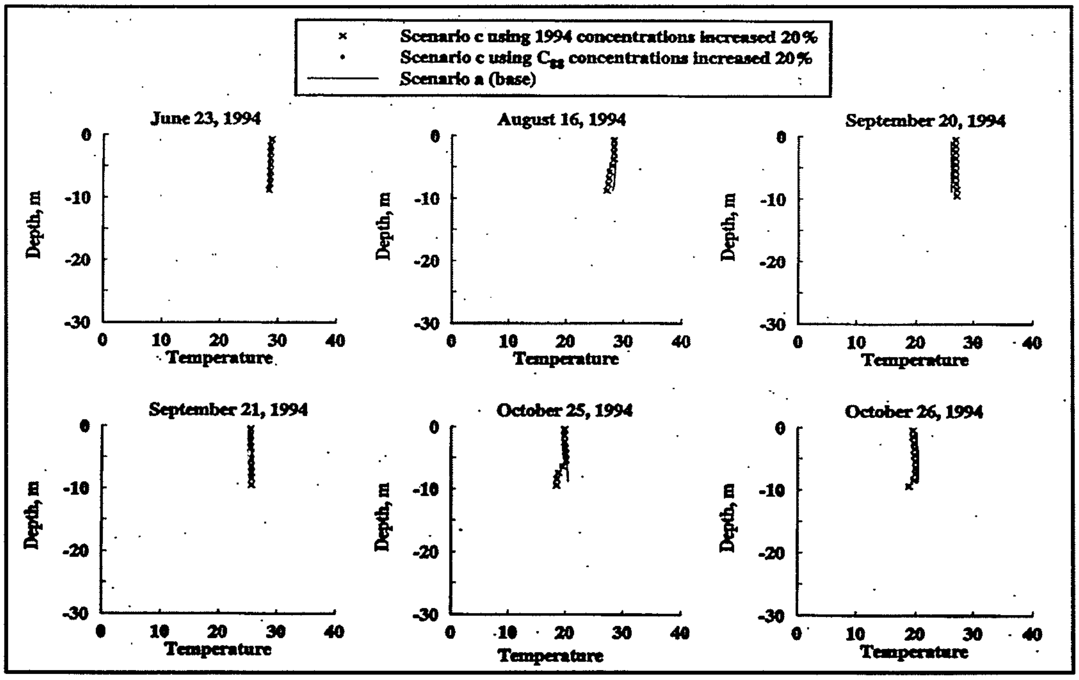


Figure 246. 1994 Neely Henry temperature scenario results for station 6

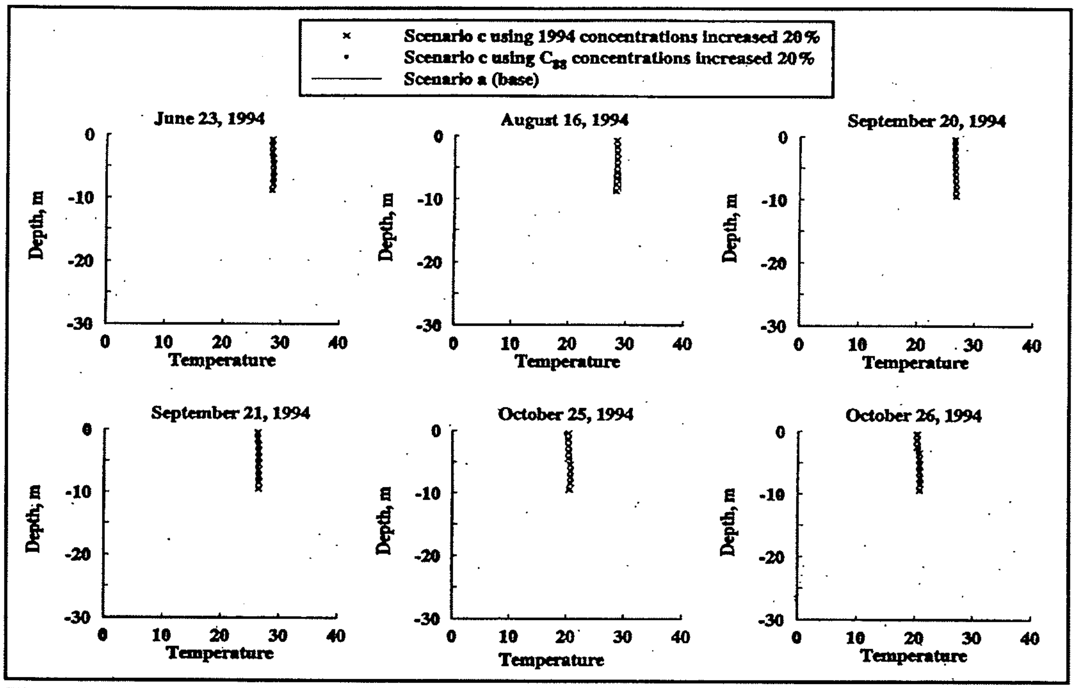


Figure 247. 1994 Neely Henry temperature scenario results for station 10

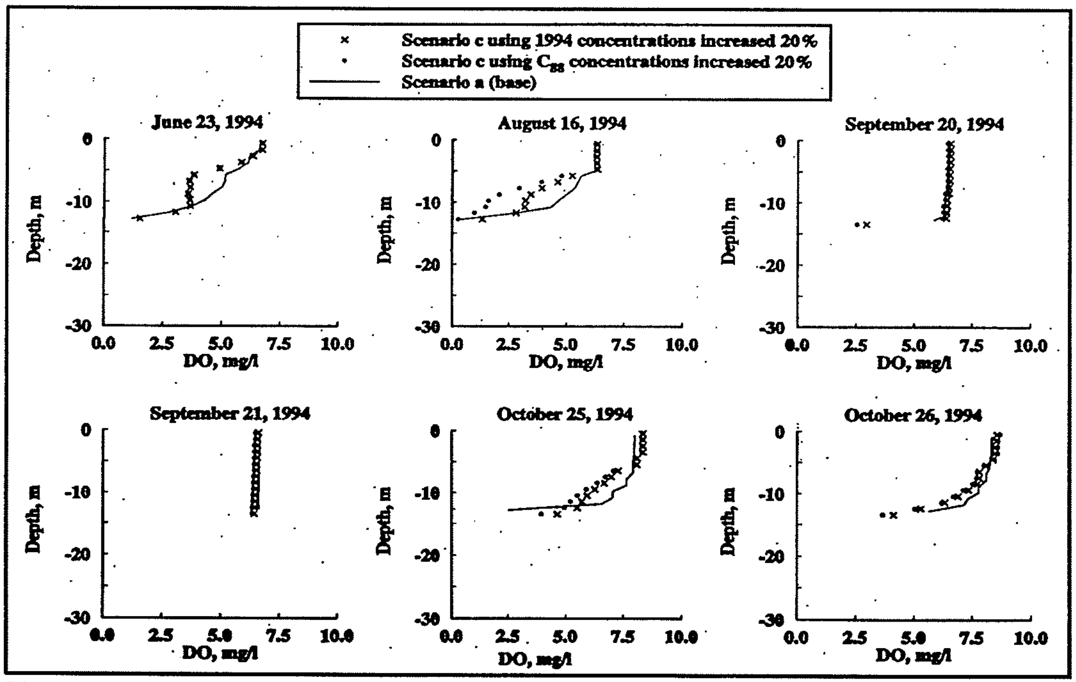
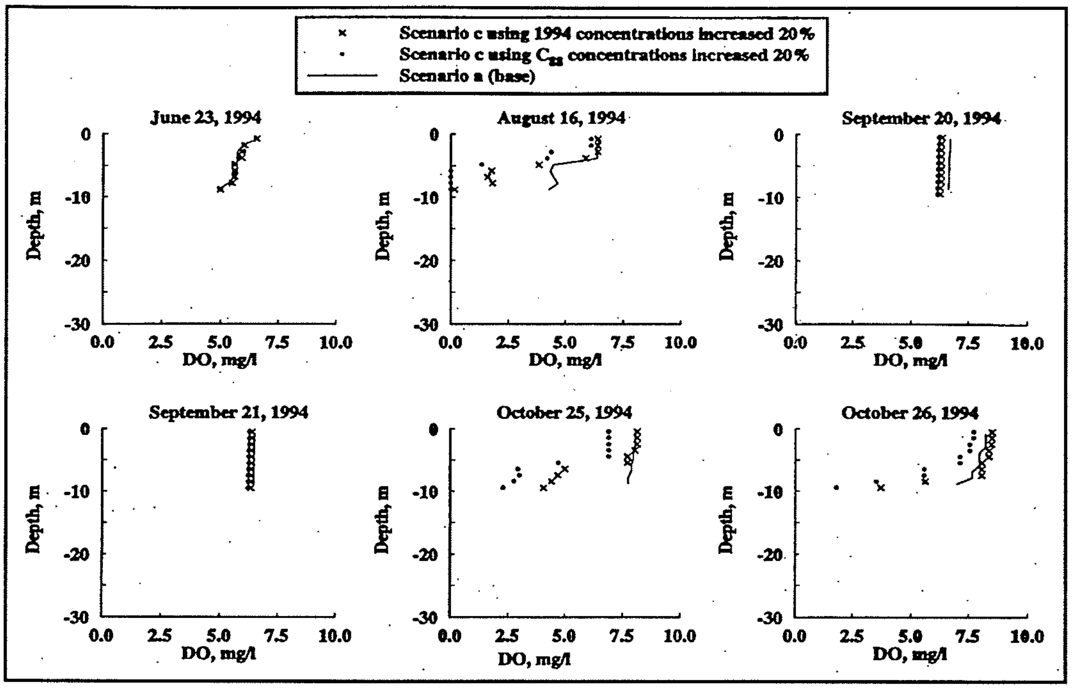


