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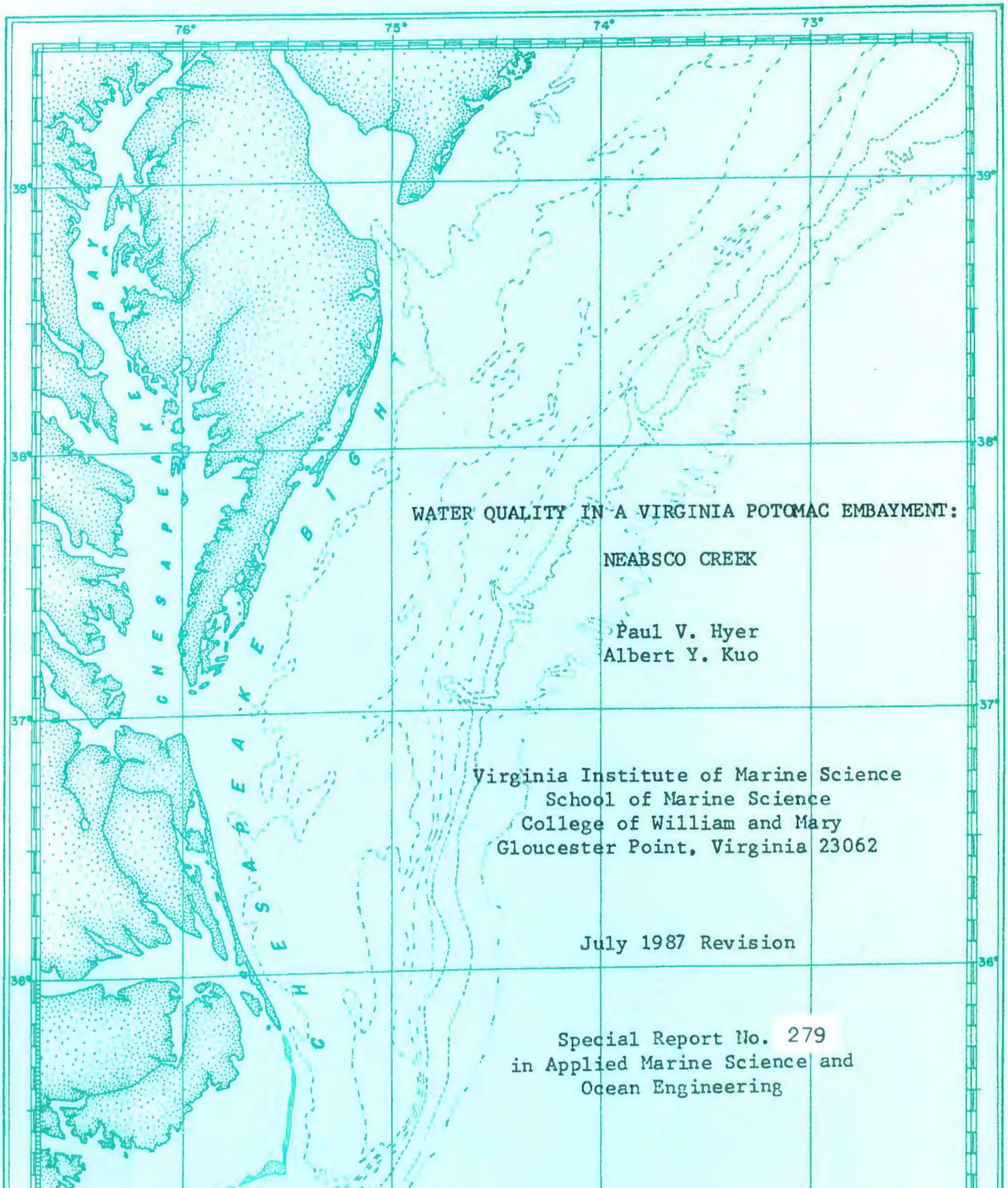

WATER QUALITY IN A VIRGINIA POTOMAC EMBAYMENT:
NEABSCO CREEK

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1. SUMMARY AND CONCLUSIONS

Neabsco Creek is a small, urbanized embayment emptying into the fresh-water tidal portion of the Potomac.

A water quality and hydrodynamic study of Neabsco Creek was carried out in the summer of 1981. The year 1981 was significantly drier than normal. The hydrodynamic study included maintaining a tide gauge for three months and installing two current meters and two tide staffs for several days and conducting a dye dispersal study over five days. The water quality study included an intensive survey lasting 27 hours and a series of slackwater runs throughout the summer. Data collected included chlorophyll, nutrients, dissolved oxygen, BOD, total suspended solids, Secchi depth and water temperature.

This study showed that chlorophyll levels were commonly at bloom levels, dissolved oxygen was normally supersaturated during daylight hours and pH levels commonly ranged from 8 to 10.

The Potomac exerts a considerable influence on the downstream reaches of Neabsco Creek and seems to play a role in maintenance of high dissolved oxygen and high chlorophyll levels near the mouth.

There are two sewage treatment plants discharging into the Neabsco. Dale City Section 1 STP and Mooney Sewage Treatment Plant, discharging on the average about 2.4 and 4.1 mgd, respectively.

Most of the nutrients received by the Creek from point and nonpoint origins are discharged into the Potomac. There are, however, internal sources and sinks, viz plankton settling and denitrification. The bottom sediment can be a source of ammonia. There is apparently also phosphorus trapping by adsorption onto suspended sediments, which then settle.

A hydrodynamic model was calibrated for tidal current using the observed tide as driving force and two current meter records for comparison. It was also calibrated for tidal range using readings from two tide staffs. The hydrodynamic model was then calibrated for mass transport using a dye study. An eight-component phytoplankton ecosystem model was calibrated against the intensive survey data and verified according to the slack water run results. The model components were: organic nitrogen, ammonia, nitrate plus nitrite, organic phosphorus, orthophosphorus, chlorophyll, CBOD and dissolved oxygen. Sensitivity studies with suppressed nutrient loadings confirmed the dominant role of the Potomac in maintaining chlorophyll levels in Neabsco Creek. The point source inputs also contribute to favorable growth conditions in the creek.

CHAPTER II. INTRODUCTION

Neabsco Creek is one of many Virginia embayments emptying into the tidal fresh portion of the Potomac River (see Figure 2-1). These embayments lie within the suburbs of D. C. and so have experienced rapid urbanization and population growth in the past thirty years. This has of course required expansion of waste treatment facilities or construction of new plants.

The Potomac itself, of course, has a long history of water quality problems including water chestnut and Anacystis (Pheiffer, 1976). These problems led to a recommendation of 95% phosphorus and BOD_5 removal from sewage treatment plants and 85% removal of nitrogen load (Brooks, 1977). It has been argued (Carpenter, et al., 1965) that pristine conditions in the Potomac were amenable to wildlife but completely inhospitable to humankind, i.e. the system has been irretrievably altered from its original state. This fact must be borne in mind by those seeking to set water quality goals.

Although the Potomac River and the embayment interact and the Potomac itself has water quality problems, the chief concern in this study is the water quality of the creek.

A. Description of Neabsco Creek

Neabsco Creek has a drainage area of about 60 square kilometers, as determined by delineating the drainage basin on topographic charts and planimetering the enclosed area. It is largely wooded but also has extensive amounts of commercial and residential development. Topographically it tends to be fairly hilly, with elevations as great as forty meters in close proximity to the tidal creeks and elevations as great as 120 m within the drainage basin. The tidal portion of the creek extends about four km from the mouth. It is fresh throughout and has tidal currents on the order of twenty cm/sec or less. There are two wastewater treatment facilities on the creek: Mooney Sewage Treatment Plant (STP) discharging into the tidal portion and Dale City Section 1 STP somewhat upstream. Large areas of the tidal creek are covered with rooted aquatic vegetation (Figure 2-2).

At various times, the Water Control Board collected water quality data from Neabsco Creek. This historical data predominantly pertains to the fluvial portion west of the bridge at U. S. Route 1. Dale Service Corporation has operated two facilities. Dale City Section 1 STP lies about 2 km upstream of the U. S. Route 1 bridge, while Dale City Section 8 STP lies about 8.5 km farther upstream. In 1975 a biological survey was conducted (a fish kill had occurred in the vicinity of Dale City Section 8 STP in 1973). It was found that residual chlorine and suspended solids were adversely affecting both fish population and benthic biota. In the same year, four stations were sampled in January and again in March to assess the results of a change in the Dale City Section 8 STP. Water quality standards appeared to be met, but there was a marked increase in total suspended solids from January to March, apparently resulting from the change in Dale City Section 8 STP operations.

In August, 1977 a stream survey was conducted with the Dale City area again being the focus of attention. In September, a nocturnal survey was conducted. Two stations were sampled: one at Route 610 in the fluvial portion and the other at Rippon Landing in the tidal portion. Stations were sampled at hourly intervals between midnight and 0800 hrs. Dale City Section 8 was not discharging at this time, (nor has it operated since) so that the fluvial station was considered a control. High tide was associated with a maximum in dissolved oxygen and pH and a minimum in ammonia, nitrate and nitrite. Dissolved oxygen levels were, with a single exception, below 4.0 mg/1 at the Rippon Landing station.

In 1978 a biological monitoring report was made subsequent to a reported sludge dumping at Dale City Section 1 STP. No evidence of damage was found.

B. Objectives of this Study

There are three primary objectives to this study. The first is to collect a comprehensive and consistent set of field data describing the conditions in Neabsco Creek. The second is to calibrate and verify a mathematical model of the system. The third is to use the mathematical model to investigate those factors which primarily determine water quality within Neabsco Creek. The fulfillment of these objectives is described in the remaining chapters of this report.

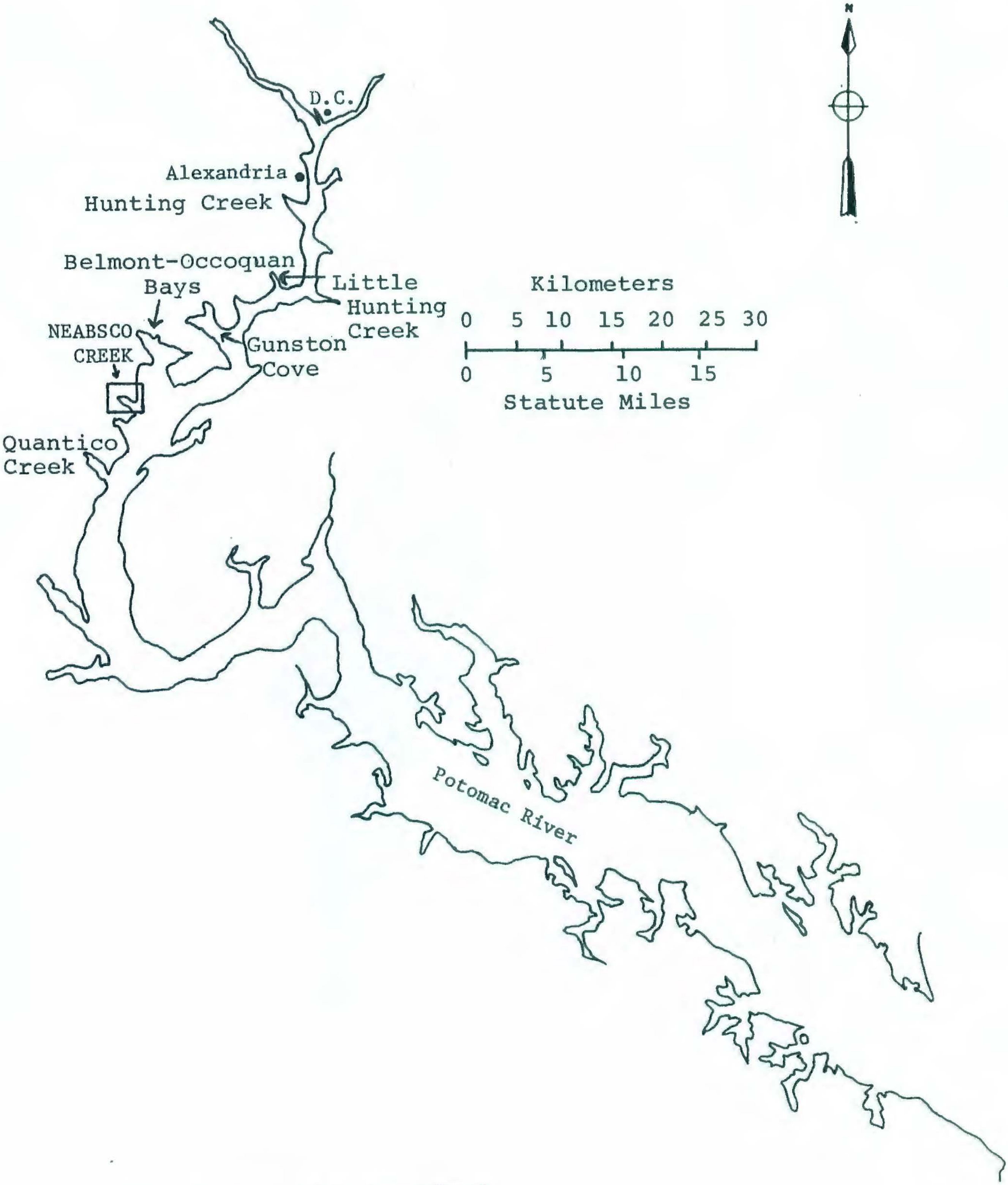

Figure 2-1. Location of Neabsco Creek.

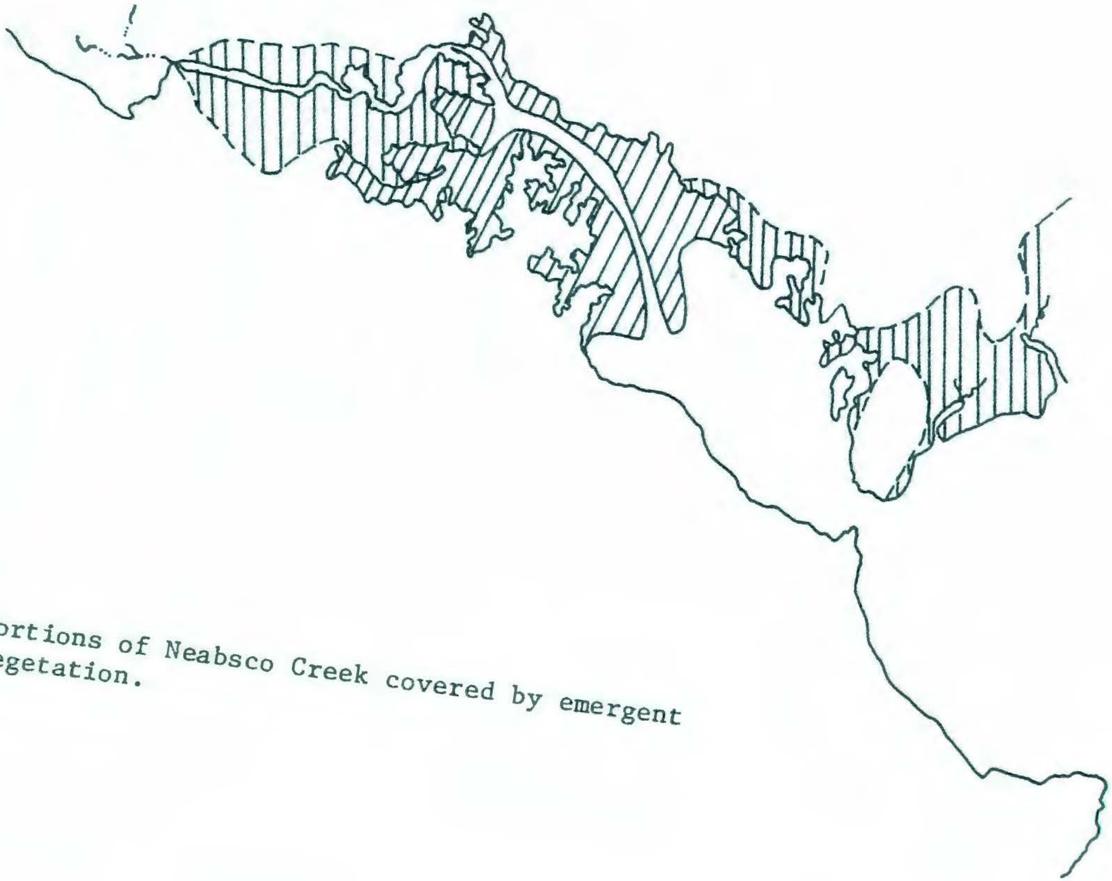

Figure 2-2. Portions of Neabsco Creek covered by emergent vegetation.

CHAPTER III. DESCRIPTION OF FIELD PROGRAM

Both hydrodynamic and water quality conditions were studied extensively in the summer of 1981.

Hydrodynamic studies provide information on water movements within the system. So-called intensive surveys provide detailed descriptions of water quality as it varies in response to tides and the day-night cycle. Slackwater surveys, on the other hand, provide a series of 'snapshots' of water quality conditions and are typically used to illustrate seasonal changes. In addition to these studies some special purpose observations were made.

A. Hydrodynamic Observations

A recording tide gauge was installed in early June and maintained until late September. The location of the gauge is shown in Figure 3-1. This Fisher-Porter gauge recorded tidal height to the nearest 0.01 ft. once every six minutes and was set to an arbitrary zero level. During an intensive survey in August, two ENDECO current meters were installed from August 17 through August 20 and speed and direction were recorded every half hour. Current speed was recorded to the nearest cm/sec and magnetic direction to the nearest degree. Data were recorded on film and sent to the meter manufacturer for data processing. Two tide staffs were also monitored during the intensive field survey.

Instream sampling for the intensive survey was preceded by a dye release at low water slack on the morning of August 18. The batch or slug of dye consisting of 33 kg of 20% solution by weight of Rhodamine WT, was released at station 3 (see Figure 3-1).

B. Intensive survey

Instream sampling was conducted at seven stations from 0800 EST on August 18 to 1000 on August 19. Stations 1-5 were reached by boat; stations 6 and 7 were reached by land. Hourly samples were taken at mid-depth for dissolved oxygen and chlorophyll 'a'. Additionally, water temperature and secchi depth were determined each hour. Every two hours, samples were taken for TKN, ammonia-nitrogen, nitrate plus nitrite-nitrogen, total phosphorus, orthophosphorus and BOD_5. On alternate hours, pH was determined. Prior to and during the survey, twelve-hour composite samples from STP's were collected and analyzed for the above nutrients. Ultimate BOD's treated with nitrification inhibitor were determined twice for each in-stream station and once for each STP composite sample.

C. Slack Water Surveys

In addition to the intensive survey, there was a series of slack water runs throughout the summer. Table 3-1 lists the dates and times of these surveys. The following quantities were determined at each of the seven instream stations: TKN, ammonia-nitrogen, nitrate plus nitrite-nitrogen, orthophosphorus, total phosphorus, chlorophyll 'a', BOD_5, dissolved oxygen, water temperature and pH. In addition, fresh water inflow was determined at the free-flowing stream. The two sewage treatment plants were monitored for TKN, ammonia-nitrogen, nitrate plus nitrite-nitrogen, orthophosphorus, total phosphorus, dissolved oxygen, water temperature, pH and volume discharge. Laboratory work (with the exception of chlorophyll 'a') was performed at the Virginia Consolidated Laboratories. Chlorophyll 'a' determination was done at VIMS.

D. Special Purpose Surveys of Benthic Materials Flux

Measurements of the benthic fluxes of ammonia, nitrate, orthophosphorus, and dissolved oxygen were conducted. Fluxes were measured twice in 1981 at stations 2, 4 and 5, which are shown in Figure 3-1. Measurements were conducted by sealing a pair of hemispherical plastic domes to the creek bottom thereby entrapping a fixed volume of bottom water in each dome. By sampling the water within each dome periodically throughout the length of the measurements, which lasted from four to eight hours, the rate of change of mass for each constituent within the dome could be calculated. This rate of change of mass was then converted to an areal mass flux rate across the sediment water interface. Individual measurements showed great variability but the aggregate result for all the embayments showed a consistent pattern. These results are summarized in Table 3-2.

E. Geometric Measurements

Several geometric inputs were needed for constructing the model. These inputs came from various sources. Depth profiles were made for several transects in the summer of 1981. These transects are indicated by the letters B through J in Figure 3-1. These bottom profiles were corrected to mean tide level, and the cross-sectional area computed from digitized bathymetry data. Channel length between transects was calculated from the topographic chart. Neabsco Creek appears on the Quantico Quadrangle, which was photorevised in 1978. This chart was also used to estimate the surface area which was flooded at high water but exposed at low water. Finally the drainage area of the entire basin was delineated by planimetry.

F. Data Presentation and Conversion

To facilitate comparison between the data and the model results, several of the parameters reported by the laboratory or collected in-situ must be converted to a more useable form. The formulae used in these conversions are detailed below.

1) TKN to Organic Nitrogen - As analyzed by the laboratory, total Kjeldahl nitrogen includes ammonia nitrogen, dissolved and detrital organic nitrogen, and the nitrogenous portion of the algal biomass. To obtain organic nitrogen, as utilized by the model, the ammonia and algal fractions must be subtracted from the TKN via the following relationship.

$$\text{Org N} = \text{TKN} - \text{NH}_3 - \text{an} * \text{CH} \qquad (3\text{-}1)$$

in which

Org N = organic nitrogen (mg/l as N)

TKN = total Kjeldahl nitrogen of sample (mg/l as N)

NH_3 = ammonia nitrogen concentration of sample (mg/l as N)

CH = chlorophyll concentration of sample (ug/l)

an = ratio of nitrogen to chlorophyll in algal biomass = 0.007 mg/ug

2) Total Phosphorus - As analyzed by the laboratory, total phosphorus includes the phosphorus bound up in algal biomass. To obtain total phosphorus independent of an algal fraction, the following relationship is utilized

$$\text{Tot P (corrected)} = \text{Tot P (laboratory)} - \text{ap} * \text{CH} \qquad (3\text{-}2)$$

in which

Tot P = total phosphorus (mg/l as P)

ap = ratio of phosphorus to chlorophyll in algal biomass = 0.001 mg/ug

The model further distinguishes between organic phosphorus and ortho phosphorus. Rather than convert the corrected values of total phosphorus to organic phosphorus, the model predictions of organic phosphorus and ortho phosphorus are summed, where appropriate, for comparison with corrected total P.

3) $CBOD_5$ to $CBOD_u$ - The majority of the BOD analyses are five-day carbonaceous biochemical oxygen demand ($CBOD_5$). These must be scaled up to ultimate carbonaceous biochemical oxygen demand ($CBOD_u$) and corrected for the respiration and decay of algae entrapped in the BOD bottle. The correction is accomplished through the relationship

$$CBOD_u = R * CBOD_5 - 2.67 * ac * CH \qquad (3\text{-}3)$$

in which

$CBOD_u$ = ultimate carbonaceous biochemical oxygen demand (mg/l)

$CBOD_5$ = five-day carbonaceous biochemical oxygen demand (mg/l)

R = ratio of $CBOD_u$ to $CBOD_5$

ac = ratio of carbon to chlorophyll in algal biomass = 0.042 mg/ug

The ratio of $CBOD_u$ to $CBOD_5$ is obtained from those samples which were analyzed for both five-day and ultimate CBOD. Although the ratio varies both spatially and temporally, it is consistent, in an average sense, when samples are grouped according to the nature of the survey and source of the sample. The observed ratios and the ratio used to correct the samples for each station are presented in Table 3-3.

4) Disk Visibility to Light Extinction - The Secchi depth measurements in-situ are summarized in Table 3-4. These data must be converted

to a light extinction coefficient and further corrected for the extinction due to algae in the water column. The conversion and correction, obtained from Sverdrup et al. (1970) and Riley (1956), yield the equation

$$k = 170/DV - 0.0088 * CH - 0.054 * CH^{0.66} \tag{3-4}$$

in which

k = light extinction coefficient (1/meter)
DV = disk visibility (cm)

5) Presentation of Converted Data - The converted values of organic nitrogen, total phosphorus, and $CBOD_u$ are listed in Appendix A along with the unconverted values of other parameters necessary for comparison of model results with field data. The light extinction coefficients are presented in subsequent chapters on model application.

G. Background Inputs

The volumetric and mass fluxes which enter Neabsco Creek from free-flowing creeks are referred to as background or nonpoint-source inputs. These inputs were measured concurrently with the majority of the field surveys. In order to conduct long-term model simulations, and to analyze the total inputs to the system, however, information on the background fluxes between surveys is necessary. This information was provided, on a daily basis for the 1981 season, by the Northern Virginia Planning District Commission through employment of a nonpoint source prediction model for the Neabsco drainage basins.

Time-series plots of the predicted daily inputs from Neabsco drainage basin are presented in Appendix B. For comparison purposes, the instantaneous flux rates and chlorophyll and DO concentrations sampled concurrently with the field surveys are indicated on the same plots. The agreement between the predictions and observations is satisfactory except for dissolved oxygen, where the values predicted by the nonpoint source model are apparently at saturation, and for ammonia, where the predicted loading does not include the Dale City Section 1 STP loading. The dissolved oxygen levels in the nonpoint source loadings were multiplied by a factor of 0.821 in the model input in order to match the field data.

Table 3-1. Dates and Stages of Slackwater Surveys in the Neabsco Creek, 1981.

Date	Hours (EST)	Stage
June 4	0200-0330	LWS
June 18	1400-1515	LWS
June 29	1100-1215	LWS
July 13	0400-0445	HWS
July 29	1055-1210	LWS
Sept. 3	0915-0950	HWS

Table 3-2.

Benthic Nutrient Exchange Rates for Potomac Embayments

($gm/m^2/day$)

Parameter	10 Percentile	30 Percentile	Median	70 Percentile	90 Percentile
Ammonia	-0.24	-0.024	0.192	0.36	1.8
Nitrate and Nitrite	-0.90	-0.31	-0.12	-0.024	0.24
Ortho-Phosphorus	-0.024	-0.0096	-0.0024	0.0144	0.06

Note: The table was derived from all data collected in the summer of 1981-1983. The embayments from which data were collected include Neabsco Creek, Four Mile Run, Hunting Creek, Little Hunting Creek, Gunston Cove, Belmont-Occoquan Bay and Aquia Creek.

Table 3-3. Ratio of $CBOD_u/CBOD_5$

Station	June 4	June 18	June 29	July 13	July 29	Aug 18	Aug 19	Sept 3	Average**
1	2.58	-	-	2.58	-	1.75*	2.37*	3.94	2.76
2	2.47	-	-	2.46	-	1.76*	2.25*	2.92	2.46
3	-	4.85	-	2.86	-	1.96*	2.19	3.95	3.01
4	-	2.35	-	-	-	2.28*	2.40	-	2.45
5	-	-	3.13	-	3.69	-	-	-	3.41
6	-	-	2.86	-	3.23	2.64*	3.59	-	3.18
Mooney STP	-	3.39	4.44	5.87	5.75	(3.73) 3.20*	3.47	3.23	4.27
Dale	-	5.00	4.05	2.10	3.94	(1.89) 1.68*	4.47	5.50	3.85

* BOD_u/BOD_6

** BOD_u/BOD_6 converted to BOD_u/BOD_5 for averaging purposes

Table 3-4. Summary of Secchi Depth Measurements

Station	Slack Water Run Secchi Depth (cm)			Intensive Secchi Depth (cm)		
	min	median	max	min	median	max
1	15	36	100	18	27	33
2	15	25	50	18	23	30
3	23	24	50	6	18	24
4	20	30	38	10	25	40
5	19	30	30	20	50	80

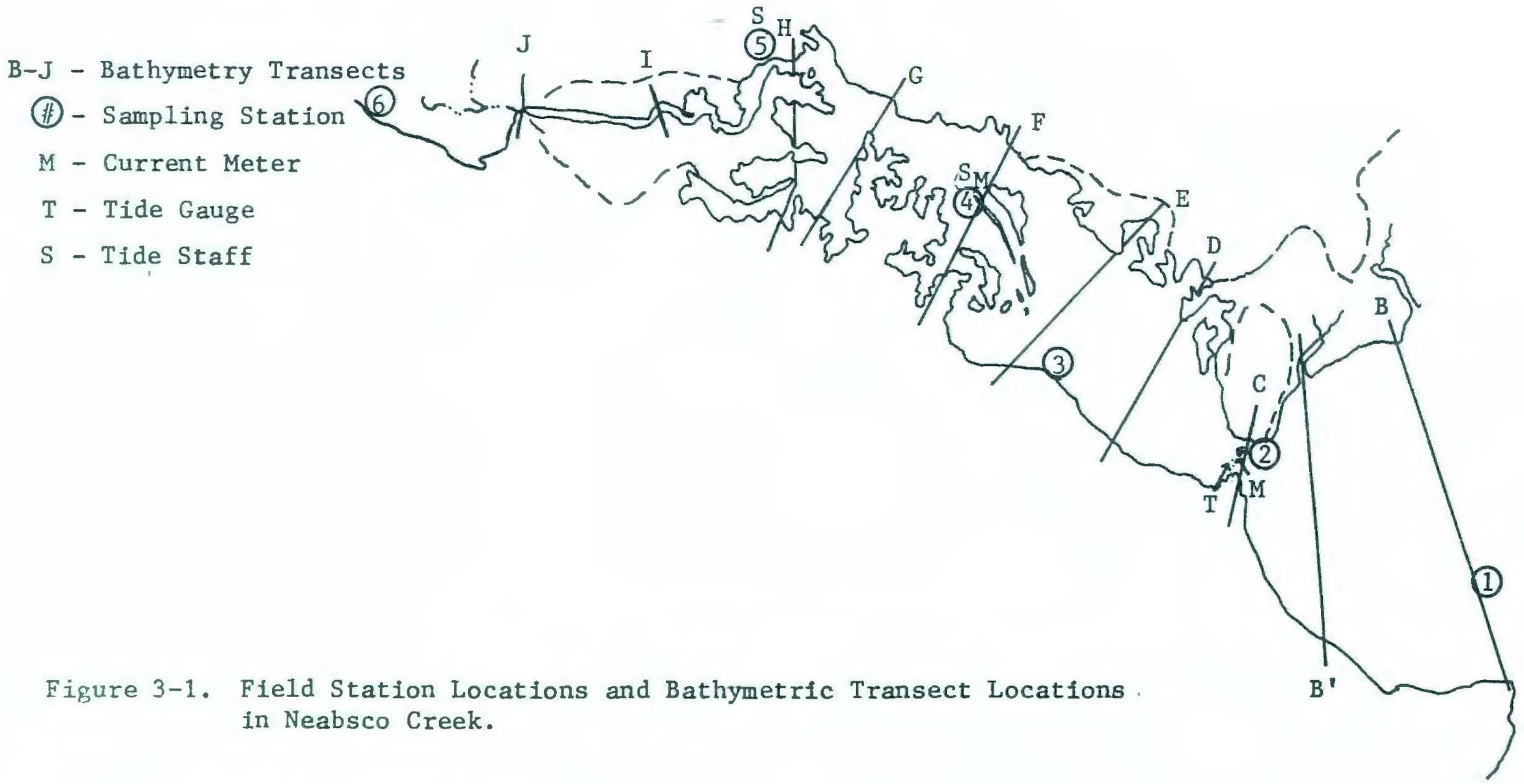

Figure 3-1. Field Station Locations and Bathymetric Transect Locations in Neabsco Creek.

