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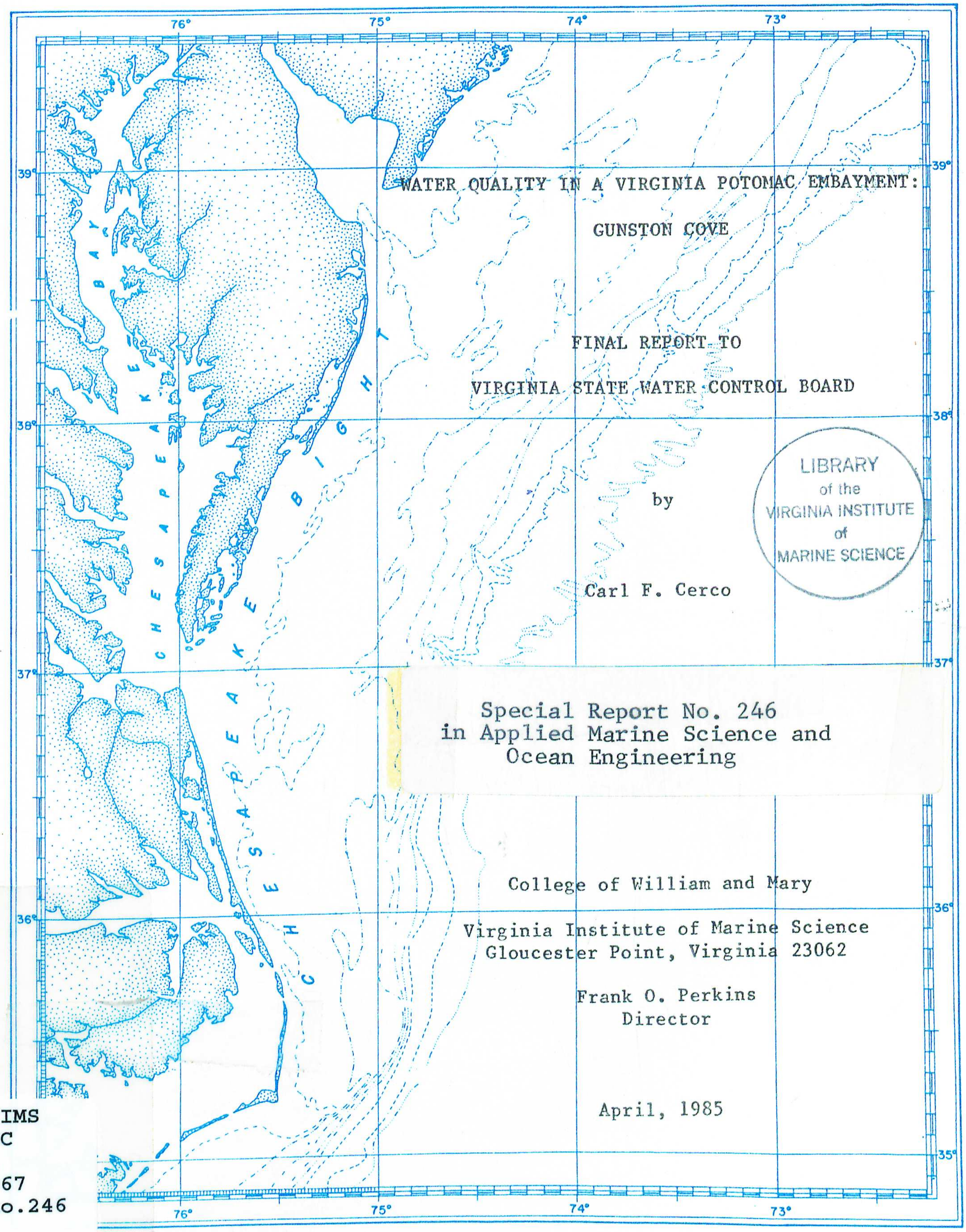

WATER QUALITY IN A VIRGINIA POTOMAC EMBAYMENT:
GUNSTON COVE

FINAL REPORT TO
VIRGINIA STATE WATER CONTROL BOARD

by

Carl F. Cerco

Special Report No. 246
in Applied Marine Science and
Ocean Engineering

College of William and Mary

Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

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CHAPTER I. SUMMARY

The Gunston Cove study had two primary objectives:

1) To collect comprehensive field data suitable to characterize the system and for use in calibrating and verifying a mathematical water-quality model.
2) To calibrate and verify a mathematical model suitable for use in determining the factors which influence water quality in the system and for use as a management tool.

The fulfillment of the objectives and the results of the study are summarized below.

Water-quality surveys were conducted in three summer seasons in the years 1979 to 1982. Sampling included a series of slackwater surveys conducted from June to October, 1979, an intensive survey conducted in September, 1979, slackwater surveys in June and September, 1980, and an intensive survey in August, 1982. The water-quality surveys were supplemented by measures of bathymetry, tide, current, and benthic nutrient and oxygen fluxes.

Two primary indicators of water quality are the algal population, quantified as the chlorophyll 'a' concentration, and the dissolved oxygen concentration. Chlorophyll concentrations in the 75 to 100 μgm/1 range were commonly observed in Gunston Cove and maximum chlorophyll observations approached 150 μgm/1. Observed dissolved oxygen concentrations were usually in the supersaturated range due to algal photosynthesis. Minimum dissolved oxygen observations were usually at or above the 5 mg/1 level.

A one-dimensional, real-time model has been applied to the system along the axis of Gunston Cove and Pohick Bay. Accotink Bay is treated as a well-mixed storage area. The model consists of hydrodynamic and water-quality submodels. The hydrodynamic submodel provides predictions of surface level, velocity and dispersion to the water-quality submodel which treats organic nitrogen, ammonia nitrogen, nitrite+nitrate nitrogen, organic phosphorus, ortho phosphorus, chlorophyll 'a', CBOD, and dissolved oxygen.

The model has been calibrated and verified against steady-state and time-variable data derived from the August, 1982, intensive survey, the September, 1979, intensive survey, and the June to August, 1979, slackwater surveys. The model is suitable for use as a management tool but if it is employed in this manner, attention should be devoted to the conditions upon which the model runs are based. The calibration and verification procedures have shown water quality in the embayment to be influenced by naturally variable and random factors such as chlorophyll growth rate and turbidity. The results of management model runs will be dependent upon the values employed to represent these and other parameters.

CHAPTER II. INTRODUCTION

This Gunston Cove investigation is part of a larger Potomac Embayments Study initiated in 1979 to survey and model a series of Virginia embayments tributary to the upper, tidal portion of the Potomac River. Prior to the study, these embayments were reported to be subject to nuisance algal blooms and accompanying undesirable dissolved oxygen fluctuations. The purpose of the study is to collect comprehensive, consistent field data describing the conditions in these embayments and to provide mathematical models which can be used both to analyze the factors which contribute to the problems in the embayments and to evaluate alternative management strategies to alleviate the undesirable conditions.

A. Description of Gunston Cove

Gunston Cove is located on the Virginia side of the Potomac River approximately 26 km downstream of Washington, D. C. and is formed by the confluence of two smaller embayments, Pohick Bay and Accotink Bay, which are the tidal termini of freeflowing Pohick and Accotink Creeks (Fig. 2-1). In this study, the tidal portions of all three embayments are collectively referred to as 'Gunston Cove'.

From the mouth of Gunston, it is approximately 5 km along the axes of Gunston and Pohick Bay to the point where the embayment narrows into Pohick Creek, the limit of interest of this study. Accotink Bay extends approximately 1.2 km from its juncture with Pohick but the upper reaches of this embayment are marshy and difficult to define. The boundaries shown in Fig. 2-1 and used in this study are based on a 1980 revision of a U.S.G.S. topographic map of the Fort Belvoir quadrangle.

Except at the mouth, where Gunston Cove merges with the Potomac River, depths in the embayment are shallow and of the order 1 to 2 meters. The tide range in the embayment averages 61 cm. Dry-weather flows in the tributary creeks are small, 0.1 to 1.0 cms (cubic meter/second), although these flows may increase by an order of magnitude or more subsequent to rainstorms.

Flow in Pohick Creek is augmented by the Lower Potomac Water Pollution Control Plant which discharges into the creek approximately 1.8 km above Pohick Bay. The design flow of the STP is 1.6 cms (36 mgd) and it is the only point source which discharges to the embayment system.

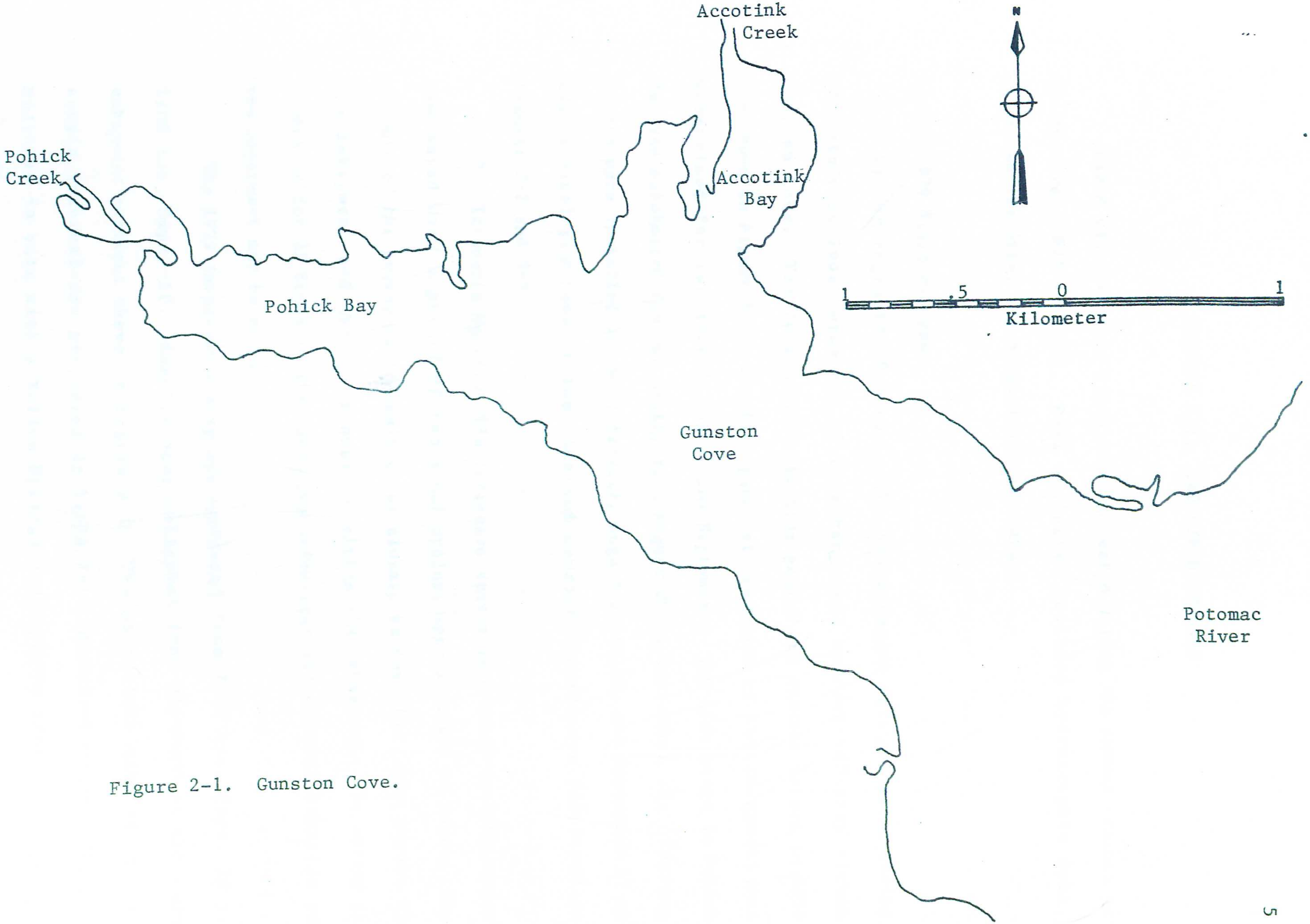


Figure 2-1. Gunston Cove.

CHAPTER III. THE FIELD PROGRAM

Field data for this study were collected during the summer seasons in the interval 1979 to 1982. Data collected included hydrographic data, water-quality data, and special-purpose data.

A. The 1979 Field Program

1) Hydrographic Surveys - The hydrographic data collected during this study includes measures of tide range and current velocity within Gunston Cove. The locations of the tide gauges and current meters in 1979 are shown in Figure 3-1. The tide gauge at the mouth of the embayment was maintained for two months, August and September. The tide gauge in Pohick Bay was maintained for one month, from August 20 to September 20. Current meters were installed in two intervals, August 20 to 28, and September 17 to 20. Typical portions of the tide and current records are displayed in Figures 3-2 and 3-3.

2) Intensive Survey - The intensive survey is a water-quality survey conducted over a period of two tidal cycles, approximately 25 hours. The purpose of the survey is to monitor, as closely as possible, the inputs to the embayment and the water quality within the embayment. The survey is conducted for 25 hours so that both the intratidal and diurnal behavior of the embayment may be noted.