Figure 248. 1994 Neely Henry DO scenario results for station 1



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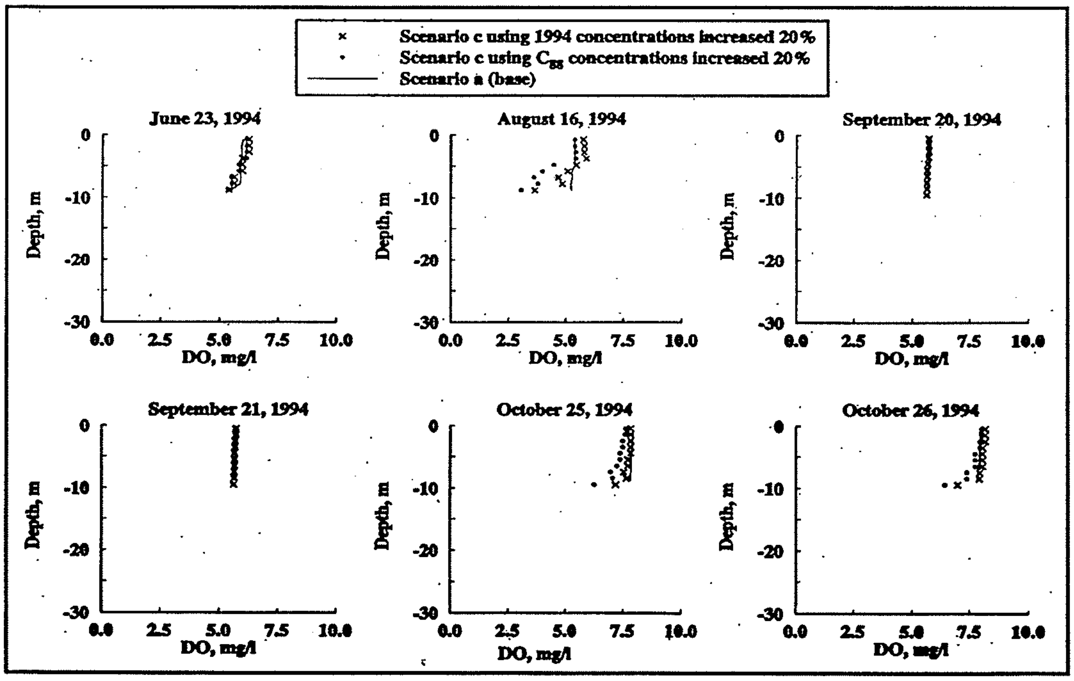


Figure 250. 1994 Neely Henry DO scenario results for station 10

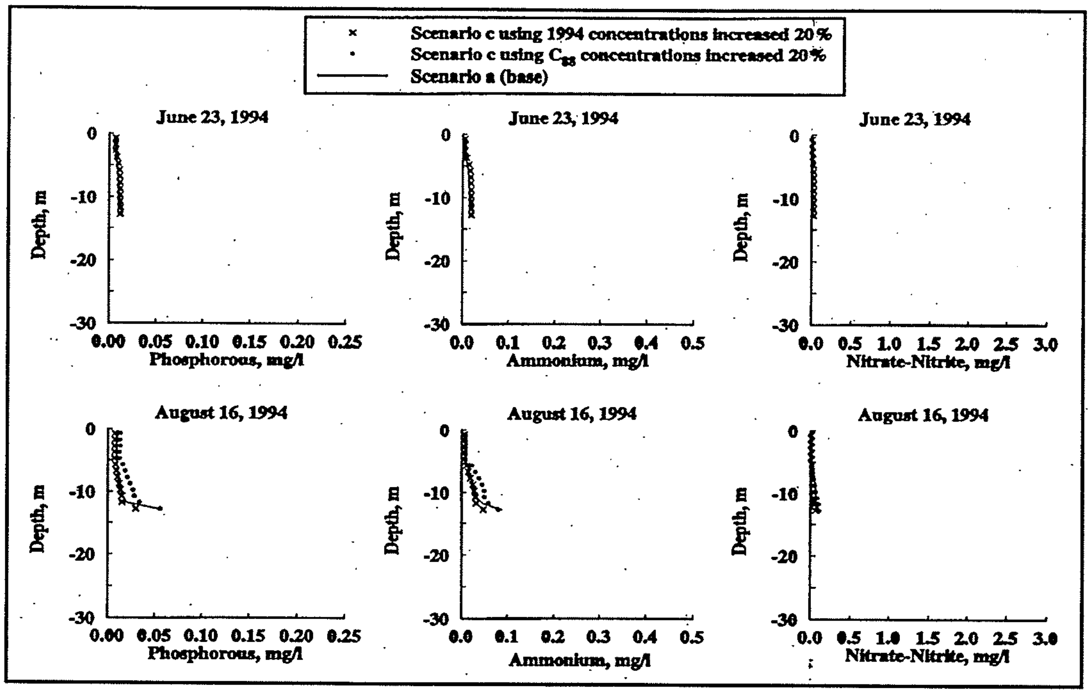
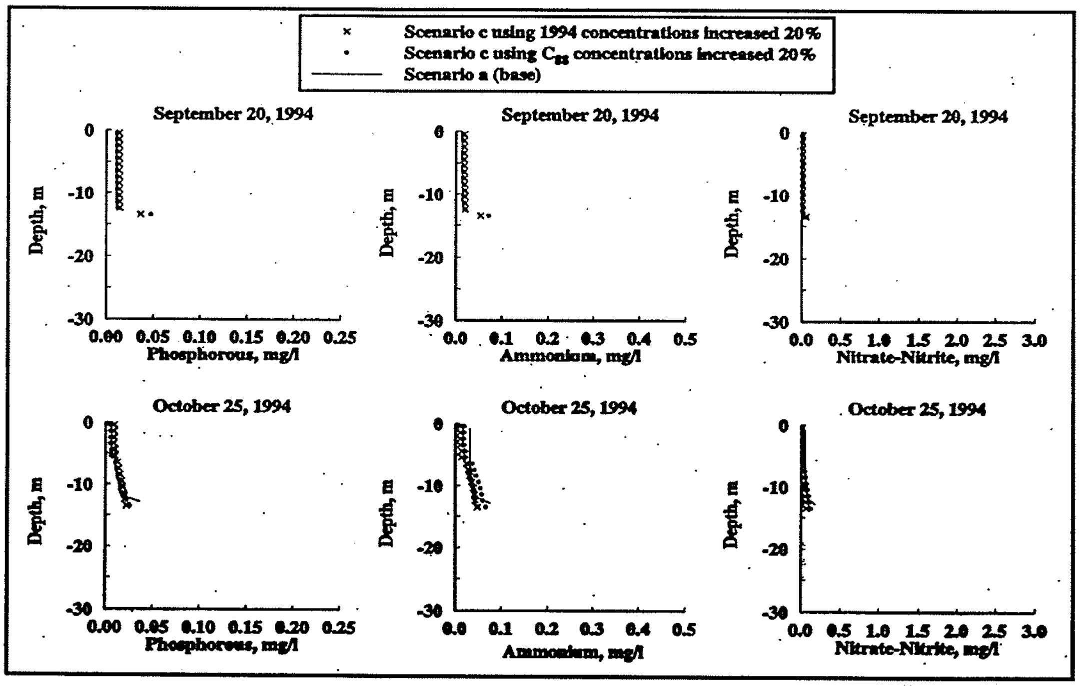


Figure 251. 1994 Neely Henry phosphorus, ammonium, and nitrate-nitrite scenario results for station 1 (Continued)



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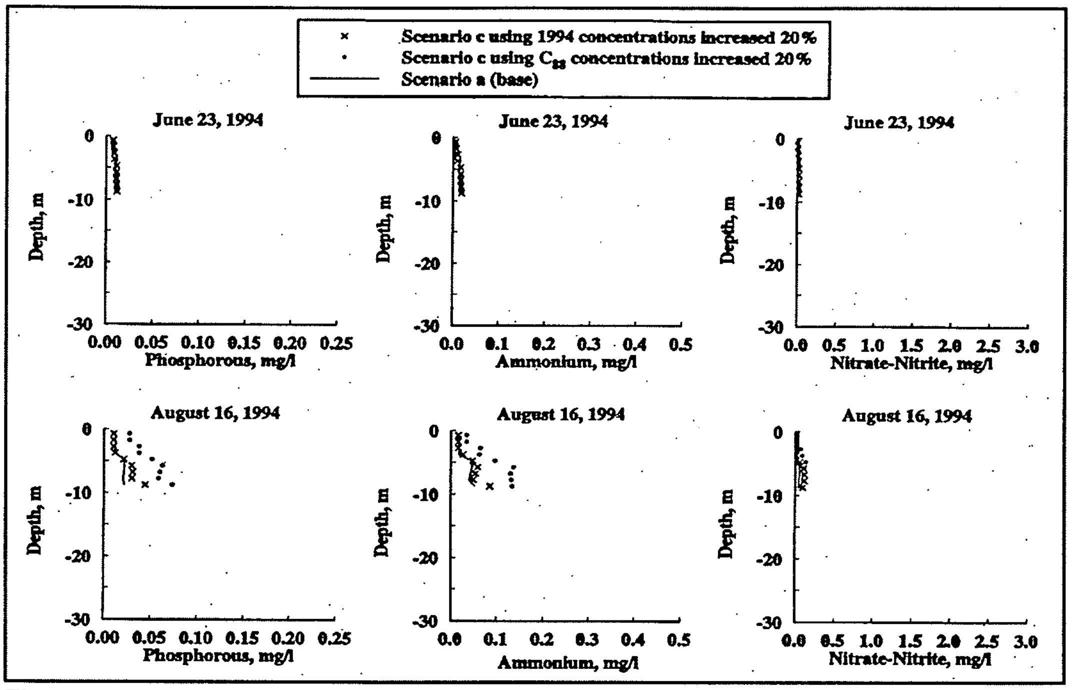
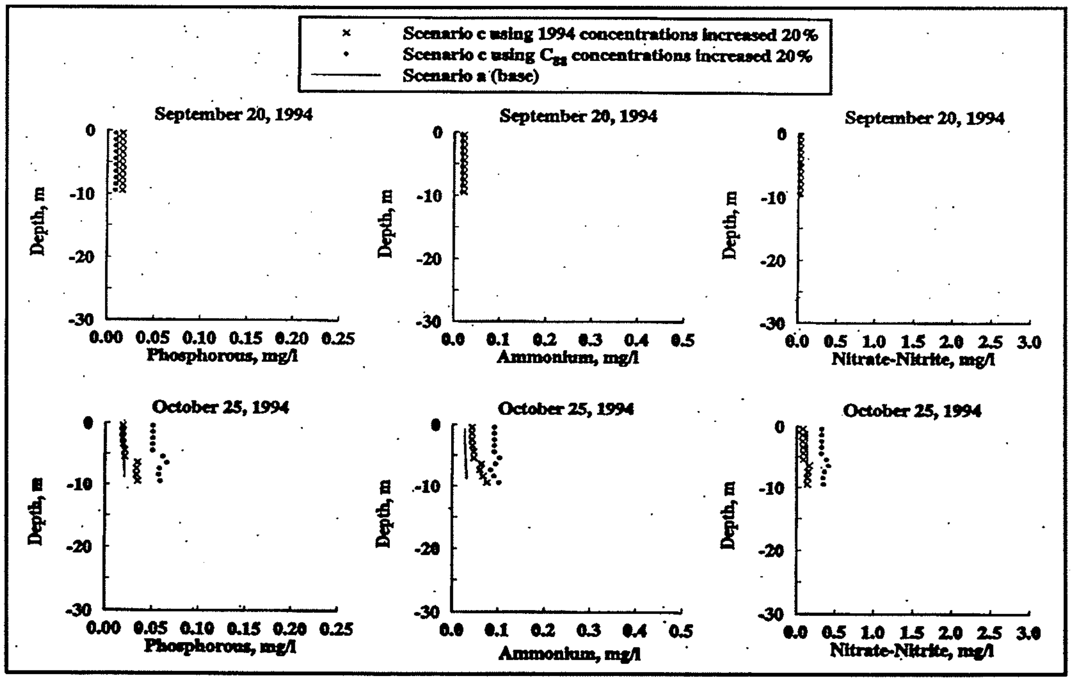