CHAPTER IV. DESCRIPTION OF THE MATHEMATICAL MODEL

The mathematical model employed in this study consists of two independent submodels, a hydrodynamic submodel and a water-quality submodel. The hydrodynamic submodel provides predictions of surface level and current velocity throughout the system and is also capable of predicting the transport of a conservative substance such as salt or dye. The water-quality submodel employs the hydrodynamic information provided by the first submodel to predict the concentrations of eight nonconservative dissolved substances: organic nitrogen, ammonia nitrogen, nitrite+nitrate nitrogen, organic phosphorus, ortho phosphorus, chlorophyll'a', carbonaceous biochemical oxygen demand, and dissolved oxygen. Both submodels are real-time and one-dimensional. That is, they predict parameter variations within a tidal cycle and along the longitudinal axis of the system, but not along the lateral or vertical axes. Details of the formulations of the models are presented in Williams and Kuo (1984). Brief summaries of the models are presented in the remainder of this chapter.

A. The Hydrodynamic Submodel

The hydrodynamic submodel is based upon the one-dimensional equations expressing the conservation of volume, momentum, and mass:

$$B \frac{\partial \eta}{\partial t} + \frac{\partial Q}{\partial x} = q \qquad (4\text{-}1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left[\frac{Q^2}{A}\right] = -gA\frac{\partial \eta}{\partial x} - gn^2 \frac{Q}{A} |Q| R^{-4/3} + \frac{\tau_s}{\rho} B \qquad (4\text{-}2)$$

$$\frac{\partial}{\partial t} (AS) + \frac{\partial}{\partial x} (QS) = \frac{\partial}{\partial x} \left[EA \frac{\partial S}{\partial x}\right] + So \qquad (4\text{-}3)$$

in which

t = time,

x = distance along river axis,

B = the surface width of the river,

η = the surface elevation referenced to mean sea level,

Q = discharge,

q = lateral inflow,

A = cross-sectional area,

n = Manning friction coefficient,

R = hydraulic radius of the cross-section,

S = concentration of dissolved substance,

τ_s = the surface shear stress,

ρ = the density of water,

E = the dispersion coefficient,

So = source or sink of dissolved substance per unit length.

The governing equations are solved by dividing the continuum to which they apply into a series of finite segments. The volume, momentum, and mass equations are next integrated over the length of each segment resulting in a system of finite-difference approximations to the original differential equations. The finite-difference equations are integrated on a high-speed computer to provide predictions of surface level, velocity, and concentration.

B. The Water-Quality Submodel

The water-quality submodel provides predictions for eight dissolved substances which interact to form a simplified aquatic or marine ecosystem. Supplied with flow and volume information from the hydrodynamic submodel, the water-quality submodel operates by solving the finite-difference approximation to mass-conservation equation, eq. 4-3, with appropriate source and sink terms for each substance. The substances are organic nitrogen, ammonia nitrogen, nitrite-nitrate nitrogen, organic phosphorus, ortho phosphorus, chlorophyll'a', carbonaceous biochemical oxygen demand, and dissolved oxygen. The interactions among these substances, as accounted for in the model, are shown in Fig. 4-1. The source and sink terms, expressed for the longitudinally-integrated finite segments, are presented in the remainder of this chapter.

1) Phytoplankton (or chlorophyll'a') - The phytoplankton population, quantified as the concentration of chlorophyll 'a', occupies a central role in the schematic ecosystem of Fig. 4-1 and influences, to a greater or lesser extent, all of the remaining non-conservative dissolved constituents. The source/sink term for phytoplankton is expressed

$$SS = V * CH * (G-R-P-Ksch /h) + WCH \qquad (4-4)$$

in which

SS = mass source or sink in model segment (mg/day)
V = segment volume (m^3)
CH = chlorophyll 'a' concentration (μg/l)
G = growth rate of phytoplankton (1/day)
R = respiration rate of phytoplankton (1/day)
P = mortality rate due to predation and other factors (1/day)
Ksch = settling rate of phytoplankton (m/day)
h = local depth (m)
WCH = external loading of chlorophyll 'a' (mg/day)

Phytoplankton growth is dependent upon nutrient availability, ambient light, and temperature. The functional relationships used in the model generally follow the forms of DiToro, et al (1971) and are as follows:

$$G = Kgr * \underbrace{Tgr}_{\text{Temp. effect}} * \underbrace{I(Ia,Is,ke,CH,h)}_{\text{Light effect}} * \underbrace{N(N2,N3,P2)}_{\text{Nutrient effect}} \qquad (4\text{-}5)$$

in which

Kgr = optimum growth rate at 20 C (1/day)

$Tgr = \theta gr^{T-20}$

T = temperature (C)

I = attenuation of growth due to suboptimal lighting

N = attenuation of growth due to nutrient limitations

$$I = \frac{2.718}{(ke * h)} * [\exp(-\alpha_1) - \exp(-\alpha_0)] \qquad (4\text{-}6)$$

$$Ke = Ke' + 0.018 * CH \qquad (4\text{-}7)$$

$$\alpha_1 = \frac{I(t)}{Is} * \exp(-Ke * h) \qquad (4\text{-}8)$$

$$\alpha_0 = \frac{I(t)}{Is} \qquad (4\text{-}9)$$

$$I(t) = \begin{cases} Ia * \frac{24}{td-tu} * \frac{\pi}{2} \sin [\pi \frac{t-tu}{td-tu}] & \text{if } tu < t < td \\ 0 & \text{if } t < tu \text{ or } t > td \end{cases} \qquad (4\text{-}10)$$

in which

Ke' = light extinction coefficient at zero chlorophyll concentration (1/meter)

Ke = light extinction coefficient corrected for self-shading of plankton (1/meter)

h = depth of water column (meters)

Is = optimum solar radiation rate (langleys/day)

I(t) = solar radiation at time t

Ia = total daily solar radiation (langleys)

tu = time of sunrise, in hours

td = time of sunset, in hours

t = time of day in hours

The nutrient effect, N, is based on the minimum limiting nutrient concept.

$$N = \text{minimum} \begin{array}{l} \dfrac{N2 + N3}{Kmn + N2 + N3} \\ \\ \dfrac{P2}{Kmp + P2} \end{array} \qquad (4\text{-}11)$$

in which

N2 = ammonia nitrogen concentration (mg/l)

N3 = nitrite+nitrate nitrogen concentration (mg/l)

P2 = ortho phosphorus concentration (mg/l)

Kmn = half-saturation concentration for inorganic nitrogen uptake (mg/l

Kmp = half-saturation concentration for ortho phosphorus uptake (mg/l)

The respiration rate, R, is a function of temperature.

$$R = a * Tr \qquad (4\text{-}12)$$

in which

a = respiration rate at 20 C (l/day)

$Tr = \theta r^{T-20}$

2) Organic Nitrogen - The source/sink term for organic nitrogen is expressed

$$SS= V * [- \frac{Kn12 * Tn12}{Kh12 + N1} * N1 + aN * Fron * (R+P) * CH \qquad (4\text{-}13)$$

$$- N1*Kn11/h + BENN1/h] + WN1$$

in which

N1 = concentration of organic nitrogen (mg/l)

Kn12 = hydrolysis rate of organic nitrogen to ammonia at 20 C (mg/l/day)

$Tn12 = \theta n12^{T-20}$

Kh12 = half-saturation concentration for hydrolysis (mg/l)

aN = ratio of organic nitrogen to chlorophyll in phytoplankton (mgN/μgm Chl)

Fron = fraction of phytoplankton nitrogen recycled to organic pool by respiration and death

Kn11 = settling rate of organic nitrogen (m/day)

BENN1 = benthic flux of organic nitrogen ($gm/m^2/day$)

WN1 = external loading of organic nitrogen (gm/day)

3) Ammonia Nitrogen - The source/sink term for ammonia nitrogen is expressed

$$SS = V * [- \frac{Kn23 * Tn23}{Kh23 + N2} * N2 + \frac{Kn12 * Tn12}{Kh12 + N1} * N1$$

$$+ aN * [(1-Fron) * (R+P) - PR * G] * CH + BENN2/h] + Wn2 \qquad (4\text{-}14)$$

in which

N2 = concentration of ammonia nitrogen (mg/l)

Kn23 = nitrification rate of ammonia to nitrate nitrogen at 20 C (mg/l/day)

$Tn23 = \theta n23^{T-20}$

Kh23 = half-saturation concentration for nitrification (mg/l)

BENN2 = benthic flux of ammonia nitrogen ($gm/m^2/day$)

PR = preference of phytoplankton for ammonia uptake

$$= \frac{N2 * N3}{(Kmn+ N2)*(Kmn+ N3)} + \frac{N2 * Kmn}{(N2+N3)*(Kmn+ N3)} \qquad (4\text{-}15)$$

WN2 = external loading of ammonia nitrogen (gm/day)

4) Nitrite+Nitrate Nitrogen - The source/sink term for nitrite-nitrate nitrogen is expressed

$$SS = V * [\frac{Kn23 * Tn23}{Kh23 + N2} * N2 - aN * G * (1-PR) * CH - N3 \qquad (4\text{-}16)$$

$$* Kn33/h + BENN3/h]+WN3$$

in which

N3 = concentration of nitrite-nitrate nitrogen (mg/l)
Kn33 = settling rate of nitrite-nitrate nitrogen (m/day)
BENN3 = benthic flux of nitrite-nitrate nitrogen ($gm/m^2/day$)
WN3 = external loading of nitrite-nitrate nitrogen (gm/day)

5) Organic Phosphorus - The source/sink term for organic phosphorus is expressed

$$SS = V * [- \frac{Kp12 * Tp12}{Khp + P1} * P1 + aP * Frop * (R+P) * CH \qquad (4\text{-}17)$$
$$- P1 * Kp11/h + BENP1/h] + WP1$$

in which

P1 = concentration of organic phosphorus (mg/l)
Kp12 = hydrolysis rate of organic to inorganic phosphorus at 20 C (mg/l/day)
Khp = half-saturation constant for hydrolysis (mg/l)
TP12 = $\theta p12^{T-20}$
aP = ratio of organic phosphorus to chlorophyll in phytoplankton (mg P/ug Chl)
Kp11 = settling rate of organic phosphorus (m/day)
BENP1 = benthic flux of organic phosphorus ($gm/m^2/day$)
WP1 = external loading of organic phosphorus (gm/day)
Frop = fraction of phytoplankton phosphorus recycled to organic pool by respiration and death

6) Ortho Phosphorus - The source/sink term for ortho phosphorus is expressed

$$SS = V * [\frac{Kp12 * Tp12}{Khp + P1} * P1 + aP * [(1-Frop) * (R+P)-G] * CH \qquad (4\text{-}18)$$

$$- P2 * Kp22/h + BENP2/h] + WP2$$

in which

P2 = concentration of ortho phosphorus (mg/l)
Kp22 = settling rate of inorganic phosphorus (m/day)
BENP2 = benthic flux of inorganic phosphorus (gm/m2/day)
WP2 = external loading of ortho phosphorus (gm/day)

7) Carbonaceous Biochemical Oxygen Demand - The source/sink term for CBOD is expressed

$$SS = V * [- Kc * Tbod * CBOD + aC * aco * P * CH \tag{4-19}$$

$$- CBOD * Ksc/h] + WCBOD$$

in which

CBOD = concentration of carbonaceous biochemical oxygen demand (mg/l)
Kc = first-order decay rate of CBOD at 20 C (1/day)
Tbod = θbod^{T-20}
aC = ratio of carbon to chlorophyll in phytoplankton (mg C/µg Chl)
aco = ratio of oxygen demand to organic carbon recycled = 2.67
Ksc = settling rate of CBOD (m/day)
WCBOD = external loading of CBOD (gm/day)

8) Dissolved Oxygen - The source sink term for dissolved oxygen is expressed

$$SS = V * [- Kc * Tbod * CBOD - ano * \frac{Kn23 * Tn23}{Kh23 + N2} * N2 \tag{4-20}$$

$$+ aco * aC * PQ * G * CH - aco * aC/RQ * R * CH$$

$$- P2 * Kp22/h + BENP2/h] + WP2$$

in which

P2 = concentration of ortho phosphorus (mg/1)
Kp22 = settling rate of inorganic phosphorus (m/day)
BENP2 = benthic flux of inorganic phosphorus (gm/m2/day)
WP2 = external loading of ortho phosphorus (gm/day)

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8) Dissolved Oxygen - The source sink term for dissolved oxygen is expressed

$$SS = V * [- Kc * Tbod * CBOD - ano * \frac{Kn23 * Tn23}{Kh23 + N2} * N2 \qquad (4-20)$$

$$+ aco * aC * PQ * G * CH - aco * aC/RQ * R * CH$$

$$+ \mathrm{Kr} * (\mathrm{DOs} - \mathrm{DO}) - \mathrm{BENDO}/h] + \mathrm{WDO}$$

in which

DO = dissolved oxygen concentration (mg/l)
ano = ratio of oxygen consumed per unit of ammonia nitrified = 4.33
PQ = photosynthesis quotient (moles O2/mole C)
RQ = respiration quotient (moles CO2/mole O2)
Kr = reaeration rate (1/day)
DOs = saturation concentration of DO (mg/l)
BENDO = sediment oxygen demand (gm/m2/day)
WDO = external loading of dissolved oxygen (gm/day)

The expression utilized to compute the reaeration coefficient, Kr, (O'Connor and Dobbins: 1958) is

$$\mathrm{Kr} = \frac{1}{h} * \mathrm{Kro} * \left[\frac{u}{h}\right]^{1/2} * \mathrm{Tdo} \qquad (4\text{-}21)$$

in which

Kr = reaeration rate (1/day)
Kro = proportionality constant
$\mathrm{Tdo} = \theta\mathrm{do}^{T-20}$
u = mean cross-sectional velocity (m/sec)

Saturation dissolved oxygen concentration, DOs, is calculated as a function of water temperature from a polynomial fitted to the tables of Carritt and Green (1967).

$$\mathrm{DO} = 14.6244 - 0.367134 * T + 0.004497 * T^2 \qquad (4\text{-}22)$$

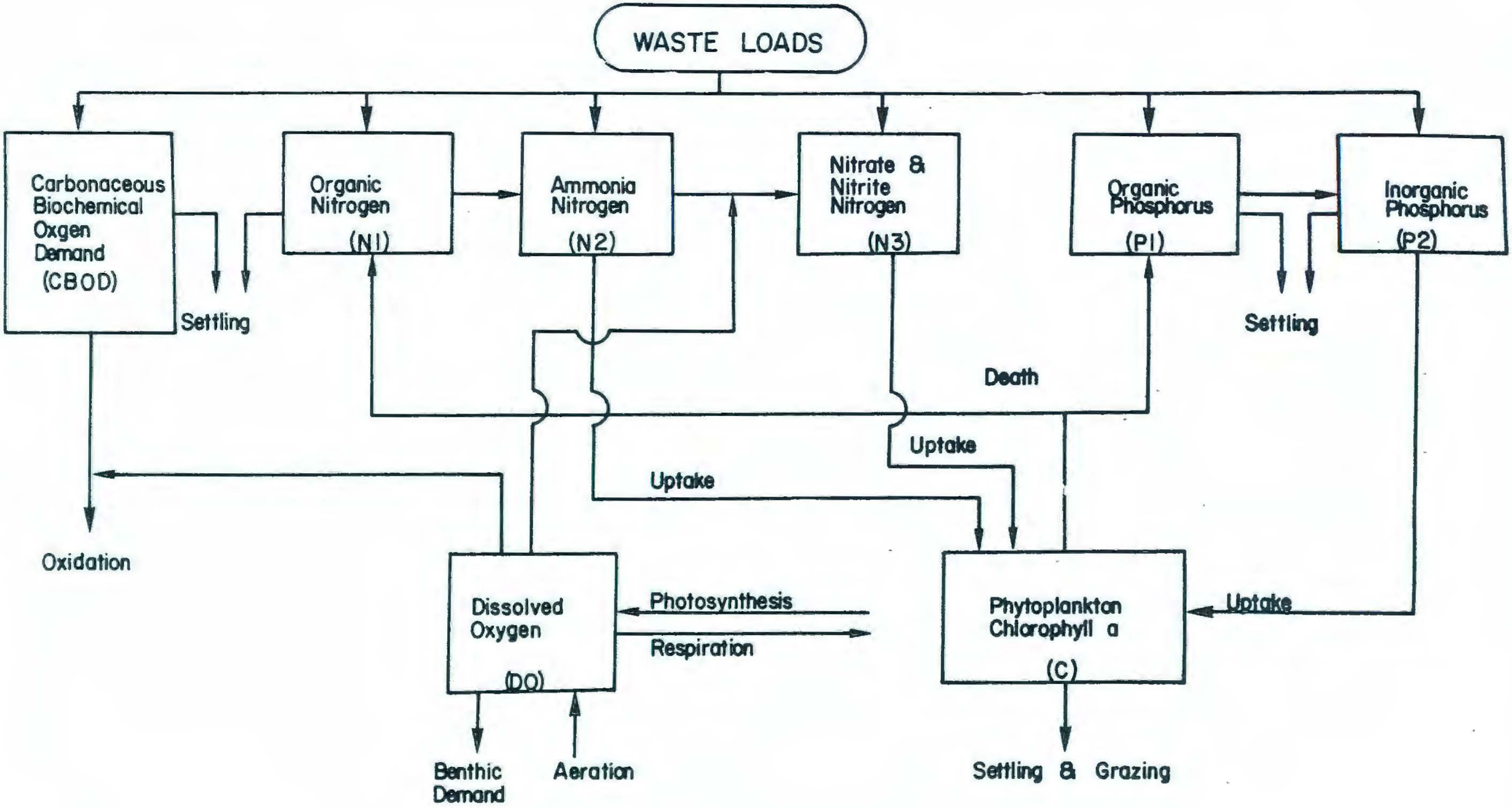


Figure 4-1. Flow diagram of phytoplankton ecosystem model.

CHAPTER V. APPLICATION OF HYDRODYNAMIC MODEL

For economy and flexibility of scheduling, the hydrodynamic and water quality submodels for the Neabsco are coupled externally. Hence each model is presented separately. The hydrodynamic model is the same as that used for Little Hunting Creek (Williams and Kuo, 1984). The reader is referred to that report for a complete description of the hydrodynamic model.

Before the hydrodynamic model can be utilized, it must be supplied with the geometry of the water body to be modelled. Next, model predictions of surface level and current velocity should be compared to field measures of these parameters. Finally, the ability of the model to predict the transport of dissolved substances should be verified through comparison of model predictions and field measures of the concentration of some conservative substance such as dye or salt. The completion of each of these procedures is detailed in the remainder of this chapter.

A. Geometry

As noted in Chapter IV, the solution to Equations 4-1 - 4-3 is accomplished through division of the water body into series of finite segments which together approximate the continuous system. The hydrodynamic model must be supplied with the geometry of each of these segments including measures of length, width, depth, cross-section, surface area, and volume, and with boundary conditions and other inputs.

The system is divided into ten segments along the axis (Figure 5-1). The geometry of these segments is derived from bathymetry measurements taken in 1981 and from a U.S.G.S. topographic map of the Quantico quadrangle photorevised in 1978. Specification of the segment geometry is complicated by the irregular shape of the embayment and by the marshy areas. Cross-sectional area, surface area, and volume cannot be considered constant, but are instead computed within the model as time-variable functions of surface level. Segment geometries of the mean-tide level are presented in Table 5-1. However, additional area and volume are flooded at high tide due to the irregular segment geometry and the intratidal volume of the marshes previously mentioned. Measures of the extent of these areas were obtained by planimetry of a topographic map.

The model has essentially three components: tidal height, volume transport and salinity (or any other conservative substance). Longitudinal velocity is a derived quantity calculated at each time step. Tidal motion is driven by a tidal height time series at the downstream boundary. Fresh water inflow may be specified at any segment. The conservative tracer is tied to a boundary condition on flood tides at the downstream end but is determined by net flux at the upstream boundary.

B. Calibration of Tide and Current

Portions of the tide record were used as input to the hydrodynamic model after removing the mean height, converting to metric units and interpolating to generate a record at one-minute intervals. During the intensive survey two tide staffs were monitored at stations 4 and 5. Apart from arbitrary zero level, the records appear quite similar (Figure 5-2). The model predictions also show this uniform tidal range.

The longitudinal component of the current meter records was used to calibrate the tidal current calculation in the model. The model run started four tidal cycles prior to the period in which the current meters were deployed, in order to eliminate transient effects. As can be seen from Figures 5-3 and 5-4 agreement is good for both magnitude and phase.

One discrepancy needs to be noted, however. The observed tidal currents seem to have two maxima per tidal cycle in the ebbing stage (positive direction). This feature is not seen in the predicted current. However, since no indication of such behavior is to be seen in the observed tidal height, it seems likely to be an artifact of the current observation. The Endeco current meter has a ducted impeller and so must come about bodily when the tidal current changes direction. In the weak current of Neabsco Creek, it is possible that a weak up-estuary current would be registered as an ebb current simply because the current meter was pointing the wrong direction, until some threshold value was reached and the current meter swung around to face the correct direction. It is clear in Figures 5-3 and 5-4 that a smooth sine curve results if the minor peak values are reflected through the x-axis.

C. Calibration of Mass Transport

In the last test of the hydrodynamic model, the ability to predict the transport of a conservative substance is examined. A dye study, conducted in August 1981 and described in Chapter III, is available for this purpose. Calibration is achieved via evaluation of the dispersion term of Eq. 4-3 and by adjustment of a weighting coefficient, which determines the dissolved substance concentration in the flow between adjacent segments. Dispersion, E, is computed by Harleman's (1971) formula

$$E = Eo*n*u*R^{5/6} + Eo' \qquad (5-1)$$

in which
E = dispersion coefficient (sq.m/sec)
Eo = proportionality constant
Eo' = constant dispersion coefficient (sq.m/sec)

n = Manning's n

u = velocity (m/sec)

R= hydraulic radius (m)

The value of Eo was kept at the value suggested by Harleman, i.e. 63.2. Calibration was achieved by adjusting Eo' and the weighting coefficient. The weighting coefficient is utilized in the equation.

$$C^* = a_i C_{i-1} + (1-a_i) C_i \tag{5-2}$$

in which

a_i = weighting coefficient for transect i

C^* = concentration of dissolved substance flowing from segment i-1 to segment i

C_{i-1} = concentration of dissolved substance in segment i-1

C_i = concentration of dissolved substance in segment i

A value of $a_i = 1.0$ corresponds to a backwards finite-difference scheme. A value of $a_i = 0.5$ corresponds to a central differencing scheme. This formulation assumes that flow is coming from the (i-1)th segment into the ith segment. When tidal flow reverses, the roles of a_i and $1-a_i$ are reversed. Details of the employment of the weighting factor in the finite difference scheme may be found in Williams and Kuo (1983). A value of 0.54 for a_i and a value of 0.1 for Eo' were used for the Neabsco Creek Hydraulic Model.

The calibration run for simulating the dye study was begun at low water slack on Aug 18, the time of the dye release. However, the dye distribution in the model was initialized according to the observed distribution at about the next high tide. The comparison of observed and simulated dye distributions is shown in Figures 5-5 to 5-10. The time reference in these figures is 0000 hours (EST) of the date of dye release. Note that the model reproduces the tidal excursion and magnitude of the dye well but sometimes misses the peak concentration, owing to the finite distance between sampling points and also the finite size of the model segments. The agreement after four tidal cycles is excellent. It is apparent from these figures that the tidal excursion in the creek is about two kilometers.

The calibrated hydrodynamic model was run to generate input files for the water quality model. For water quality calibration, the run extended from low water on July 29 through the end of the intensive survey on August 19, for a total of 40.5 tidal cycles. For water quality verification, the run extended from low water on June 18 through the same stage on September 3 for a total of 149 tidal cycles.

It should be noted that comparison of model predictions to data which is both temporally and spatially variable is a most rigorous test. Agreement is much more difficult to obtain than under conditions in which spatially-variable but temporally-constant data is employed. Thus, the result of this calibration of mass transport is considered to be most satisfactory.

Table 5-1. Geometry of Neabsco Creek

Transect	Top Width (m)	Cross-sectional Area (m^2)	Average Depth (m)	Distance Between Transects (km)	Drainage Area (km^2)	Change in Surface Area from LW to HW (m^2 x 1000)
B	1155	1950	1.7			
				0.43	0.80	107
B_1	745	860	1.2			
				0.25	0.29	18
C	121	240	2.0			
				0.44	0.50	27
D	636	506	0.8			
				0.40	0.61	19
E	742	283	0.4			
				0.46	1.03	161
F	22	28	1.2			
				0.49	1.07	276
G (estimated)	60	60	1.0			
				0.36	10.1	83
H	36	27	0.8			
				0.58	0.74	158
I	7.5	3.3	0.4			
				0.50	0.74	40
J (estimated)	6.0	2.4	0.4			
Headwaters						

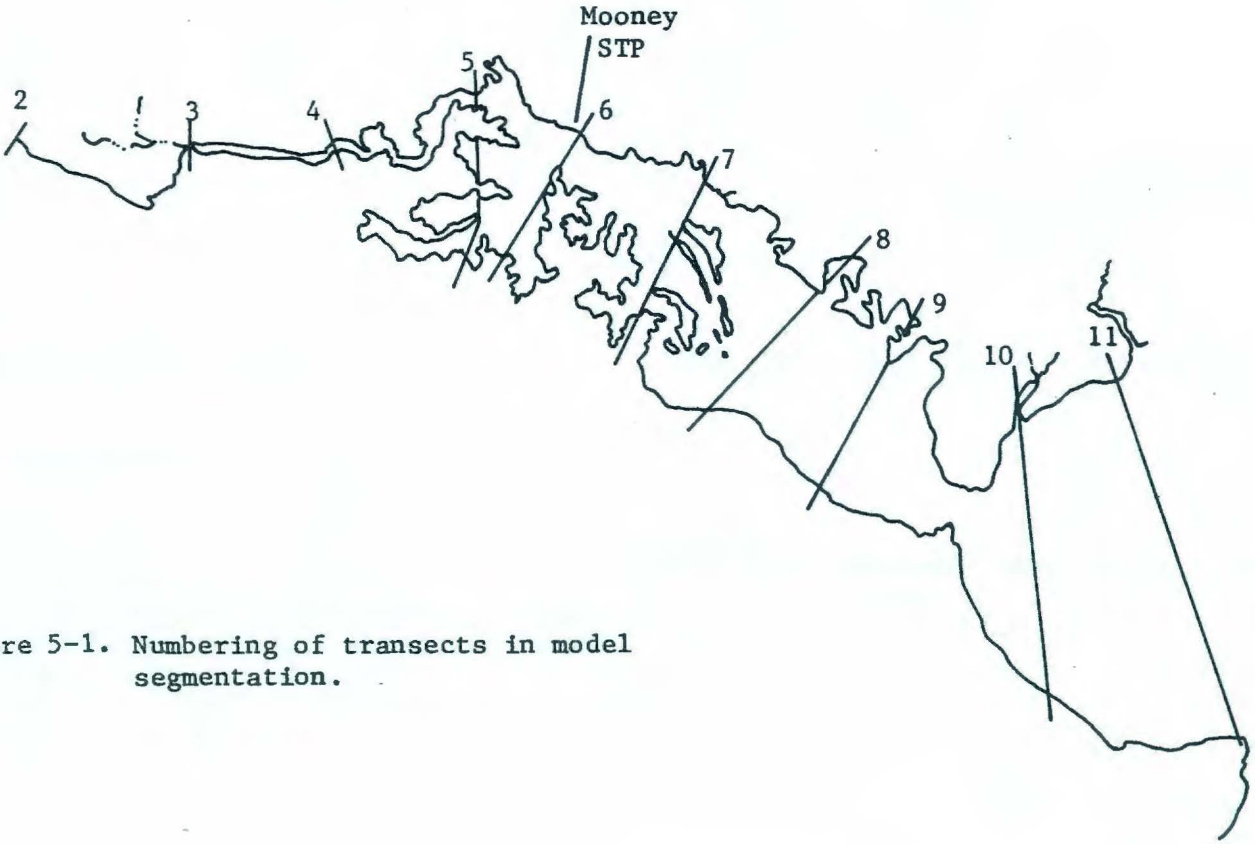
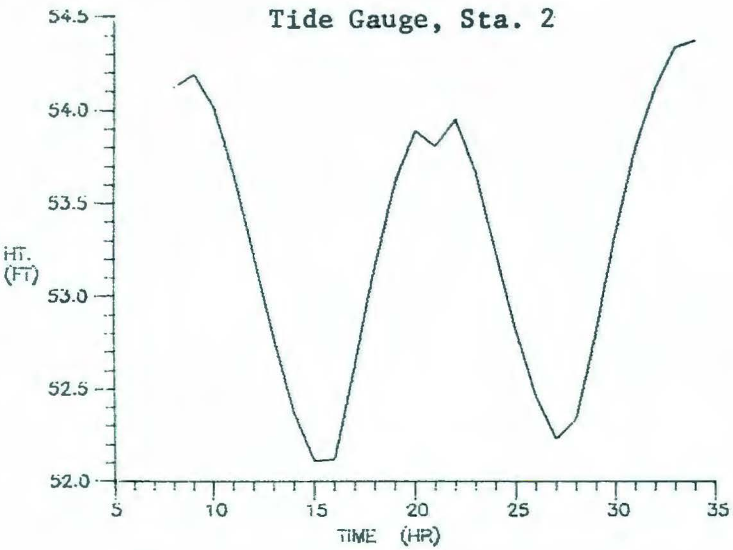
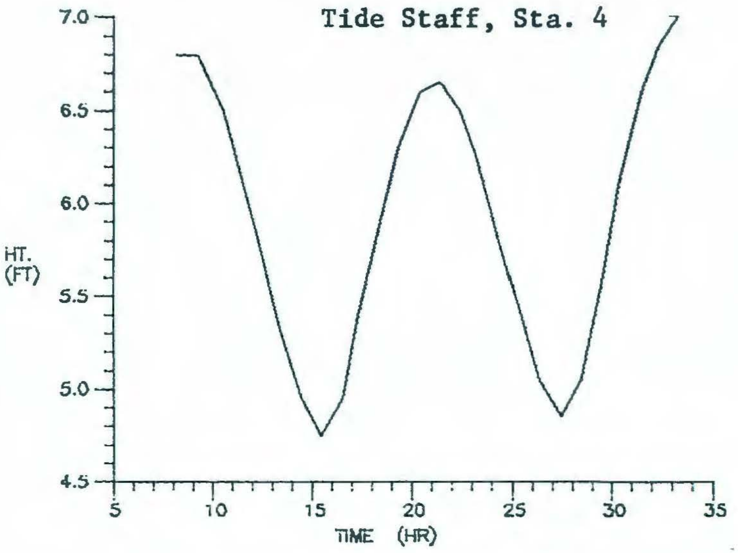


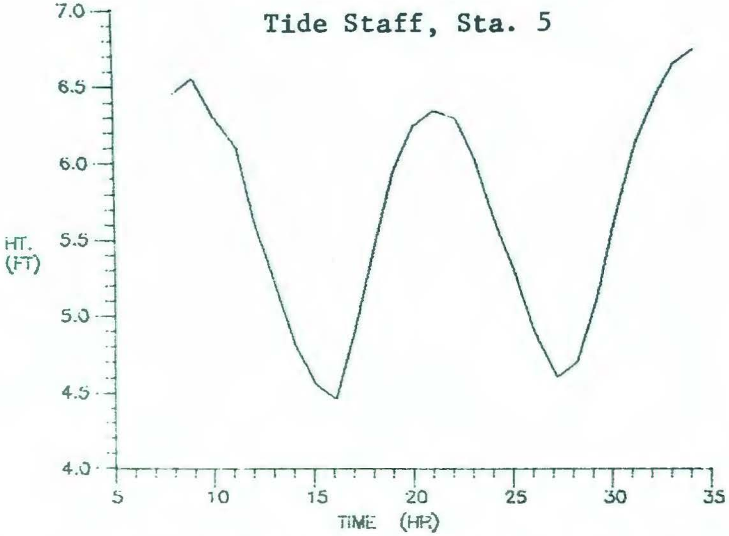
Figure 5-1. Numbering of transects in model segmentation.