The 1979 intensive survey was conducted from 1900 hrs. Sept. 19 to 2100 hrs. Sept. 20. Samples were collected from mid-depth at the eight embayment stations shown in Figure 3-1. The parameters sampled and the sample interval are presented in Table 3-1. Dissolved oxygen (D.O.) was measured in situ with a Yellow Springs Instruments probe. Nitrogen, phosphorus, and BOD samples were iced and delivered within 24 hrs. to the Commonwealth of Virginia Consolidated Laboratories for analysis. Chlorophyll samples were frozen for subsequent analysis at the Virginia Institute of Marine Science.

In order to measure the inputs to the Gunston Cove system, several locations external to the embayment were also sampled. Prior to and during the intensive survey, three twelve-hour composite samples were collected from the STP effluent (Sta. 10), the freeflowing portion of Pohick Creek above the STP (Sta. 11), and the freeflowing portion of Accotink (Sta. 12). The composites were analyzed for the parameters listed in Table 3-1 except that D.O. and temperature were sampled in situ rather than obtained from composites.

3) Dye Study - Concurrent with the intensive survey, a dye dispersion study was conducted in order to provide data for verification of the mass-transport portion of the water-quality model. During the six-hour period prior to commencement of the intensive survey, 6.8 kg of Rhodamine WT fluorescent dye were continuously released at the Pohick Bay location shown in Fig. 3-1. Dye samples were subsequently collected in the eight embayment stations hourly during the intensive survey and in slackwater surveys conducted two, four, and six tidal cycles after completion of the intensive.

4) Slackwater Surveys - Slackwater surveys provide an instantaneous view of water quality in the embayment during an interval of slack tidal current. A series of these surveys was conducted at approximately two-week intervals from early June through mid-October 1979 (Table 3-2). Due to problems encountered in navigation, all surveys were conducted during periods of daylight slack-before-ebb. These surveys are less comprehensive than the intensive surveys, but provide valuable data for examination of

long-term trends in water quality and for verification of the mathematical model.

The slackwater sample stations and sample parameters are the same as for the intensive survey (Fig. 3-1, Table 3-1). The STP effluent and the freeflowing streams were sampled concurrently with each survey and an additional station (Sta. 9) was sampled approximately 100 meters below the confluence of the STP outfall and Pohick Creek. During the majority of the surveys, flow in the streams was gauged as well.

B. The 1980 Field Program

1) Slackwater Surveys - To verify that the conditions observed in 1979 are typical and recurrent, slackwater surveys were conducted on June 25 and September 4, 1980.

C. The 1982 Field Program

1) Hydrographic Surveys - As part of the 1982 sampling program, tide gauges and a current meter were placed at the locations shown in Figure 3-4. The tide gauges were in operation from August 19 to August 30 and the current meter from August 23 to August 26. The tide and current records are shown in Figures 3-5 through 3-7.

2) Slackwater and Intensive Surveys - The 1982 slackwater and intensive surveys were designed to provide a comprehensive data set for model calibration. Two slackwater surveys were conducted, on August 19 and August 23, followed by a 26-hr. intensive survey from 1830 hrs. August 24 to 2030 hrs. August 25. The parameters sampled during the intensive survey and the intensive survey stations are presented in Table 3-3 and Figure 3-4.

The parameters and stations sampled during the slackwater surveys were the same as the intensive survey except Stations P1 and A1 were not sampled.

Three stations external to the embayment were sampled as well: the STP effluent (Sta. 10), the freeflowing portion of Pohick Creek upstream of the STP (Sta. 11), and the freeflowing portion of Accotink Creek (Sta. 12). During the slackwater surveys, grab samples were collected at each of these stations. Prior to and concurrent with the intensive survey, two 24-hr. composite samples were collected at each station. Flows in the streams were gauged four times on August 19, 23, 24, 25.

Samples from the 1982 intensive survey were treated in the same manner and analyzed by the same agencies as the 1979 samples.

3) Dye Study - A dye dispersion study was conducted in association with the 1982 intensive water quality survey. Six hours prior to the intensive survey, 5.7 kg of Rhodamine WT fluorescent dye were released from the rear of a boat which traversed the portion of Pohick Bay indicated in Fig. 3-4. Dye samples were subsequently collected in the embayment stations at two-hour intervals during the intensive survey and in slackwater surveys conducted one, two, and six tidal cycles after the intensive survey.

D. Special-Purpose Surveys

1) Benthic Materials Flux - Preliminary calibration of the water quality model with the 1979 data indicated there were sources and sinks of nutrients in the cove other than the measured inflows. It was hypothesized that these were due to fluxes of materials between the bottom sediments and the overlying water. To verify this hypothesis, measurements of the benthic fluxes of ammonia, nitrate, ortho phosphorus, and dissolved oxygen were

conducted. Fluxes were measured during September, 1981, and during July, 1982, at the stations shown in Figure 3-8.

Measurements were conducted by sealing a hemispherical plastic dome to the cove bottom thereby entrapping a fixed volume of bottom water. By sampling the water within the dome periodically during the duration of the measurements, which lasted from four to eight hours, the rate of change of mass for each constituent within the dome was calculated. This rate of change of mass was then converted to an areal mass flux rate across the sediment-water interface.

E. Data Presentation and Conversion

All of the water quality data collected during the 1979, 1980, and 1982 seasons is presented in Appendix A. To allow 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.

$$\text{ORG N} = \text{TKN} - NH_4 - aN * CH \qquad (3\text{-}1)$$

in which

ORG N = organic nitrogen

TKN = total Kjeldahl nitrogen of sample

NH_4 = ammonia nitrogen concentration of sample

CH = chlorophyll concentration of sample

aN = ratio of nitrogen to chlorophyll in algal biomass

= 0.007 mg/μgm

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

$$\text{TOT P (corrected)} = \text{TOT P (laboratory)} - aP * CH \tag{3-2}$$

in which

TOT P = total phosphorus

aP = ratio of phosphorus to chlorophyll in algal biomass

= 0.001 mg/μgm

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 field data.

3) CBOD5 to CBODu - The majority of the BOD analyses are five-day carbonaceous biochemical oxygen demand (CBOD5). These must be scaled-up to ultimate carbonaceous biochemical oxygen demand (CBODu) and corrected for the respiration and decay of algae entrapped in the BOD bottle. The correction is accomplished through the relationship

$$CBOD_u = R * CBOD_5 - 2.67 * aC * CH \tag{3-3}$$

in which

$CBOD_u$ = ultimate carbonaceous biochemical oxygen demand

$CBOD_5$ = five-day carbonaceous biochemical oxygen demand

R = ratio of $CBOD_u$ to $CBOD_5$

aC = ratio of carbon to chlorophyll in algal biomass

= 0.05 mg/μgm

The ratio of $CBOD_u$ to $CBOD_5$ is obtained from the 25-30% of the slackwater and intensive survey 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 groupings and the ratio used to correct the samples in each grouping are presented in Table 3-4.

4) Disk Visibility to Light Extinction - The Secchi depth measured in-situ 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 Holmes (1970) and Stefan and Cardoni (1983) yield the equation

$$Ke = 145/DV - 0.018 * CH \qquad (3\text{-}4)$$

in which

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

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

F. Background Inputs

The volumetric and mass fluxes which enter Gunston Cove through freeflowing Pohick and Accotink 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, however, information on the background fluxes between surveys is necessary. This information was provided, on a daily basis for the 1979 season, by the Northern Virginia Planning District Commission through employment of a nonpoint-source prediction model for the Pohick and Accotink drainage basins.

Time-series plots of the predicted daily inputs from Pohick and Accotink Creeks are presented in Appendix C. 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 the chlorophyll concentrations. For this constituent, a typical background concentration of 3 μgm/l was utilized in all model runs.

TABLE 3-1. Parameters and Sampling Interval - 1979 Intensive Survey

Parameter	Interval
Total Kjeldahl Nitrogen	two hours
Ammonia Nitrogen	two hours
Nitrate + Nitrite Nitrogen	two hours
Total Phosphorus	two hours
Ortho Phosphorus	two hours
Chlorophyll ´a´	one hour
CBOD5	two hours
pH	one hour
Temperature	one hour
Secchi Depth	one hour
Dissolved Oxygen	one hour
Total Organic Carbon	two hours
CBODu	one per tidal cycle

TABLE 3-2. Dates of 1979 Slackwater Surveys

June 5
June 19
July 5
July 18
August 6
August 16
August 28
August 29
September 13
October 2
October 16

TABLE 3-3. Parameters and Sampling Intervals - 1982 Intensive Survey

Parameter	Interval
Total Kjeldahl Nitrogen	four hours
Ammonia Nitrogen	four hours
Nitrate + Nitrite Nitrogen	four hours
Total Phosphorus	four hours
Ortho Phosphorus	four hours
Chlorophyll ´a´	two hours
CBOD5	four hours
pH	two hours
Temperature	two hours
Secchi Depth	two hours
Dissolved Oxygen	two hours
Total Organic Carbon	four hours
CBODu	one per tidal cycle

TABLE 3-4. Ratio of CBODu/CBOD5

Grouping	Ratio
Slackwater Embayment Samples, 1979	2.6
Intensive Embayment Samples, 1979	2.6
Freeflowing Stream Samples, 1979	2.1
Slackwater Embayment Samples, 1980	2.3
Freeflowing Stream Samples, 1980	2.1
Slackwater Embayment Samples, 1982	2.2
Intensive Embayment Samples, 1982	2.2
Freeflowing Stream Samples, 1982	2.2

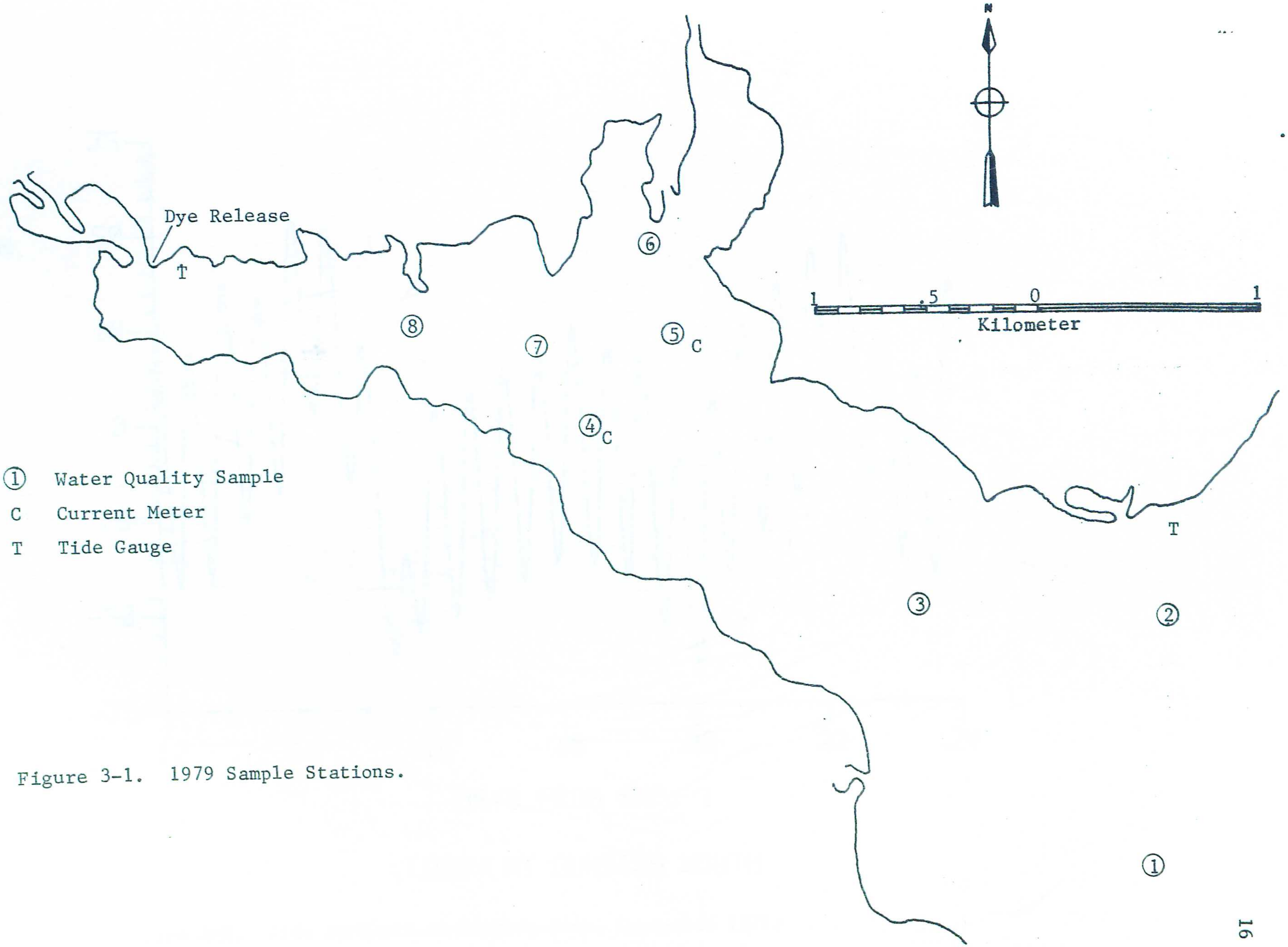


Figure 3-1. 1979 Sample Stations.