Figure 252. 1994 Neely Henry phosphorus, ammonium, and nitrate-nitrite scenario results for station 6 (Continued)



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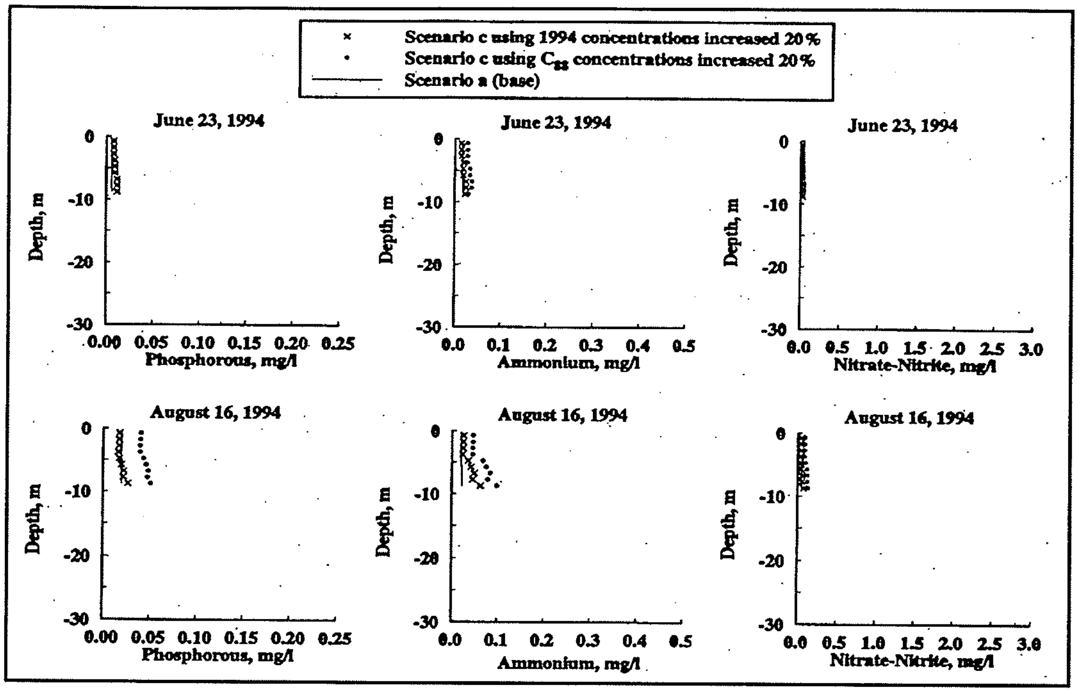
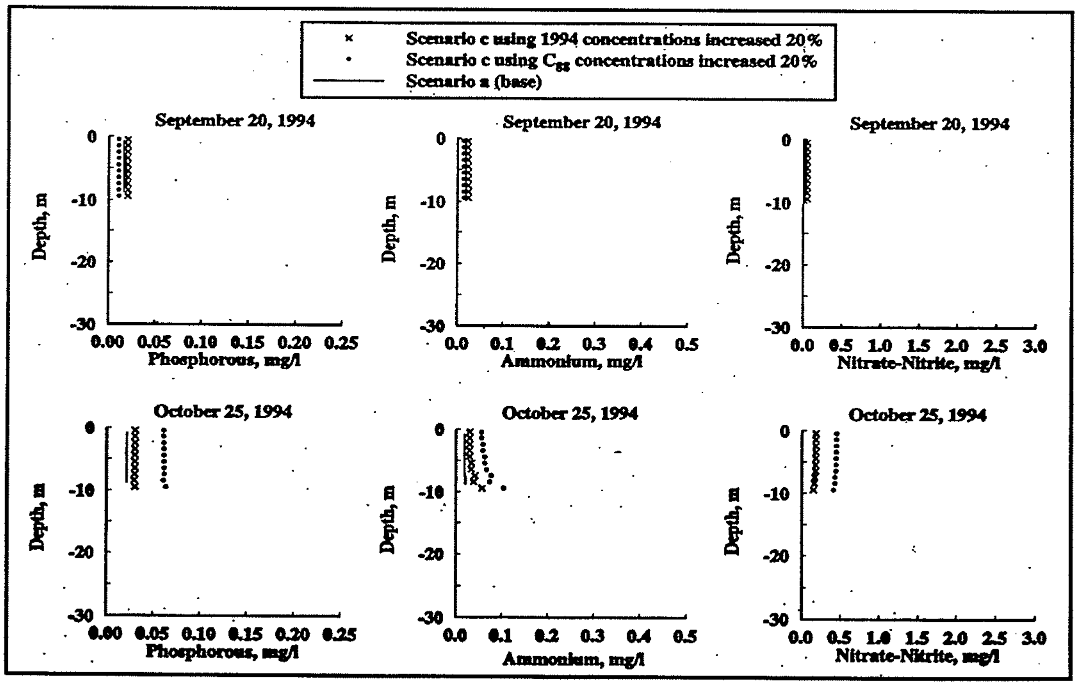


Figure 253. 1994 Neely Henry phosphorus, ammonium, nitrate-nitrite scenario results for station 10 (Continued)



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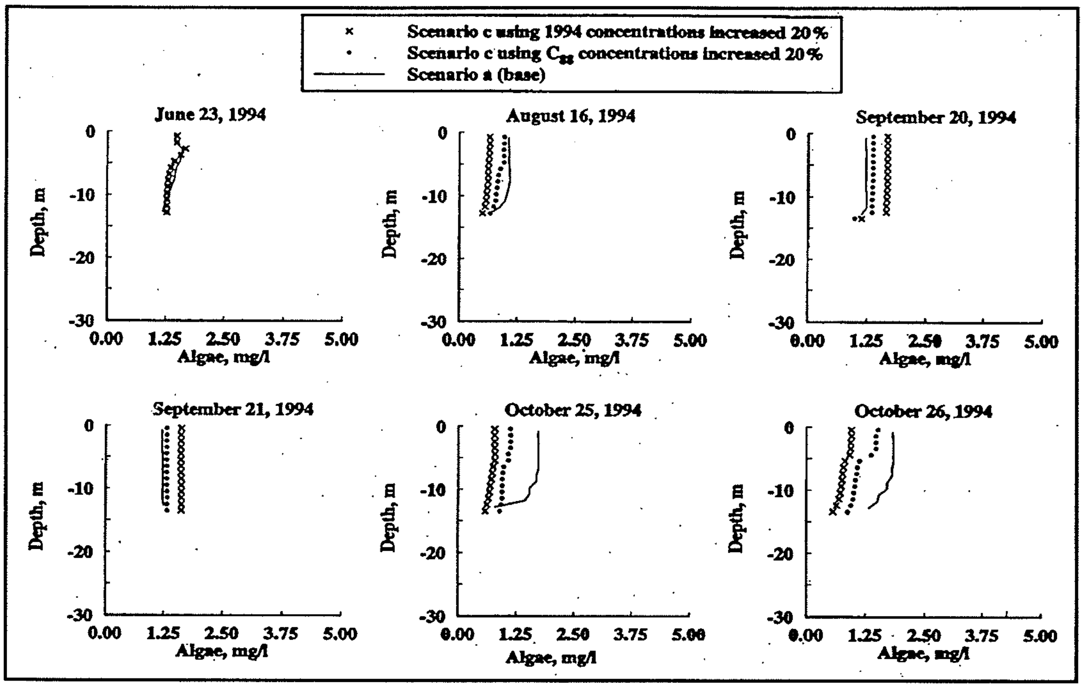
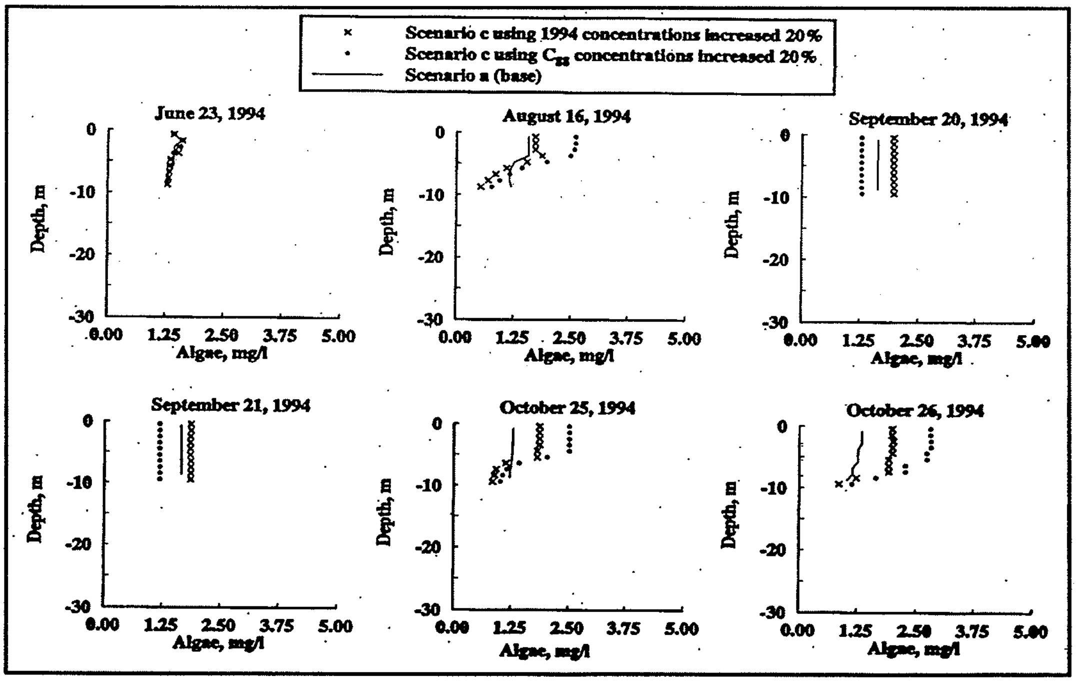