Time (hr) beginning 0000 hrs Aug 18



Time (hr) beginning 0000 hrs Aug 18



Time (hr) beginning 0000 hrs Aug 18

Figure 5-2. Observed tides during intensive survey.

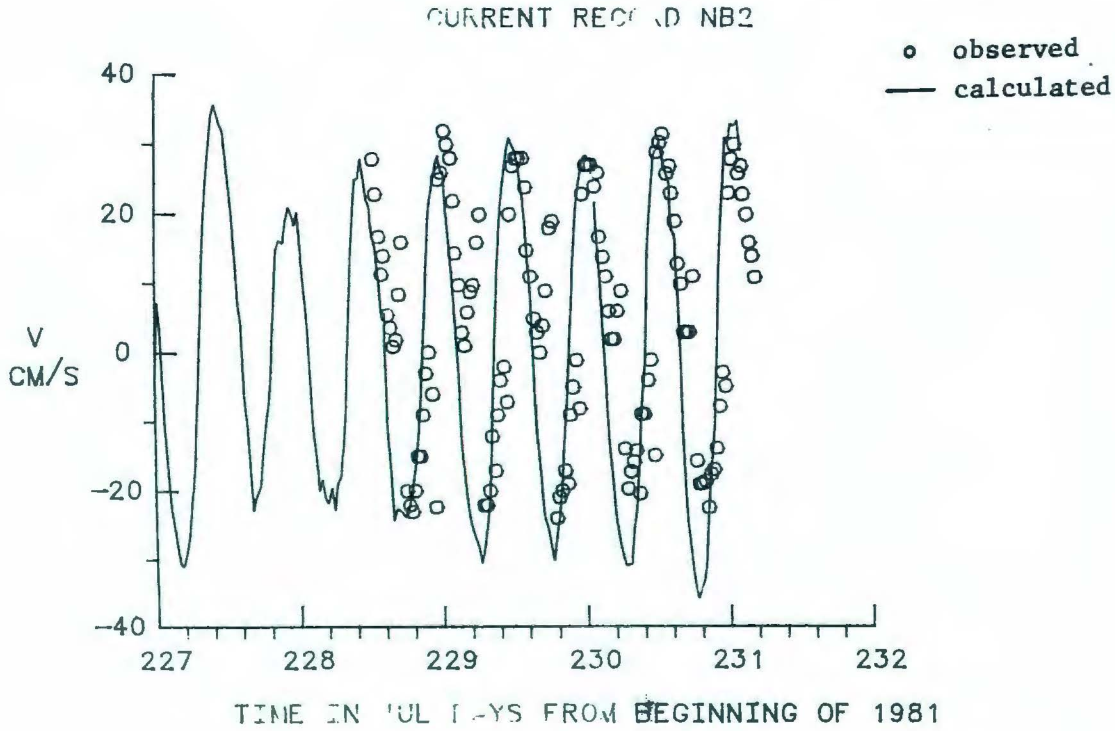


Figure 5-3. Tidal current calibration for station 2.

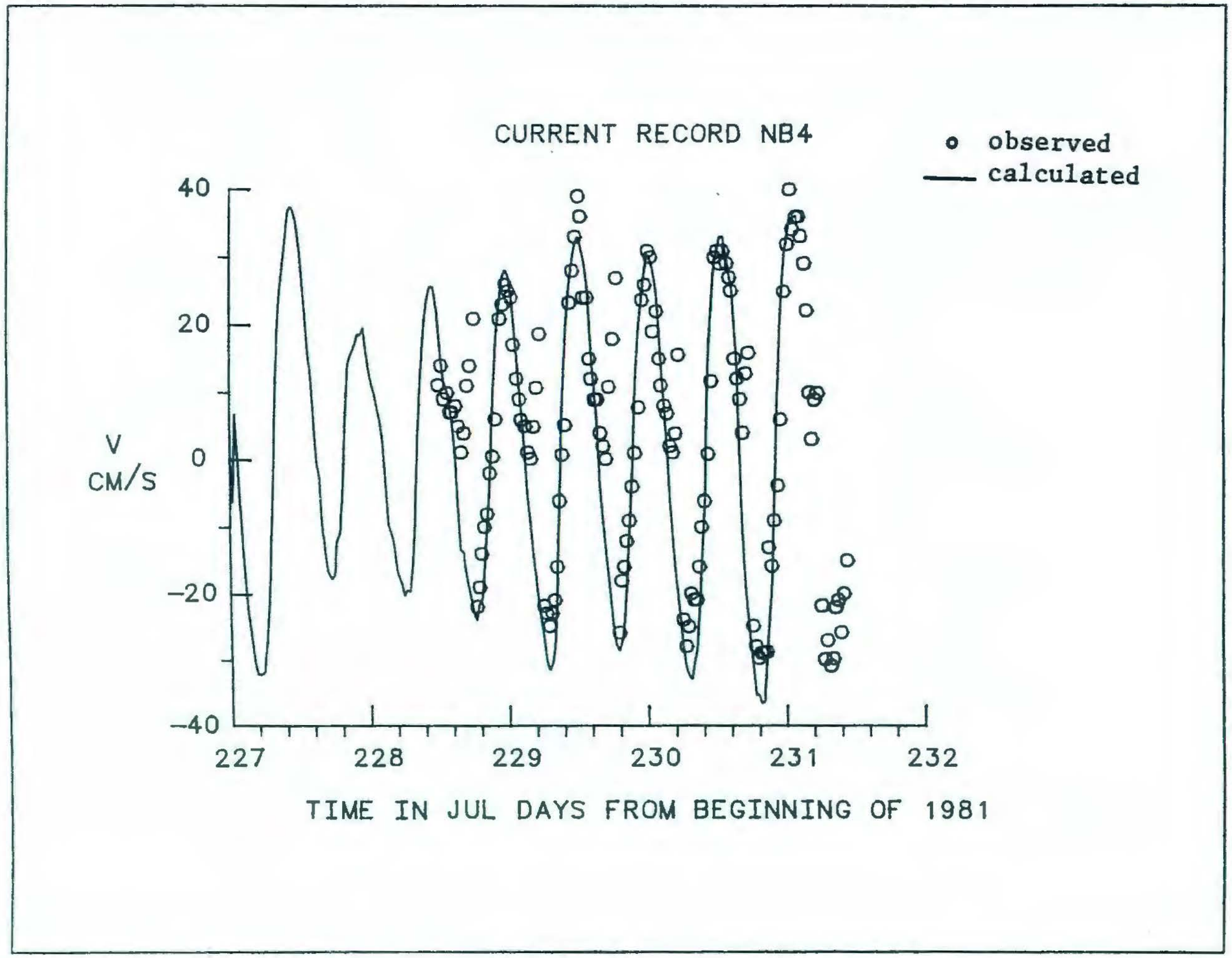


Figure 5-4. Tidal current calibration for station 4.

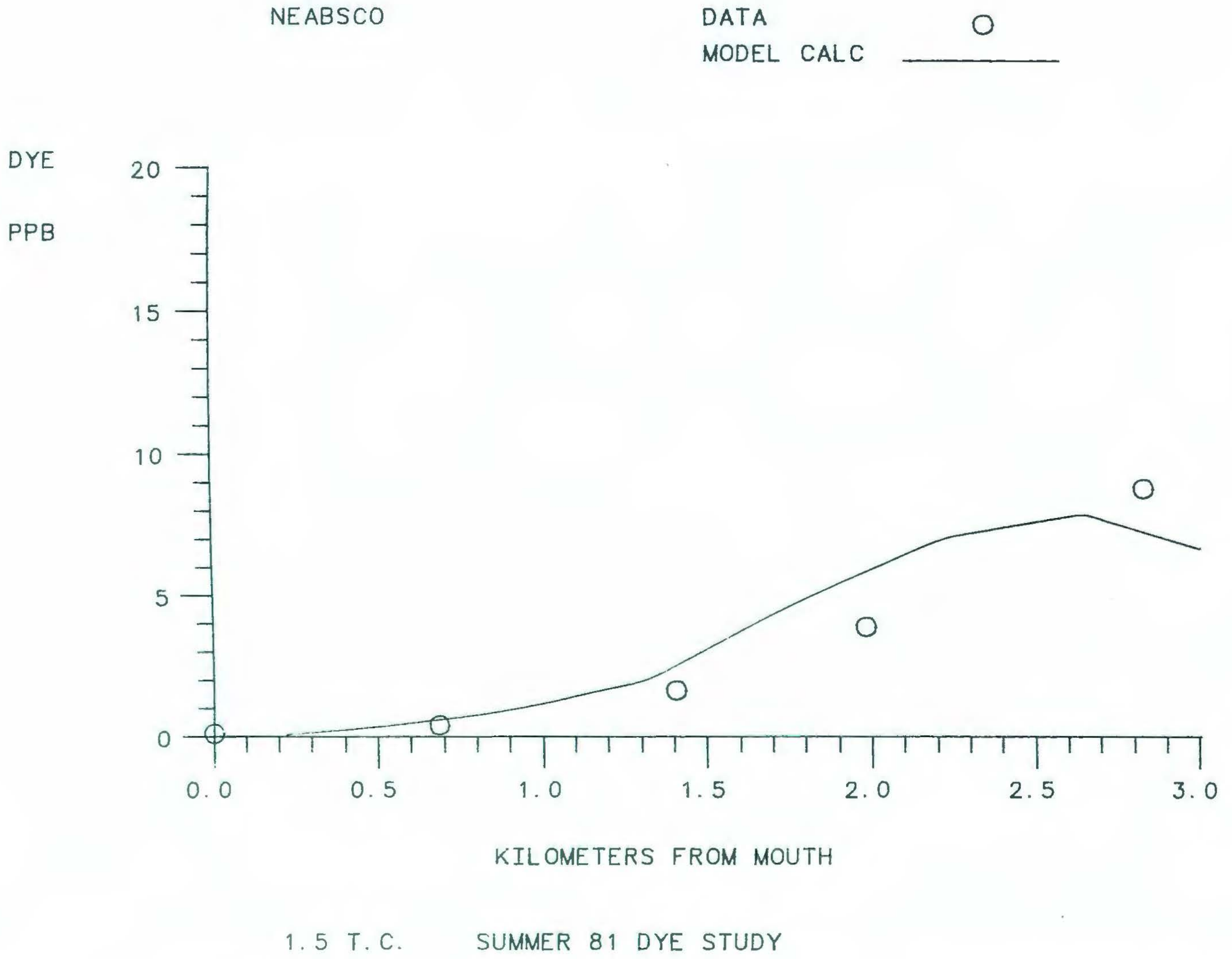


Figure 5-5. Dye dispersion calibration results 1.5 tidal cycles after dye release.

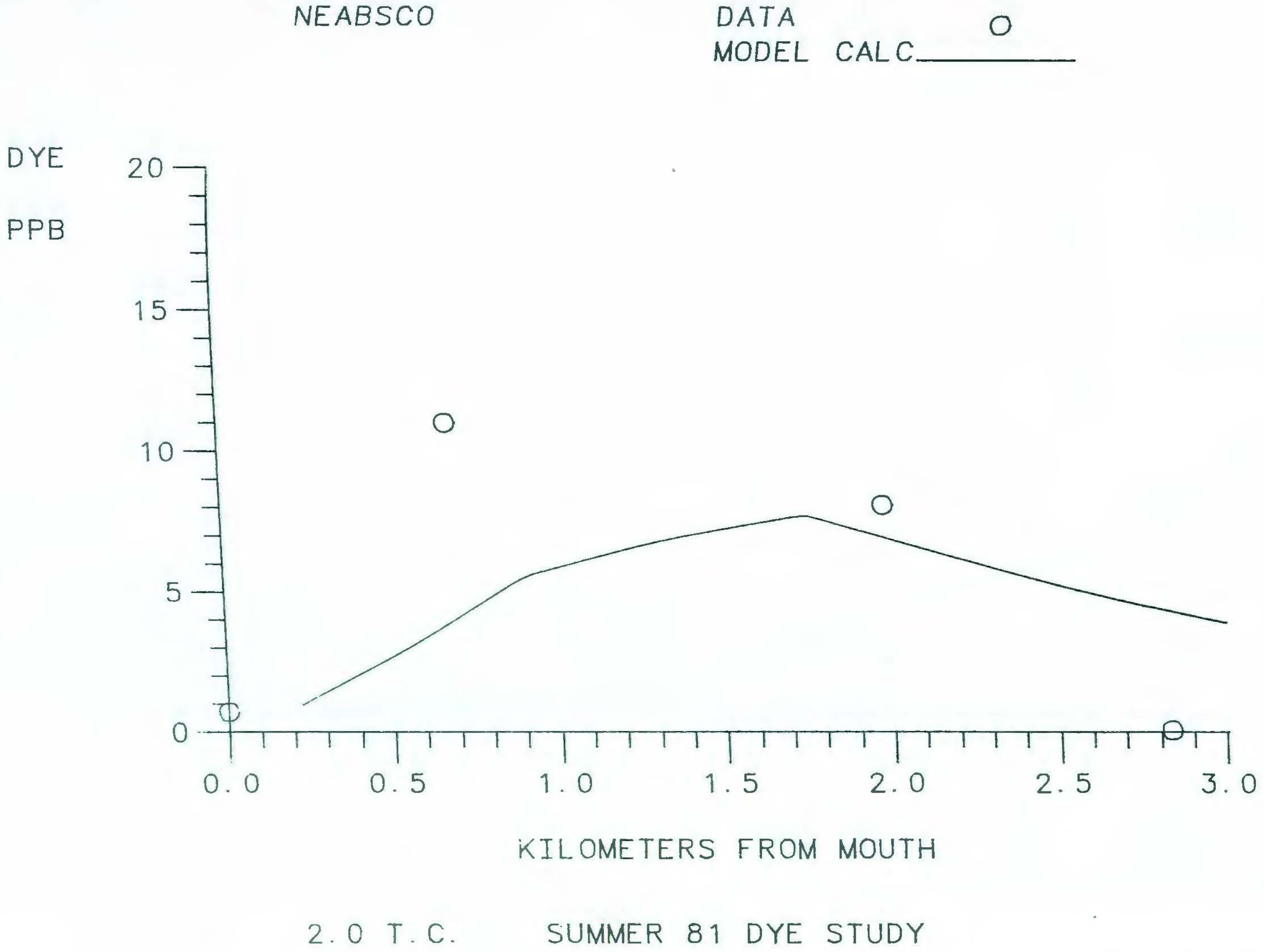


Figure 5-6. Dye dispersion calibration results 2.0 tidal cycles after dye release.

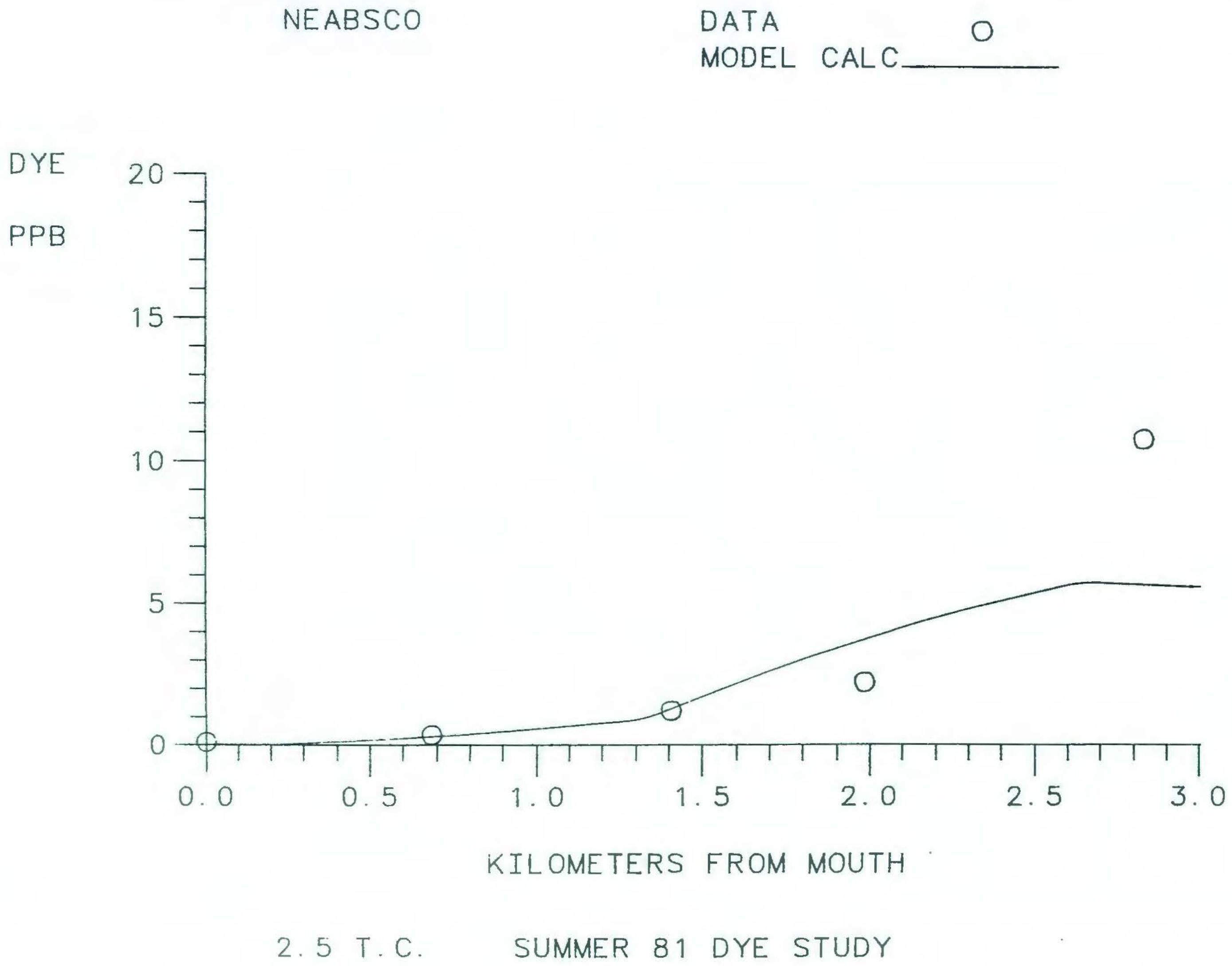


Figure 5-7. Dye dispersion calibration results 2.5 tidal cycles after dye release.

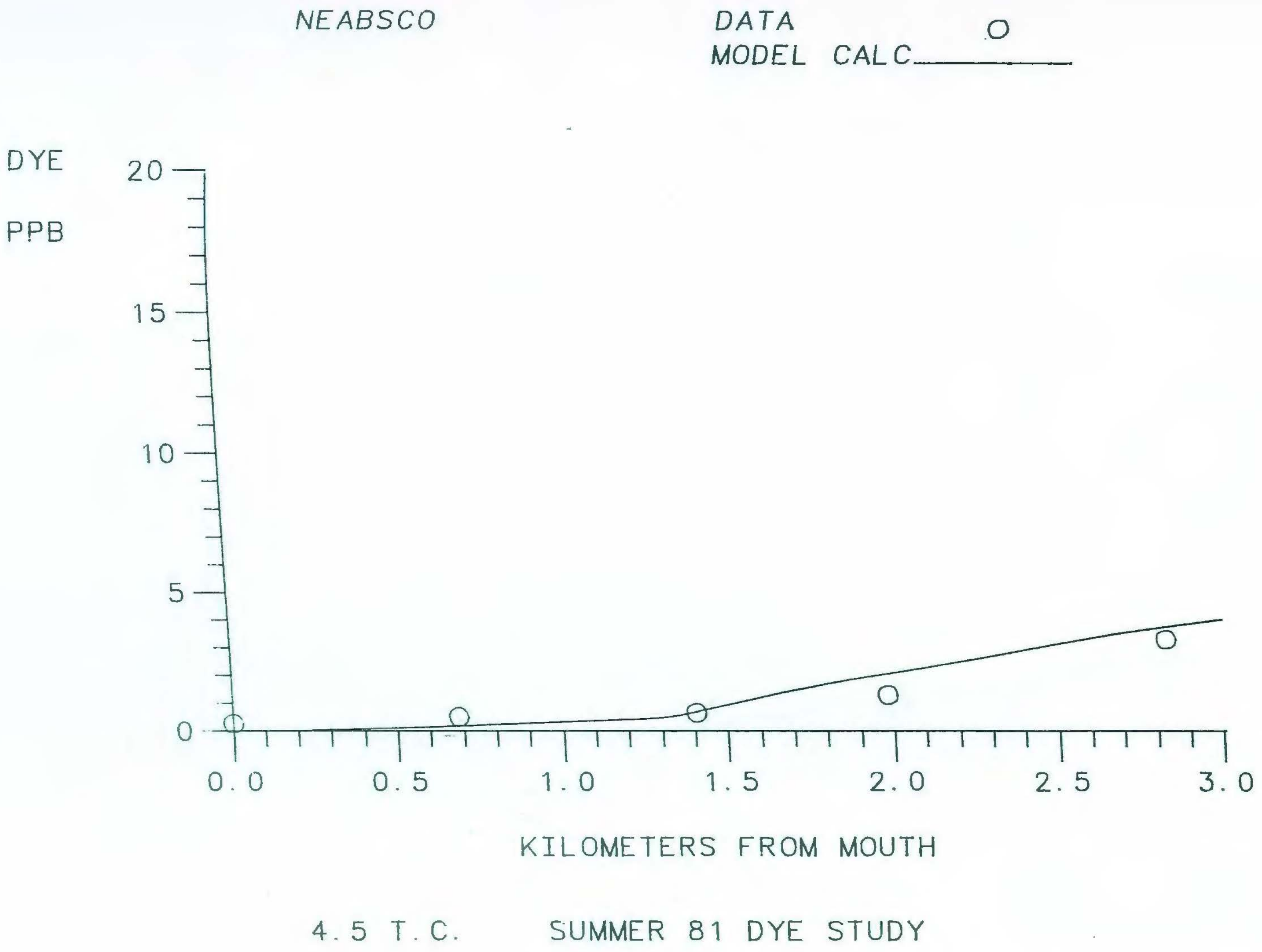


Figure 5-8. Dye dispersion calibration results 4.5 tidal cycles after dye release.

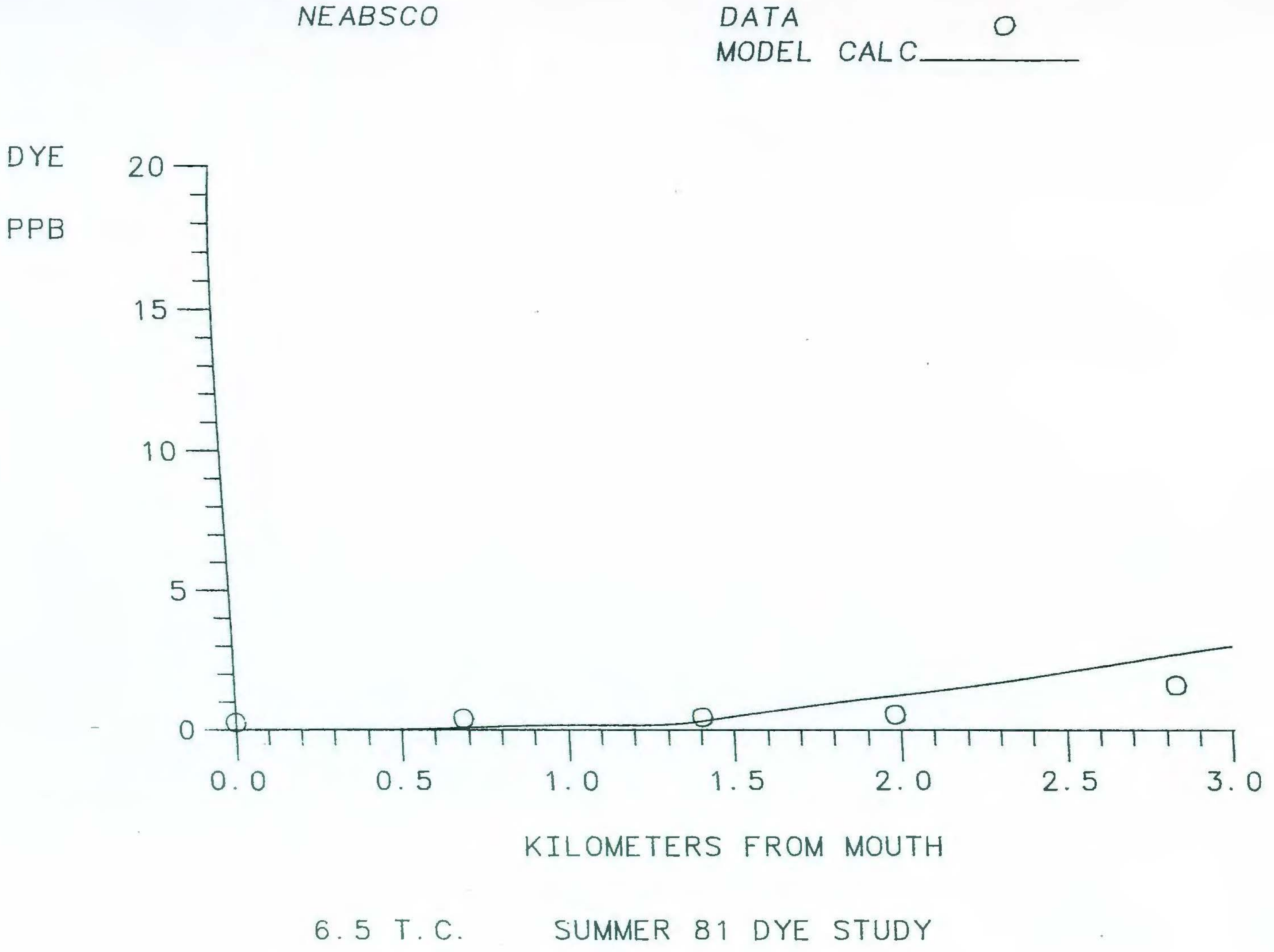


Figure 5-9. Dye dispersion calibration results 6.5 tidal cycles after dye release.