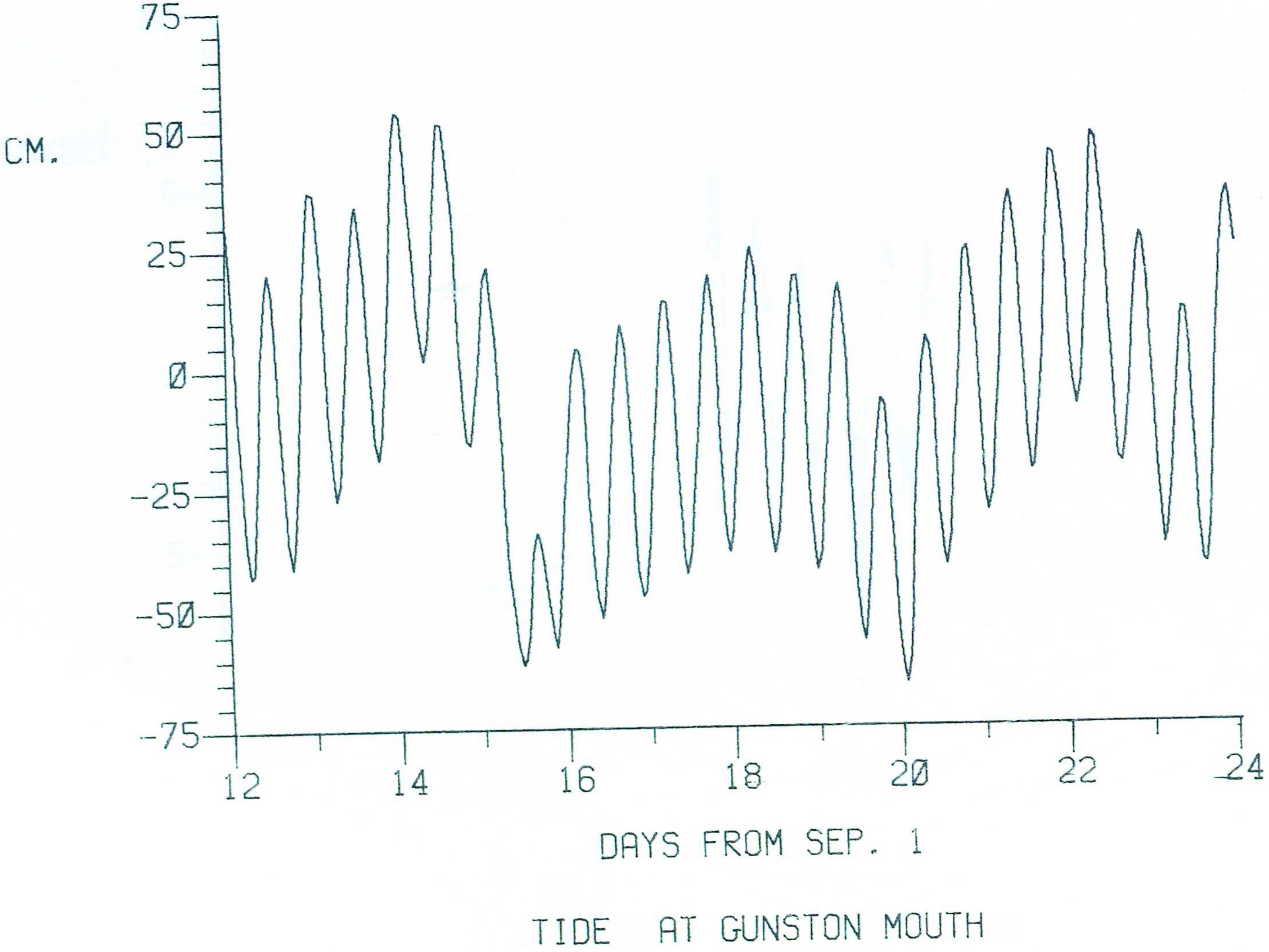


Figure 3-2. Tide at Mouth of Gunston Cove, September 1979.

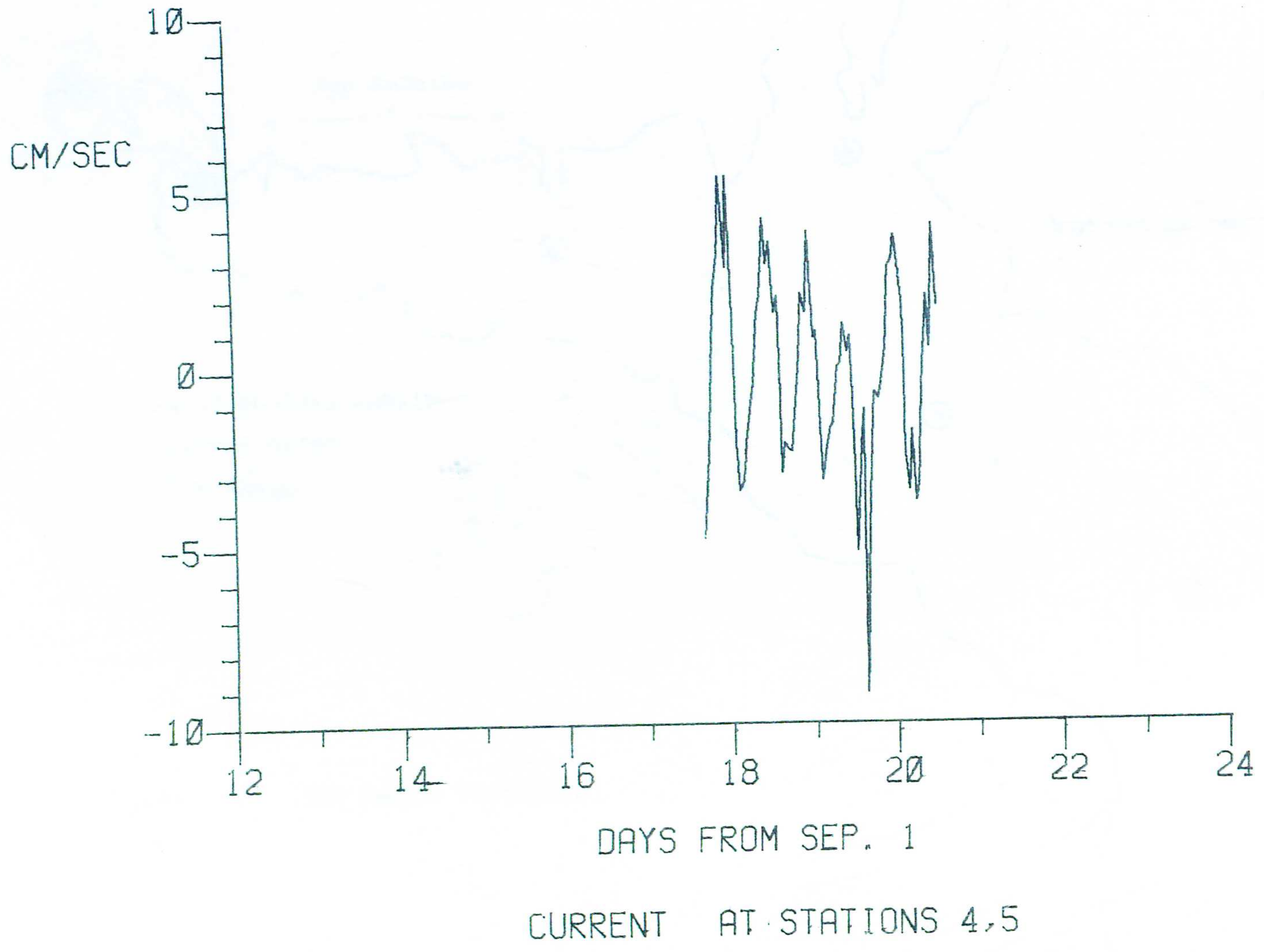


Figure 3-3. Current Velocity in Gunston Cove, September 1979.

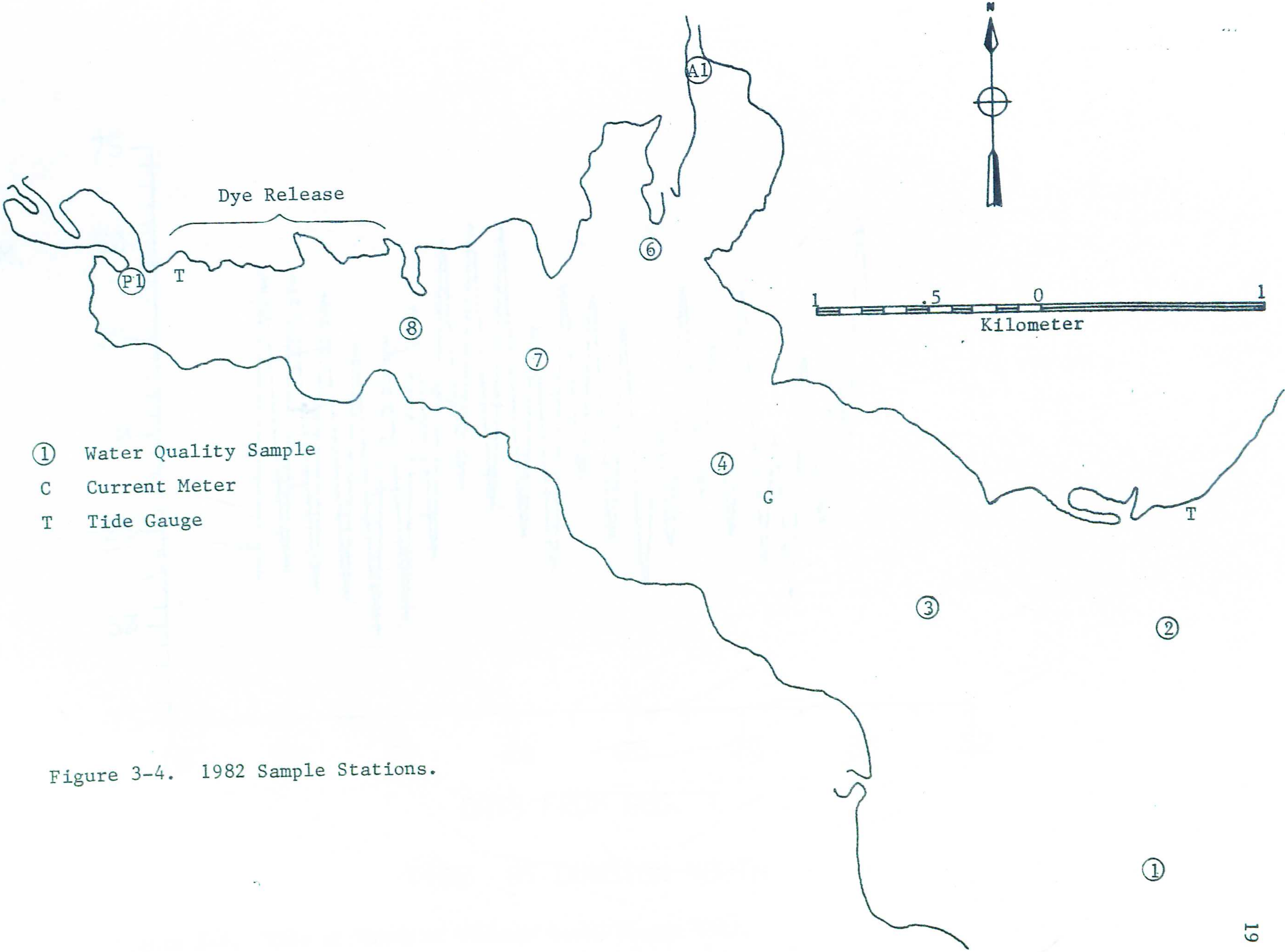


Figure 3-4. 1982 Sample Stations.