Figure 254. 1994 Neely Henry algae scenario results for station 1



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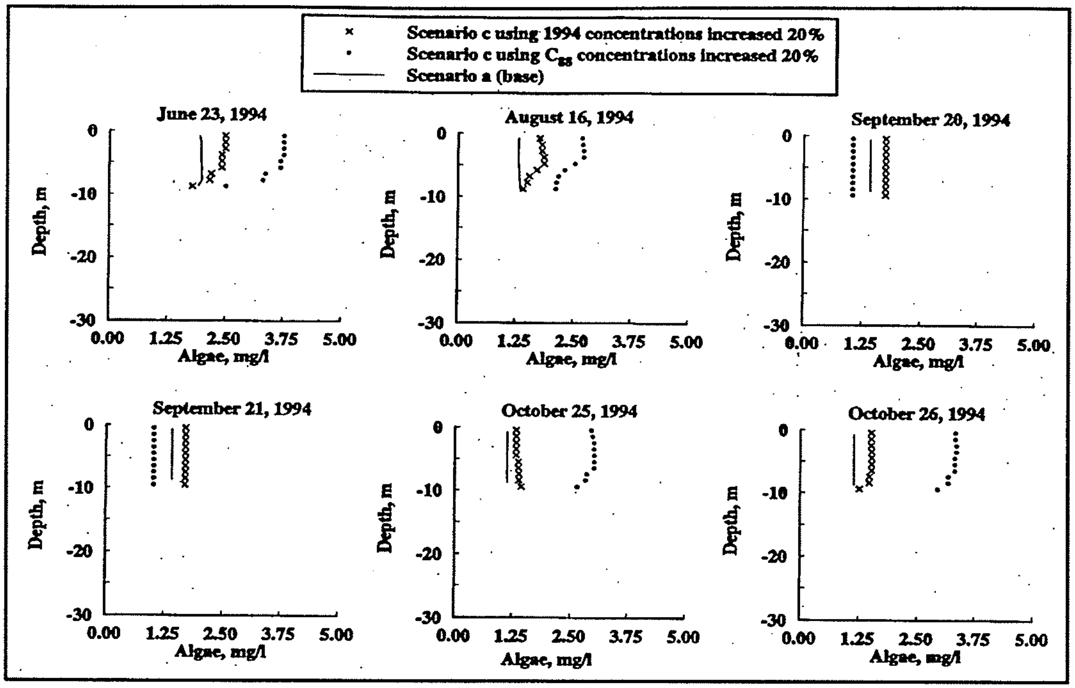

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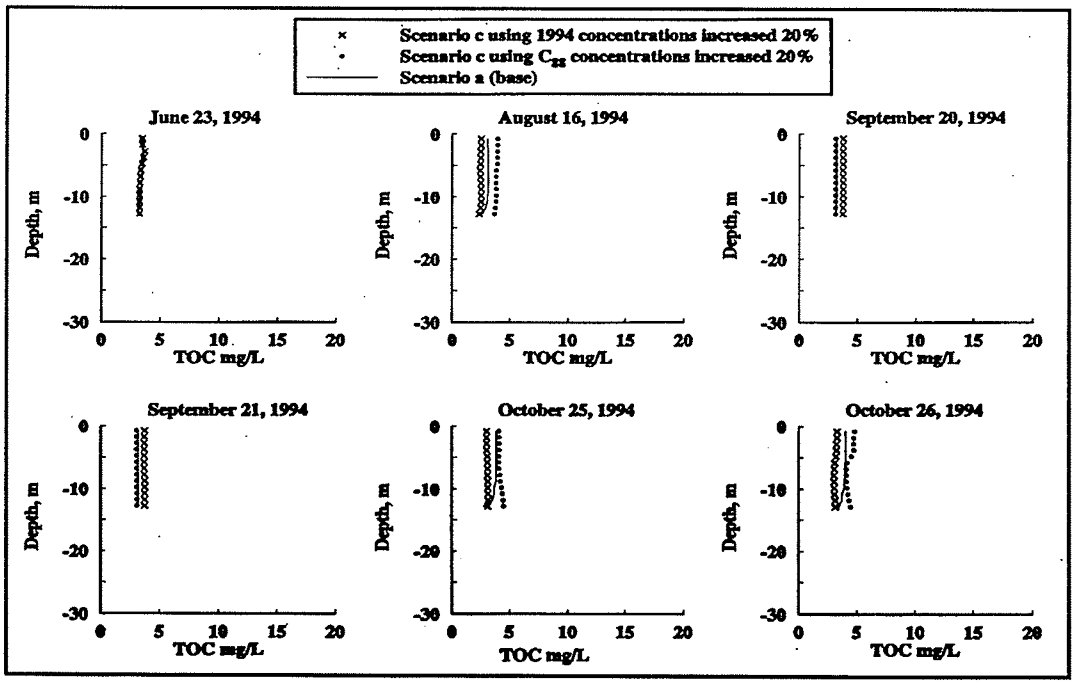
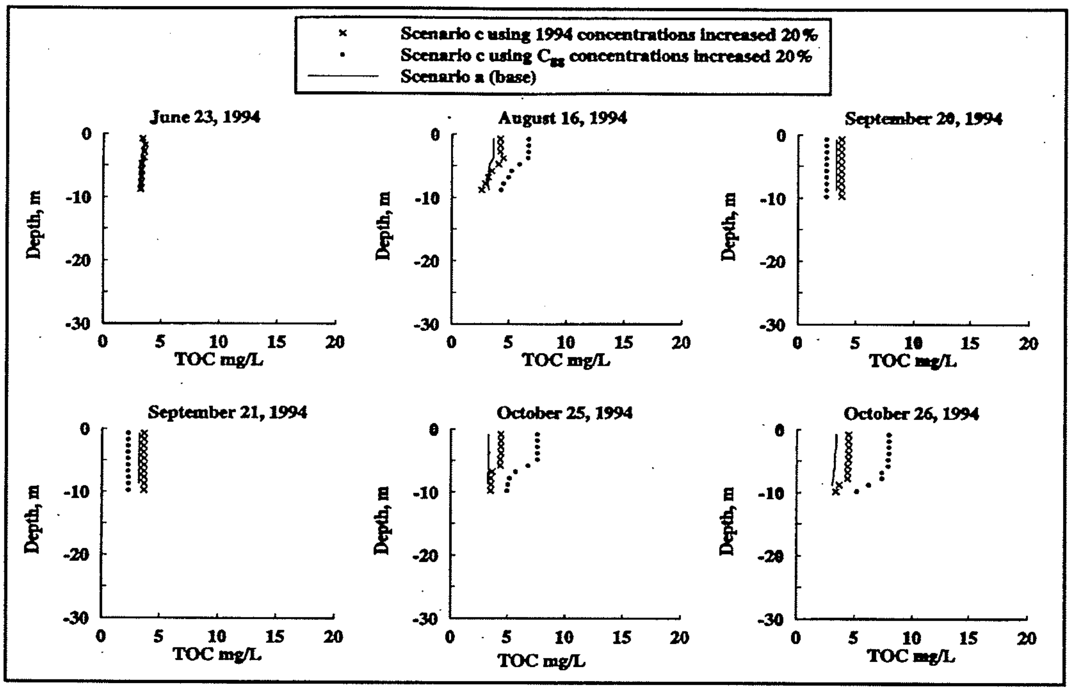


Figure 257. 1994 Neely Henry TOC scenario results for station 1



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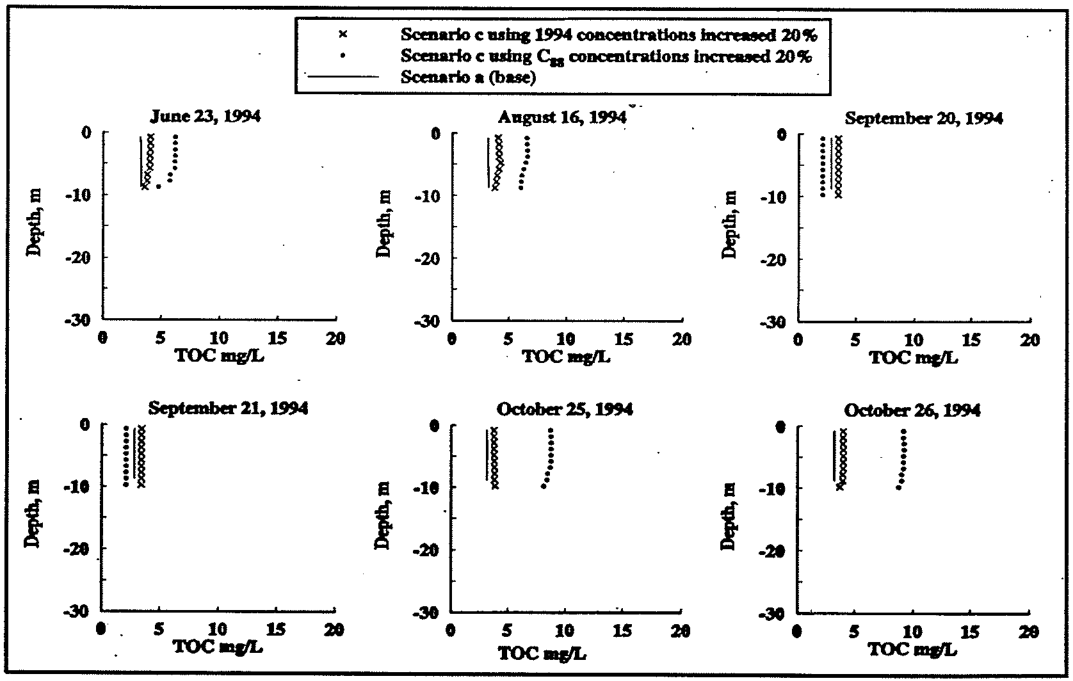