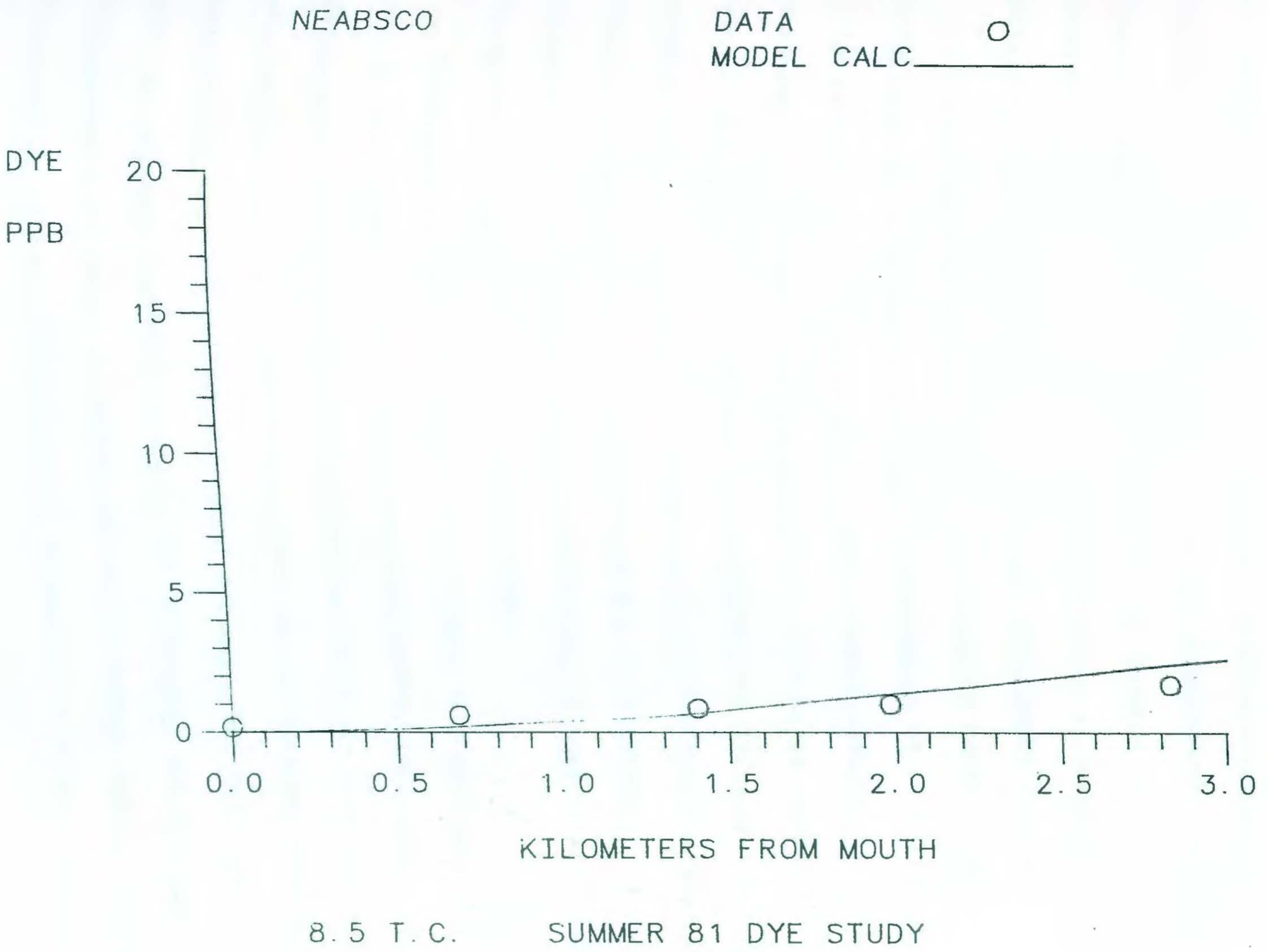


Figure 5-10. Dye dispersion calibration results 8.5 tidal cycles after dye release.

CHAPTER VI. CALIBRATION AND VERIFICATION OF THE WATER QUALITY MODEL

A. Rationale for Calibration and Verification

Application of the water-quality model is similar to that of the hydrodynamic model. The model must be supplied with appropriate input data and boundary conditions and then calibrated to reproduce the observed system behavior through the adjustment of various coefficients, most notably the biogeochemical rate constants described in Chapter IV. Following the calibration, the selection of coefficients should be verified through comparison of model predictions with additional independent field data.

Calibrating and verifying the water-quality model is much more difficult than the hydrodynamic model due to the number of predicted parameters to be calibrated - organic, ammonia, and nitrate nitrogen, total and ortho phosphorus, chlorophyll, CBOD, and DO - and to the large number of coefficients which may be adjusted in attaining the calibration. In some instances it may be possible for alternate sets of calibration parameters to provide roughly equivalent calibrations and verifications. To avoid this situation, it is desirable to minimize the number of coefficients evaluated through fitting of model results to field data.

There are a variety of sources for the input data sets and coefficients used in this model. Among these are measurements, literature values, and calibration. Measurements include inputs such as loads from STP effluents and temperature. Literature values exist for coefficients which have been evaluated in published studies of similar systems. For this modelling effort, one primary literature source is the Calibration and Verification of a Mathematical Model of the Eutrophication of the Potomac Estuary (Thomann and Fitzpatrick, 1982), (hereinafter referred to as the 'COG Report').

Calibration parameters are those which are obtained through adjustment of the model to reproduce field observations.

The number of calibration parameters employed in the calibration and verification procedures is minimized through adherence to the following principles in evaluating model parameters:

1) Utilize measurements of system inputs and biogeochemical constants and coefficients whenever these are available.
2) Utilize values from the literature when measurements are not available.
3) Utilize calibration values only when no other sources are available or when other sources are proven unsuitable.

B. Consistency of the Calibration and Verifications

To be of optimal use, a water quality model ought to employ consistent values of biogeochemical constants and transformation rates. That is, these values should be transferrable when the model is used to provide predictions for comparison with independent sets of observations. Coefficients which are not constant should be calculable based on ambient conditions of temperature, light, wind, etc. If the model is not consistent, then its predictive value is reduced since any predictions will depend upon the coefficients selected from the range of values previously employed.

The ideal of consistency imposes a dilemma upon the modeller: he must provide a consistent model of an inconsistent world. In the prototype, biogeochemical constants and rates need not be consistent from survey to survey, season to season, or year to year, yet in the model this must be so.

In the calibration and verifications to follow, the principle of consistency is adhered to wherever possible. The trade-off is that predictions and observations do not always agree as closely as they might if the model were adjusted to each survey individually. Discrepancies between predictions and observations must therefore be regarded as illustrative of the variability inherent in natural processes rather than indicative solely of shortcomings of the model. Adjustments of model coefficients between runs are performed only when they are crucial to the success of the simulation and indicate a significant variability in the process being simulated.

C. The Calibration and Verification Data Bases

From the data described in Chapter III, two independent data sets were determined to be suitable for model use. These are the August 1981 intensive survey and the June-September 1981 series of slackwater surveys. Initial calibration is achieved using the 1981 intensive survey with verifications conducted employing the 1981 slackwater survey sequence.

D. Calibration Coefficients for the August 1981 Intensive Survey

The calibration is conducted by using the observations collected in the July 29 slackwater survey as initial conditions in a model simulation of the period from July 29 to August 19. Model predictions for the period 0800 hrs August 18 - 1100 hrs August 19 are then compared with the intensive survey data collected in the same interval. In successive model runs, calibration parameters are adjusted until agreement is achieved between the model predictions and the data. The primary criterion considered in achieving calibration is agreement between predicted and observed daily-average concentrations of the eight water quality parameters. Parameters and rate constants are summarized in Table 6-1.

To conduct the simulation, the model requires data on ambient conditions and external inputs to the system, and values for a number of constants and coefficients. The manner in which these are obtained and the values employed are as significant as the achievement of calibration itself.

Therefore, all model inputs and coefficients and their origins are presented before the calibration results.

1) External Inputs and Ambient Conditions - Daily solar radiation is a daily varying value obtained from Smithsonian Institution Data (Klein and Goldberg, 1982). Light extinction coefficients are derived from Secchi-depth measurements and are shown in Table 6-2.

Point source loadings were obtained from treatment plant monitoring being carried out concurrently with the intensive survey. Tables 6-3 and 6-4 show the loadings for the two treatment plants. Dale City Section 1 STP loading was input directly to model segment 2. In preparing the model inputs, the following modifications were made to these data:

- ultimate CBOD was calculated using separate decay constants for each plant as determined by long-term incubation studies.
- based on an estimated travel time of one day, ultimate CBOD from Dale City Section 1 STP was reduced 17% to allow for decay during the time of travel from that plant to the upstream boundary of the modeled portions. This calculation was based on the calibration CBOD decay rate.
- eighteen percent of the ammonia loading from Dale City Section 1 STP was shifted to nitrate to allow for nitrification during the time of travel. This calculation was based on the calibration nitrification rate.
- ten percent of the organic nitrogen loading from Dale City Section 1 STP was shifted to ammonia to allow for transformations during time of travel. This calculation was based on the calibration hydrolysis rate.

- o the loading from Mooney STP was divided equally between model segments 5 and 6, since it is introduced at the transect between these segments.

Daily nonpoint source loadings were supplied by the Northern Virginia Planning District Commission (NVPDC). Appendix B shows the comparison between these loadings and observed values at station 6. The only major discrepancies are in dissolved oxygen, where the NVPDC DO concentrations are apparently at saturation levels, and in ammonia, where the NVPDC loading does not include the Dale City Section 1 STP loading. For ultimate BOD no systematic difference was discernable. The dissolved oxygen levels in the nonpoint source loadings were multiplied by a factor of 0.82 so that model inputs matched the field data. The upstream boundary condition was established by the point and nonpoint loadings into segment 2, rather than being fixed to agree with field data at station 6. Thus the model can be used to test loading scenarios for Dale City Section 1 STP.

Downstream water quality boundary conditions are shown in Table 6-5. These are based on field data. The water temperatures used in the water quality model are shown in Table 6-6.

2) Phytoplankton-Related Coefficients - The phytoplankton-related coefficients employed in the calibration are presented in Table 6-1.

3) Nitrogen-Related Coefficients - The nitrogen-related coefficients and benthic exchange rates employed in the calibration are presented in Table 6-1.

4) Phosphorus-Related Coefficients - The phosphorus-related coefficients employed in the calibration are presented in Table 6-1.

5) CBOD- and DO-Related Coefficients - The coefficients related to CBOD and DO that were employed in the calibration are presented in Table 6-1.

The coefficient Kro = 3.93 is the metric equivalent of Kro = 12.9 given by O'Connor and Dobbins (1958) for the English system of units. As with the previous benthic fluxes, sediment oxygen demand, BENDO, is based on a number of field measurements. Model values are listed in Table 6-1.

E. Calibration Results

Field data and model predictions for the August, 1981 intensive survey have been plotted against distance from the creek mouth in Figures 6-1 and 6-2. Circles indicate mean observed values while the vertical bars represent the range of observations. The solid lines represent the model predicted average values while the two dashed lines show the range of values predicted by the model.

F. Verification with the June-September 1981, Slackwater Surveys

The model was verified against six slack water surveys that were carried out in the Neabsco in 1981 (see Table 3-1). Since the first of these surveys took place before the beginning of the tide record used to drive the hydrodynamic model, it was not used. The second slack water run (June 18) was used as initial condition. The remaining four runs were compared with predictions generated in a single continuous simulation extending 149 tidal cycles.

1) External Inputs and Ambient Conditions - Evaluation of external inputs and ambient conditions for the seasonal run is problematical in that daily measures of stream flow, temperature, boundary conditions, etc., are unavailable. These were measured only in conjunction with the slackwater surveys. Thus there are inter-survey gaps of approximately two-weeks duration in the data base. These gaps were filled by assuming the STP loads, temperature, and downstream boundary conditions observed in the slackwater surveys were constant during the interval beginning one week prior to the

survey and extending until one week prior to the next slackwater survey. Water temperature and boundary conditions were updated ten days prior to the day of the survey. Values of these three parameters, reproduced from model listings, are presented in Tables 6-3 to 6-6. Background flows and loads from freeflowing Neabsco Creek were obtained from the NVPDC model and are shown in Appendix B.

2) Constants and Coefficients - All constants and coefficients employed in the 1981 seasonal verification are identical to those of the calibration run, including the chlorophyll growth rate and extinction coefficients.

3) Verification Results - Results of the seasonal verification are presented as plots of predictions and observations along the Neabsco Creek axis (Figures 6-3 through 6-6). The figures indicate the instantaneous data points as circles and the range of predicted concentrations indicated by a pair of dashed lines in the twenty-four-hour interval centered on the time of the survey.

In evaluating the verification results, consideration must be given to the sparsity and variability of the observations and to the potential effects of processes active in the prototype but not included in the model. Random spatial and temporal variability in the data is manifested in the form of extreme data points which the model cannot replicate. Prototype processes not included in the model are, for example, wind events which push embayment water out into the Potomac or cause dilution of the embayment with river water.

While the model will not reproduce all individual data points, it is expected to represent the spatial trends and approximate magnitude of the observations in each survey. Based on these criteria, the seasonal run is a credible verification of the ability of the model to simulate the long-term behavior of the embayment, although discrepancies between the observations and predictions do occur.

Some of the deviations between field data and predicted results are due to time variations of conditions not taken into account in the model. To cite one example, the low values of chlorophyll and dissolved oxygen seen on July 29 are probably due to extremely high turbidity. Although this day was sunny, there had been a heavy rainstorm the day before and the field crew performing the slack run noted 'Stream very muddy-orangish.' This observation is reinforced by the secchi-depth measurements tabulated in Appendix A.

The model underpredicts chlorophyll levels for the final run on September 3. While the model takes into account the diminishing sunlight and shortening of day length occuring at that time of year, it maintains the same saturation light level of 250 ly/day. It seems likely that the phytoplankton would adapt to the changing season by becoming more light sensitive or by alteration of speciation, but those possible adaptions are not incorporated in the model.

Table 6-1. Parameters and Rate Constants for Neabsco Creek Ecosystem Model

Quantity	Units	Value	Source or Methods of Determination
Carbon-Chlorophyll Ratio	mg/ug	0.042	previous embayment calibrations
Nitrogen-Chlorophyll Ratio	mg/ug	0.007	previous embayment calibrations
Phosphorus-Chlorophyll Ratio	mg/ug	0.001	previous embayment calibrations
Photosynthesis Quotient	-	1.4	calibration
Respiratory Quotient	-	1.0	calibration
Michaelis Constant for Nitrogen Inhibition	mg/l	0.025	previous embayment calibrations
Michaelis Constant for Phosphorus Inhibition	mg/l	0.001	previous embayment calibrations
Optimum Phytoplankton Growth Rate at 20°C	1/day	2.368	calibration
Saturation Light Level	lgs/da	250	calibration
Respiration Rate at 20 °C	1/day	0.165	calibration
Phytoplankton Settling Rate	m/day	0.1	previous embayment calibrations

Grazing and Other Death Factors	1/day	0.0	previous embayment calibrations
Hydrolysis Rate at 20 °C	mg/1/day	0.075	calibration
Half Saturation Concentration for Hydrolysis	mg/1	1.0	calibration
Nitrification Rate at 20 °C	mg/1/day	0.1	calibration
Half Saturation Concentration for Nitrification	mg/1	1.0	calibration
Nitrate Removal Rate	m/day	0.05	calibration
Organic Phosphorus Mineralization Rate at 20 °C	mg/1/day	0.16	calibration
Half Saturation Concentration for Mineralization	mg/1	1.0	calibration
Organic Phos. Settling Rate	m/day	0.1	calibration
SRP Settling Rate	m/day	0.12	calibration
CBOD Decay Rate at 20 °C	1/day	0.15	calibration
WREA Wind Reaeration	1/day	0.	calibration
Kro Proportionality Constant		3.93	literature

Bottom Exchange Rates at 20 °C gm/sq m/day		
Dissolved Oxygen	-1.6	measured
Organic Nitrogen	0.	measured
Ammonia	0.1	measured
Nitrate-Nitrite	0.0	measured
Organic Phosphorus	0.	measured
Ortho Phosphorus	0.	measured
Exponential Base for Temperature Dependence		
SOD	1.065	literature
BOD, Hydrolysis, Nitrification, and Mineralization	1.047	literature
Growth and Respiration	1.039	calibration
Fraction of nitrogen recycled to organic pool	1.0	calibration
Fraction of phosphorus recycled to organic pool	1.0	calibration

Table 6-2. Extinction Coefficients Used in Model

Model Segment	Extinction Coefficient m^{-1}
2	8.0
3	8.0
4	8.0
5	8.0
6	8.0
7	8.0
8	5.9
9	4.5
10	4.5
11	4.0

Table 6-3. Point Source Loadings as Input to Water Quality Models - Dale Service Corp.

Date	Flow m^3/sec	Organic Nitrogen (kg/day)	Ammonia Nitrogen (kg/day)	Nitrate plus Nitrite (kg/day)	Organic Phosphorus (kg/day)	Ortho-Phosphorus (kg/day)	Ultimate CBOD (kg/day)	Dissolved Oxygen (mg/1)
June 18	0.10	0.	121	27	0.8	0.9	44	6.9
June 29	0.10	71	101	21	0.9	31	175	6.9
July 13	0.10	57	99	21	0.	22	180	5.2
July 29	0.10	30	60	16	2.6	19	136	7.1
Aug 18	0.094	2.3	63	19	0.2	2.0	91	6.4
Sept 3	0.13	0.	57	36	1.4	0.8	36	6.5

Table 6-4. Point Source Loadings as Input to Water Quality Models - Mooney STP

Date	Flow m^3/sec	Organic Nitrogen (kg/day)	Ammonia Nitrogen (kg/day)	Nitrate plus Nitrite (kg/day)	Organic Phosphorus (kg/day)	Ortho-Phosphorus (kg/day)	Ultimate CBOD (kg/day)	Dissolved Oxygen (mg/1)
Jun 18	0.32	24	2.8	628	0	154	68	8.4
Jun 29	0.24	16	2.0	428	0	108	92	8.5
July 13	0.32	30	2.8	468	0	134	67	7.5
July 29	0.40	28	3.4	444	20	172	113	8.4
Aug 18	0.28	31	6.0	462	7.2	144	167	8.3
Sept 3	0.30	12	2.6	586	0	26	68	8.2

Table 6-5. Downstream Boundary Conditions Used in Water Quality Models (mg/1)

Date of Observation	Organic Nitrogen	Ammonia Nitrogen	Nitrate plus Nitrite	Organic Phosphorus	Ortho Phosphorus	Chlorophyll (μg/1)	Ultimate CBOD	Dissolved Oxygen
June 18	0.9	0.1	0.3	0.10	0.006	30.	9.5	9.0
June 29	0.8	0.1	0.0	0.09	0.10	33.	5.0	9.2
July 13	1.0	0.1	0.4	0.08	0.02	30.	10.5	10.0
July 29	0.7	0.1	0.13	0.05	0.06	42.	5.0	10.0
Aug. 18	0.8	0.1	0.10	0.01	0.06	45.	5.5	13.0
Sept. 3	0.4	0.1	0.3	0.08	0.06	62.	7.0	8.8

Table. 6-6. Water Temperature used in Water Quality Models

Date	Water Temperature (^{o}C)
June 18	29.0
June 29	27.1
July 13	28.8
July 29	26.4
August 18	25.0
September 3	24.0

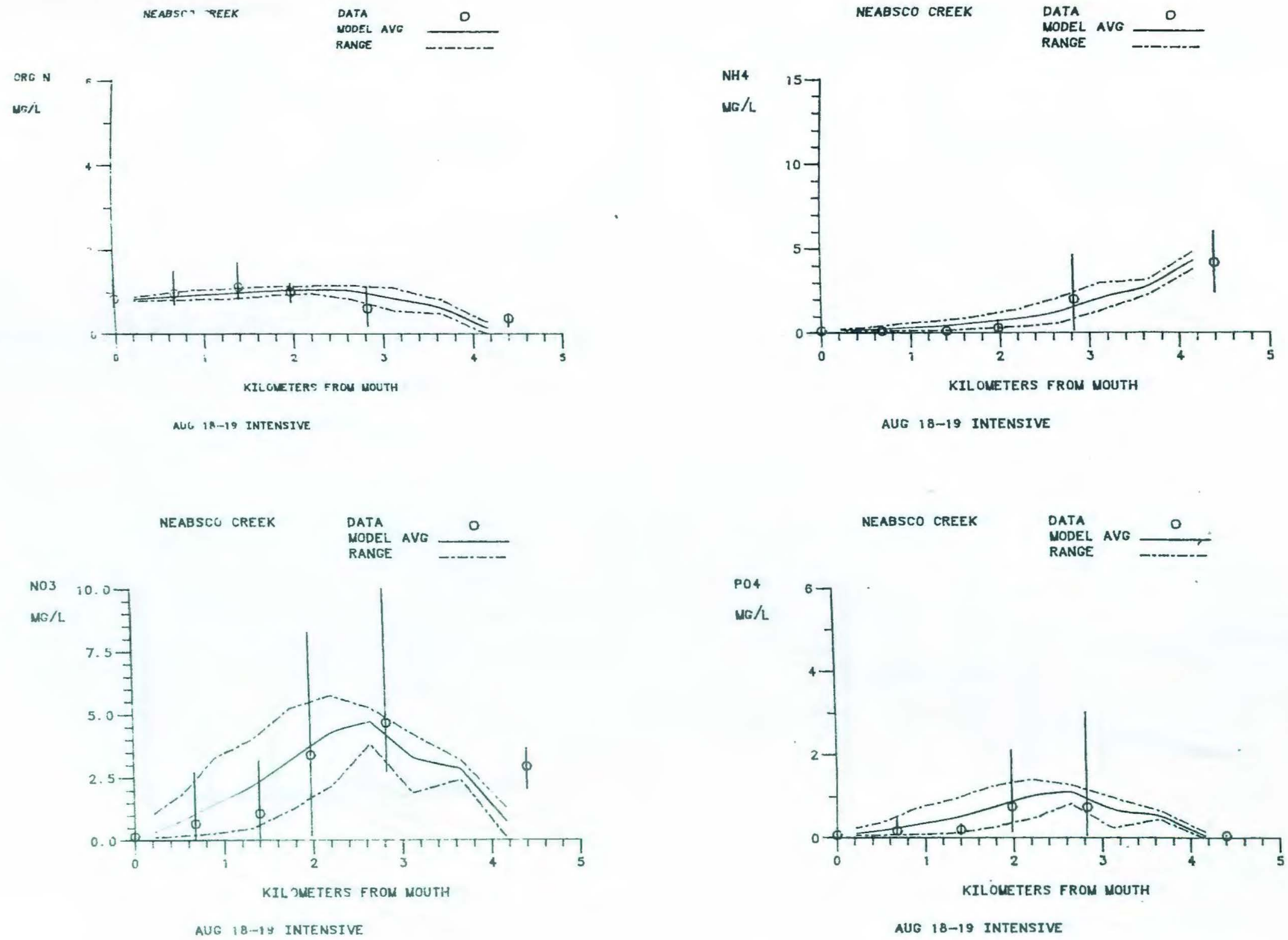


Figure 6-1. Model calibration results - nitrogen and orthophosphorus.

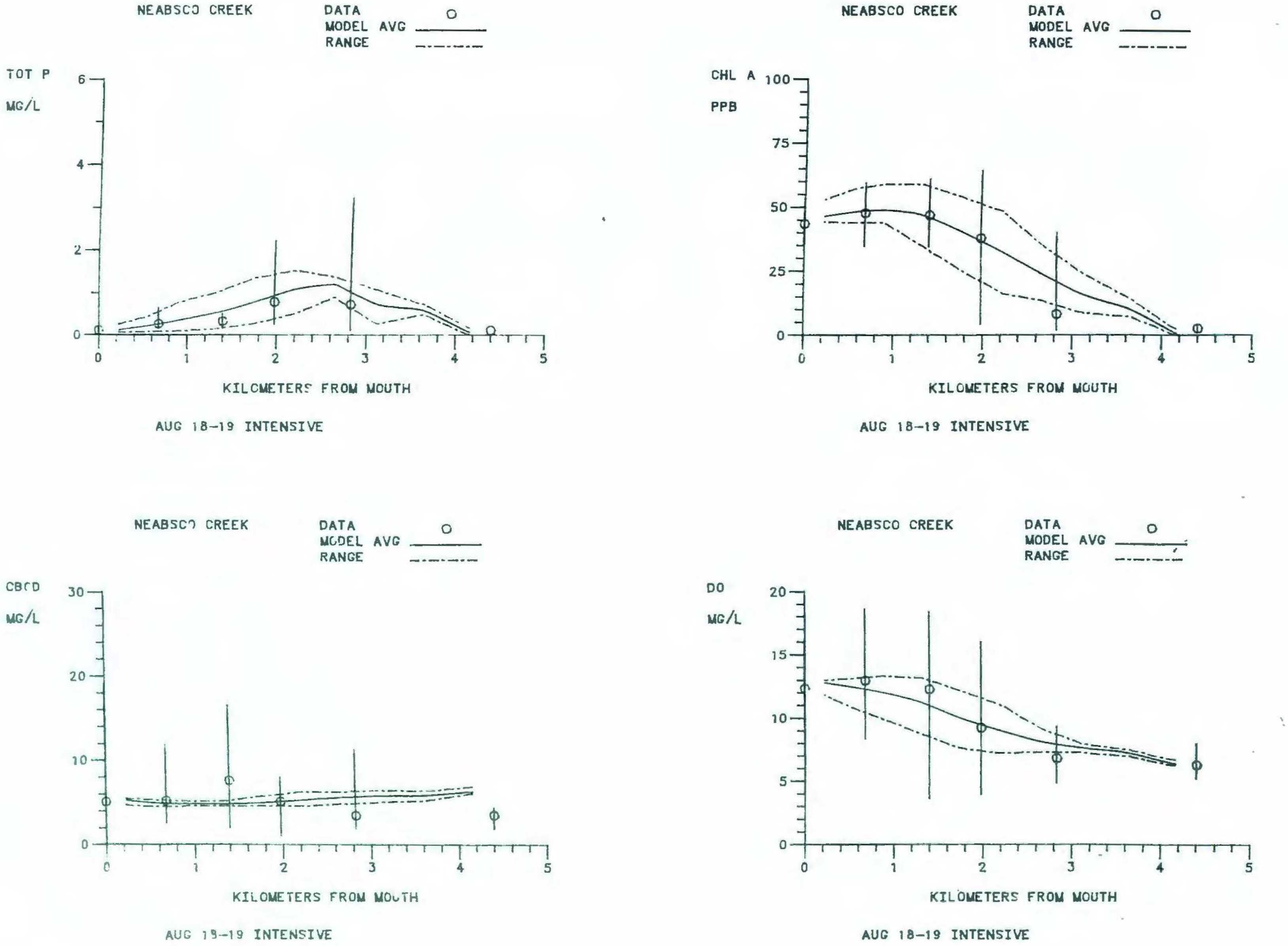


Figure 6-2. Model calibration results - total phosphorus, chlorophyll, CBOD and DO.