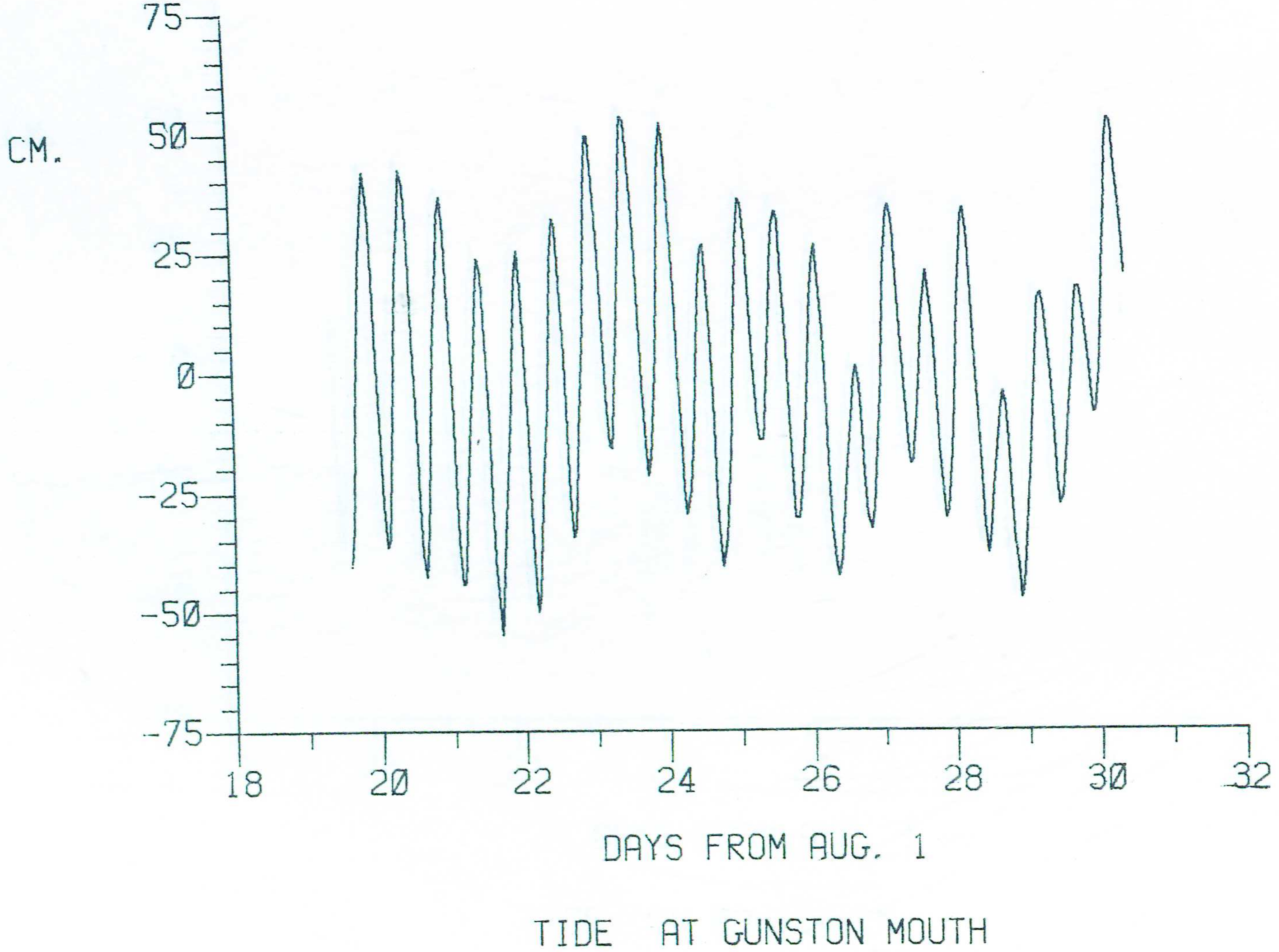


Figure 3-5. Tide at Mouth of Gunston Cove, August 1982.

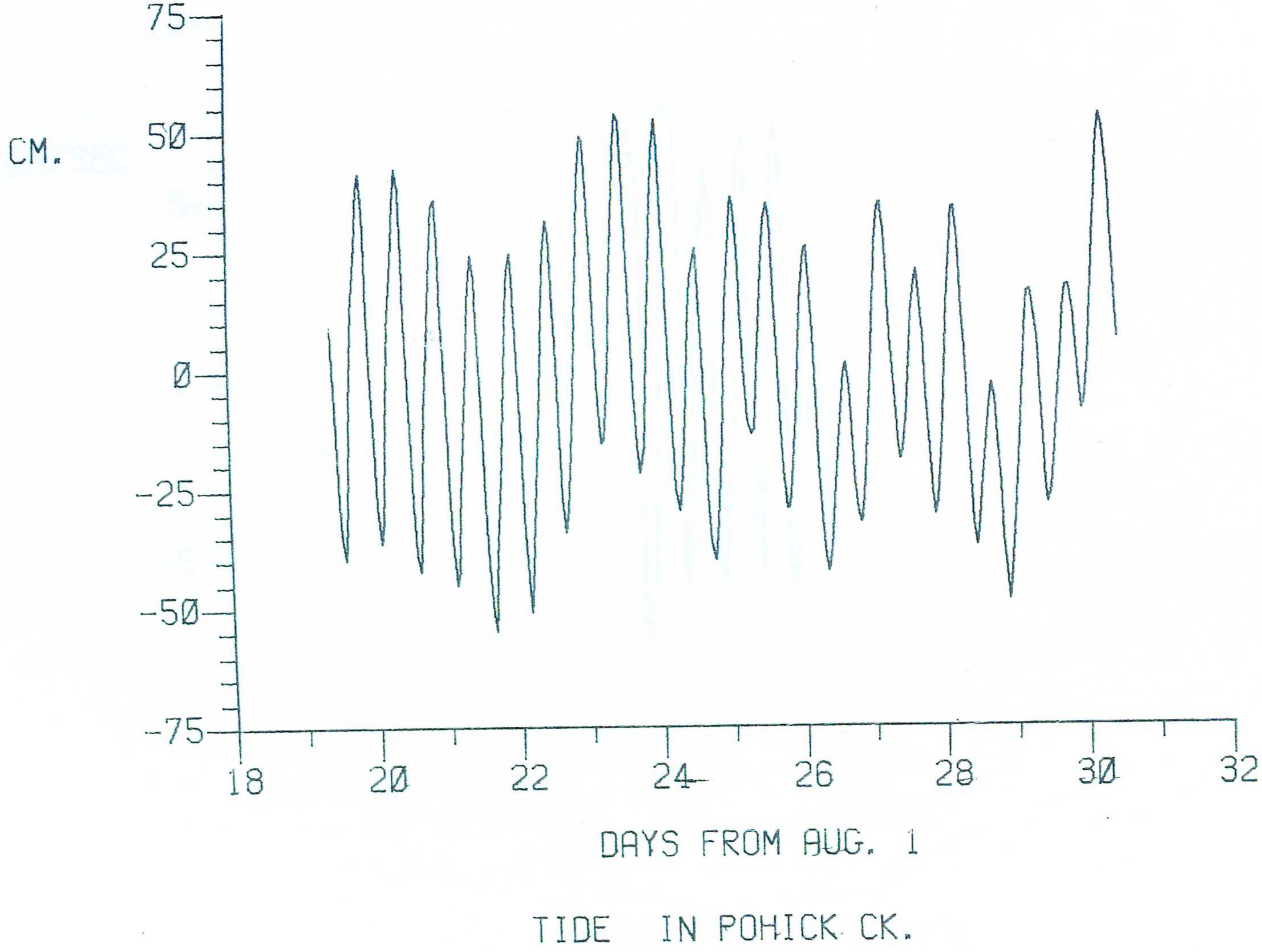


Figure 3-6. Tide at Head of Pohick Bay, August 1982.

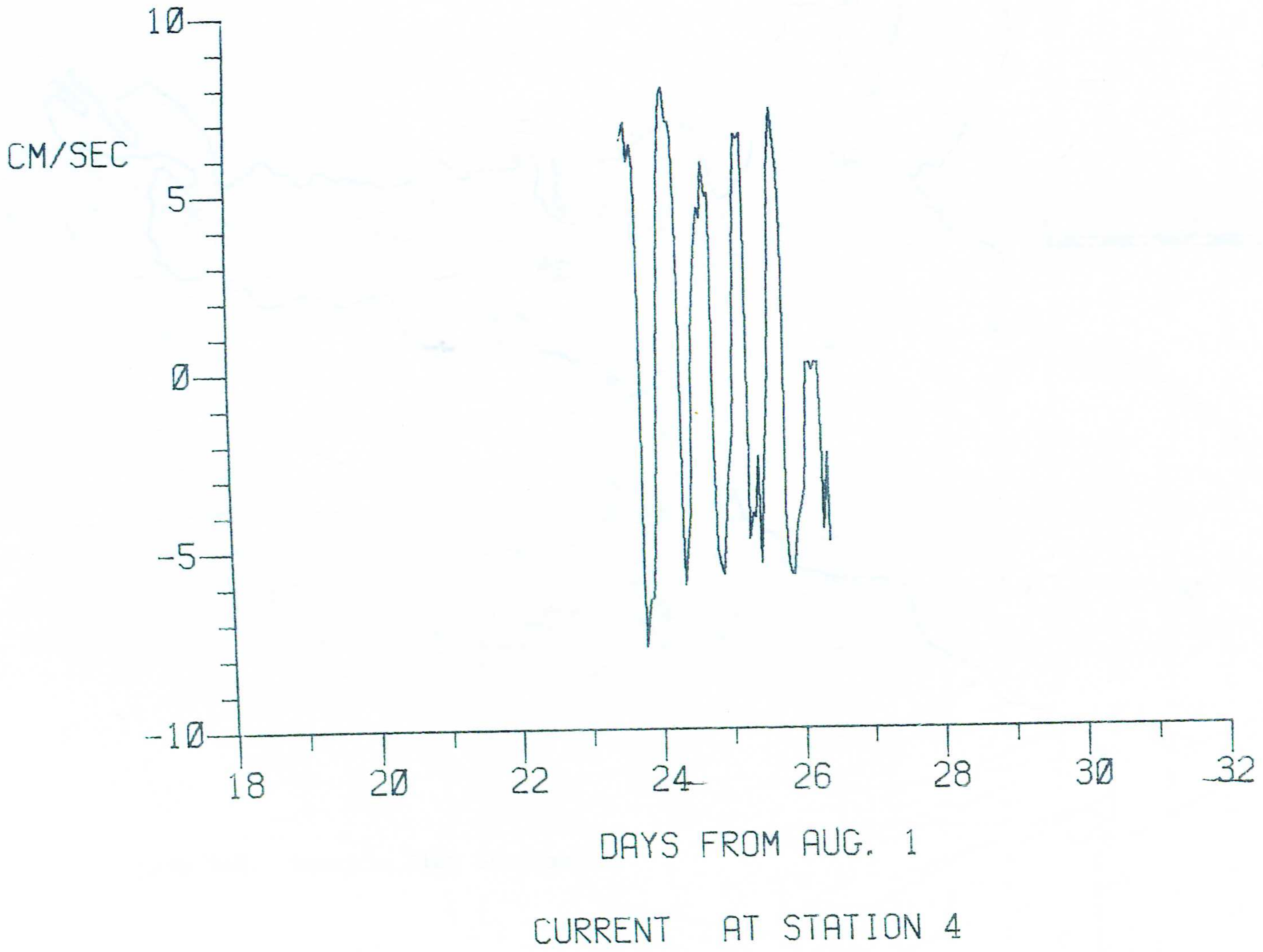


Figure 3-7. Current Velocity in Gunston Cove, August 1982.

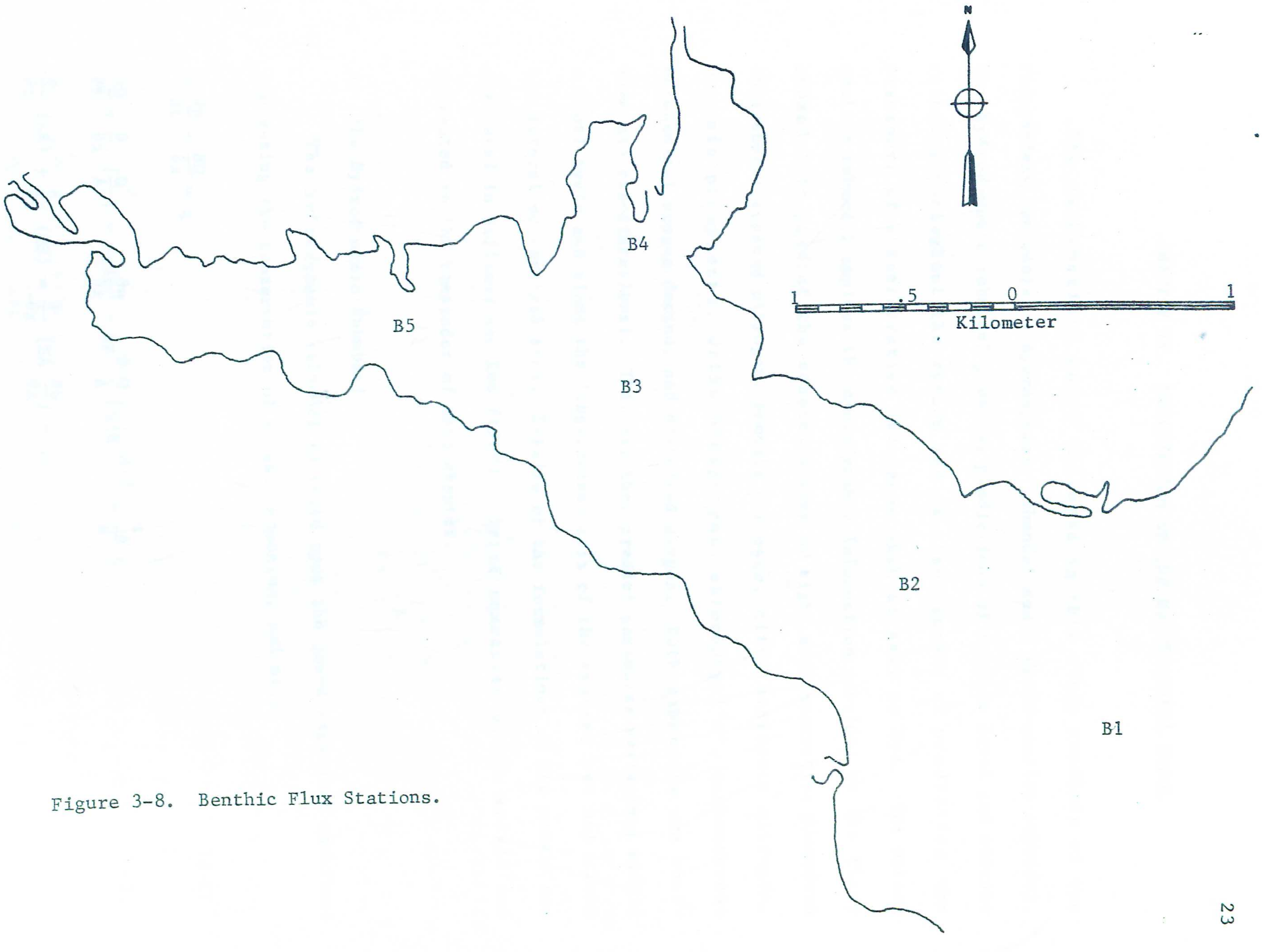


Figure 3-8. Benthic Flux Stations.