Figure 259. 1994 Neely Henry TOC scenario results for station 10

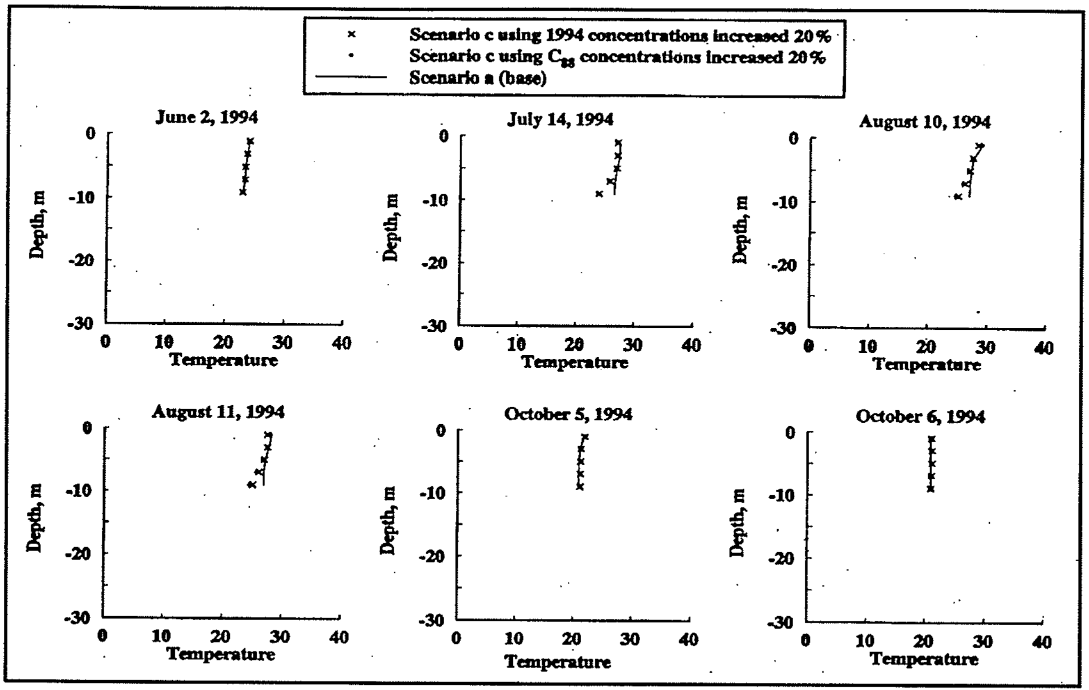


Figure 260. 1994 Weiss temperature scenario results for station 1

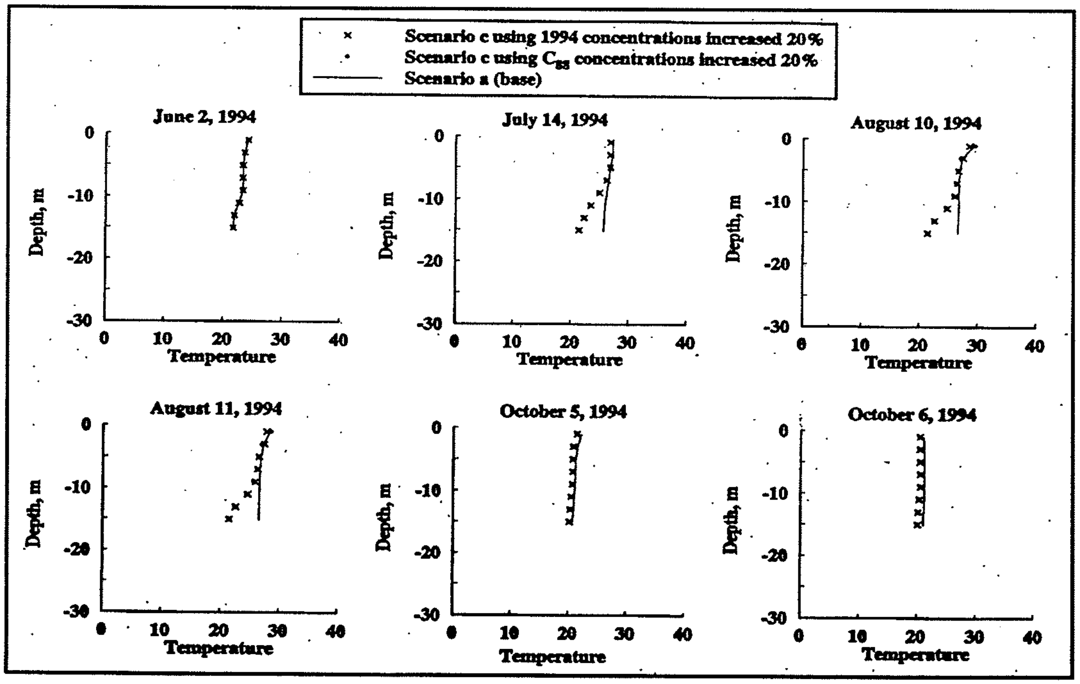


Figure 261. 1994 Weiss temperature scenario results for station 3

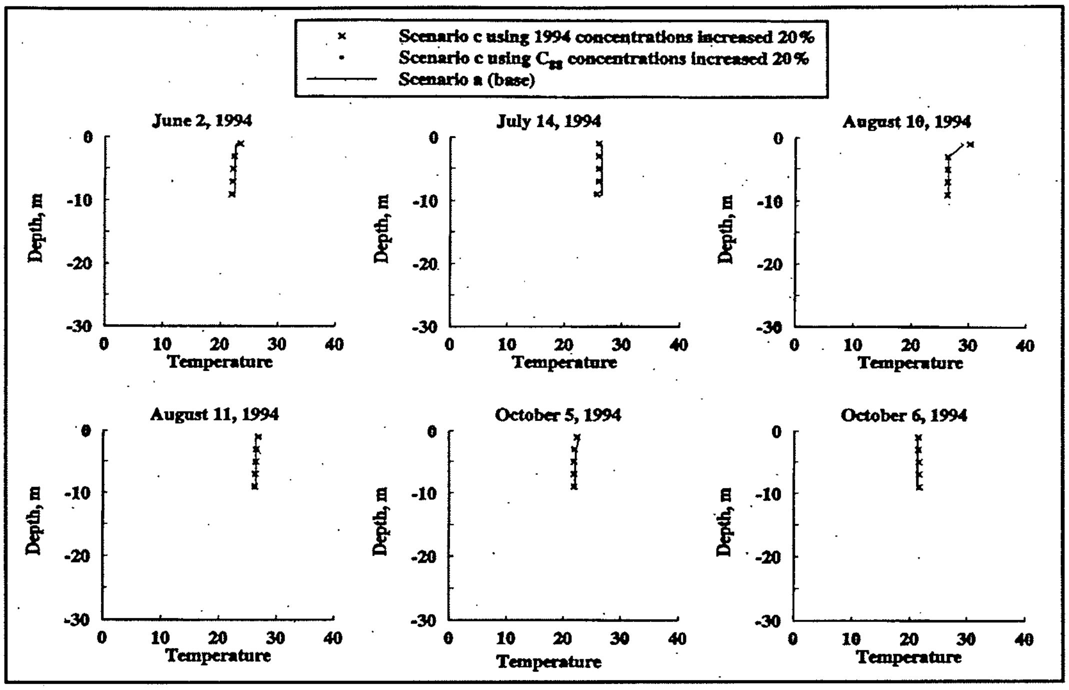


Figure 262. 1994 Weiss temperature scenario results for station 6

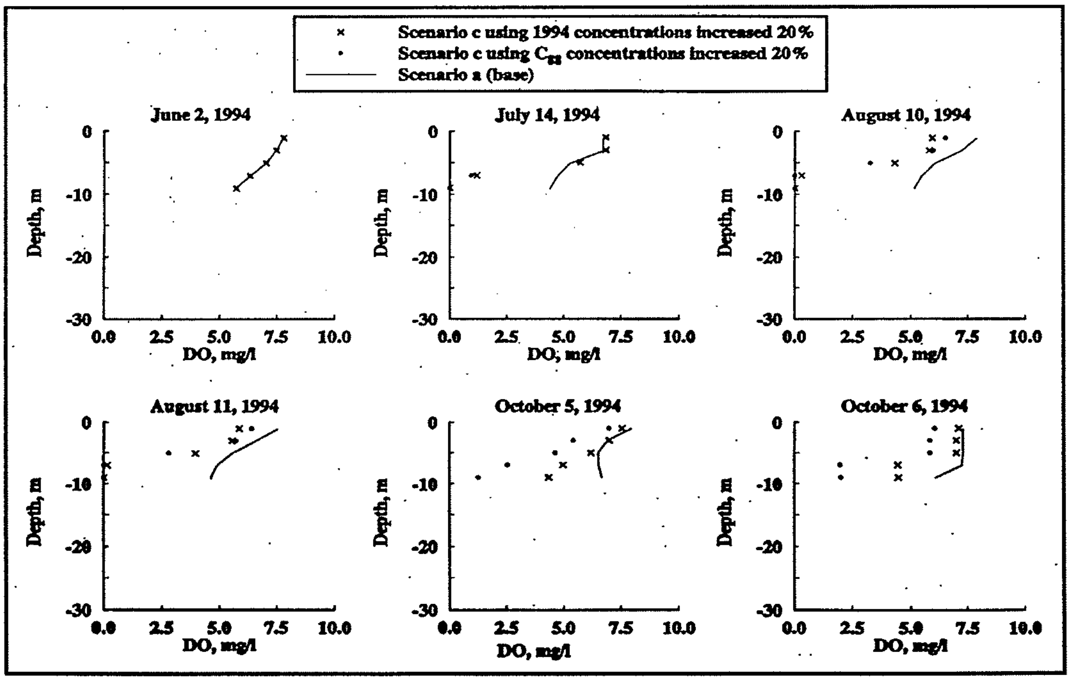


Figure 263. 1994 Weiss DO scenario results for station 1