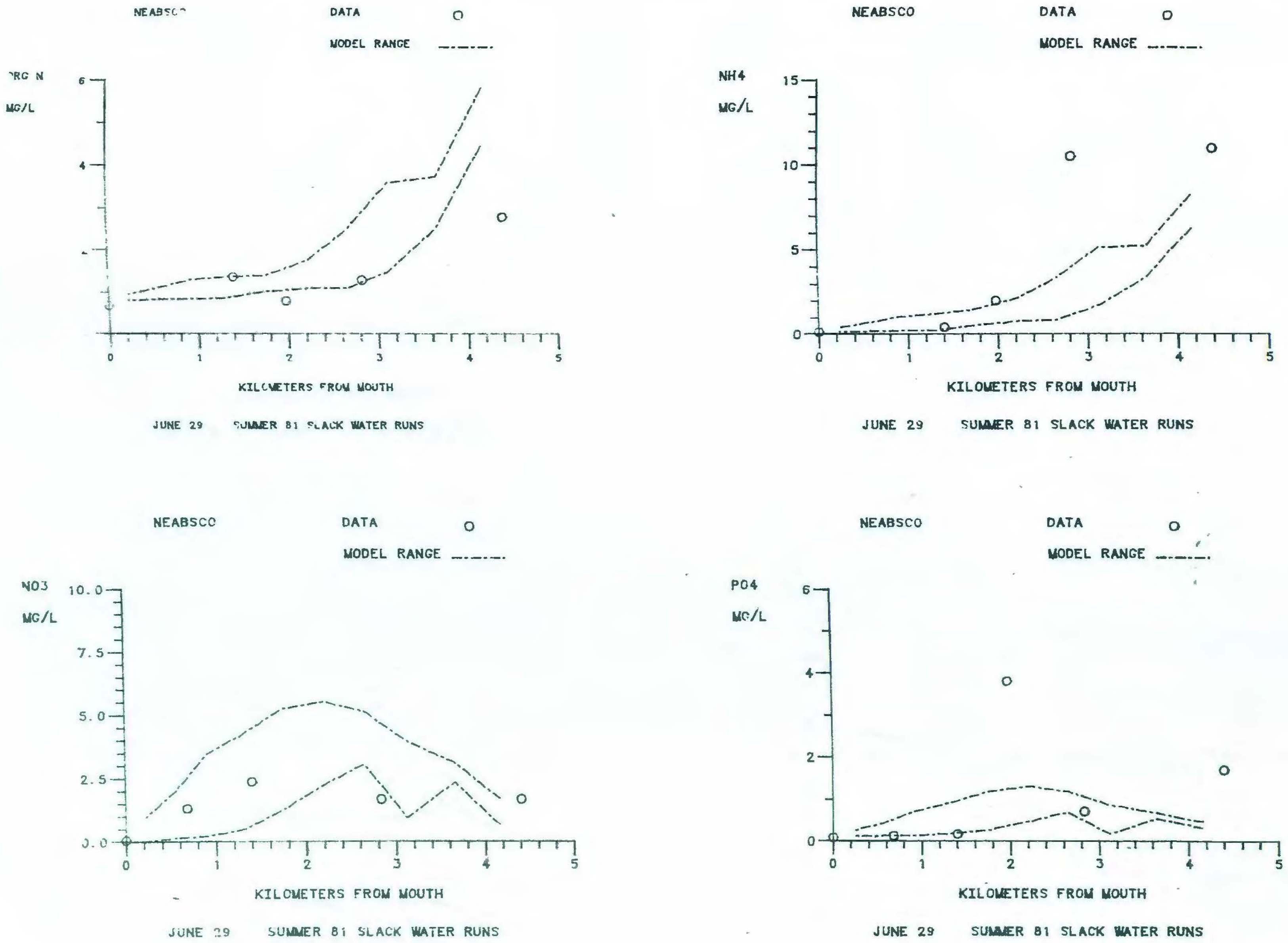
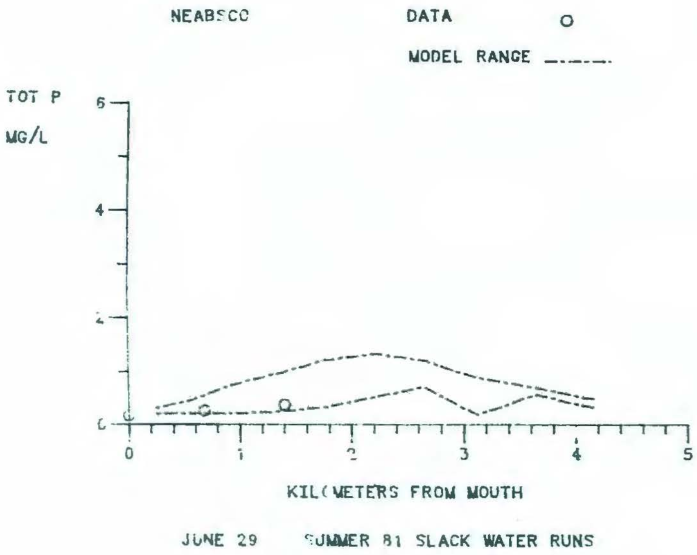
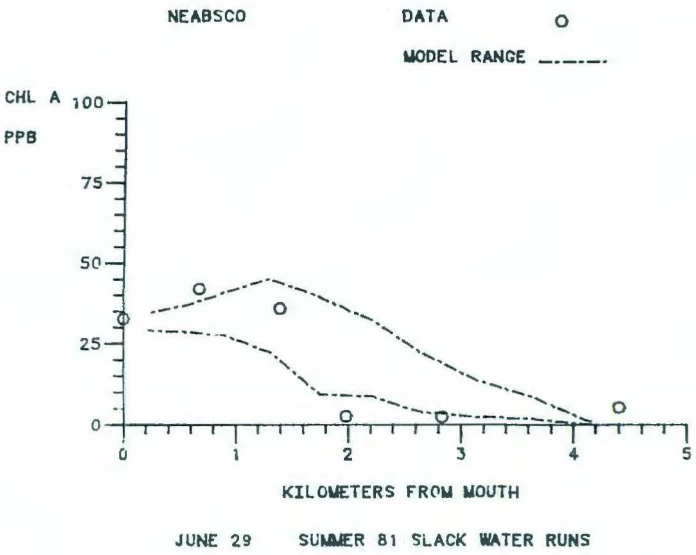
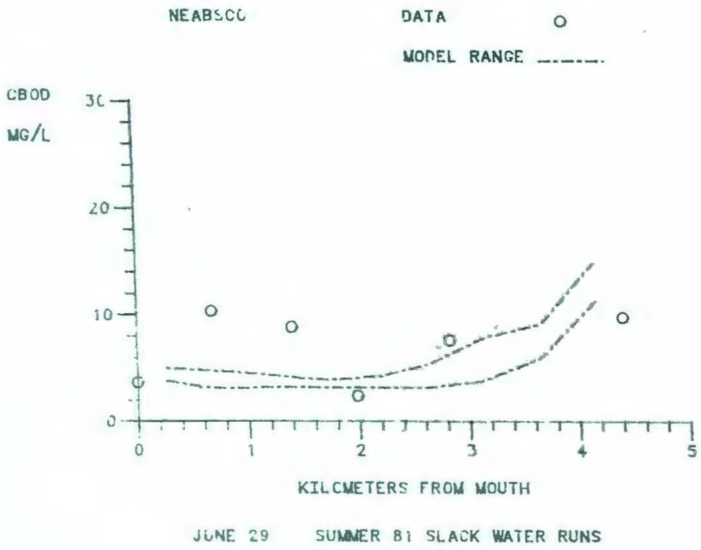
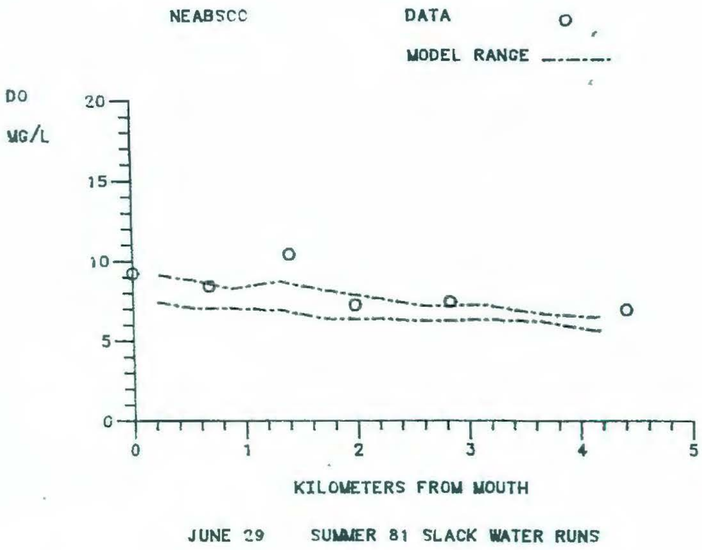


Figure 6-3. Water quality verification for June 29.


NEABSCO
DATA ○
MODEL RANGE
TOT P
MG/L
6
4
2
0
0
1
2
3
4
5
KILOMETERS FROM MOUTH
JUNE 29 SUMMER 81 SLACK WATER RUNS


NEABSCO
DATA ○
MODEL RANGE
CHL A
PPB
100
75
50
25
0
0
1
2
3
4
5
KILOMETERS FROM MOUTH
JUNE 29 SUMMER 81 SLACK WATER RUNS


NEABSCO
DATA ○
MODEL RANGE
CBOD
MG/L
30
20
10
0
0
1
2
3
4
5
KILOMETERS FROM MOUTH
JUNE 29 SUMMER 81 SLACK WATER RUNS


NEABSCO
DATA ○
MODEL RANGE
DO
MG/L
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15
10
5
0
0
1
2
3
4
5
KILOMETERS FROM MOUTH
JUNE 29 SUMMER 81 SLACK WATER RUNS

(Cont'd)

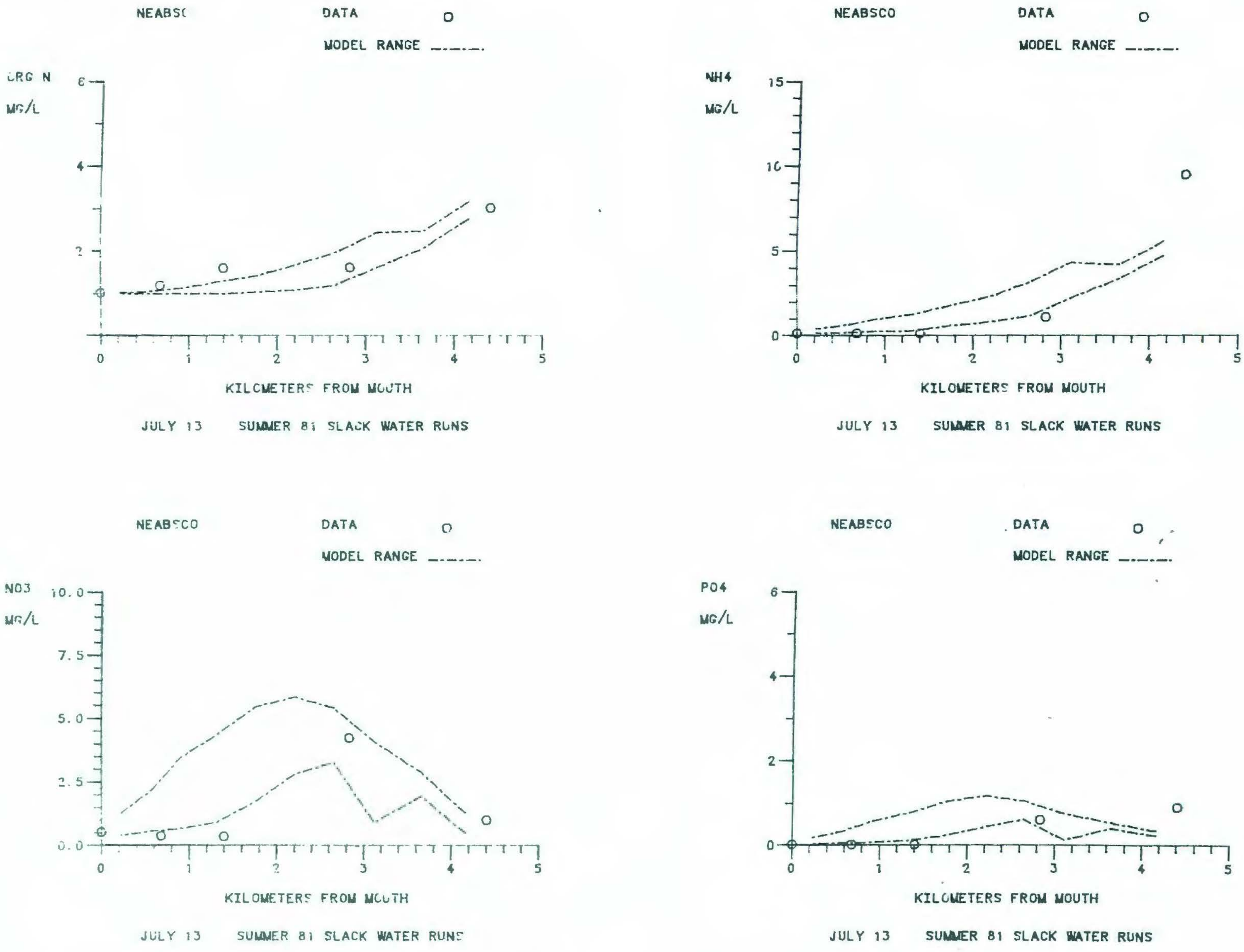
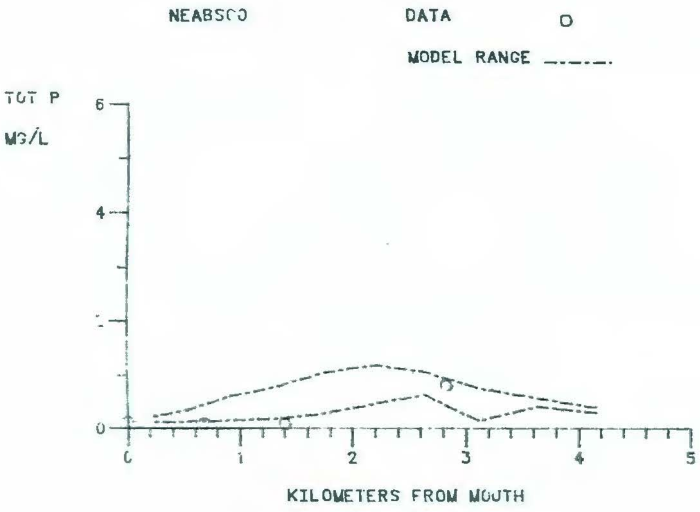
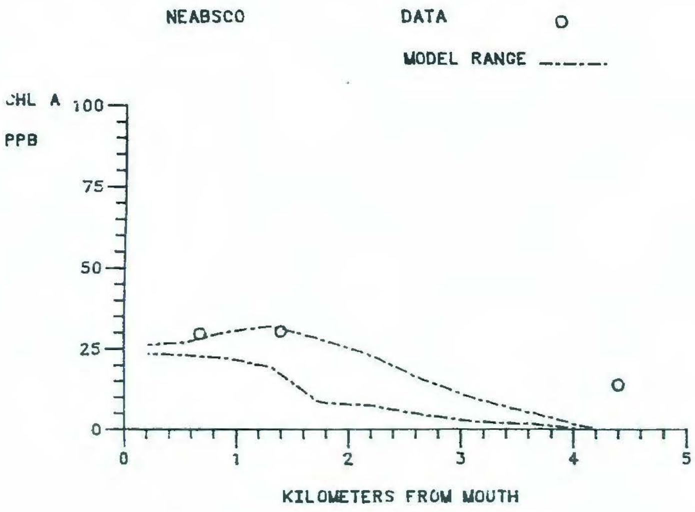


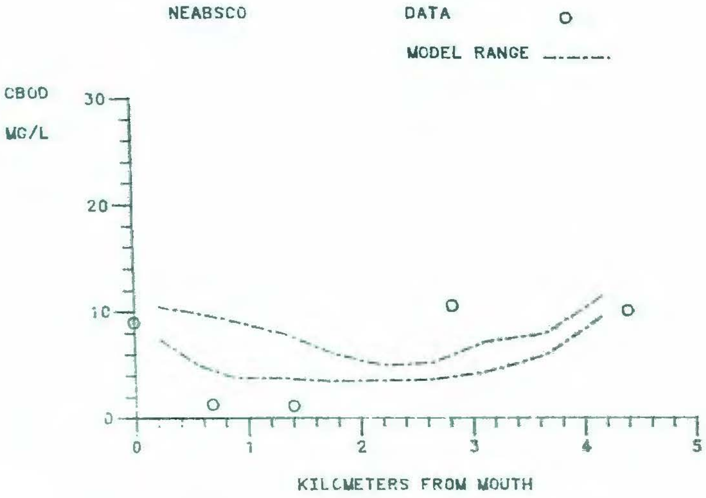
Figure 6-4. Water quality verification for July 13.



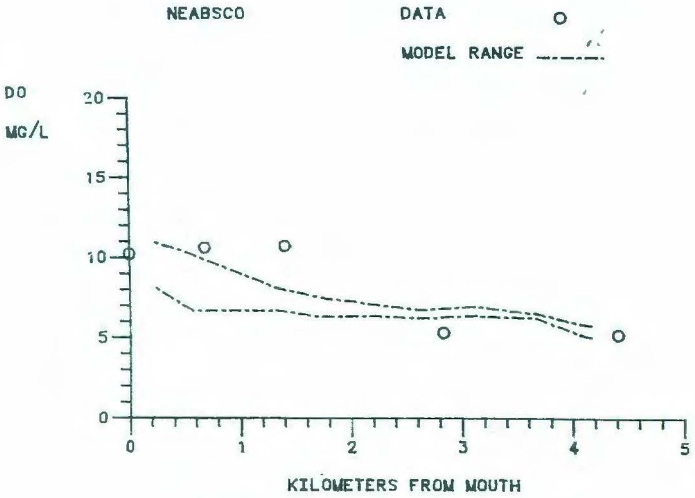
JULY 13 SUMMER 81 SLACK WATER RUNS



JULY 13 SUMMER 81 SLACK WATER RUNS



JULY 13 SUMMER 81 SLACK WATER RUNS



JULY 13 SUMMER 81 SLACK WATER RUNS

(Cont'd)

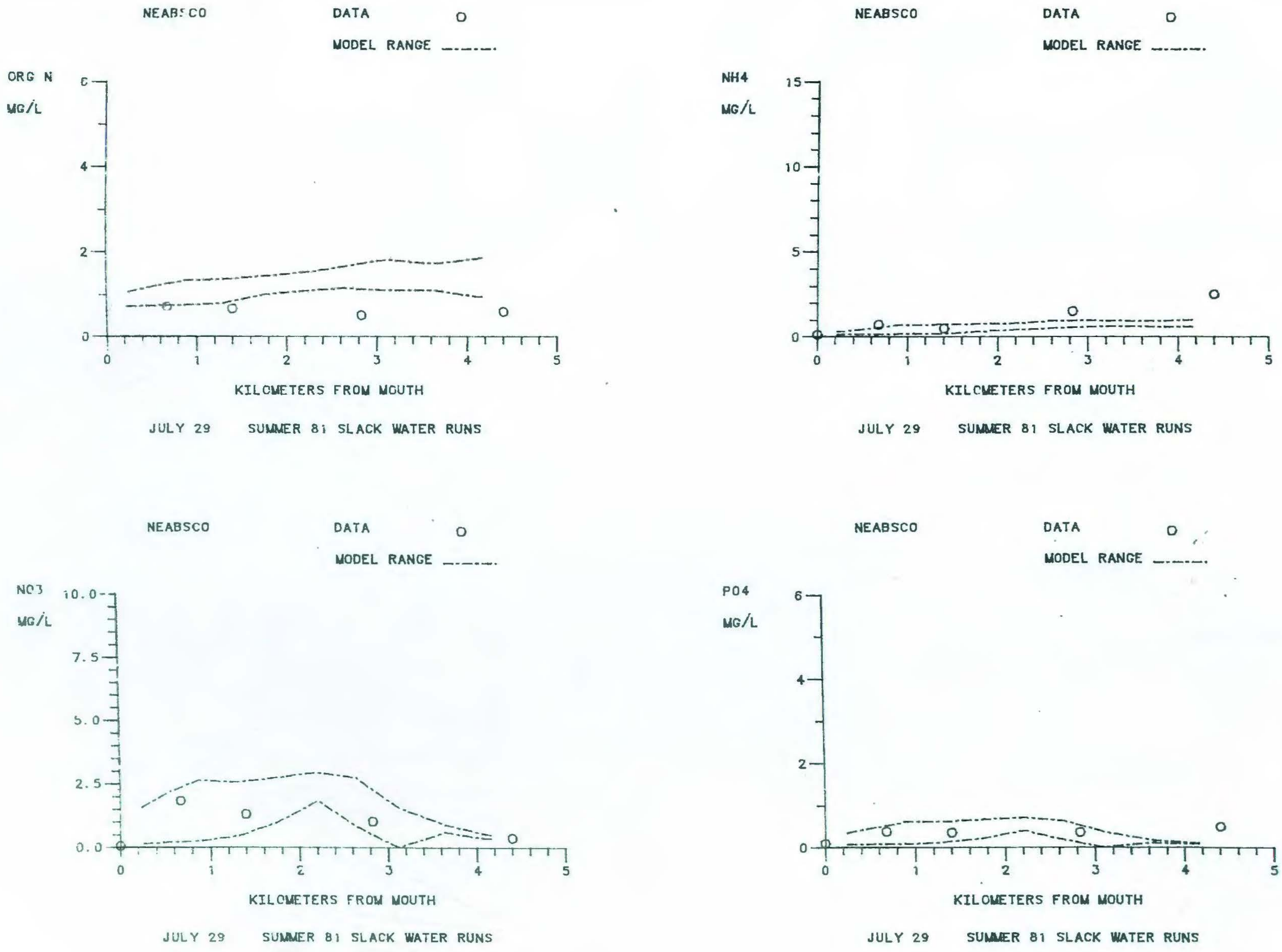
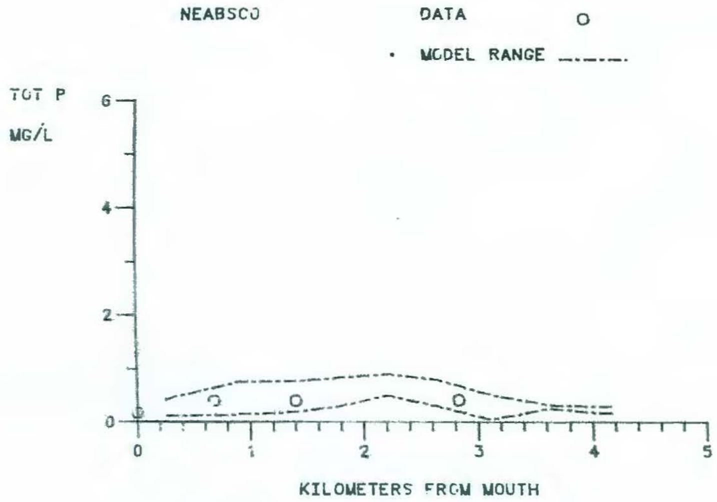
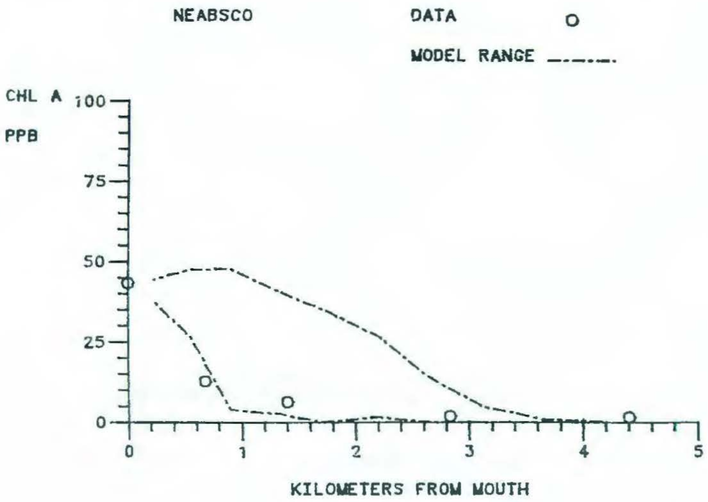


Figure 6-5. Water quality verification for July 29.



JULY 29 SUMMER 81 SLACK WATER RUNS



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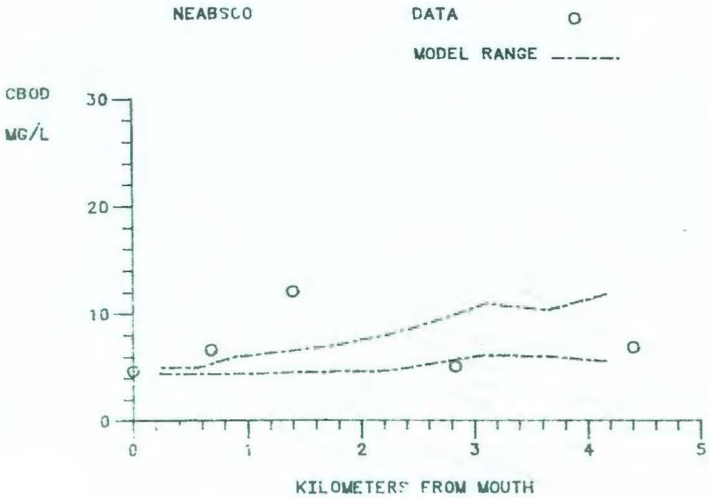
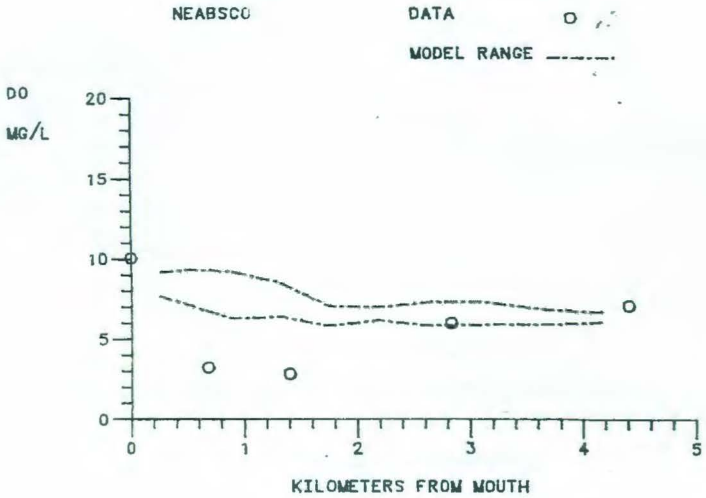


JULY 29 SUMMER 81 SLACK WATER RUNS



JULY 29 SUMMER 81 SLACK WATER RUNS

(Cont'd)

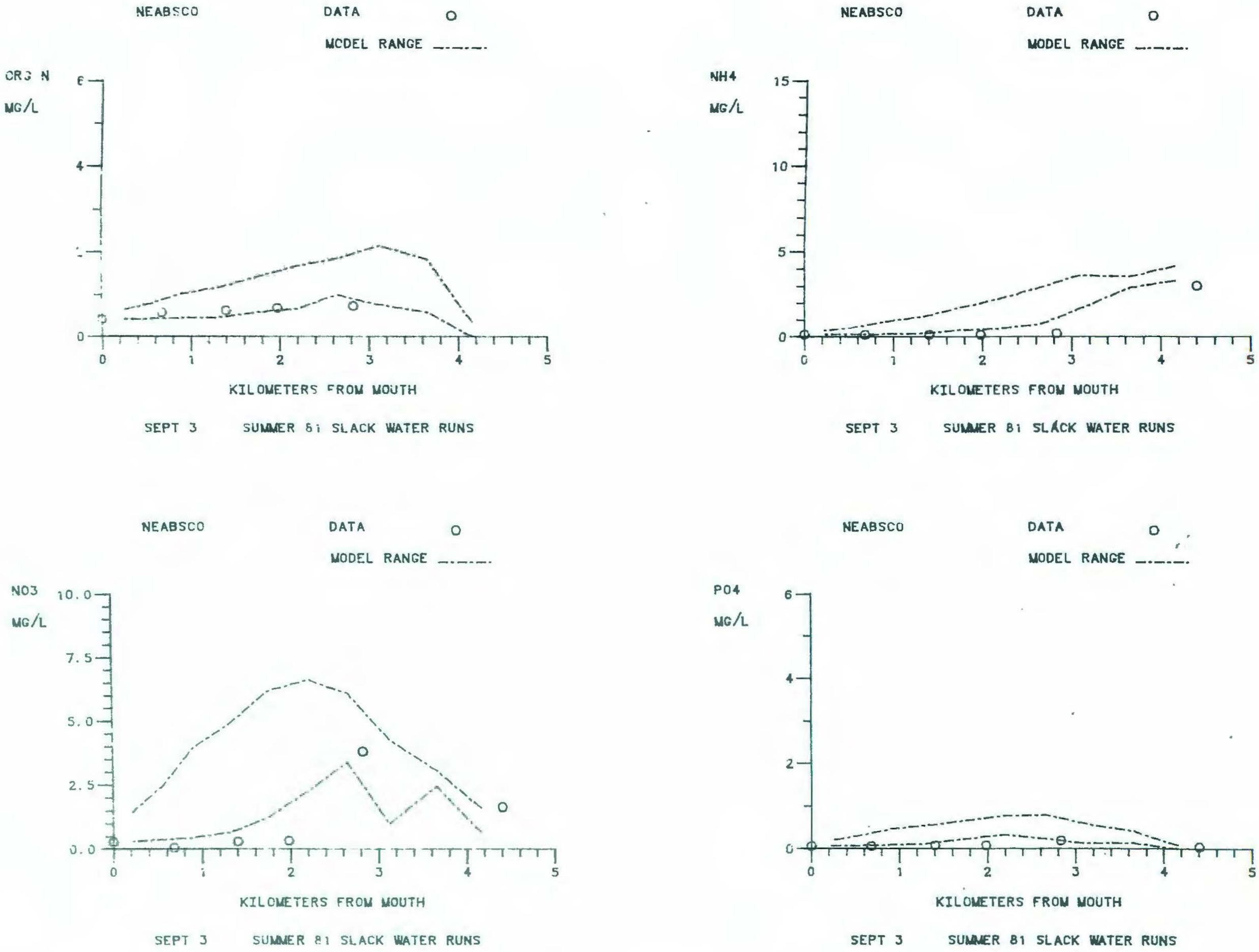
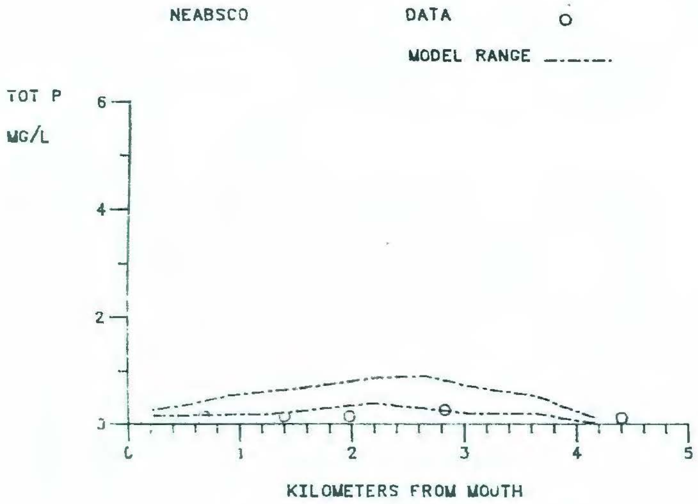
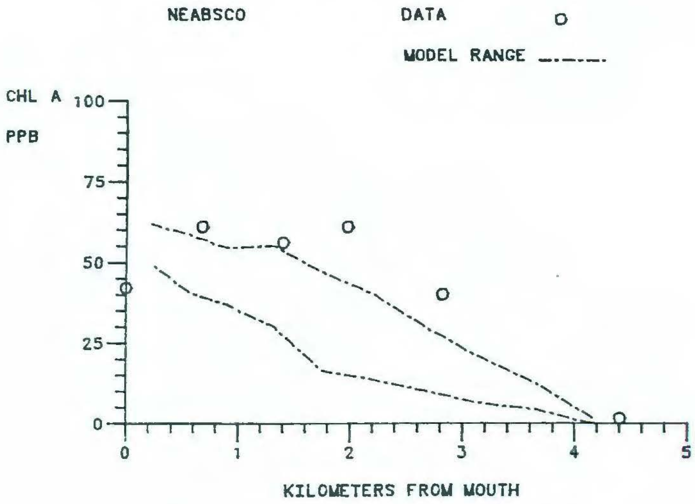


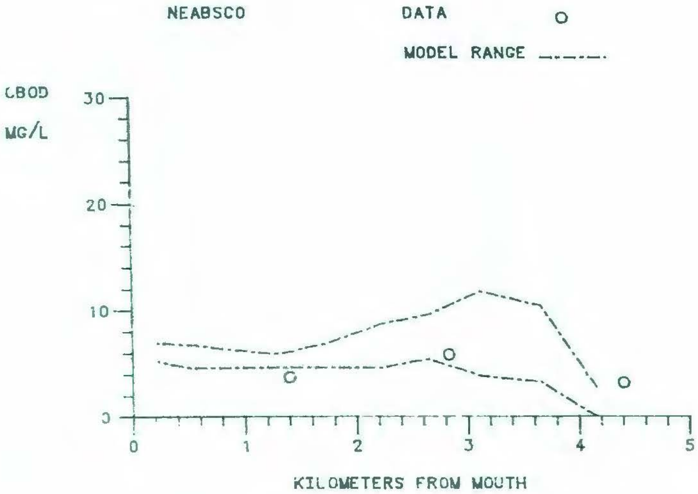
Figure 6-6. Water quality verification for September 3.