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:

$$B \frac{\partial \eta}{\partial t} + \frac{\partial Q}{\partial x} = q \tag{4-1}$$

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

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

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.

1) Modification for Accotink Bay - The system of equations 4-1 to 4-3 is one-dimensional. That is, the equations calculate variations in surface level, velocity, and concentration in the longitudinal direction only. The Gunston Cove system cannot be well-approximated as one-dimensional, however, due to the branching of Pohick and Accotink Bays. Predictions are desired along the axis extending from the mouth of Gunston Cove to the head of Pohick Bay and along the perpendicular to this axis which extends into Accotink Bay. Because little field data is available from Accotink Bay, the

additional complexity of a completely two-dimensional model is not warranted, however. Instead, all of Accotink is treated as a single, well-mixed water body which exchanges volume and mass with the adjacent portions of Pohick and Gunston. By assuming the surface elevation in Accotink is the same as in adjacent Pohick and Gunston, two zero-dimensional equations describing flow into (or out of) Accotink and substance concentrations within Accotink may be derived

$$Q = SA \frac{\partial \eta}{\partial t} - Qf \qquad (4\text{-}4)$$

$$\frac{\partial VS}{\partial t} = Qin * Sin + Qf * Sf + SS \qquad (4\text{-}5)$$

in which

Qin = flow into Accotink Bay from adjacent Gunston and Pohick

Qf = flow into Accotink Bay from freeflowing Accotink Creek

SA = surface area of Accotink Bay

V = volume of Accotink Bay

S = concentration of dissolved substance in Accotink

Sin = dissolved substance concentration in the flow Qin

Sf = dissolved substance concentration in the flow Q_f

SS = sources and sinks of dissolved substance

The exchange of flow between Accotink and Gunston-Pohick is treated as a lateral flow in the one-dimensional equation 4-1. The exchange of dissolved substance is treated as a source or sink in the one-dimensional equation 4-3.

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

$$SS = V * CH * (G-R-P-Ksch\ /h) + WCH \qquad (4\text{-}6)$$

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:

$$G = Kgr * \underset{\text{Temp. effect}}{Tgr} * \underset{\text{Light effect}}{I(Ia, Is, Ke, CH, h)} * \underset{\text{Nutrient effect}}{N(N2, N3, P2)} \qquad (4\text{-}7)$$

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

$$I = \frac{2.718}{(Ke * h)} * [\exp(-\alpha_1) - \exp(-\alpha_0)] \qquad (4\text{-}8)$$

$$Ke = Ke' + 0.018 * CH \qquad (4\text{-}9)$$

$$\alpha_1 = \frac{I(t)}{Is} * \exp(-Ke * h) \qquad (4\text{-}10)$$

$$\alpha_0 = \frac{I(t)}{Is} \qquad (4\text{-}11)$$

$$I(t) = \begin{cases} Ia * \dfrac{24}{td-tu} * \dfrac{\pi}{2} \sin\left[\pi \dfrac{t-tu}{td-tu}\right] & \text{if } tu < t < td \\ 0 & \text{if } t < tu \text{ or } t > td \end{cases} \qquad (4\text{-}12)$$

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.

$$N = \text{minimum} \begin{cases} \dfrac{N2 + N3}{Kmn + N2 + N3} \\[2ex] \dfrac{P2}{Kmp + P2} \end{cases} \qquad (4\text{-}13)$$

in which

N2 = ammonia nitrogen concentration (mg/1)

N3 = nitrite+nitrate nitrogen concentration (mg/1)

P2 = ortho phosphorus concentration (mg/1)

Kmn = half-saturation concentration for inorganic nitrogen uptake (mg/1

Kmp = half-saturation concentration for ortho phosphorus uptake (mg/1)

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

$$R = a * Tr \qquad (4\text{-}14)$$

in which

a = respiration rate at 20 C (1/day)

$Tr = \theta_r^{T-20}$

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

$$SS = V * [- \frac{Kn12 * Tn12}{Kh12 + N1} * N1 + aN * Fron * (R+P) * CH \qquad (4\text{-}15)$$

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

in which

N1 = concentration of organic nitrogen (mg/1)

Kn12 = hydrolysis rate of organic nitrogen to ammonia at 20 C (mg/1/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

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

$$+ aN \ast [(1-Fron) \ast (R+P) - PR \ast G] \ast CH + BENN2/h] + WN2 \qquad (4\text{-}16)$$

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

$$= \frac{N2 \ast N3}{(Kmn + N2) \ast (Kmn + N3)} + \frac{N2 \ast Kmn}{(N2+N3) \ast (Kmn + N3)} \qquad (4\text{-}17)$$

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

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

$$SS = V \ast [\frac{Kn23 \ast Tn23}{Kh23 + N2} \ast N2 - aN \ast G \ast (1-PR) \ast CH - N3 \qquad (4\text{-}18)$$

$$\ast Kn33/h + BENN3/h] + WN3$$

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

$$SS = V * [- \frac{Kp12 * Tp12}{Khp + P1} * P1 + aP * Frop * (R+P) * CH \qquad (4\text{-}19)$$

$$- P1 * Kp11/h + BENP1/h] + WP1$$

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

$$SS = V * [\frac{Kp12 * Tp12}{Khp + P1} * P1 + aP * [(1-Frop) * (R+P)-G] * CH \qquad (4\text{-}20)$$

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

in which

P2 = concentration of ortho phosphorus (mg/1)
Kp22 = settling rate of inorganic phosphorus (m/day)
BENP2 = benthic flux of inorganic phosphorus (gm/m^2/day)
WP2 = external loading of ortho phosphorus (gm/day)

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

$$SS = V * [- Kc * Tbod * CBOD + aC * aco * P * CH \qquad (4\text{-}21)$$

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

in which

CBOD = concentration of carbonaceous biochemical oxygen demand (mg/1)
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/ug 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

$$SS = V * [- Kc * Tbod * CBOD - ano * \frac{Kn23*Tn23}{Kh23+ N2} * N2 \qquad (4\text{-}22)$$

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

$$+ Kr * (DOs - DO) - BENDO/h] + WDO$$

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 ($gm/m^2/day$)

WDO = external loading of dissolved oxygen (gm/day)

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

$$Kr = \frac{1}{h} * Kro * \left[\frac{u}{h}\right]^{1/2} * Tdo \tag{4-23}$$

in which

Kr = reaeration rate (1/day)

Kro = proportionality constant

$Tdo = \theta_{do}^{T-20}$

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).

$$DO = 14.6244 - 0.367134 * T + 0.004497 * T^2 \tag{4-24}$$

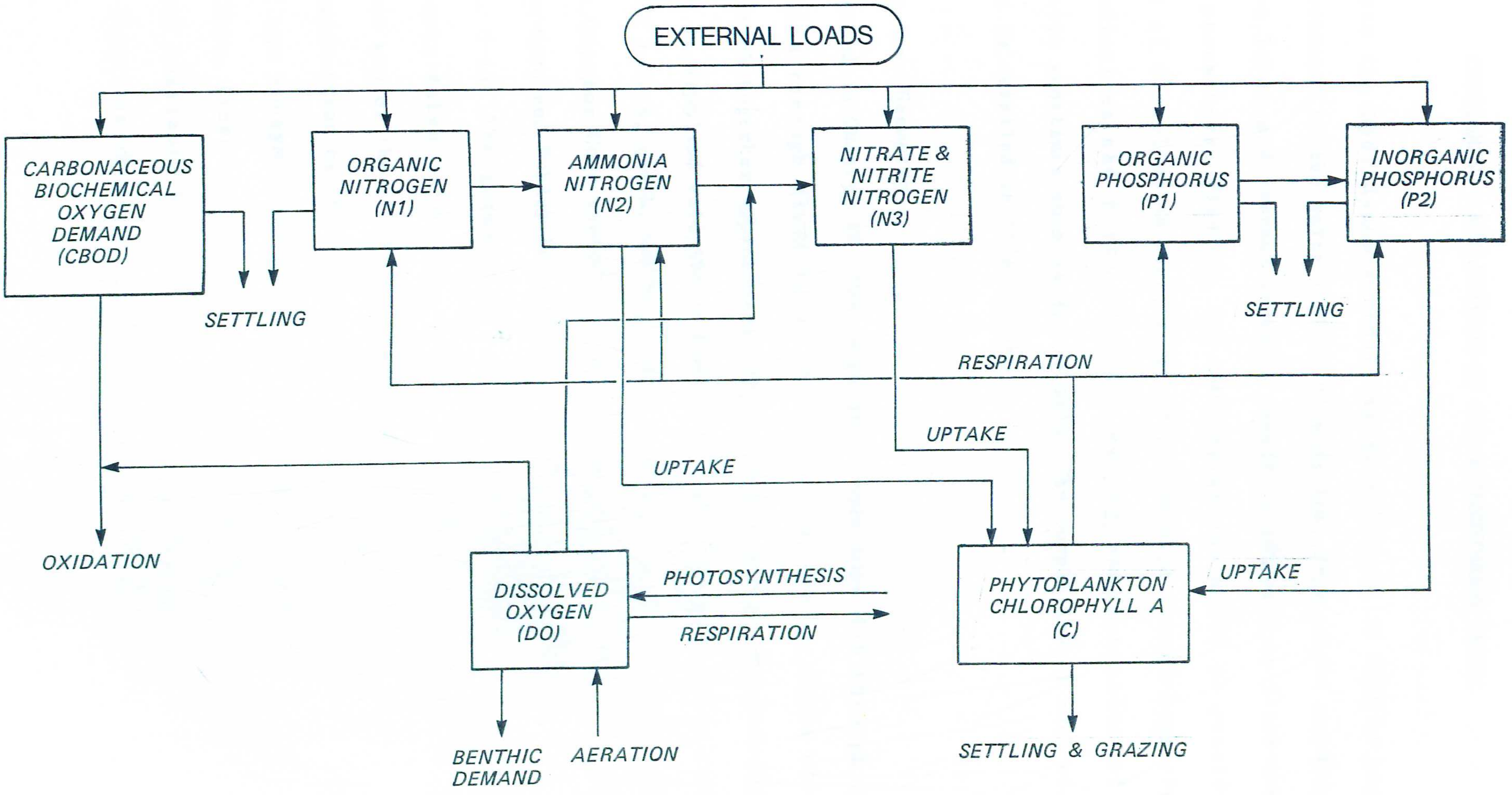


Figure 4-1. Schematic of ecosystem model.

CHAPTER V. APPLICATION 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 this chapter.

A. Gunston Cove Geometry

As noted in Chapter IV, the solution to equations 4-1 through 4-3 is accomplished through division of the water body into a 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.

The Gunston Cove system is divided into seven segments along the axis of Gunston Cove and Pohick Bay, and a single segment representing Accotink Bay (Fig. 5-1). The geometry of these segments is derived from bathymetry measurements taken in April, 1983, (Fig. 5-2) and from a U.S.G.S. topographic map of the Ft. Belvoir quadrangle photorevised in 1980.

Specification of the segment geometry is complicated by the irregular shape of the embayment and by the marshy areas at the heads of Pohick and Accotink Bays. 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 at the mean-tide level are presented in Table 5-1. Note that for some of these segments, the surface area and volume are larger than the product of the segment length and transect width or area. The additional area and volume are 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.

B. Calibration and Verification of Tide and Current

In this section, the ability of the model to predict surface level and current velocity within the embayment is tested. This is accomplished by completing a series of model runs employing observed tides at the mouth of Gunston Cove and observed freshwater flows as boundary conditions. The predicted tides at the head of Pohick Bay and currents within Gunston Cove are then compared with measurements collected at these locations. The first set of comparisons is deemed a calibration in that agreement between predictions and observations is obtained by calibrating the bottom friction term, expressed as Manning's n, in Eq. 4-2. Subsequent comparisons are verifications that the selected friction parameter, $n = 0.03$, is correct.