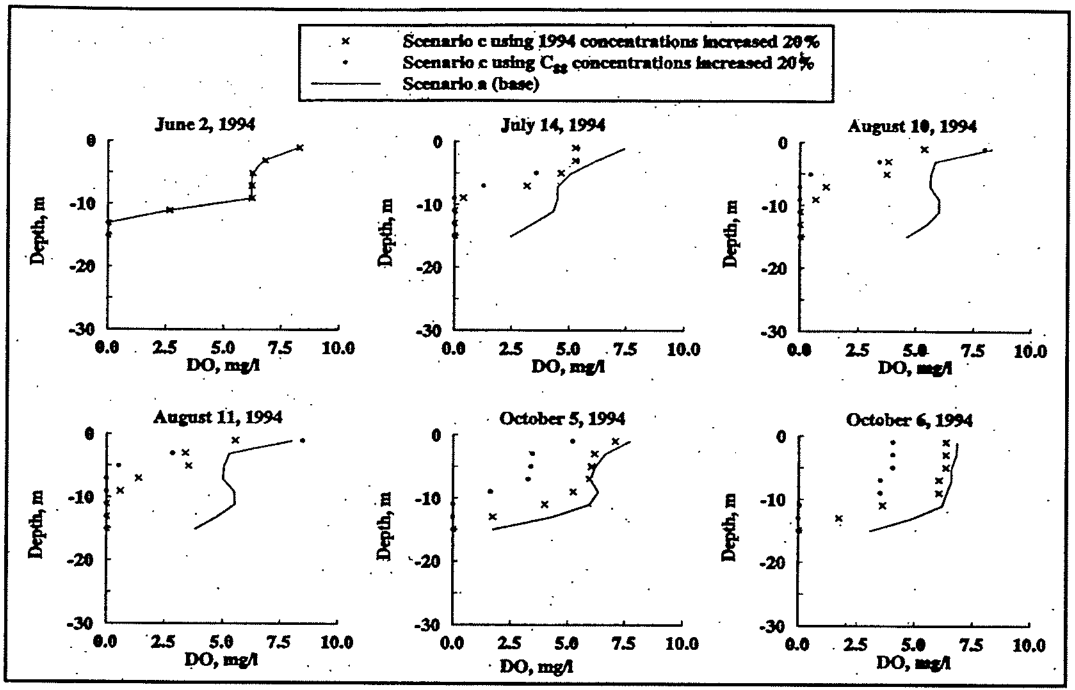


Figure 264. 1994 Weiss DO scenario results for station 3

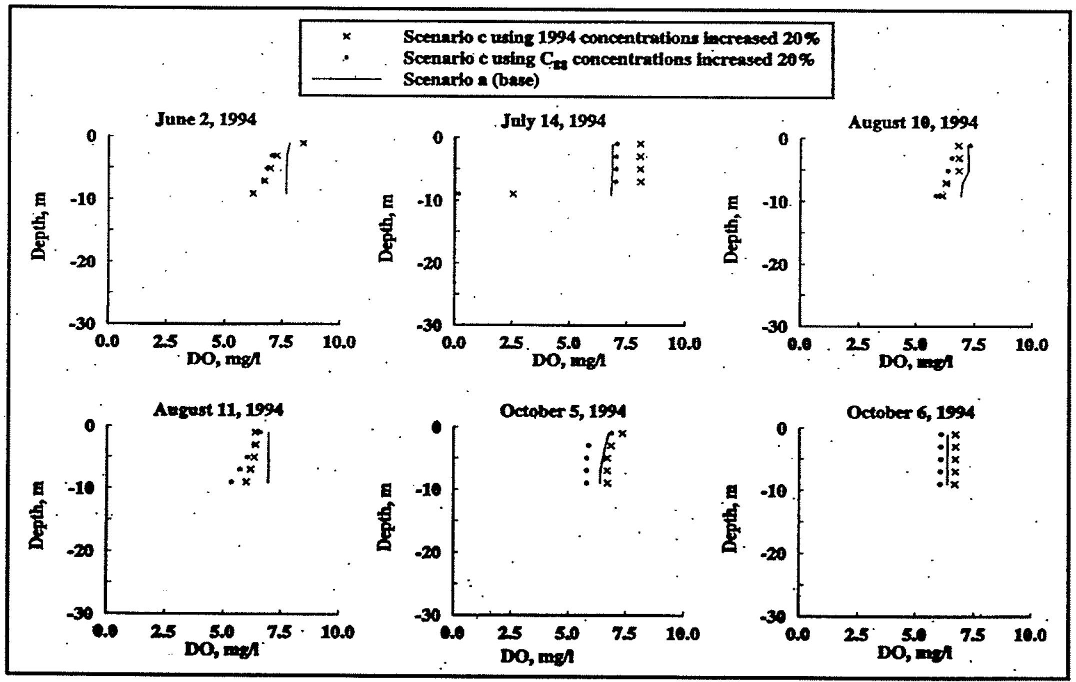


Figure 265. 1994 Weiss DO scenario results for station 6

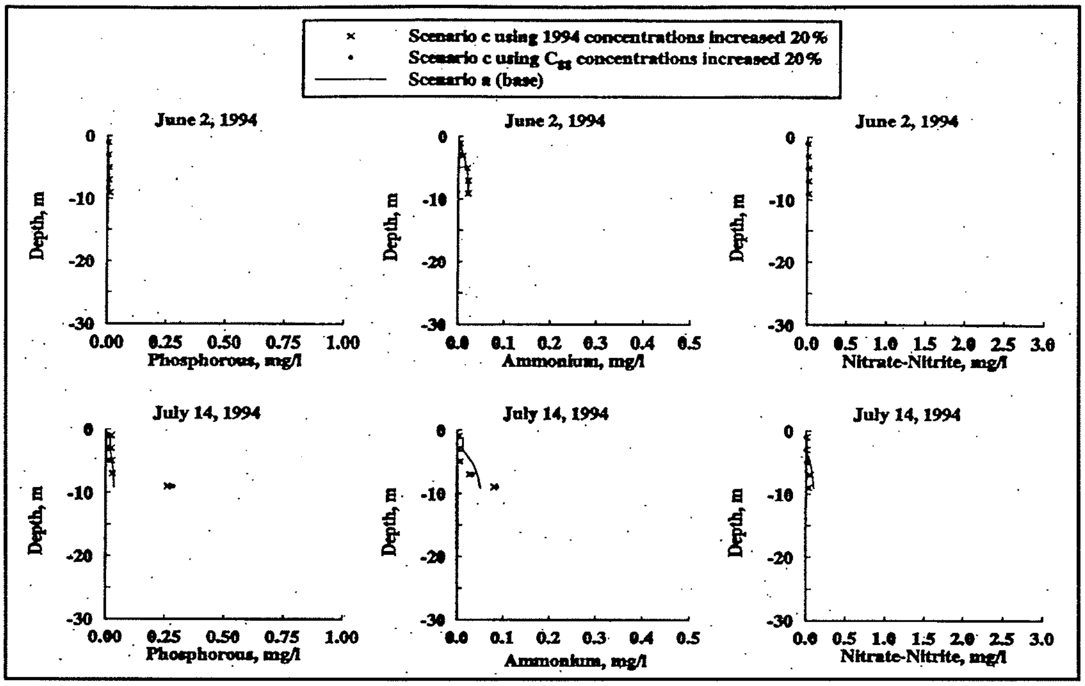


Figure 266. 1994 Weiss phosphorus, ammonium, and nitrate-nitrite scenario results for station 1 (Continued)

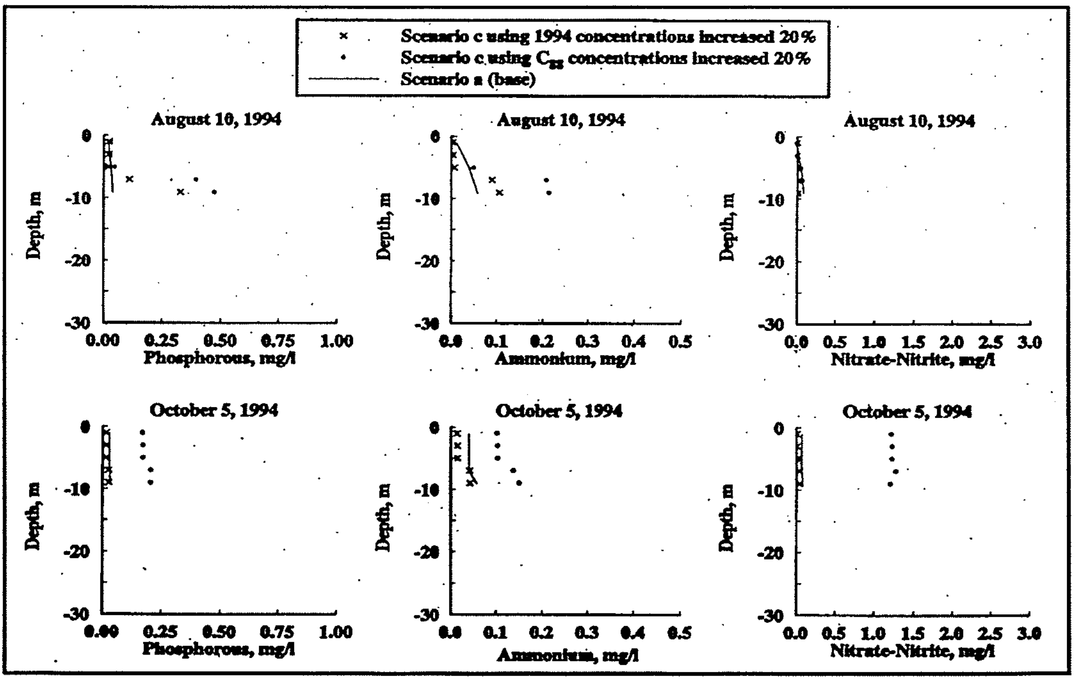


Figure 266. (Concluded)

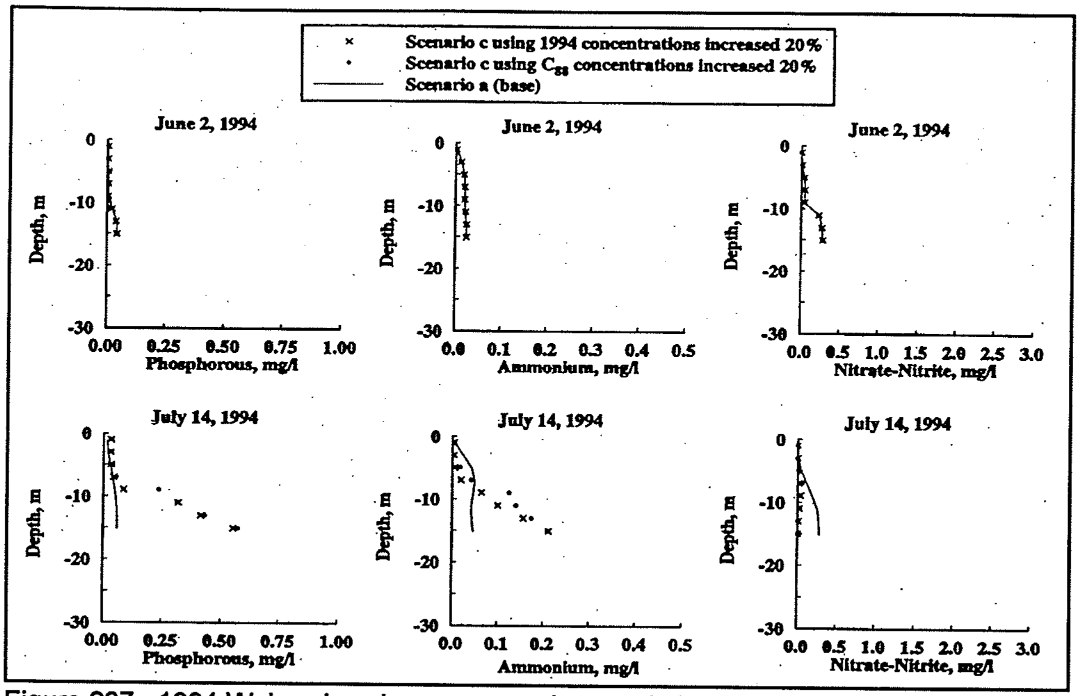
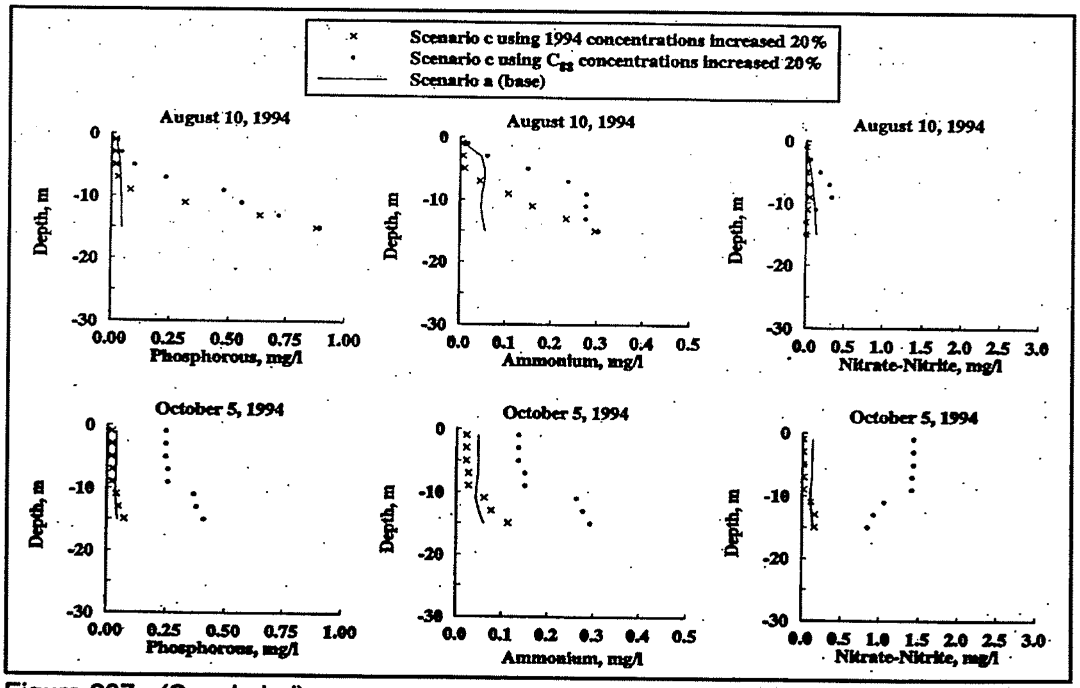