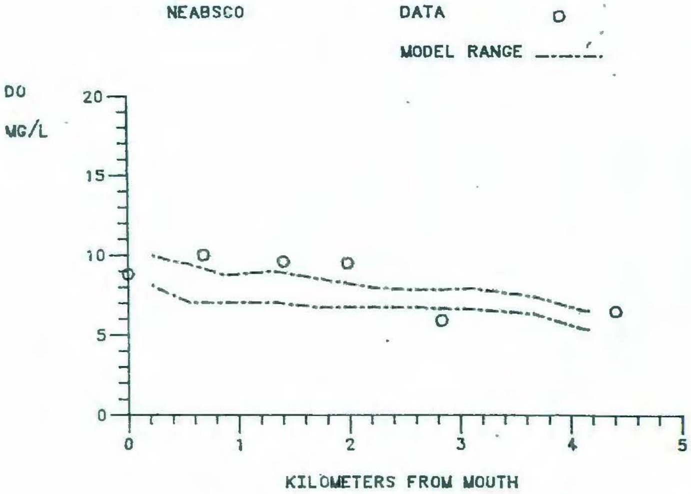
SEPT 3 SUMMER 81 SLACK WATER RUNS



SEPT 3 SUMMER 81 SLACK WATER RUNS



SEPT 3 SUMMER 81 SLACK WATER RUNS



SEPT 3 SUMMER 81 SLACK WATER RUNS

(Cont'd)

CHAPTER VII. SENSITIVITY ANALYSIS

Sensitivity analysis is the process in which the effects on model predictions of alterations in calibration or input parameters are examined. The first portion of the analysis herein is directed towards examining the sensitivity of the model to alterations in values of calibration parameters which are only approximately known or which vary in an unpredictable manner in the natural system. Parameters towards which the sensitivity of the model is tested include:

organic nitrogen hydrolysis rate,
ammonium nitrification rate,
organic phosphorus mineralization rate,
sediment oxygen demand,
sediment uptake of nitrate,
sediment ammonium release,
light extinction coefficient.

Sensitivity analysis can also be used as a tool to examine the processes which determine water quality in the natural system. Among the processes examined are:

effects of phosphorus point sources,
effects of nitrogen point sources,
effects of phosphorus boundary conditions,
effects of nitrogen boundary conditions,
effects of chlorophyll boundary conditions.

The sensitivity analysis is conducted by creating a standard set of model predictions based on average observed conditions and calibration parameters for the 1981 season. In successive model runs, a calibration parameter is altered and resulting predictions are compared to the standard set.

A. Sensitivity to Hydrolysis, Nitrification, and Mineralization.

Sensitivity of the model to organic nitrogen hydrolysis, ammonium nitrification, and organic phosphorus mineralization is evaluated by increasing and decreasing each of the rates by fifty percent. The extreme values tested represent the range over which the rates are expected to vary. The effects on both the initial substances and the end products of the reactions are minimal (Figures 7-1 to 7-3). The implication of these runs is that model results are not strongly dependent on the values of the rates arrived at through calibration.

B. Sensitivity to Sediment Oxygen Demand.

Sediment oxygen demand (SOD) employed in the model, 1.6 $gm/m^2/day$ at 20 °C, is in the mid-range of observations (0.8 to 2.6 $gm/m^2/day$ at 20 °C). Sensitivity to SOD is examined by increasing and decreasing SOD in the model by fifty percent. The extreme values examined approximate the extreme values observed. Results indicate dissolved oxygen (DO) varies as much as 2 to 3 mg/L as SOD is varied from minimum to maximum values (Figure 7-4). The implication of this analysis is that DO predictions may differ from observations by as much as 2 to 3 mg/L due to natural variability in SOD.

C. Sensitivity to Sediment Nitrate Uptake.

The model transfers nitrate from the water to the sediments through a first-order process mathematically equivalent to settling. The necessity of including this process is examined in a model run in which nitrate removal is set to zero. A run is also conducted in which the removal rate is doubled. Results indicate the sediments remove about 1 mg/L nitrate from the central portion of the creek (Figure 7-5). Comparison of these results with the model calibration (Figure 6-1) indicate nitrate predictions would be too high in the absence of loss to the sediments. Similar comparison indicates a substantial increase in the removal rate employed would result in nitrate predictions which are too low.

D. Sensitivity to Sediment Ammonium Release.

The model employs sediment ammonium release typical of values observed in sevral embayments (Table 3-2). Sensitivity to the release is examined in model runs in which release is doubled and eliminated. The extreme values alter predicted ammonium concentration by less than 0.5 mg/L (Figure 7-6). The calibration of the model is not strongly dependent on the ammonium release rate employed.

E. Sensitivity to Light Extinction Coefficient.

In the model, light extinction varies along the longitudinal axis of the creek but is temporally constant (Table 6-2). In Neabsco Creek, light extinction varies in time but sufficient information is not available to model the variability. The effects of assuming temporally constant light extinction are examined by increasing and decreasing extinction by twenty percent. Results indicate the predicted chlorophyll concentration is sensitive to the extinction coefficient employed (Figure 7-7). In particular, a twenty percent decrease in extinction results in a fifty percent increase in chlorophyll concentration. The prime implication of this finding is that discrepancies between predicted and observed chlorophyll may be largely attributed to variations in light extinction.

F. Sensitivity to Point-Source Phosphorus.

A model run was made in which point-source discharge of phosphorus to the creek was eliminated. Results indicate point sources contribute almost all the phosphorus observed in the creek (Figure 7-8). The chlorophyll concentration is little affected by phosphorus elimination, however. The implication is that the algal population observed in the creek may be supported by phosphorus sources other than point sources.

G. Sensitivity to Point-Source Nitrogen.

A model run was made in which point-source discharge of nitrogen to the creek was eliminated. Results indicate the point sources contribute almost all the ammonium and nitrate observed but little of the organic nitrogen (Figure 7-9). The chlorophyll concentration of the creek is more sensitive to elimination of nitrogen than phosphorus. The decrease in chlorophyll is only about ten percent of the concentration which prevails in the presence of point-source nitrogen, however.

H. Sensitivity to Phosphorus and Nitrogen Boundary Conditions.

Model runs were made in which phosphorus and nitrogen concentrations at the mouth of the creek were set to zero. Results of the runs are consistent with the sensitivity analyses of point sources. Elimination of the downstream sources of phosphorus, ammonium, and nitrate has little effect on concentration within the creek (Figures 7-10, 7-11). Elimination of the downstream source of organic nitrogen reduces concentration in the lower two kilometers, however (Figure 7-11).

I. Sensitivity to Chlorophyll Boundary Condition.

Sensitivity to the downstream chlorophyll boundary condition was examined by increasing and decreasing the chlorophyll concentration at the mouth of the creek by twenty percent. Results indicate the chlorophyll concentration in the lower two kilometers of the creek responds in direct proportion to alterations in the boundary condition (Figure 7-12). The implication of the analysis is that the chlorophyll concentration observed in Neabsco Creek is partially-dependent on the concentration which prevails outside the creek.

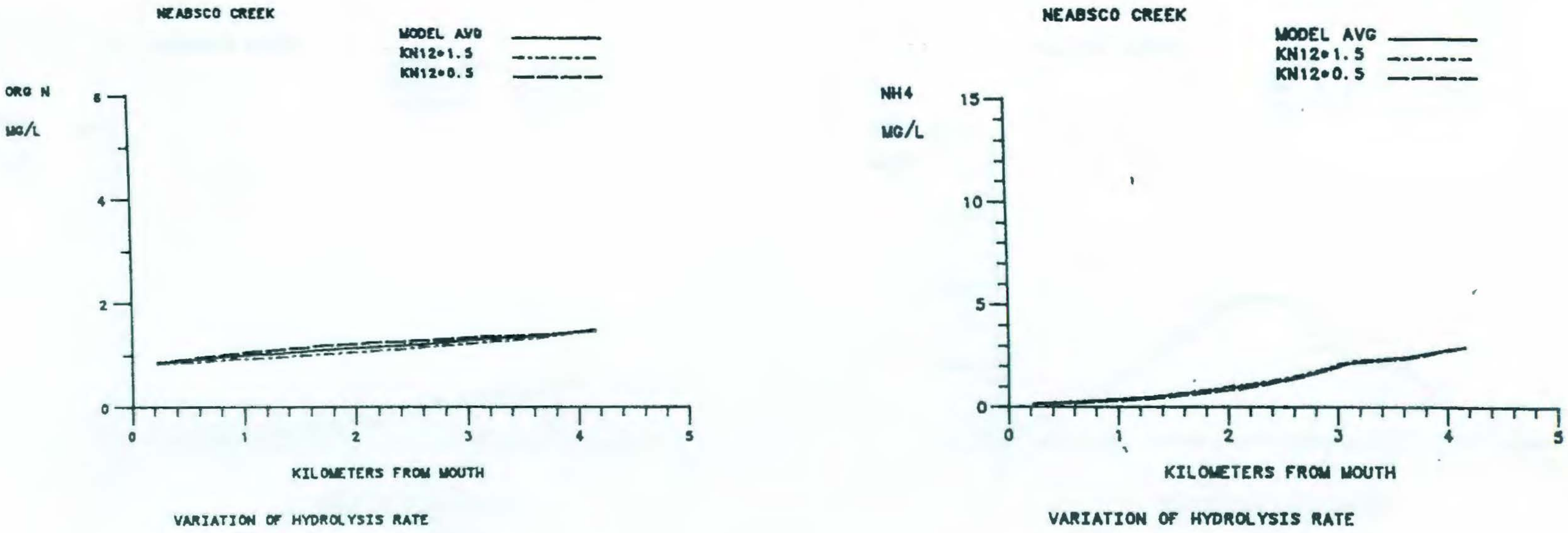


Figure 7-1. Effect on organic nitrogen and ammonia of increasing or decreasing hydrolysis rate.

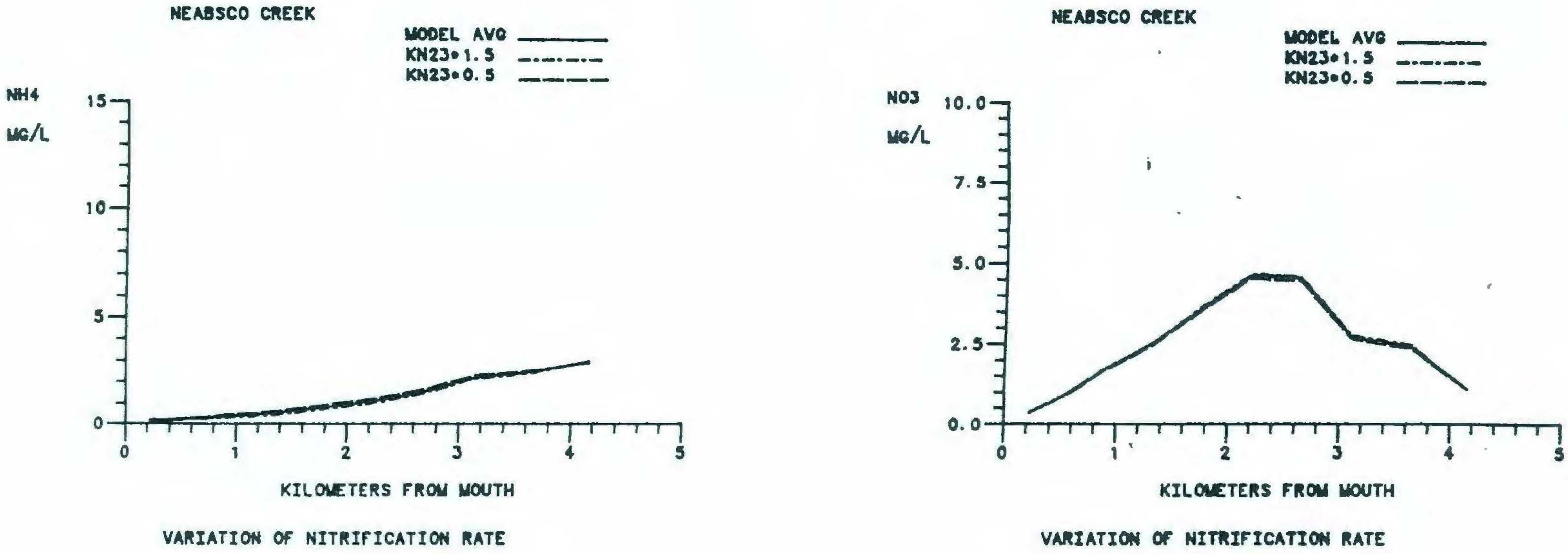


Figure 7-2. Effect on ammonia and nitrate plus nitrite of increasing or decreasing nitrification rate.

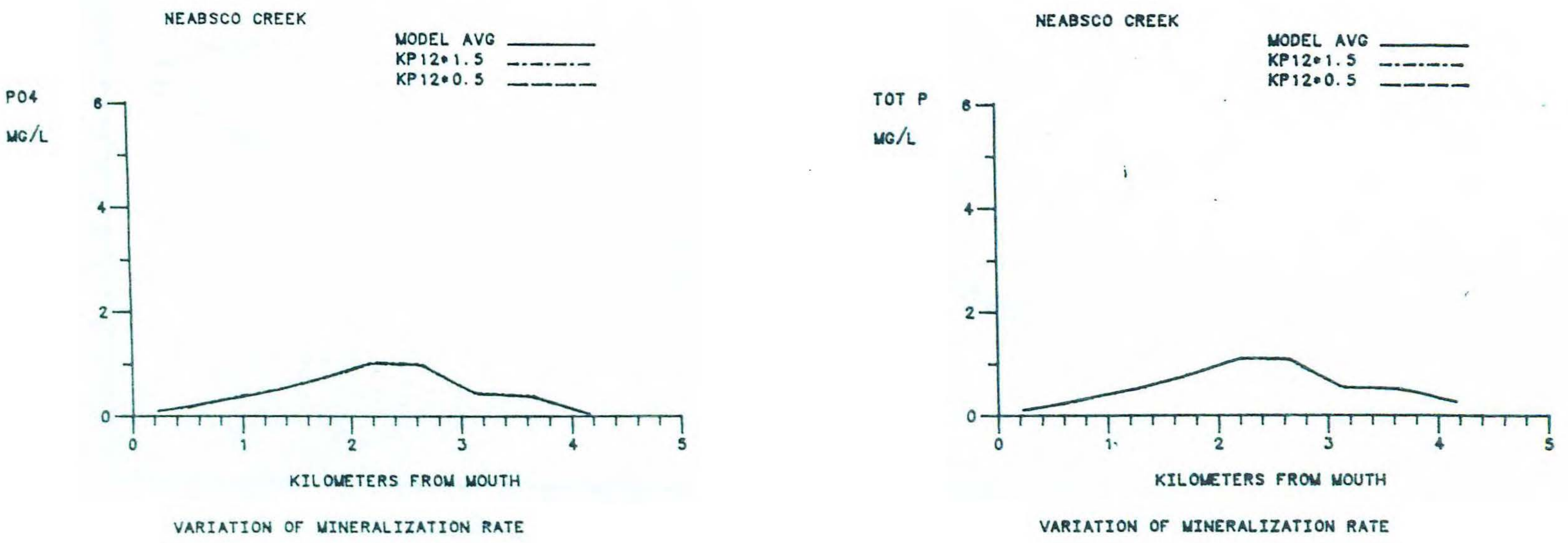


Figure 7-3. Effect on phosphorus components of increasing or decreasing mineralization rate.

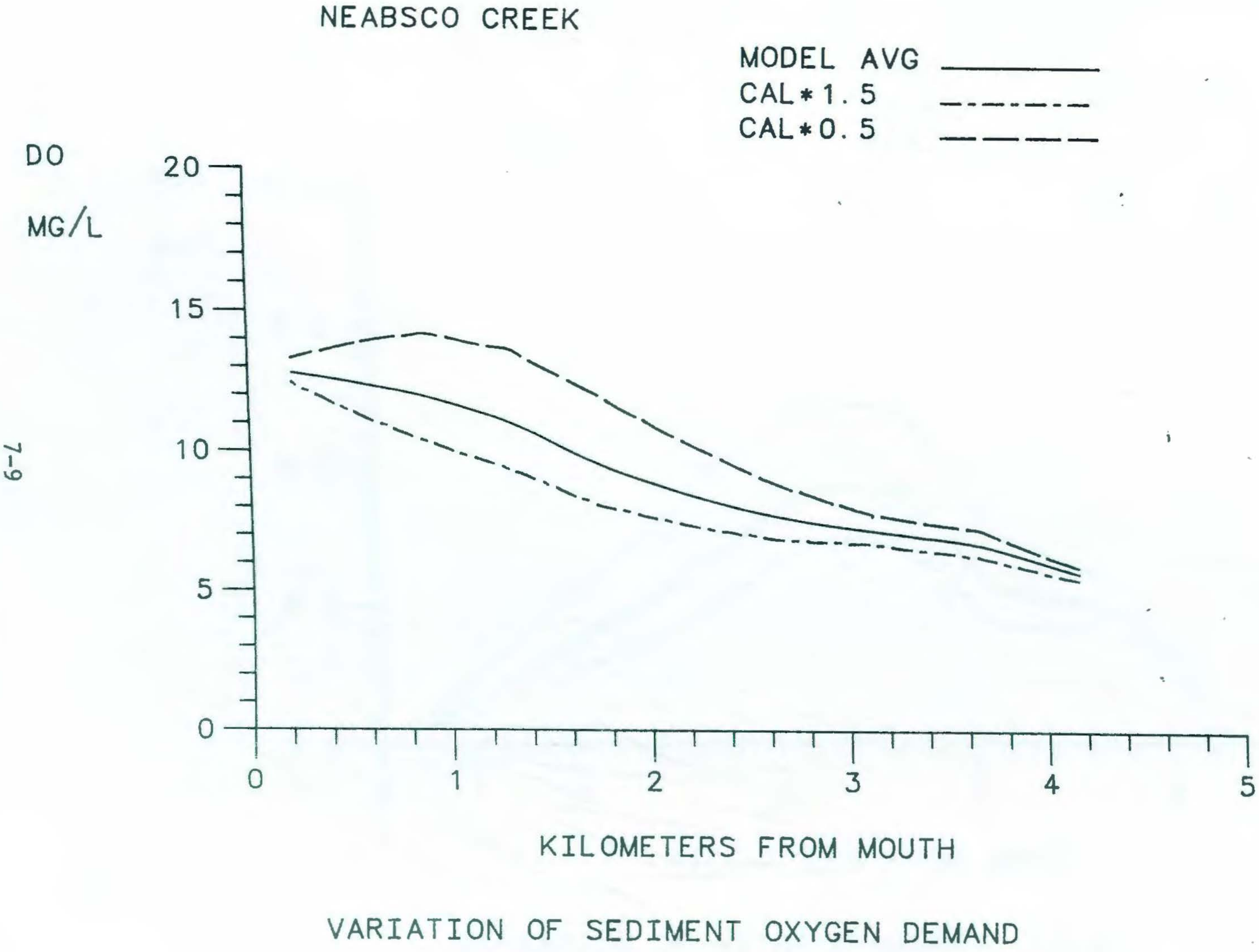


Figure 7-4. Effect on dissolved oxygen of increasing or decreasing the sediment oxygen demand.

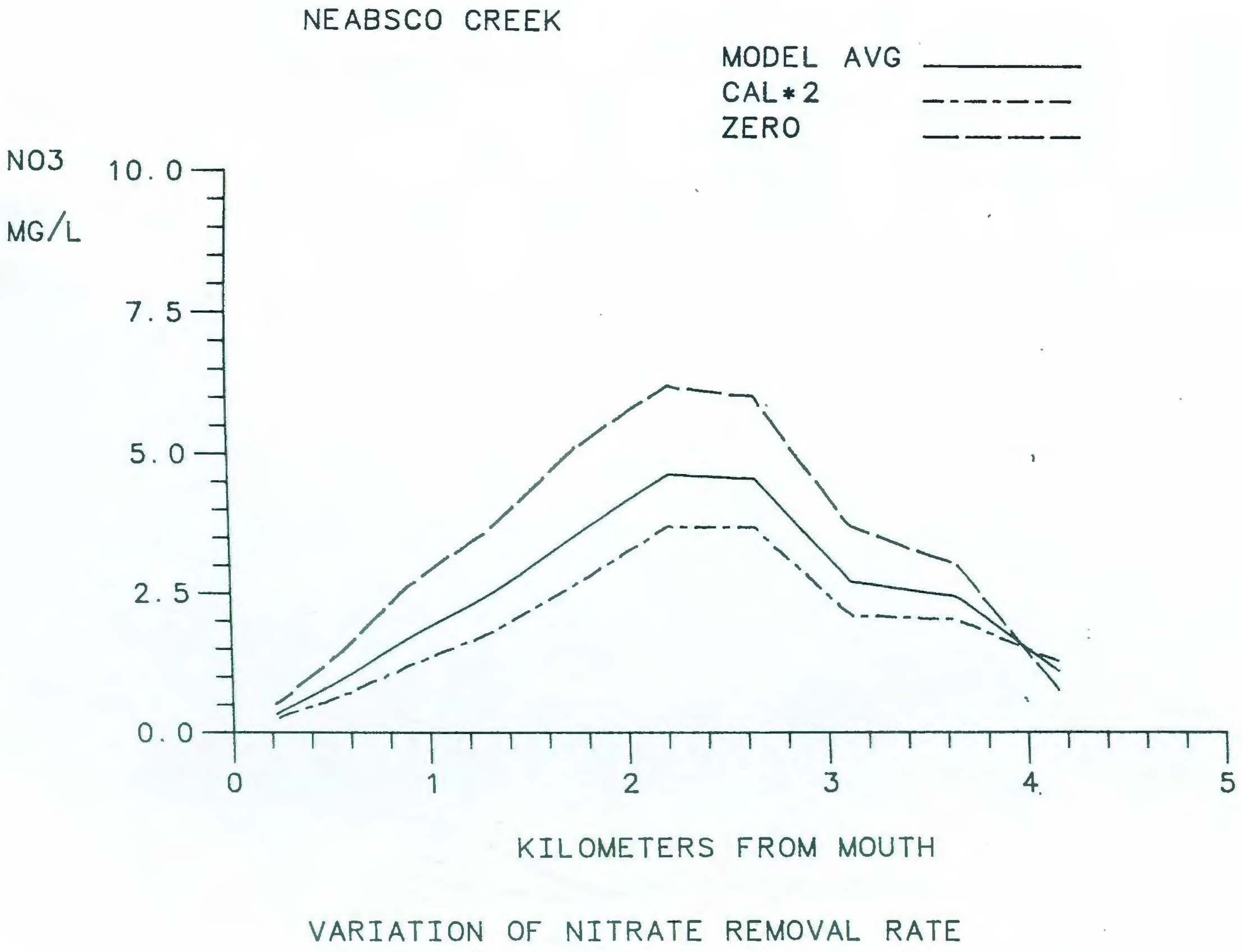


Figure 7-5. Effect on nitrate plus nitrite of increasing or decreasing nitrate removal rate.

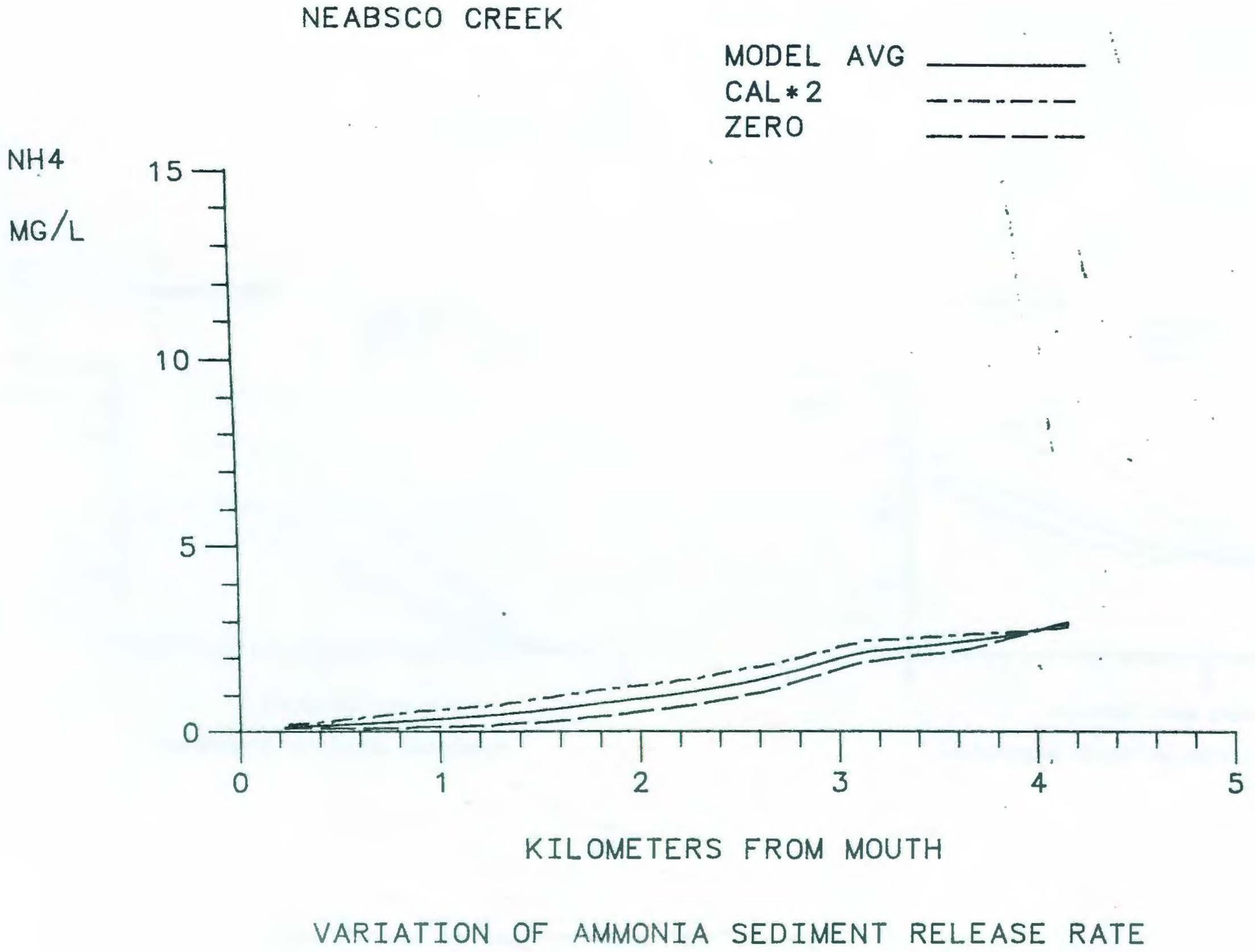


Figure 7-6. Effect on ammonia of increasing or decreasing ammonia sediment release rate.