Of the hydrodynamic data collected in 1979 and 1982, and described in Chapter III, three independent data sets were found to be suitable for model use. These data sets and their usages are

August 1982	Calibration of tide in Pohick Bay and current in Gunston Cove
August 1979	Verification of tide in Pohick Bay

September 1979 Verification of currents in Gunston Cove

Predictions and observations for August, 1982, are presented in Figures 5-3 through 5-5. August, 1979, results are shown in Figures 5-6 and 5-7, and September, 1979, results are shown in Figures 5-8 and 5-9.

In all cases, predicted and observed tides at the mouth of Gunston are in perfect agreement, as they should be, since the tides at the Gunston mouth are input to the model as boundary conditions. Attention is directed to the comparisons of predictions and observations at the head of Pohick (Figs. 5-4 and 5-7), the point most-distant from the imposed boundary. The near perfect agreement there demonstrates that the model is capable of predicting accurately the surface level throughout the Gunston-Pohick system.

Comparisons of the predicted and observed currents are less ideal than the tides (Figs. 5-5 and 5-9). Discrepancies exist here largely due to the means of collecting velocity data and to conceptual differences between the model and the data. The current meters employed measure velocity instantaneously at a single point in the spatial domain. The model, however, provides predictions averaged temporally over a model time step, $\Delta t = 29$ minutes, and spatially along the lateral and vertical axes. Thus the model provides relatively smooth, deterministic currents for comparison with data affected by spatial non-uniformities, random turbulence, wind gusts, and boat traffic. Allowing for these elements, the model predictions of current are excellent and more than sufficient for their intended use.

C. Calibration and Verification of Mass Transport

In the last test of the hydrodynamic model, the ability to predict the transport of a conservative substance is examined. Two dye studies, conducted in August, 1982, and September, 1979, and described in Chapter III are available for this purpose, as is a set of dissolved chlorides data collected in September, 1982, by a Fairfax County sampling team.

Calibration is achieved via evaluation of the dispersion term of Eq. 4-3 and by adjustment of a weighting coefficient, α, which determines the dissolved substance concentration in the flow between adjacent segments.

Dispersion, E, is computed by Taylor's formula

$$E = Eo * n * u * R^{5/6} \tag{5-1}$$

in which

E = dispersion coefficient (m^2/sec)

Eo = proportionality constant

n = Manning's friction coefficient

u = velocity (m/sec)

R = hydraulic radius (m)

A value of Eo = 60 was found suitable for model use.

The weighting coeficient α is utilized in the equation

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

in which

α_i = weighting coefficient for transect i $(0.5 < \alpha < 1.0)$

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 $\alpha = 1.0$ corresponds to a backwards finite-difference scheme. A value of $\alpha = 0.5$ corresponds to a central difference scheme. Details of the employment of the weighting factor in the finite-difference scheme may be found in Williams and Kuo (1984). Values of α found suitable for the Gunston Cove system are presented in Table 5-2.

Calibration was initially achieved using the August, 1982, dye study. Verification was accomplished using the September, 1979, dye study and the September, 1982, chlorides survey. Results of these procedures are presented in the remainder of this chapter.

1) August, 1982, Dye Study - In conventional dye studies of large water bodies, sufficient time is allowed between the dye release and the initiation of sampling for the dye to mix uniformly laterally and vertically and to form a smooth distribution longitudinally. In small embayments such as Gunston Cove, however, the luxury of an extended initial mixing period is not available. The residence time of the embayment is too short and the risk of a ruinous meteorological event is great. If a lengthy mixing period were allowed, much of the dye would be lost from the system and a wind event or rainstorm might render the data set useless.

Without a lengthy mixing period, the dye distribution in the embayment is patchy and non-uniform which poses problems in the interpretation of the samples and in specification of initial conditions for the model. Dye concentration in the initial samples fluctuates widely due as much to the random distribution of dye as to any deterministic transport process. Because the initial dye distribution cannot be discerned, model initial conditions based on the distribution cannot be specified.

The problem of posing initial conditions is solved by specifying the initial mass of dye in the system rather than the initial spatial distribution of dye. The dye mass, 5.7 kg, is assumed to be uniformly distributed in the model segments comprising the portion of the embayment into which the dye was dumped, segments 3 and 4. The resulting initial concentration in these segments is 5 ppb.

Due to the patchy initial distribution of the dye, agreement cannot be expected between predictions and observations of instantaneous dye concentration. Instead, tidal-average dye distributions for the first two tidal cycles are compared with tidal-averages of the real-time model predictions. By averaging the data over this interval, the random component of the dye distribution is largely suppressed. Subsequent to the first two tidal cycles of the study, only slackwater dye data is available. These are compared with the range of dye concentrations predicted by the model for the appropriate cycles.

To summarize, the August, 1982, dye calibration is conducted in the following manner:

1) Initial dye concentration in model segments 3 and 4 is specified based on the mass of dye released to the system.
2) Tidal-average values of field data are compared with tidal-average values of model predictions for two tidal cycles following the dye release.

3) Slackwater field data are compared with the range of model predictions for 3, 4, and 8 tidal cycles after the dye release.

Results of the dye calibration, along the Gunston-Pohick axis, are shown in Figure 5-10. Good agreement is noted between the predicted and observed average dye concentrations for the first two tidal cycles. Qualitative agreement is attained in the slackwater data and model predictions for subsequent tidal cycles although some data points lie outside the model range. This may be attributed as much to the limited number of data points as to any shortcomings in the model, however.

It should be noted that comparison of model predictions to data which is both temporally and spatially variable is the most rigorous test to which a model can be subjected. 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.

2) September, 1979, Dye Study - Initial conditions for the model simulation of the 1979 dye study are obtained in the same manner as the 1982 study. Since the dye was discharged at a single location and during a flood tide, the dye is assumed to be mixed uniformly in model segment 2 and an initial concentration of 33 ppb is employed.

The presentation of predictions and observations (Fig. 5-11) for the first two tidal cycles is similar to that of 1982. Tidal-average data are compared to the model range of concentrations. Presentation of the slackwater surveys, cycles 5, 7, and 9, differs slightly, however. In these surveys, data was collected in transects extending across the embayment rather than at single points. Thus the data shows the lateral mean and range of the instantaneous data.

In assessing the results of this verification, particular attention should be devoted to the change in peak dye concentration through the course of the survey. The model successfully predicts the decline of dye from a peak concentration of approximately 20 ppb in cycle 1 to a concentration of approximately 1 ppb in cycle 9.

The longitudinal predictions of dye concentration within any tidal cycle are similar to the observed distributions, although numerous data points fall outside the model range. This must be attributed to the non-uniform distribution of the dye and to the limited number of data points as well as to any shortcomings in the model.

3) September, 1982, Chlorides Survey - A set of dissolved chlorides data was collected in Gunston Cove on September 15, 1982, as part of the regular monitoring program conducted by personnel of the Lower Potomac WPCP. This data was deemed suitable for additional verification of the mass-transport portion of the Gunston Cove model.

No flow data or initial conditions were available for use with this data set. Since several days of dry weather preceded the survey, it was assumed that the dry-weather flows measured in August prevailed in September as well, and that the chlorides distribution was at steady state. Initial conditions were provided by assuming a linear gradient of chlorides from the mouth of Gunston to the head of Pohick. The model was run until the predicted chlorides distribution achieved a steady state.

The predicted and observed chlorides concentrations are presented in Figure 5-12. Agreement is close, and enhances the preceding calibration and verification conducted with dye data.

TABLE 5-1. SEGMENT GEOMETRIES AT MEAN TIDE

Transect	Segment	Distance from Mouth (m)	Length (m)	Surface Width (m)	Depth (m)	Cross Sectional Area (m^2)	Surface Area ($10^5 m^2$)	Volume ($10^6 m^3$)
2		5130		21	0.9	19		
	2		800				1.81	0.13
3		4330		432	0.7	316		
	3		610				3.18	0.26
4		3720		610	0.9	549		
	4		580				3.70	0.44
5		3140		700	1.5	1050		
	5		700				5.91	0.95
6		2440		854	1.7	1452		
	6		820				9.58	1.63
7		1620		1040	2.1	2184		
	7		795				8.75	1.88
8		825		1160	2.2	2552		
	8		825				13.3	2.93
9		0		2260	2.2	4972		
	9							
10		3050		500	1.4	700		
	10		980				3.45	0.39
11		4030		205	0.5	103		

TABLE 5-2. Finite-Difference Weighting Factors

Transect	α
2	1.00
3	0.75
4	0.60
5	0.60
6	0.60
7	0.60
8	0.60
10	0.75

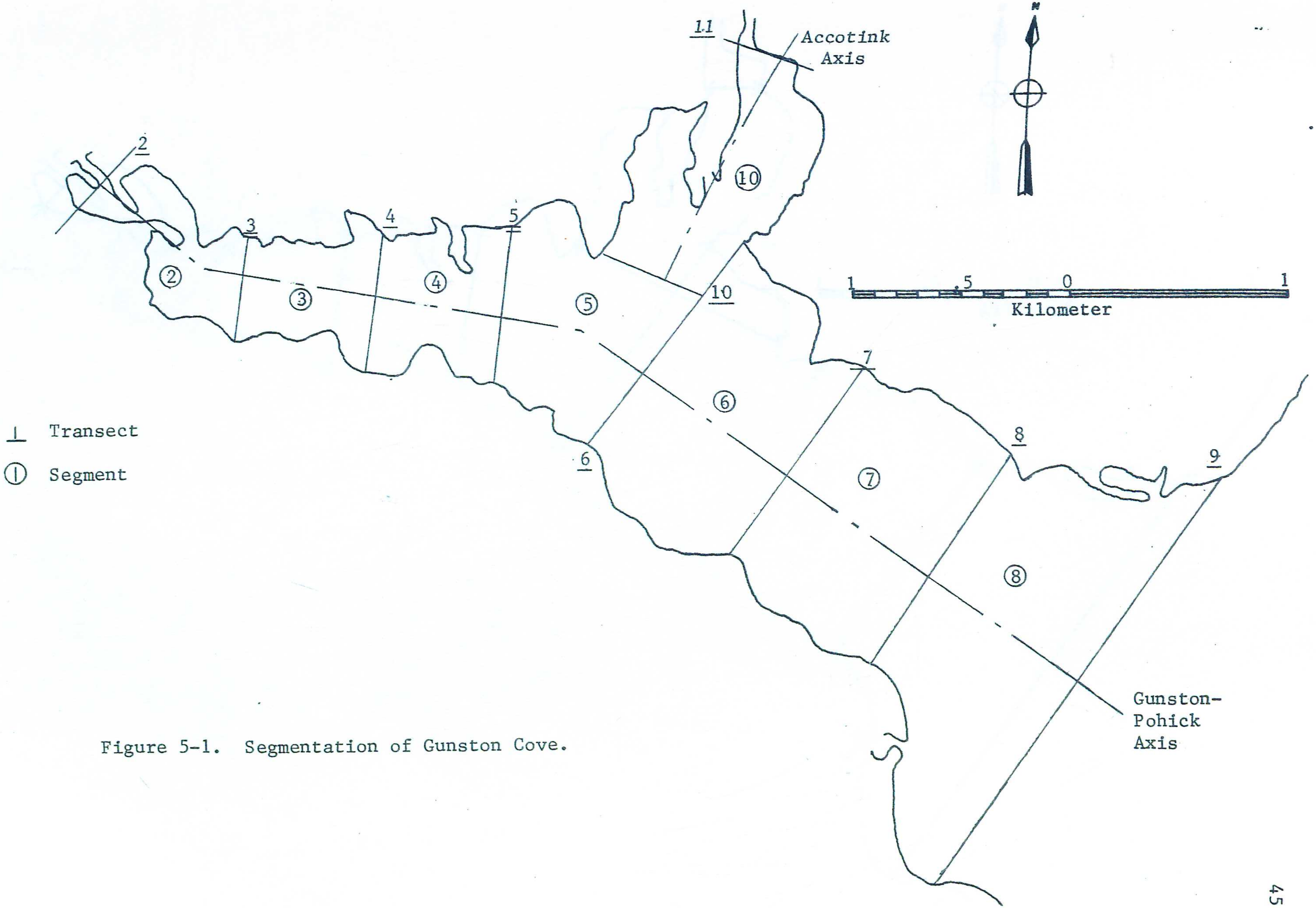


Figure 5-1. Segmentation of Gunston Cove.