Figure 267. 1994 Weiss phosphorus, ammonium, and nitrate-nitrite scenario results for station 3 (Continued)



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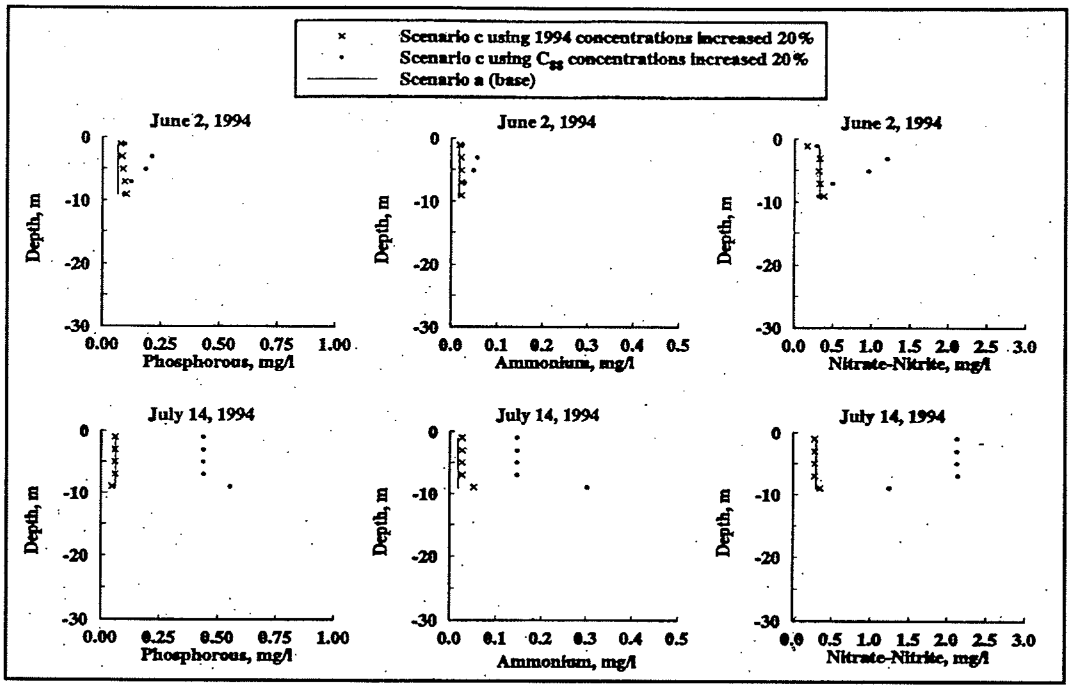
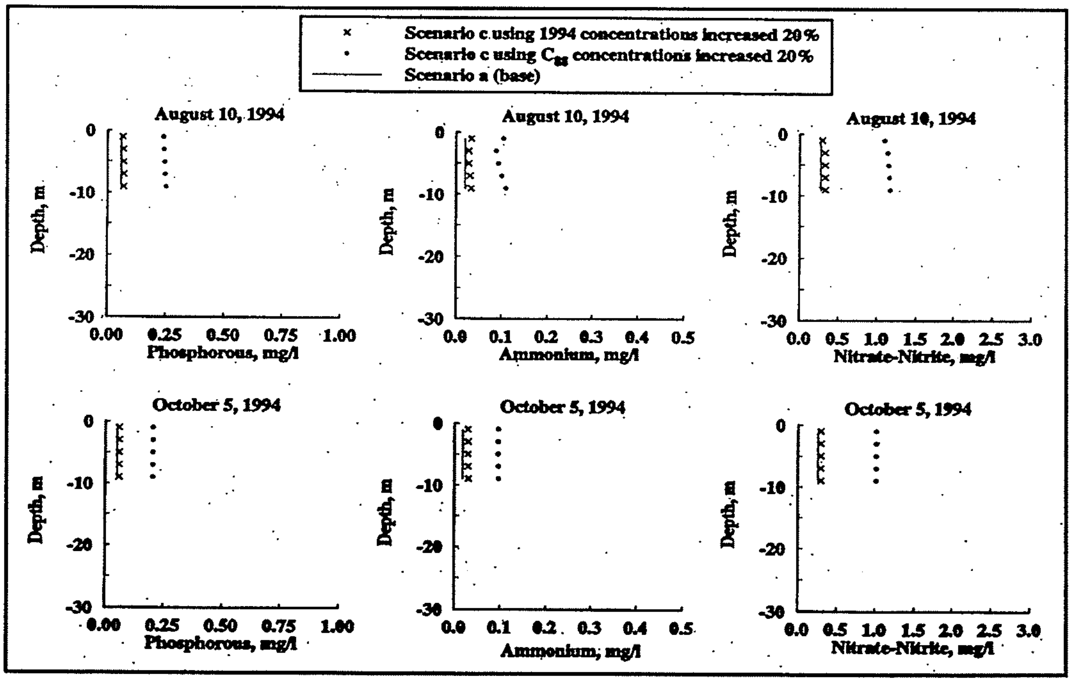


Figure 268. 1994 Weiss phosphorus, ammonium, and nitrate-nitrite scenario results for station 6 (Continued)



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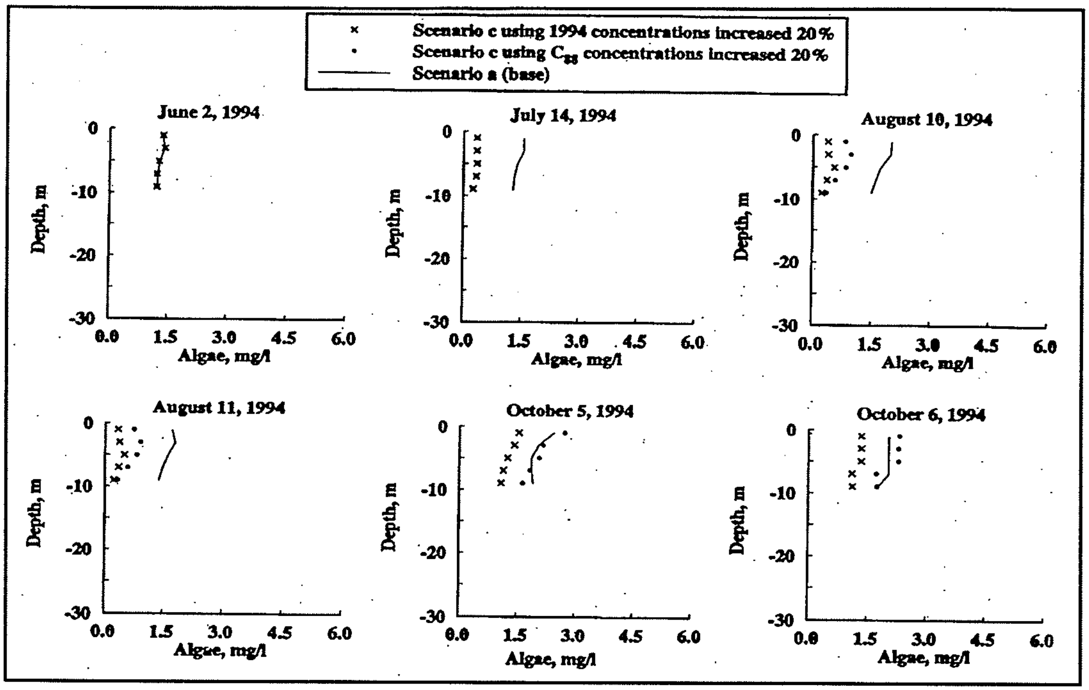
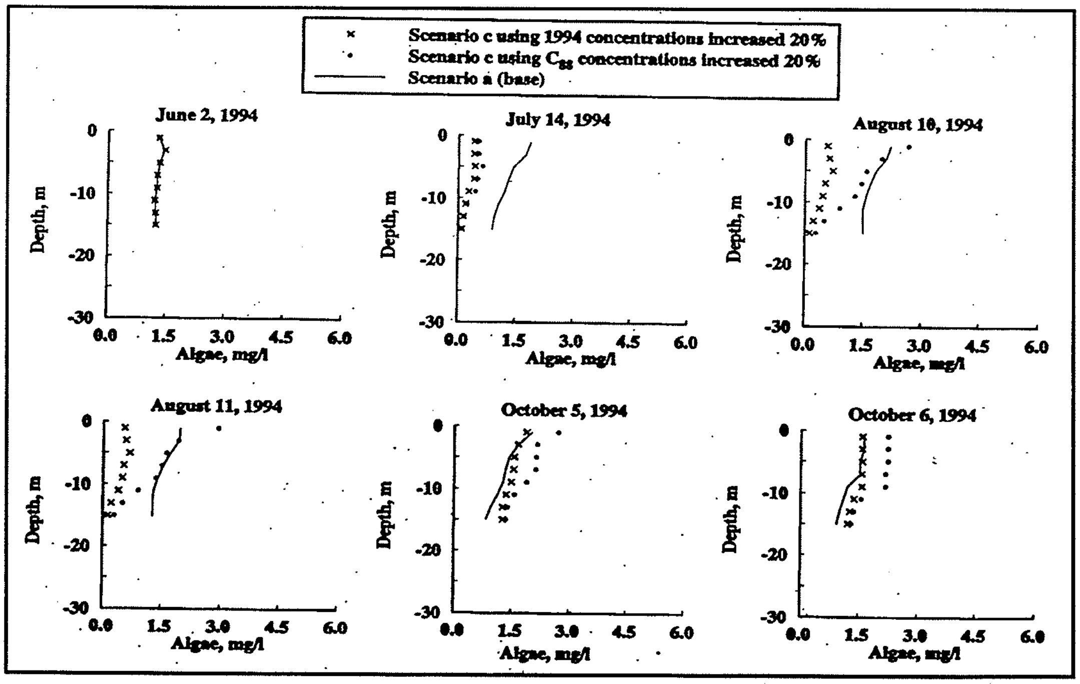