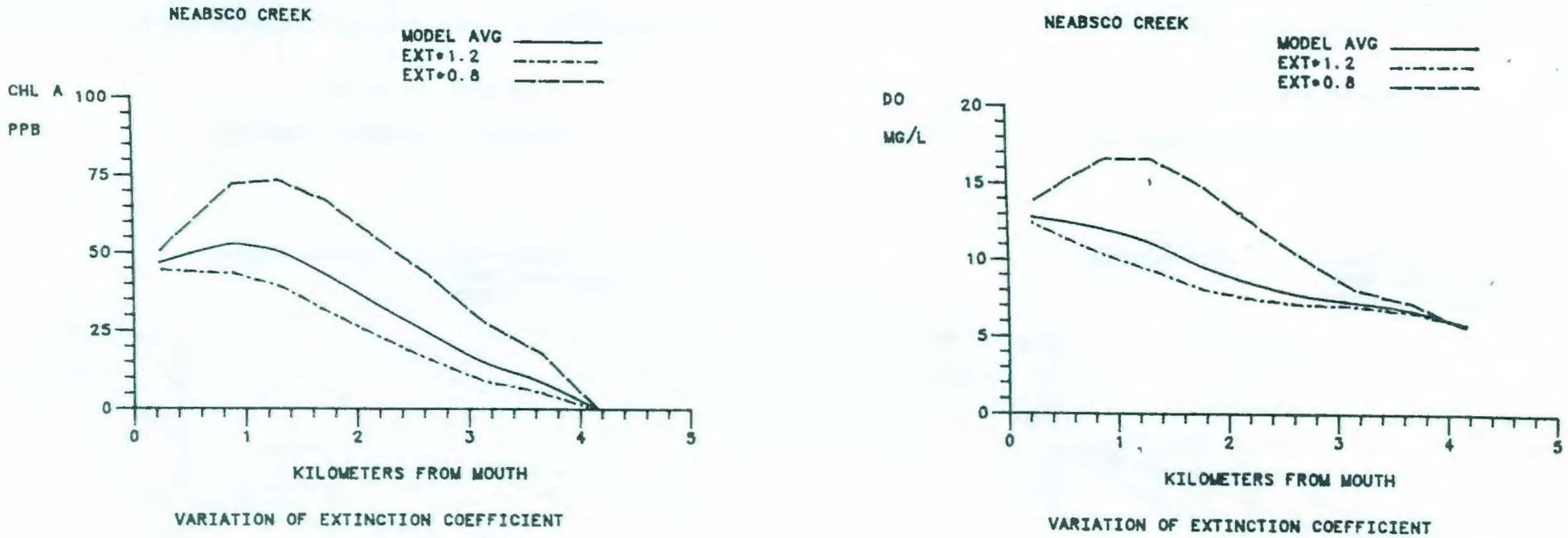


Figure 7-7. Sensitivity to increasing or decreasing extinction coefficient.

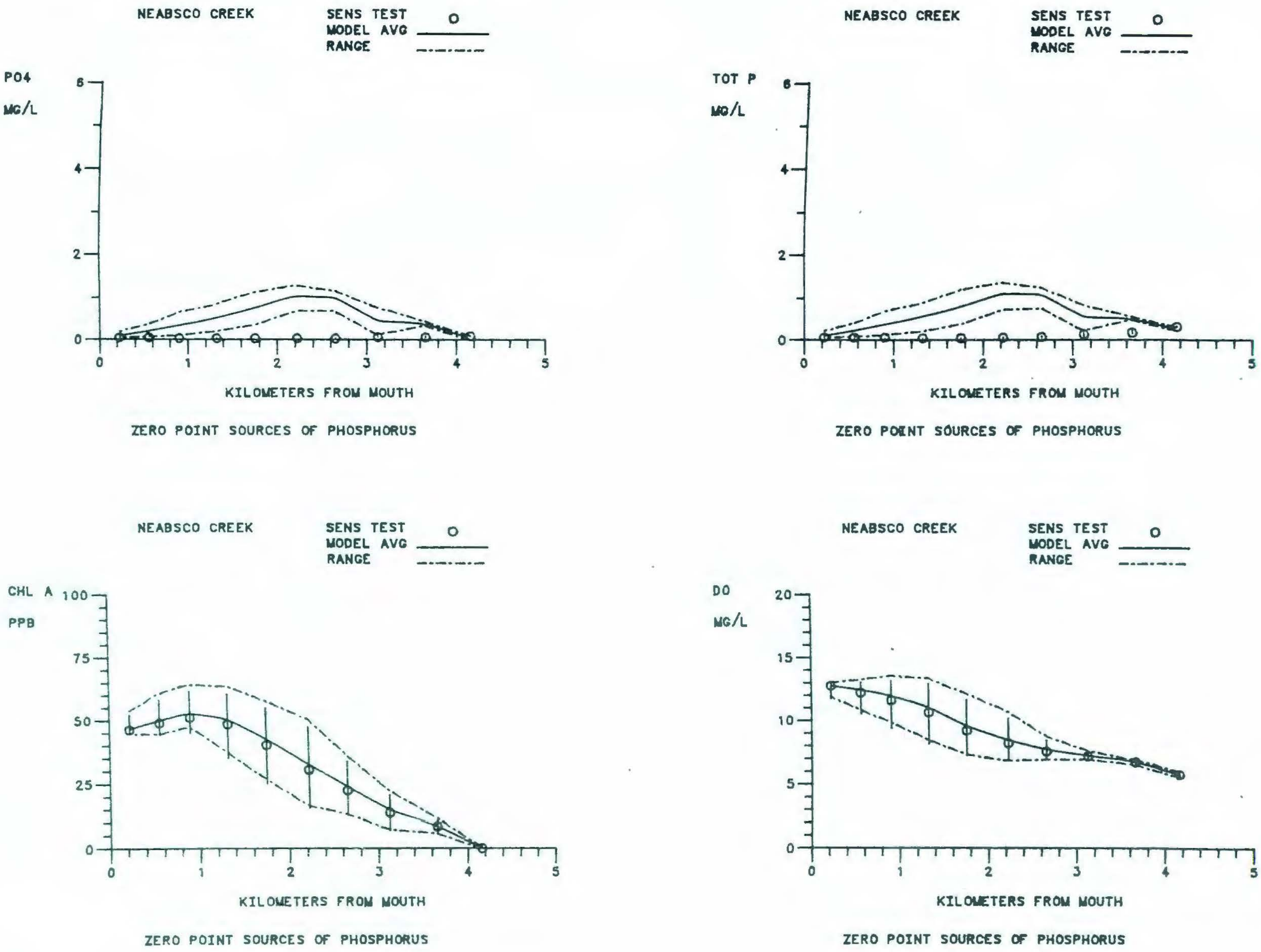


Figure 7-8. Water quality model response to elimination of phosphorus point sources.

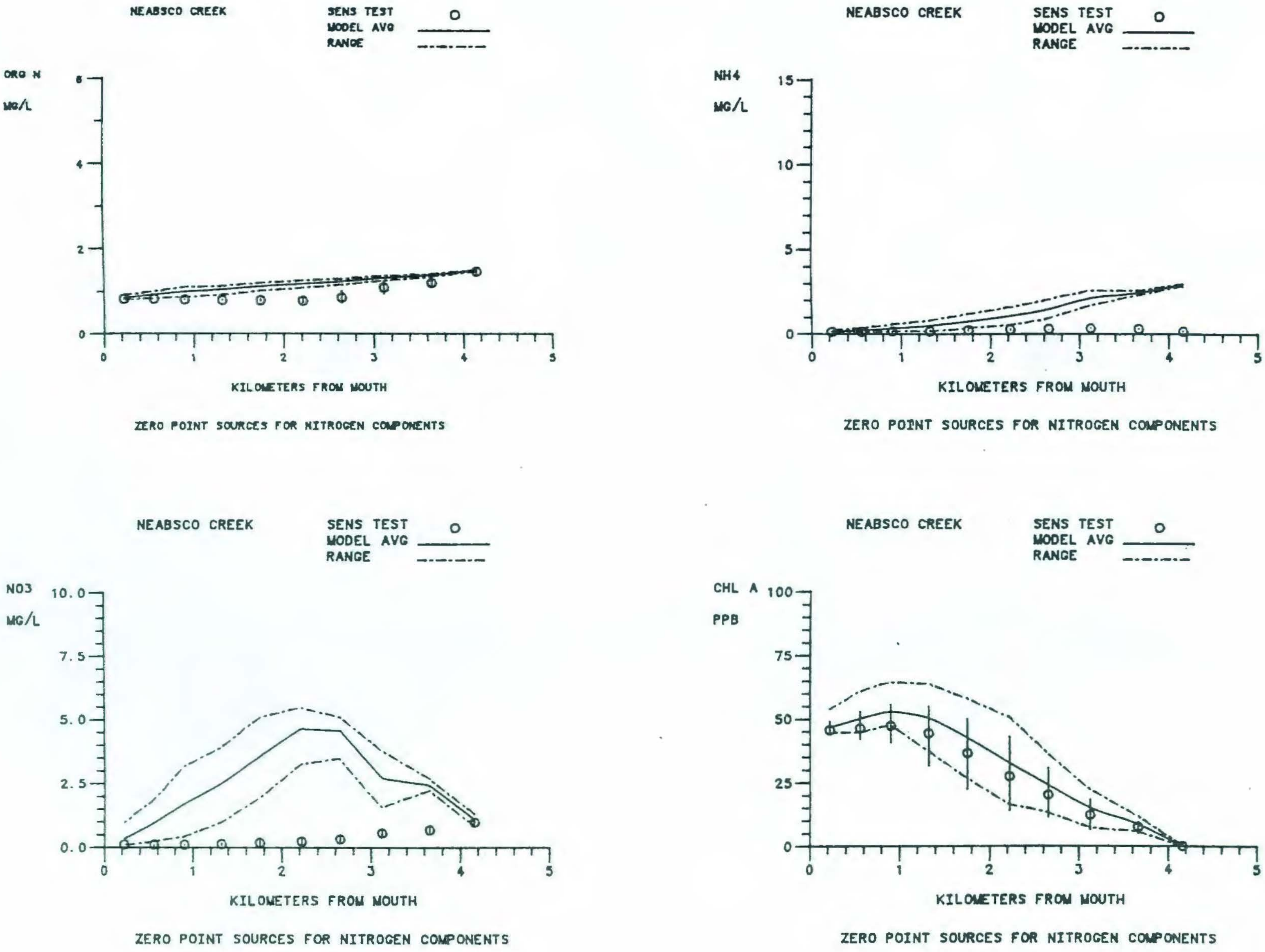


Figure 7-9. Water quality model response to elimination of nitrogen point sources.

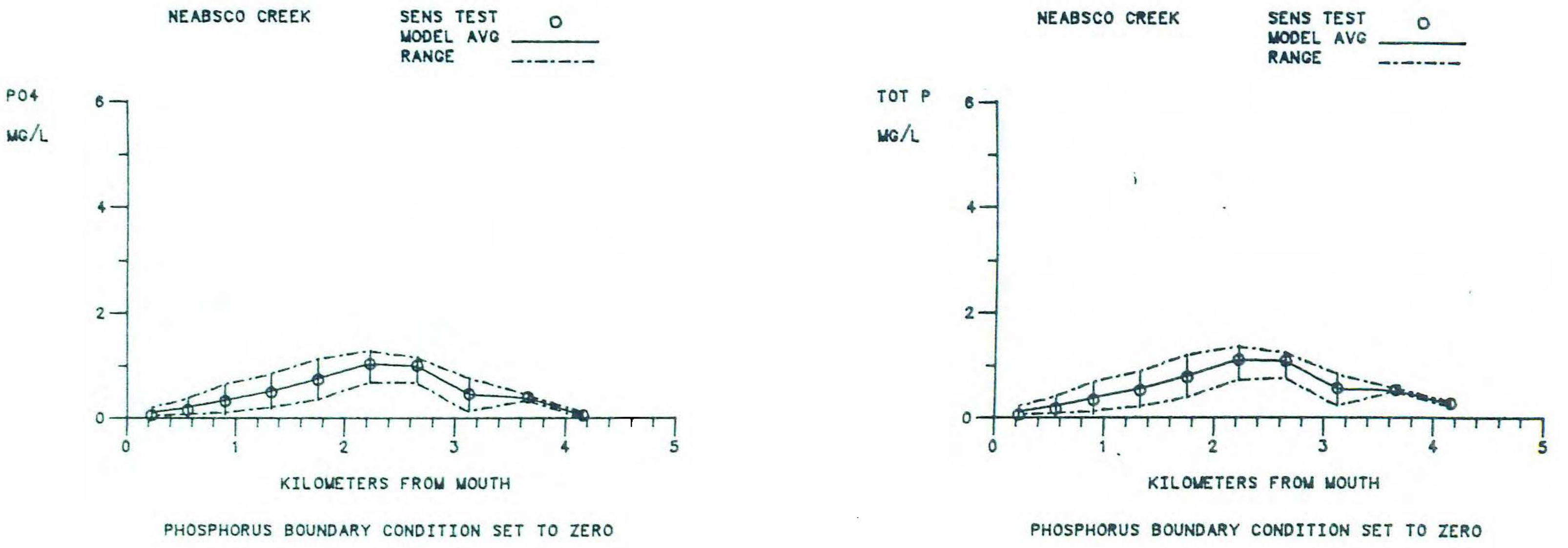


Figure 7-10. Effect on phosphorus components of setting downstream boundary conditions to zero.

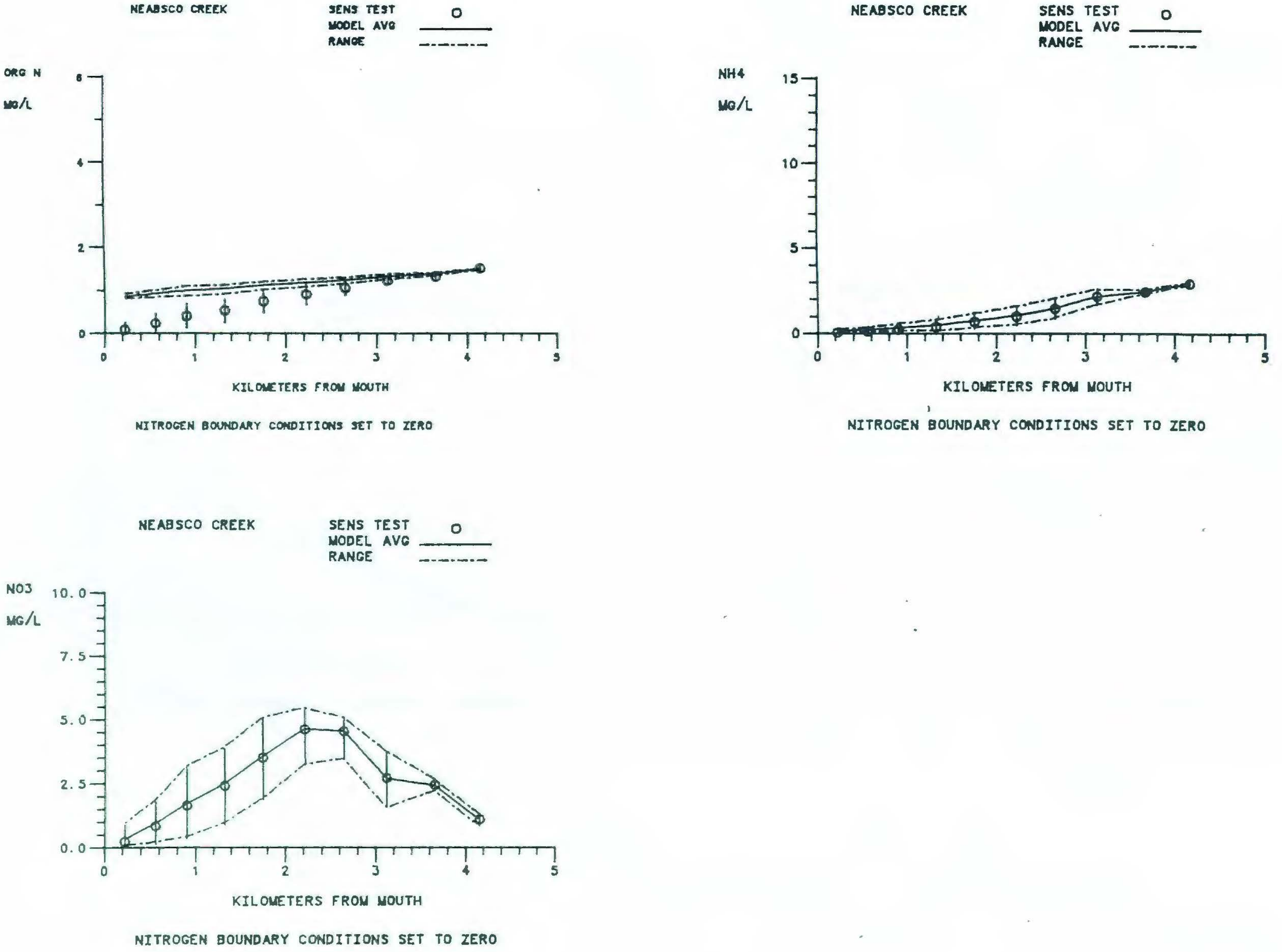


Figure 7-11. Effect on nitrogen components of setting downstream boundary conditions to zero.

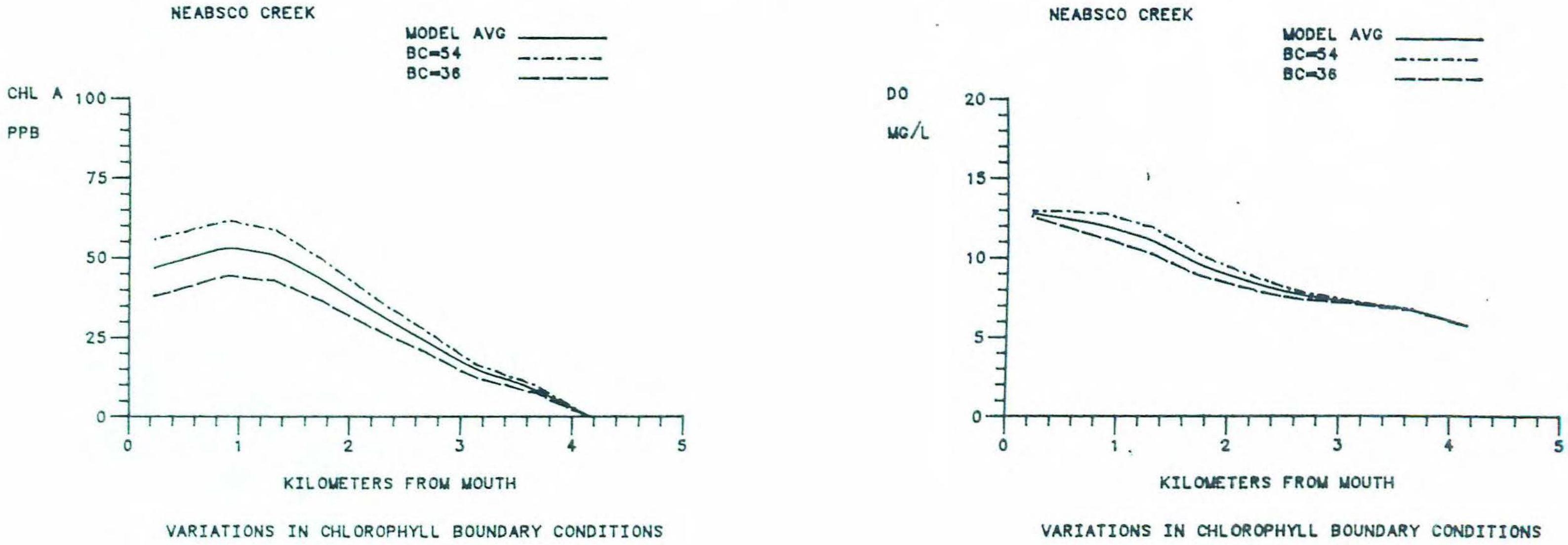


Figure 7-12. Sensitivity to increasing or decreasing chlorophyll boundary conditions.

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Appendix A. Water Quality Observations

Table A-1

Water Quality Data from August 1981 Intensive survey

1

Orgn mg/1	NH3 mg/1	NO2,3 mg/1	ORGP mg/1	PO4 mg/1	CHLA ug/1	BODU mg/1	DOXY mg/1	TEMP C	SECD cm	FLOW cfs	pH	TIME EST	STA	DATE
0.76	0.10	0.06	0.08	0.07	49.25	2.96	7.90	23.5	30	999.	999.	07:59	N1	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	42.98	-9.00	9.50	23.6	24	999.	10.0	09:00	N1	18-08-81
0.74	0.10	0.26	0.00	0.06	36.72	18.32	4.00	24.5	30	999.	999.	10:08	N1	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	33.05	-9.00	9.40	25.7	33	999.	9.6	11:02	N1	18-08-81
0.85	0.10	0.27	0.01	0.05	35.21	2.27	11.60	25.8	33	999.	999.	12:00	N1	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	47.95	-9.00	13.80	25.8	30	999.	10.0	13:04	N1	18-08-81
0.93	0.10	0.06	0.09	0.06	53.21	3.33	14.20	25.6	30	999.	999.	14:10	N1	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	38.02	-9.00	14.60	26.2	21	999.	10.0	15:00	N1	18-08-81
1.30	0.10	0.06	0.05	0.05	-9.00	13.62	14.20	26.0	30	999.	999.	15:59	N1	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	47.52	-9.00	15.90	26.4	27	999.	10.0	17:01	N1	18-08-81
0.77	0.10	0.10	0.01	0.04	47.66	2.13	14.40	26.3	24	999.	999.	18:04	N1	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	39.53	-9.00	15.50	26.3	999.	999.	10.0	19:10	N1	18-08-81
0.85	0.10	0.06	0.01	0.05	35.64	4.45	15.00	26.0	999.	999.	999.	19:56	N1	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	33.26	-9.00	14.20	25.9	999.	999.	999.	21:05	N1	18-08-81
0.65	0.10	0.19	0.02	0.04	35.64	2.18	12.20	27.5	999.	999.	999.	22:00	N1	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	36.72	-9.00	12.60	27.1	999.	999.	999.	23:00	N1	18-08-81
0.75	0.10	0.19	-0.00	0.05	50.32	-0.66	12.20	27.1	999.	999.	999.	23:55	N1	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	52.10	-9.00	13.80	27.1	999.	999.	999.	01:00	N1	19-08-81
1.00	0.10	0.06	0.10	0.06	43.20	0.72	12.30	27.1	999.	999.	999.	01:55	N1	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	44.28	-9.00	13.10	27.1	999.	999.	999.	02:55	N1	19-08-81
0.82	0.10	0.29	0.06	0.09	53.65	0.97	12.90	27.1	999.	999.	999.	04:00	N1	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	50.99	-9.00	12.20	27.1	999.	999.	999.	05:00	N1	19-08-81
0.84	0.10	0.17	-0.00	0.06	52.10	-1.00	11.10	27.1	21	999.	999.	05:55	N1	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	50.99	-9.00	11.20	27.1	18	999.	8.0	06:55	N1	19-08-81
0.82	0.10	0.07	0.09	0.07	40.39	2.40	11.20	27.1	21	999.	999.	07:50	N1	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	37.15	-9.00	11.60	27.1	21	999.	9.5	09:00	N1	19-08-81
0.74	0.20	0.07	0.00	0.06	37.15	4.16	11.40	27.1	18	999.	999.	09:45	N1	19-08-81
0.80	0.10	0.19	0.08	0.08	42.98	3.20	9.30	23.8	23	999.	999.	08:25	N2	18-09-81
-9.00	-9.00	-9.00	-9.00	-9.00	43.42	-9.00	9.50	23.9	24	999.	10.0	09:06	N2	18-08-81
0.88	0.10	0.13	0.08	0.07	46.22	2.37	12.80	24.3	27	999.	999.	10:15	N2	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	37.15	-9.00	14.40	25.0	30	999.	10.0	11:08	N2	18-08-81
0.94	0.10	0.06	0.05	0.10	51.19	5.88	15.50	25.5	23	999.	999.	12:06	N2	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	16.00	24.9	24	999.	10.0	13:11	N2	18-08-81

Orgn mg/l	NH3 mg/l	NO2,3 mg/l	ORGP mg/l	PO4 mg/l	CHLA ug/l	BODU mg/l	DOXY mg/l	TEMP C	SECD cm	FLOW cfs	pH	TIME EST	STA	DATE
1.07	0.10	2.71	0.15	0.50	47.52	6.58	14.20	25.0	21	999.	999.	14:16	N2	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	46.11	-9.00	14.90	25.3	21	999.	999.	15:06	N2	18-08-81
1.40	0.10	1.80	0.15	0.25	-9.00	6.69	14.00	25.6	21	999.	999.	16:07	N2	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	54.00	-9.00	18.60	26.6	18	999.	999.	17:08	N2	18-08-81
0.88	0.10	0.18	0.04	0.10	59.41	4.32	16.40	26.2	18	999.	999.	18:11	N2	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	34.56	-9.00	15.80	26.3	999.	999.	999.	19:20	N2	18-08-81
0.79	0.10	0.10	0.10	0.06	44.93	4.84	15.30	26.0	999.	999.	999.	20:16	N2	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	52.10	-9.00	14.20	25.8	999.	999.	999.	21:10	N2	18-08-81
0.71	0.10	0.10	0.10	0.06	41.69	3.23	14.10	27.5	999.	999.	999.	22:10	N2	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	43.85	-9.00	14.90	27.1	999.	999.	999.	23:10	N2	18-08-81
0.70	0.10	0.15	0.05	0.09	56.53	-1.82	13.60	27.1	999.	999.	999.	00:00	N2	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	53.21	-9.00	12.60	27.1	999.	999.	999.	01:10	N2	19-08-81
1.12	0.10	1.77	0.06	0.39	53.65	-1.28	9.60	27.1	999.	999.	999.	02:00	N2	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	46.44	-9.00	8.30	27.1	999.	999.	999.	03:00	N2	19-08-81
1.50	0.10	1.40	0.12	0.28	-9.00	11.15	8.50	27.1	999.	999.	999.	04:10	N2	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	58.08	-9.00	11.30	27.1	999.	999.	999.	05:08	N2	19-08-81
1.19	0.10	0.35	0.11	0.15	44.06	2.78	11.10	27.1	24	999.	999.	06:05	N2	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	50.32	-9.00	11.50	27.1	18	999.	9.0	07:05	N2	19-08-81
0.88	0.10	0.21	0.05	0.10	46.01	3.97	11.40	27.1	24	999.	999.	08:00	N2	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	48.17	-9.00	11.40	27.1	21	999.	8.5	09:05	N2	19-08-81
0.92	0.10	0.10	0.09	0.07	40.61	3.43	11.00	27.0	21	999.	999.	10:05	N2	19-08-81
0.92	0.10	0.12	0.05	0.10	54.00	2.53	9.10	23.6	24	999.	999.	08:30	N3	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	49.03	-9.00	10.40	23.6	24	999.	10.0	09:12	N3	18-08-81
0.86	0.10	0.06	0.07	0.08	48.17	3.20	13.00	24.0	24	999.	999.	10:23	N3	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	54.00	-9.00	15.00	24.6	24	999.	10.0	11:17	N3	18-08-81
1.70	0.10	1.11	0.19	0.21	-9.00	11.83	14.80	24.4	21	999.	999.	12:15	N3	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	46.01	-9.00	11.80	24.2	18	999.	7.8	13:20	N3	18-08-81
1.06	0.10	3.15	0.14	0.33	34.13	5.22	10.20	24.5	15	999.	999.	14:27	N3	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	34.99	-9.00	13.40	25.9	18	999.	8.8	15:18	N3	18-08-81
1.00	0.10	2.25	0.11	0.25	42.55	7.39	15.80	26.7	12	999.	999.	16:17	N3	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	15.80	26.0	12	999.	9.6	17:16	N3	18-08-81
1.05	0.10	0.60	0.07	0.18	50.11	6.30	18.40	26.1	18	999.	999.	18:19	N3	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	49.68	-9.00	17.00	26.0	999.	999.	999.	19:27	N3	18-08-81
0.97	0.10	0.08	0.15	0.10	47.52	8.20	16.90	25.9	999.	999.	999.	20:26	N3	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	50.54	-9.00	16.90	25.8	999.	999.	999.	21:17	N3	18-08-81
0.87	0.10	0.06	0.07	0.08	46.44	1.76	15.10	27.0	999.	999.	999.	22:20	N3	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	53.87	-9.00	16.80	27.1	999.	999.	999.	23:20	N3	18-08-81
1.40	0.10	0.80	0.26	0.24	-9.00	10.14	13.50	27.1	999.	999.	999.	00:10	N3	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	42.12	-9.00	7.20	27.1	999.	999.	999.	01:20	N3	19-08-81