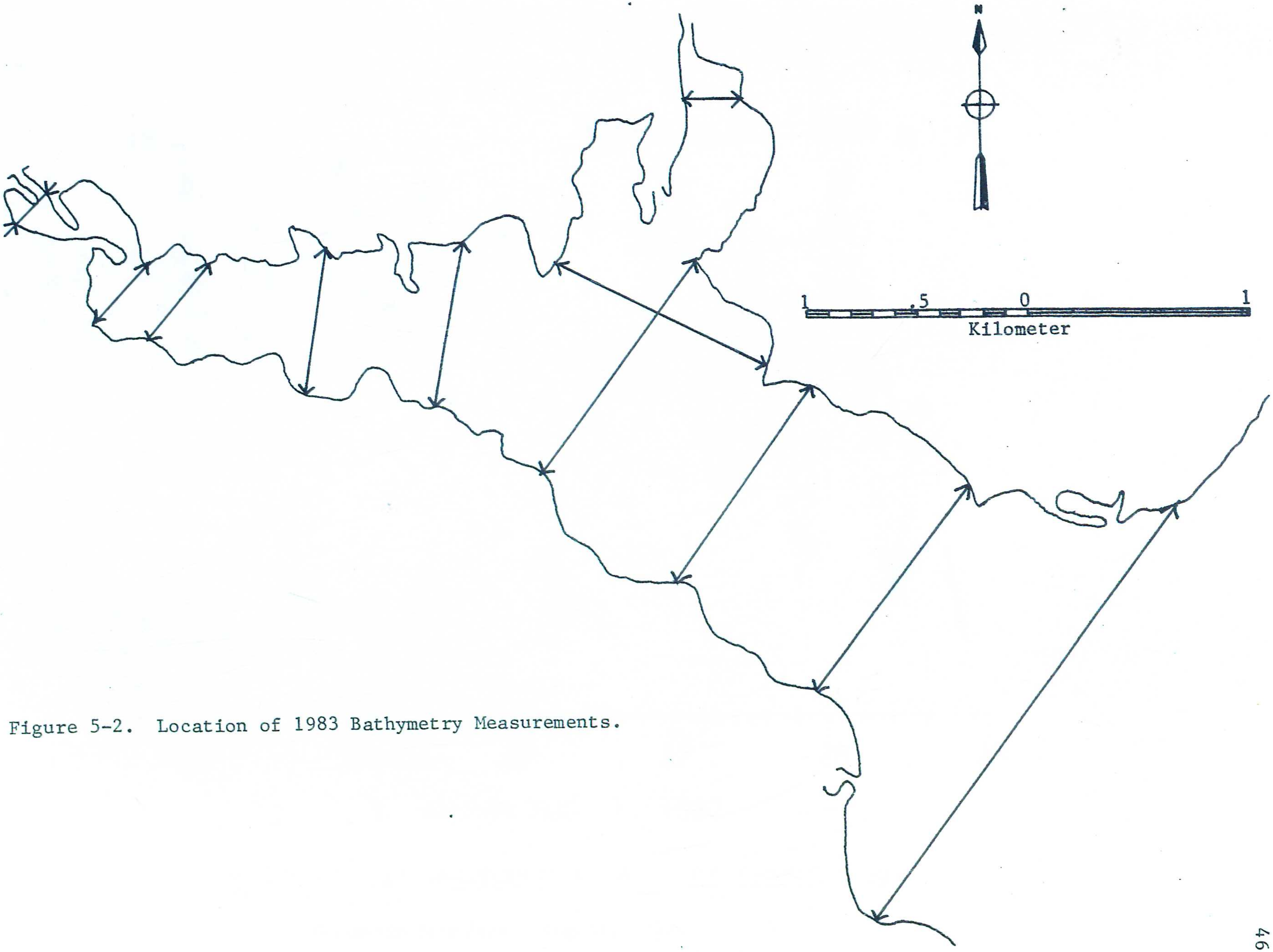


Figure 5-2. Location of 1983 Bathymetry Measurements.

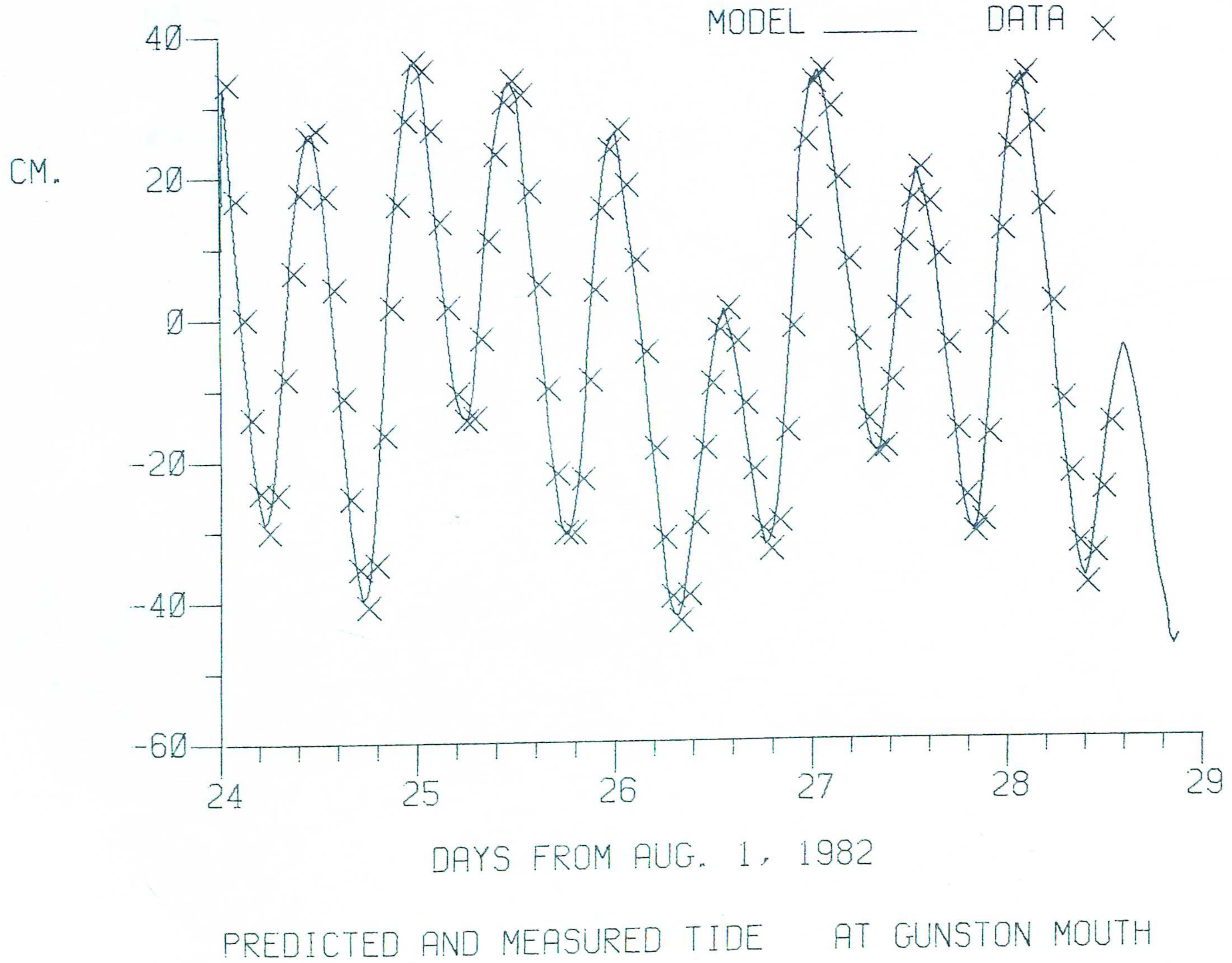


Figure 5-3. Open-Mouth Boundary - August, 1982.

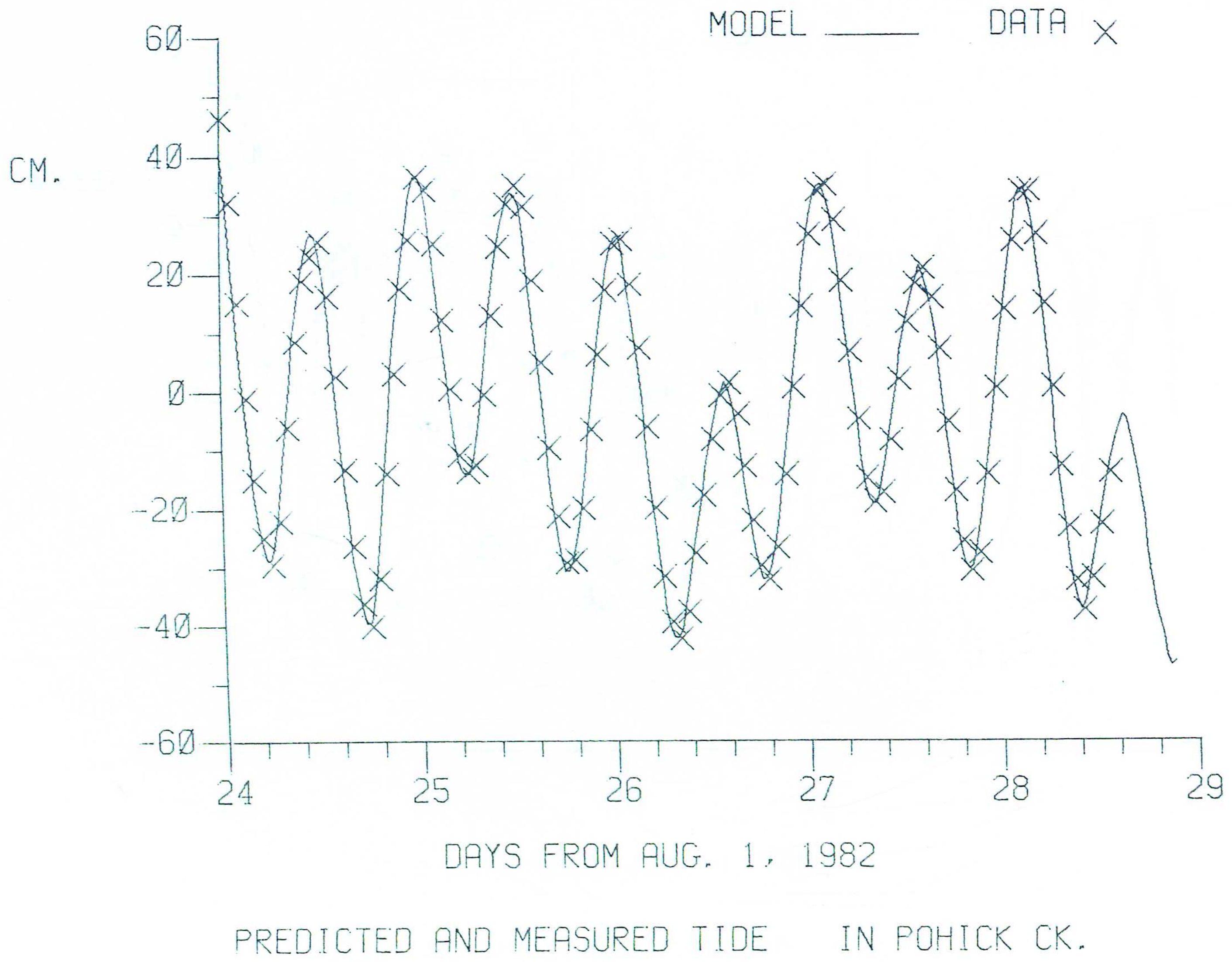


Figure 5-4. Calibration of Tide - August, 1982.

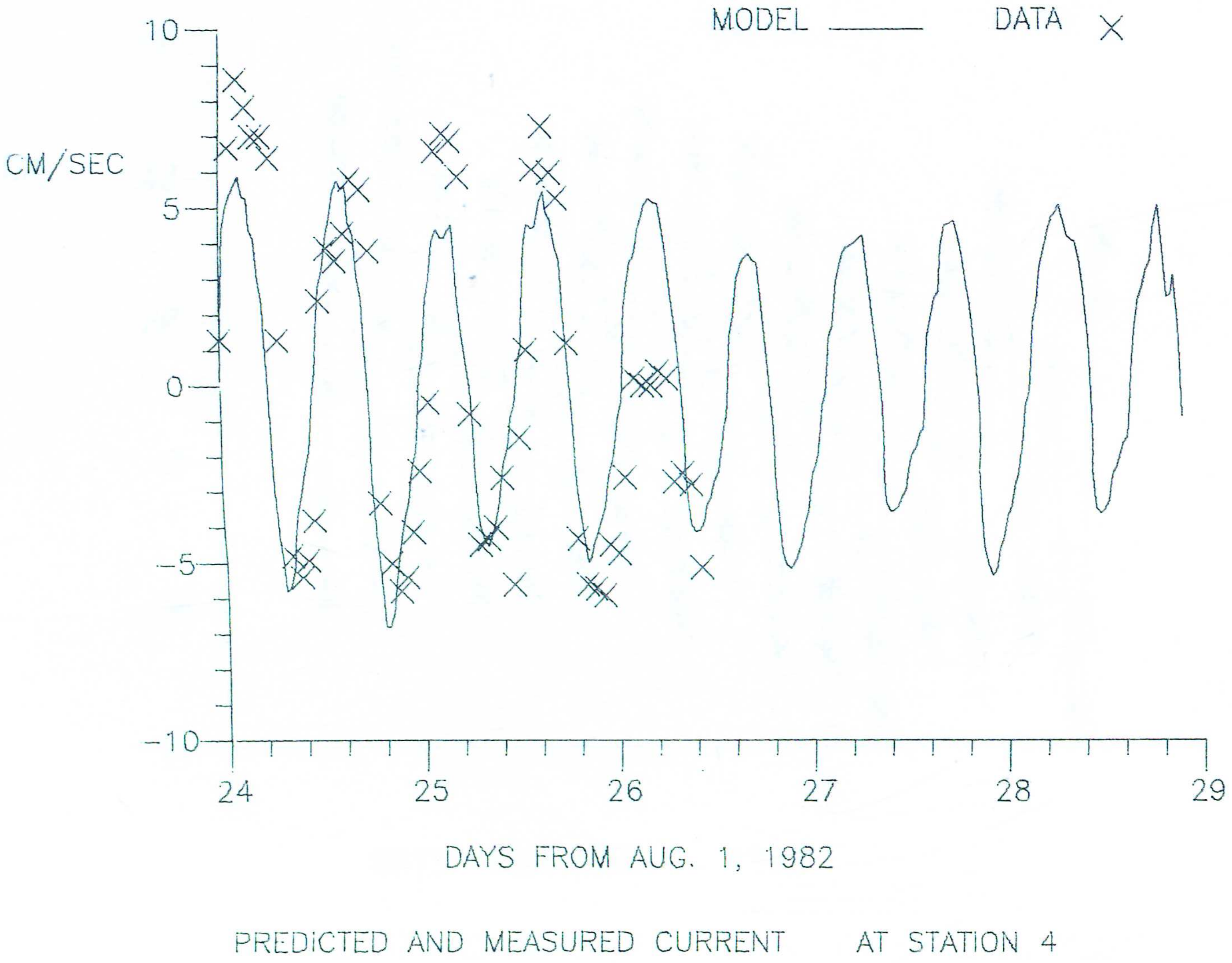


Figure 5-5. Calibration of Current - August, 1982.