Figure 269. 1994 Weiss algae scenario results for station 1



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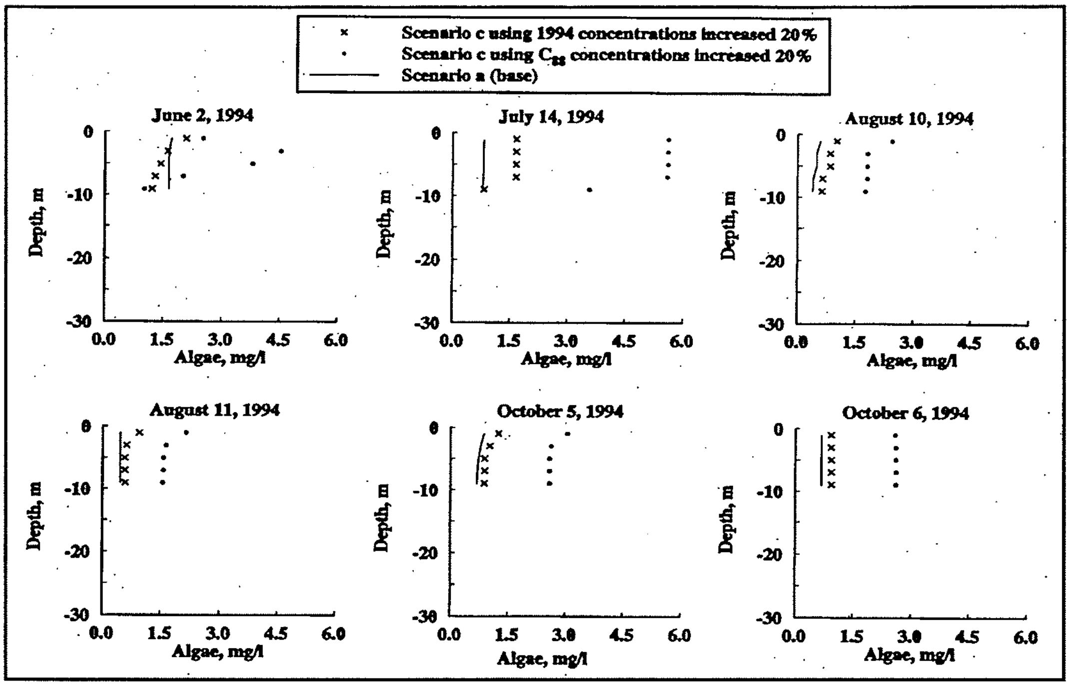

Figure 271. 1994 Weiss algae scenario results for station 6

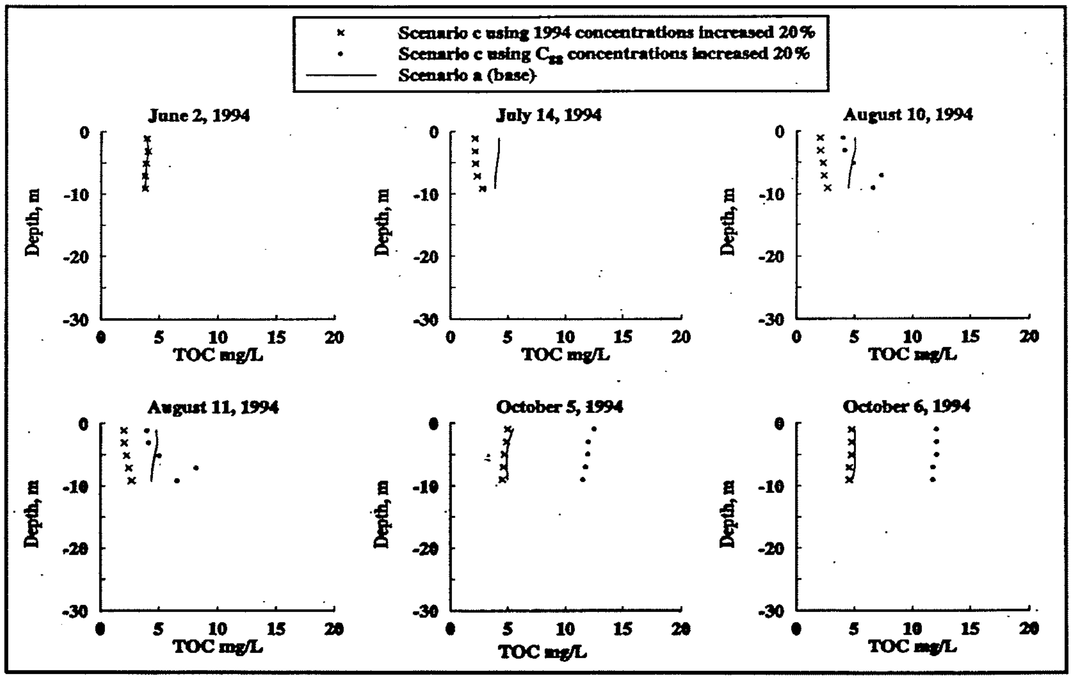

Figure 272. 1994 Weiss TOC scenario results for station 1

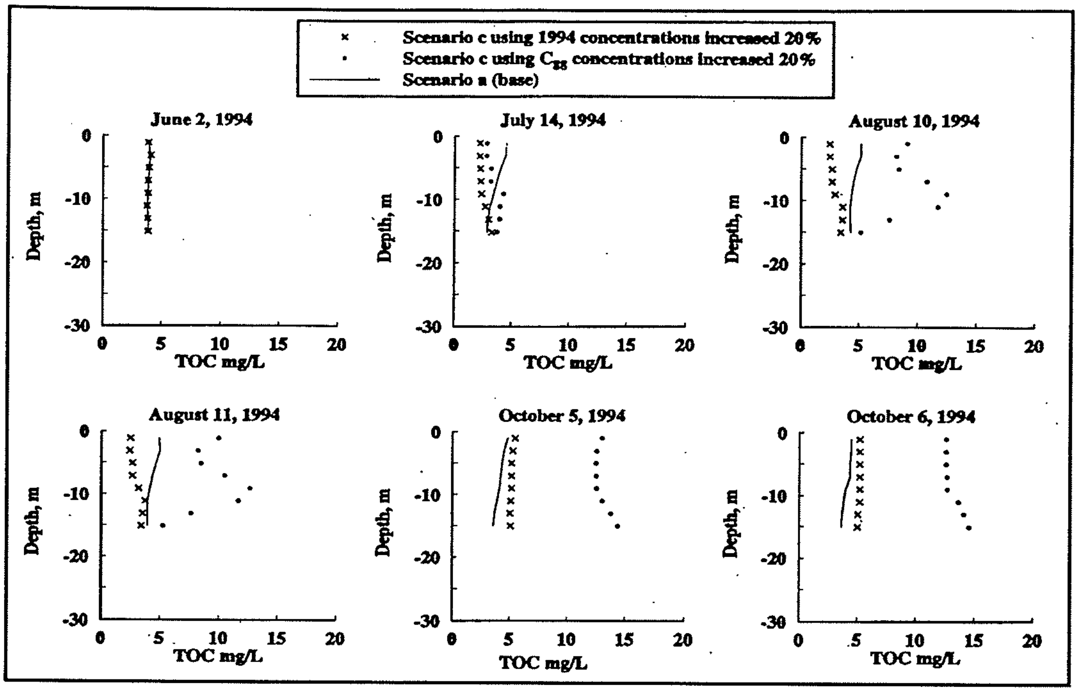

Figure 273. 1994 Weiss TOC scenario results for station 3

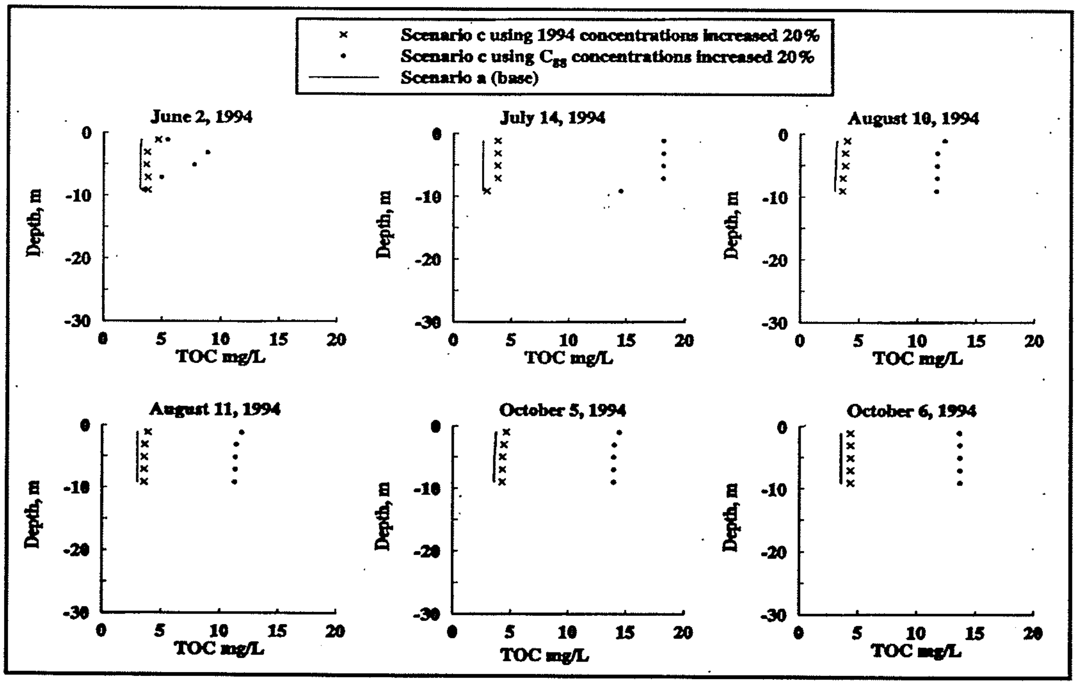

Figure 274. 1994 Weiss TOC scenario results for station 6

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

CE-QUAL-W2, a two-dimensional, longitudinal and vertical, laterally averaged reservoir hydrodynamic and water quality model, was applied to Walter F. George, Weiss, and H. Neely Henry Reservoirs during the Alabama-Coosa-Tallapoosa/Apalachicola-Chattahoochee-Flint (ACT/ACF) comprehensive water resource study. Concern for future water quality conditions related to changes in reservoir operations initiated this study. CE-QUAL-W2 was applied to all reservoirs for 2 years (calibration/verification for six water quality constituents of interest). Calibration results for all reservoirs and years were affected by having limited inflow and in-lake profile data. For verification, 1994 data were used for all reservoirs and were given greater confidence because substantially more data were collected. Given the limitations to the boundary conditions to drive the model, favorable results were obtained for all years modeled. After calibration and verification were considered acceptable, three trial scenario runs identified by the study partners were conducted to determine effects of lower water allocations with existing or increased 1994 loads using the 1994 verification results as the base run for scenario comparisons. In general, the scenario results showed that lower water allocations with existing loads reduced travel times and increased organic matter concentrations. This in turn increased temperature stratification, reduced dissolved oxygen, increased nutrient release from sediments, and increased algal and total organic carbon concentrations at the upstream stations.

15. SUBJECT TERMS

ACT/ACF, CE-QUAL-W2, Modeling, Two-dimensional, Water quality

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