Orgn mg/l	NH3 mg/l	NO2,3 mg/l	ORGP mg/l	PO4 mg/l	CHLA ug/l	BODU mg/l	DOXY mg/l	TEMP C	SECD cm	FLOW cfs	pH	TIME EST	STA	DATE
1.24	0.20	3.06	0.13	0.33	37.69	3.02	5.10	27.1	999.	999.	999.	02:15	N3	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	47.52	-9.00	3.60	27.1	999.	999.	999.	03:15	N3	19-08-81
1.50	0.10	2.12	0.17	0.23	-9.00	8.45	4.40	27.1	999.	999.	999.	04:20	N3	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	42.55	-9.00	9.20	27.1	999.	999.	999.	05:15	N3	19-08-81
1.27	0.10	0.85	0.10	0.25	47.52	1.61	11.00	27.1	12	999.	999.	06:15	N3	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	60.97	-9.00	11.00	27.1	9	999.	999.	07:10	N3	19-08-81
0.95	0.10	0.25	0.13	0.13	35.21	4.39	11.60	27.1	6	999.	999.	08:05	N3	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	50.76	-9.00	12.30	27.1	12	999.	8.8	09:15	N3	19-08-81
1.06	0.10	0.08	0.15	0.10	49.03	1.39	11.80	27.0	12	999.	999.	10:10	N3	19-08-81
1.03	0.10	0.50	0.10	0.15	53.14	7.68	9.70	22.5	20	999.	999.	08:15	N4	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	58.54	-9.00	11.90	22.9	20	999.	9.0	09:15	N4	18-08-81
1.06	0.10	2.58	0.00	0.75	48.60	4.64	-9.00	23.0	20	999.	9.0	10:30	N4	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	48.60	-9.00	9.20	22.9	20	999.	8.0	11:20	N4	18-08-81
1.03	0.20	3.01	0.08	0.48	38.45	6.81	9.50	22.9	20	999.	7.6	12:20	N4	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	7.40	23.8	20	999.	7.4	13:20	N4	18-08-81
0.82	0.80	6.29	0.14	1.25	11.20	7.61	7.30	23.2	40	999.	7.3	14:25	N4	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	3.89	-9.00	8.00	24.3	40	999.	7.4	15:25	N4	18-08-81
0.76	0.70	8.24	0.09	2.10	5.18	6.40	8.20	24.0	40	999.	7.4	16:30	N4	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	13.18	-9.00	8.20	24.2	20	999.	8.3	17:20	N4	18-08-81
1.10	0.10	2.50	0.16	0.40	42.77	5.89	13.20	25.4	10	999.	8.9	18:25	N4	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	64.29	-9.00	13.80	24.7	999.	999.	999.	19:20	N4	18-08-81
1.22	0.10	1.00	0.01	0.24	53.87	8.52	16.00	24.5	999.	999.	999.	20:25	N4	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	51.84	-9.00	12.80	24.1	999.	999.	999.	21:25	N4	18-08-81
1.04	0.10	1.00	0.01	0.24	50.76	6.68	13.80	25.0	999.	999.	999.	22:25	N4	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	42.55	-9.00	11.40	23.9	999.	999.	999.	23:15	N4	19-08-81
1.21	0.20	4.00	0.01	0.75	42.12	1.03	7.60	23.5	999.	999.	999.	00:18	N4	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	22.68	-9.00	4.10	21.7	999.	999.	999.	01:21	N4	19-08-81
0.92	0.50	6.98	-0.00	1.60	11.53	2.54	3.90	21.0	999.	999.	999.	02:19	N4	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	7.09	-9.00	4.60	20.3	999.	999.	999.	03:23	N4	19-08-81
0.85	0.70	7.97	0.24	1.75	7.13	3.48	4.30	20.7	999.	999.	999.	04:23	N4	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	4.30	20.4	999.	999.	999.	05:22	N4	19-08-81
0.94	0.30	2.42	0.05	0.50	52.10	3.90	5.70	21.2	30	999.	7.9	06:19	N4	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	48.17	-9.00	9.50	22.6	40	999.	8.9	07:25	N4	19-08-81
0.98	0.10	0.60	0.03	0.21	60.30	3.90	11.60	23.1	30	999.	999.	08:20	N4	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	49.90	-9.00	11.20	23.4	30	999.	8.9	09:13	N4	19-08-81
1.13	0.10	0.17	0.11	0.14	53.57	6.09	11.80	23.7	30	999.	999.	10:12	N4	19-08-81
1.05	0.50	7.21	0.28	1.80	22.03	3.06	7.40	21.0	20	999.	7.4	08:00	N5	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	21.60	-9.00	6.40	21.2	20	999.	7.9	09:00	N5	18-08-81
0.57	1.80	5.00	-0.00	0.95	4.00	6.65	-9.00	21.2	40	999.	7.3	10:05	N5	18-08-81

Orgn mg/l	NH3 mg/l	NO2,3 mg/l	ORGP mg/l	PO4 mg/l	CHLA ug/l	BODU mg/l	DOXY mg/l	TEMP C	SECD cm	FLOW cfs	pH	TIME EST	STA	DATE
-9.00	-9.00	-9.00	-9.00	-9.00	2.18	-9.00	5.20	21.4	40	999.	6.7	11:10	N5	18-08-81
0.58	2.60	3.99	-0.00	0.33	2.48	1.97	6.60	21.4	40	999.	6.7	12:05	N5	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.59	-9.00	8.10	23.2	80	999.	6.6	13:05	N5	18-08-81
0.39	2.70	3.04	0.02	0.08	1.73	2.13	9.30	23.6	70	999.	6.6	14:05	N5	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.10	-9.00	9.30	24.3	80	999.	7.4	15:05	N5	18-08-81
0.28	2.50	3.14	0.03	0.07	2.16	2.04	8.90	24.6	50	999.	6.9	16:05	N5	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	1.94	-9.00	9.20	24.0	80	999.	7.5	17:05	N5	18-08-81
0.50	2.20	3.09	0.02	0.08	-9.00	2.50	7.70	24.3	60	999.	6.9	18:10	N5	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.66	-9.00	-9.00	23.9	999.	999.	999.	19:05	N5	18-08-81
1.00	0.70	11.30	0.20	3.00	-9.00	2.50	8.00	25.0	999.	999.	999.	20:05	N5	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	4.88	-9.00	7.50	22.7	999.	999.	999.	21:05	N5	18-08-81
0.58	1.90	3.92	0.03	0.37	2.38	1.99	7.00	22.5	999.	999.	999.	22:10	N5	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	1.68	-9.00	6.80	21.8	999.	999.	999.	23:05	N5	18-08-81
0.49	1.80	3.50	0.02	0.08	1.84	2.11	4.80	21.7	999.	999.	999.	00:08	N5	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.44	-9.00	5.10	20.1	999.	999.	999.	01:11	N5	19-08-81
0.19	3.20	2.95	0.05	0.05	1.94	2.09	5.20	19.3	999.	999.	999.	02:04	N5	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	3.21	-9.00	5.90	19.0	999.	999.	999.	03:10	N5	19-08-81
-0.00	4.60	2.70	0.05	0.05	3.55	4.24	5.00	18.9	999.	999.	999.	04:09	N5	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.00	-9.00	6.60	18.6	999.	999.	999.	05:11	N5	19-08-81
0.28	3.00	3.60	0.10	0.40	2.55	11.96	5.30	19.5	50	999.	6.3	06:07	N5	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	4.75	-9.00	5.90	20.7	50	999.	7.2	07:15	N5	19-08-81
1.05	0.30	7.47	-0.00	2.00	20.74	3.83	5.30	21.1	40	999.	999.	08:12	N5	19-09-81
-9.00	-9.00	-9.00	-9.00	-9.00	39.53	-9.00	6.70	21.7	30	999.	7.8	09:05	N5	19-08-81
1.12	0.10	4.11	0.16	0.90	39.96	3.99	6.90	22.1	30	999.	999.	10:04	N5	19-08-81
0.49	5.50	2.00	0.05	0.05	1.86	4.44	6.20	18.0	999.	999.	999.	08:00	N6	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.98	-9.00	6.40	18.4	999.	999.	6.9	09:05	N6	18-08-81
0.48	3.60	2.95	0.04	0.06	2.27	2.67	7.00	19.0	999.	999.	999.	10:00	N6	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.68	-9.00	7.60	19.9	999.	999.	7.3	11:00	N6	18-08-81
0.48	3.00	3.00	0.04	0.06	3.24	5.71	7.90	21.5	999.	999.	999.	12:00	N6	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	3.24	-9.00	7.90	22.4	999.	999.	6.8	13:00	N6	18-08-81
0.37	2.70	3.00	0.04	0.06	3.77	5.56	8.00	22.9	999.	999.	999.	14:00	N6	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.59	-9.00	7.90	23.7	999.	999.	6.9	15:00	N6	18-08-81
0.39	2.40	3.35	0.04	0.06	1.90	2.77	7.30	24.0	999.	999.	999.	16:00	N6	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	1.62	-9.00	6.90	24.2	999.	999.	6.9	17:00	N6	18-08-81
0.19	2.60	3.65	0.04	0.06	1.43	6.22	6.00	23.7	999.	999.	999.	18:00	N6	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	1.81	-9.00	5.60	23.0	999.	999.	6.6	19:00	N6	18-08-81
0.49	2.60	3.35	0.05	0.05	1.84	6.10	5.30	22.3	999.	999.	999.	20:00	N6	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.38	-9.00	5.20	21.5	999.	999.	999.	21:00	N6	18-08-81
0.28	3.90	3.25	0.05	0.05	2.48	5.92	5.40	20.4	999.	999.	999.	22:10	N6	18-08-81

Orgn mg/l	NH3 mg/l	NO2,3 mg/l	ORGP mg/l	PO4 mg/l	CHLA ug/l	BODU mg/l	DOXY mg/l	TEMP C	SECD cm	FLOW cfs	pH	TIME EST	STA	DATE
-9.00	-9.00	-9.00	-9.00	-9.00	3.02	-9.00	5.70	20.1	999.	999.	999.	23:00	N6	18-08-81
0.48	5.10	3.00	0.05	0.05	3.43	5.65	5.80	19.6	999.	999.	999.	00:05	N6	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	3.02	-9.00	5.90	19.2	999.	999.	999.	00:59	N6	19-08-81
0.48	6.00	2.65	0.05	0.05	2.81	5.83	6.00	19.1	999.	999.	999.	02:02	N6	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.81	-9.00	5.80	18.9	999.	999.	999.	03:05	N6	19-08-81
0.48	6.00	2.55	0.05	0.05	2.42	2.63	5.80	18.7	999.	999.	999.	04:01	N6	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.42	-9.00	5.40	18.7	999.	999.	999.	05:04	N6	19-08-81
0.18	6.00	2.55	0.05	0.05	2.33	5.96	5.30	18.7	999.	999.	999.	06:00	N6	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.22	-9.00	5.30	18.7	999.	999.	6.6	06:53	N6	19-08-81
0.19	3.90	2.65	0.04	0.06	1.64	3.84	5.70	19.0	999.	999.	999.	08:00	N6	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	5.90	19.3	999.	999.	6.4	08:57	N6	19-08-81
0.38	5.10	2.80	0.05	0.05	2.27	5.98	6.70	18.9	999.	999.	999.	09:59	N6	19-08-81
-0.00	0.20	0.06	0.08	0.02	2.27	0.02	7.60	17.1	999.	999.	999.	08:30	N7	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.53	-9.00	7.70	17.8	999.	999.	6.4	09:25	N7	18-08-81
0.08	0.20	0.06	0.08	0.02	2.76	2.53	7.80	18.6	999.	999.	999.	10:15	N7	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.27	-9.00	8.00	19.3	999.	999.	6.4	11:10	N7	18-08-81
0.20	0.10	0.06	0.08	0.02	-9.00	3.31	8.10	20.5	999.	999.	999.	12:15	N7	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.97	-9.00	7.80	21.2	999.	999.	6.3	13:15	N7	18-08-81
0.08	0.10	0.06	0.08	0.02	2.16	2.70	7.90	21.4	999.	999.	999.	14:20	N7	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	3.41	-9.00	7.80	21.8	999.	999.	6.3	15:15	N7	18-08-81
0.09	0.10	0.06	0.08	0.02	2.14	2.71	7.60	21.7	999.	999.	999.	16:15	N7	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	1.79	-9.00	7.20	21.4	999.	999.	6.4	17:10	N7	18-08-81
0.09	0.10	0.06	0.08	0.02	1.04	3.02	7.10	20.8	999.	999.	999.	18:15	N7	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	1.86	-9.00	7.00	20.5	999.	999.	6.5	19:15	N7	18-08-81
0.09	0.10	0.06	0.08	0.02	0.80	3.08	7.00	20.0	999.	999.	999.	20:15	N7	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	0.69	-9.00	7.00	19.8	999.	999.	999.	21:00	N7	18-08-81
-0.00	0.10	0.06	0.08	0.02	0.69	3.12	7.30	19.2	999.	999.	999.	22:00	N7	18-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	0.15	-9.00	7.20	18.7	999.	999.	999.	23:07	N7	18-08-81
0.10	0.10	0.06	0.08	0.02	0.52	3.16	6.80	18.4	999.	999.	999.	00:15	N7	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	0.60	-9.00	7.20	18.3	999.	999.	999.	01:05	N7	19-08-81
0.10	0.30	0.06	0.08	0.02	0.65	3.13	7.20	18.1	999.	999.	999.	02:10	N7	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	6.90	18.2	999.	999.	999.	03:15	N7	19-08-81
0.09	0.20	0.06	0.08	0.02	1.80	2.80	7.10	18.1	999.	999.	999.	04:11	N7	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	0.39	-9.00	7.10	18.0	999.	999.	999.	04:55	N7	19-08-81
0.39	0.20	0.06	0.08	0.02	1.34	2.93	7.00	18.0	999.	999.	999.	06:09	N7	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	1.21	-9.00	7.00	18.1	999.	999.	6.3	07:06	N7	19-08-81
-0.00	0.20	0.07	0.09	0.01	1.99	1.09	7.20	18.5	999.	999.	999.	08:09	N7	19-08-81
-9.00	-9.00	-9.00	-9.00	-9.00	2.42	-9.00	7.30	18.7	999.	999.	6.3	09:05	N7	19-08-81
0.18	0.20	0.07	0.08	0.02	2.59	2.58	7.60	19.2	999.	999.	999.	10:09	N7	19-08-81

Orgn mg/l	NH3 mg/l	NO2,3 mg/l	ORGP mg/l	PO4 mg/l	CHLA ug/l	BODU mg/l	DOXY mg/l	TEMP C	SECD cm	FLOW cfs	pH	TIME EST	STA	DATE
1.50	0.60	20.01	0.30	6.50	-9.00	5.70	8.40	23.2	999.	9.73	9.1	10:05	N8	18-08-81
1.10	0.20	19.51	0.20	6.50	-9.00	8.60	8.40	23.2	999.	9.73	9.1	10:05	N8	18-08-81
1.30	0.10	20.51	0.40	6.50	-9.00	5.90	-9.00	999.	999.	9.73	999.	20:50	N8	18-08-81
1.30	0.10	17.51	1.40	5.00	-9.00	9.70	8.20	23.7	999.	999.	8.8	10:50	N8	19-08-81
0.50	7.50	0.66	0.00	0.10	-9.00	23.50	6.90	22.9	999.	3.39	6.5	09:05	N9	18-08-81
0.60	8.50	0.61	0.02	0.18	-9.00	25.90	6.90	22.9	999.	3.39	6.5	09:05	N9	18-08-81
0.00	11.00	0.96	0.02	0.08	-9.00	7.20	7.70	22.5	999.	999.	6.8	21:00	N9	18-08-81
0.00	10.00	0.35	0.22	0.08	-9.00	10.30	7.70	22.5	999.	999.	6.8	10:00	N9	19-08-81

Table A-2

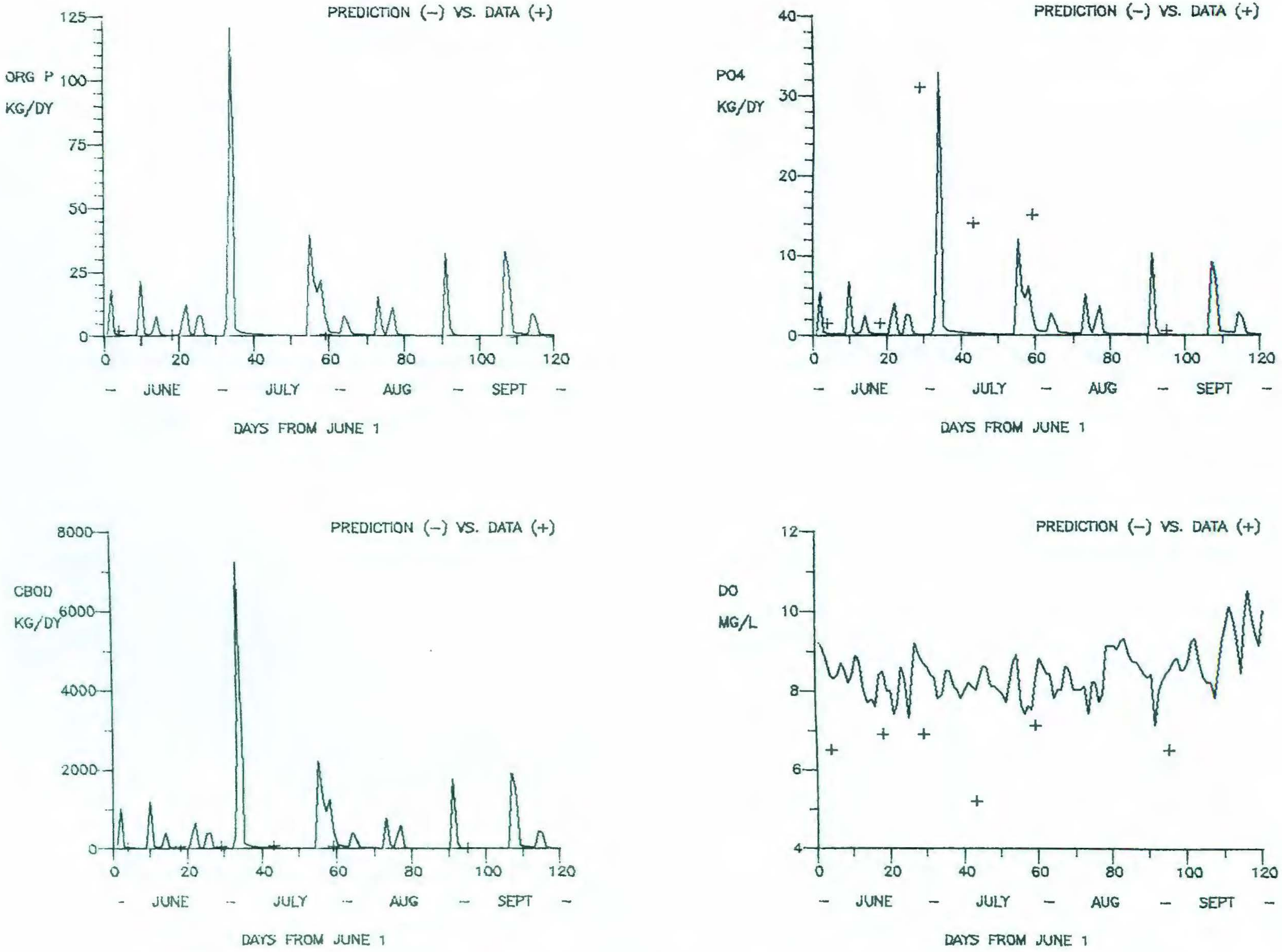
Water Quality Data from Slack Water Runs

Summer, 1981

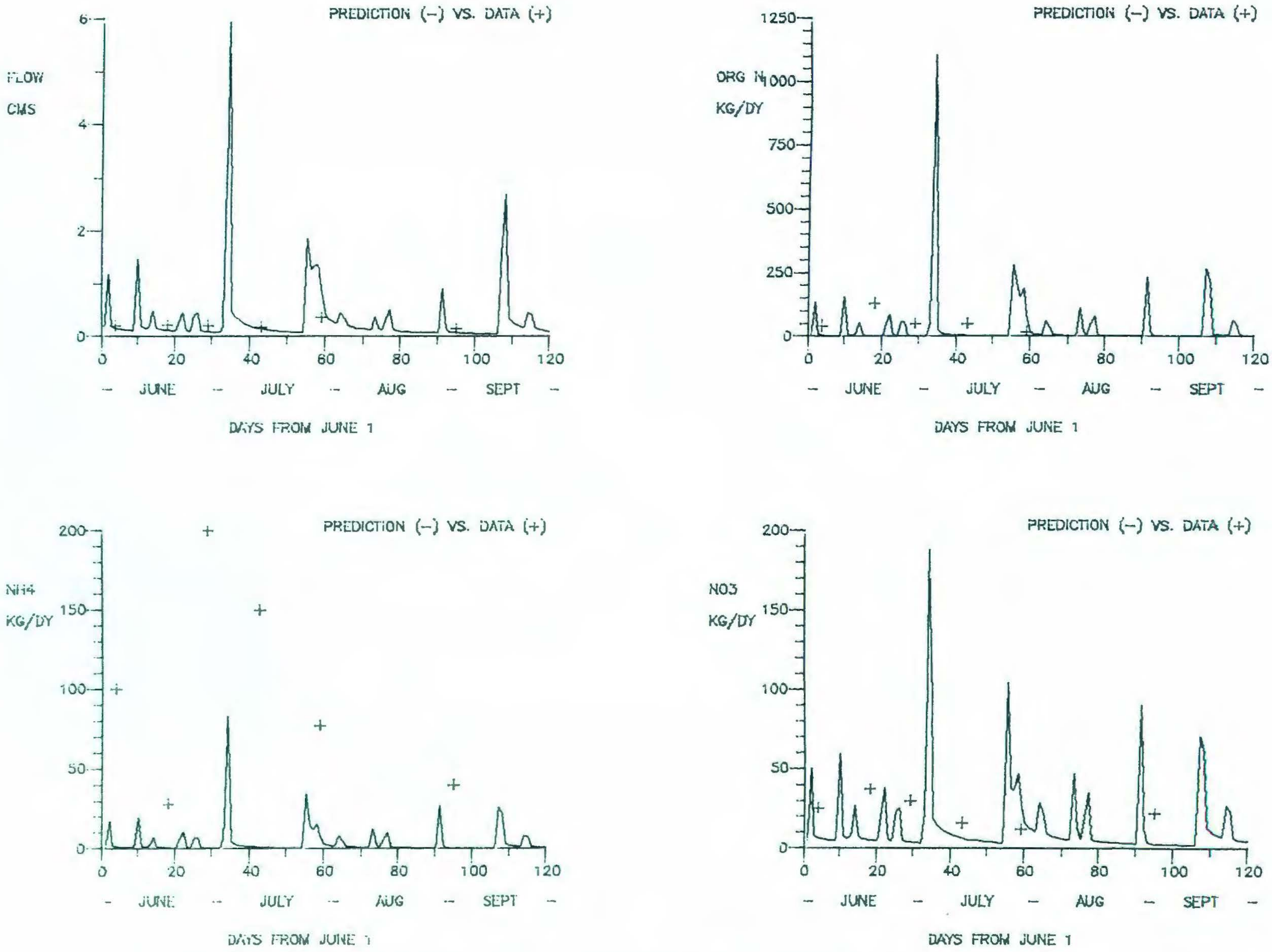
Orgn mg/l	NH3 mg/l	NO2,3 mg/l	ORGP mg/l	PO4 mg/l	CHLA ug/l	BODU mg/l	DOXY mg/l	TEMP C	SECD cm	FLOW cfs	pH	TIME EST	STA	DATE
0.41	0.10	0.43	0.06	0.01	27.70	2.96	10.10	22.5	999.	999.	999.	02:00	N1	04-06-81
0.59	0.60	2.00	0.08	0.10	15.70	-9.00	5.60	22.0	999.	999.	999.	02:15	N2	04-06-81
0.96	1.30	3.61	0.09	0.30	5.90	18.30	4.60	21.5	999.	999.	999.	02:35	N3	04-06-81
1.08	1.60	5.55	0.10	0.50	3.20	-9.00	4.40	20.5	999.	999.	999.	03:10	N4	04-06-81
0.48	3.50	1.40	0.04	0.06	3.50	2.27	7.00	19.0	999.	999.	999.	03:30	N5	04-06-81
2.18	5.50	1.35	0.12	0.08	2.20	-9.00	6.50	19.5	999.	7.46	7.6	03:45	N6	04-06-81
0.20	0.20	0.17	0.09	0.01	0.70	3.33	7.60	19.0	999.	1.48	6.5	03:30	N7	04-06-81
2.40	3.30	0.71	0.00	4.40	-9.00	-9.00	6.80	20.5	999.	7.75	6.7	05:45	N8	04-06-81
4.80	15.00	0.06	0.20	0.50	-9.00	13.62	7.00	20.5	999.	1.55	6.8	04:30	N9	04-06-81
0.75	0.10	0.23	0.10	0.06	35.60	-9.00	13.00	29.0	50	999.	9.7	15:15	N1	18-06-81
1.01	0.10	1.30	0.16	0.10	41.50	2.13	13.20	30.0	50	999.	8.7	15:00	N2	18-06-81
0.91	1.50	2.36	0.02	0.47	13.50	-9.00	6.50	29.0	25	999.	7.3	14:20	N3	18-06-81
0.58	1.40	2.36	0.01	0.37	16.80	4.45	6.20	29.5	30	999.	7.3	14:15	N4	18-06-81
0.85	1.40	3.08	0.03	0.26	6.90	-9.00	4.80	27.5	30	999.	7.3	14:00	N5	18-06-81
6.99	1.50	2.00	0.02	0.08	1.40	2.18	6.90	22.8	999.	7.66	6.8	09:45	N6	18-06-81
0.27	0.20	0.12	0.07	0.03	4.20	-9.00	7.10	22.3	20	0.64	6.8	10:55	N7	18-06-81
0.80	0.10	22.01	0.00	5.40	-9.00	-0.66	8.40	23.0	999.	11.63	7.3	11:35	N8	18-06-81
0.00	17.80	0.06	0.09	0.11	-9.00	-9.00	7.90	22.0	999.	3.41	6.5	12:15	N9	18-06-81
0.67	0.10	0.06	0.09	0.08	32.80	0.72	9.20	28.1	23	999.	9.8	11:00	N1	29-06-81
-0.00	-9.00	1.29	0.14	0.12	42.10	-9.00	8.40	26.1	15	999.	9.1	11:15	N2	29-06-81
1.35	0.40	2.35	0.19	0.17	36.00	0.97	10.40	28.2	23	999.	8.5	13:00	N3	29-06-81
0.78	2.00	16.45	-0.00	3.80	2.60	-9.00	7.20	25.9	38	999.	7.8	12:30	N4	29-06-81
1.28	10.50	1.65	-0.00	0.70	2.20	-1.00	7.40	27.1	30	999.	7.0	12:15	N5	29-06-81
2.76	11.00	1.65	-0.00	1.70	5.30	-9.00	6.90	21.8	999.	7.42	8.2	11:00	N6	29-06-81
0.17	0.30	0.10	0.08	0.02	4.90	2.40	7.30	22.0	999.	0.37	7.0	11:40	N7	29-06-81
0.70	0.10	20.51	0.00	5.20	-9.00	-9.00	8.50	22.5	999.	8.53	7.6	12:00	N8	29-06-81
9.00	13.00	0.05	0.10	3.50	-9.00	4.16	7.90	22.5	999.	3.57	7.4	13:25	N9	29-06-81
1.00	0.10	0.52	0.08	0.02	-9.00	3.20	10.20	28.5	999.	999.	9.1	04:00	N1	13-07-81
1.19	0.10	0.38	0.05	0.02	29.38	-9.00	10.60	29.0	999.	999.	9.4	04:10	N2	13-07-81
1.59	0.10	0.36	0.05	0.02	30.24	2.37	10.70	29.0	999.	999.	9.4	04:20	N3	13-07-81
-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	999.	999.	999.	999.	999.	N4	13-07-81
1.60	1.10	4.22	0.20	0.60	-9.00	5.88	5.30	26.9	999.	999.	7.5	04:45	N5	13-07-81
3.00	9.50	1.00	-0.00	0.90	13.82	-9.00	5.20	23.0	999.	6.46	7.1	05:30	N6	13-07-81

Orgn mg/l	NH3 mg/l	NO2,3 mg/l	ORGP mg/l	PO4 mg/l	CHLA ug/l	BODU mg/l	DOXY mg/l	TEMP C	SECD cm	FLOW cfs	pH	TIME EST	STA	DATE
0.60	0.30	0.08	0.09	0.01	-9.00	6.58	6.40	23.1	999.	0.53	6.2	05:15	N7	13-07-81
1.10	0.10	17.01	0.00	4.90	-9.00	-9.00	6.50	24.0	999.	999.	7.5	07:45	N8	13-07-81
7.50	13.50	0.05	0.00	2.60	-9.00	6.69	7.90	24.0	999.	3.41	6.6	06:45	N9	13-07-81
0.70	0.10	0.06	0.07	0.09	43.20	-9.00	10.00	28.0	100	999.	10.0	10:55	N1	29-07-81
0.71	0.70	1.83	0.02	0.37	12.74	4.32	3.20	26.7	35	999.	6.3	11:05	N2	29-07-81
0.66	0.50	1.30	0.05	0.34	6.26	8.19	2.80	26.0	50	999.	6.4	11:30	N3	29-07-81
-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	-9.00	999.	999.	999.	999.	999.	N4	29-07-81
0.49	1.50	1.02	0.04	0.36	1.77	4.84	6.00	25.5	30	999.	6.2	12:10	N5	29-07-81
0.59	2.50	0.38	-0.00	0.50	1.60	-9.00	7.10	31.1	10	12.54	6.9	11:00	N6	29-07-81
0.18	0.20	0.17	0.06	0.14	2.33	3.23	6.90	25.0	10	2.03	6.4	11:45	N7	29-07-81
0.80	0.10	13.01	0.60	5.00	-9.00	-9.00	8.40	25.5	999.	13.95	7.8	12:00	N8	29-07-81
3.80	8.00	0.38	0.30	2.20	-9.00	-1.82	7.50	24.0	999.	3.57	6.8	12:30	N9	29-07-81
0.41	0.10	0.27	-0.00	0.06	42.12	-9.00	8.80	24.0	15	999.	9.5	09:15	N1	03-09-81
0.57	0.10	0.06	0.08	0.06	60.97	-1.28	10.00	24.0	15	999.	9.5	09:25	N2	03-09-81
0.61	0.10	0.29	0.07	0.07	56.09	-9.00	9.60	24.0	23	999.	9.6	09:35	N3	03-09-81
0.67	0.10	0.33	0.06	0.08	60.97	11.15	9.50	24.0	20	999.	9.6	09:50	N4	03-09-81
0.72	0.20	3.79	0.07	0.19	39.91	-9.00	5.90	24.0	19	999.	7.5	10:05	N5	03-09-81
-0.00	3.00	1.63	0.05	0.05	1.51	2.78	6.50	22.7	999.	5.41	7.8	09:25	N6	03-09-81
0.06	0.10	0.06	0.06	0.03	6.21	-9.00	7.00	22.0	999.	0.69	6.9	10:00	N7	03-09-81
0.50	0.10	22.51	0.00	1.00	-9.00	3.97	8.20	25.0	999.	10.60	9.5	10:15	N8	03-09-81
0.00	6.30	1.38	0.13	0.07	-9.00	-9.00	7.60	26.0	999.	4.50	7.2	10:45	N9	03-09-81

Appendix B



Comparison of nonpoint source model predictions with Station 6 observations - phosphorus, CBOD, and dissolved oxygen.



Comparison of nonpoint source model predictions with station 6 observations - flow and nitrogen components.