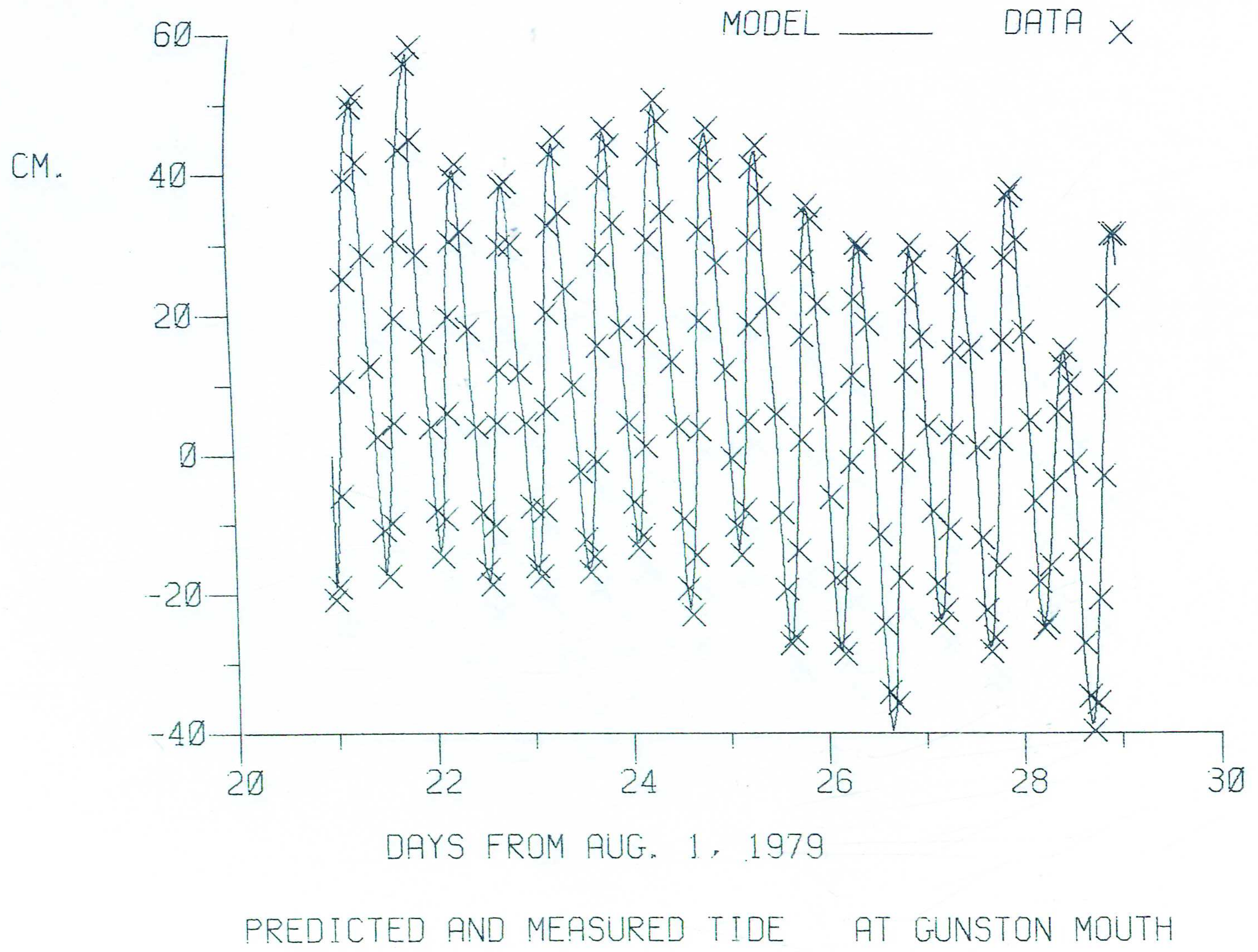


Figure 5-6. Open-Mouth Boundary - August, 1979.

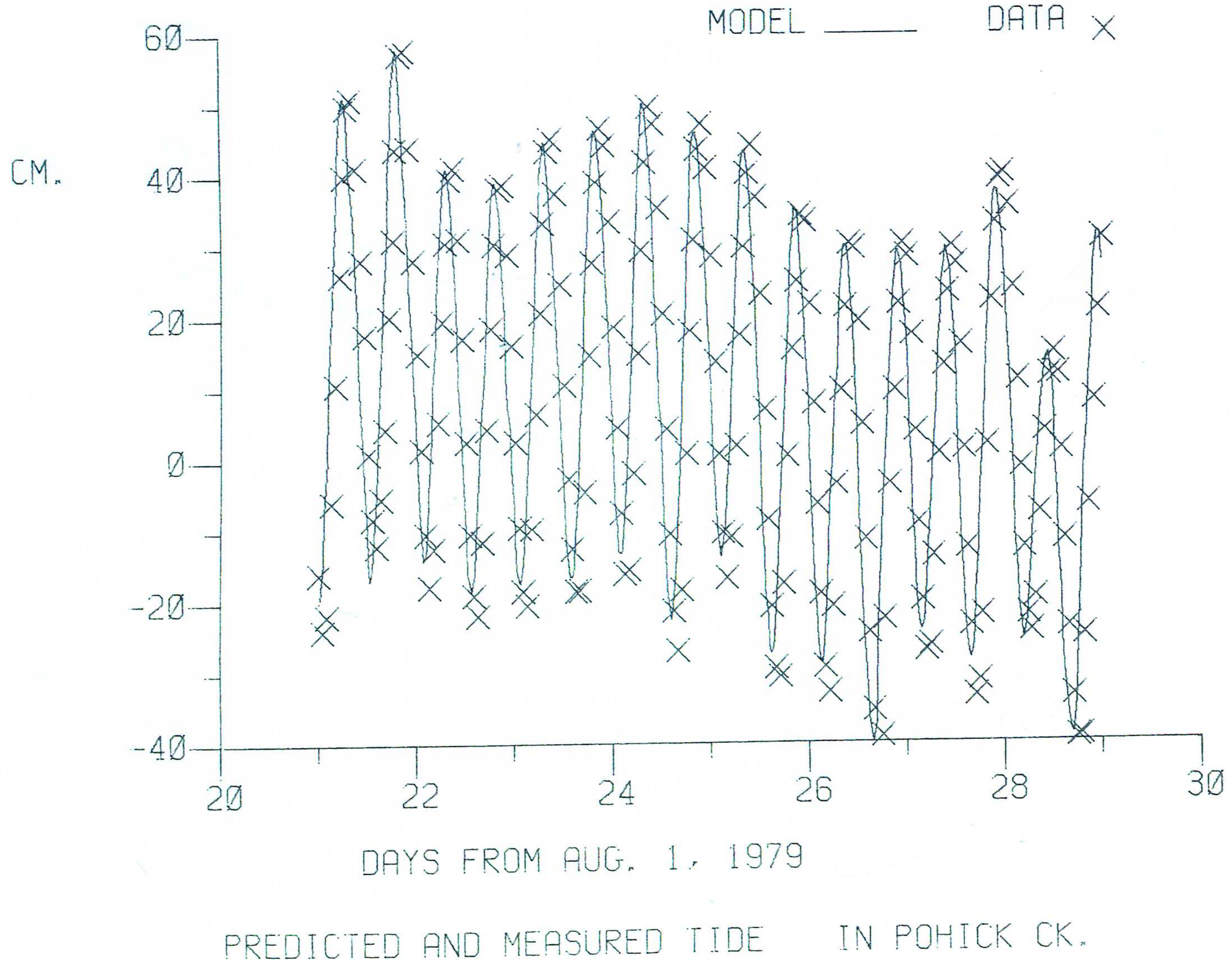


Figure 5-7. Verification of Tide - August, 1979.

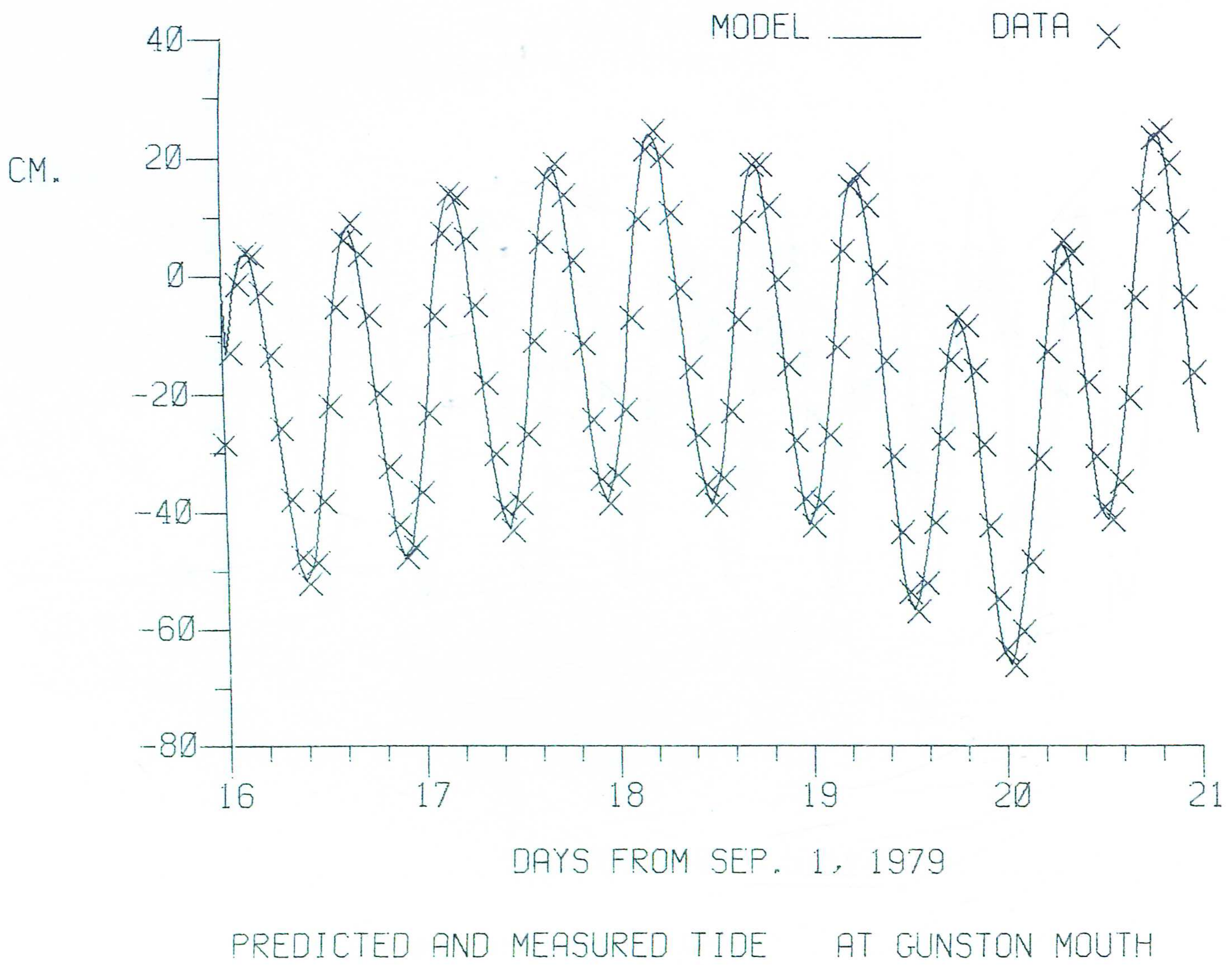
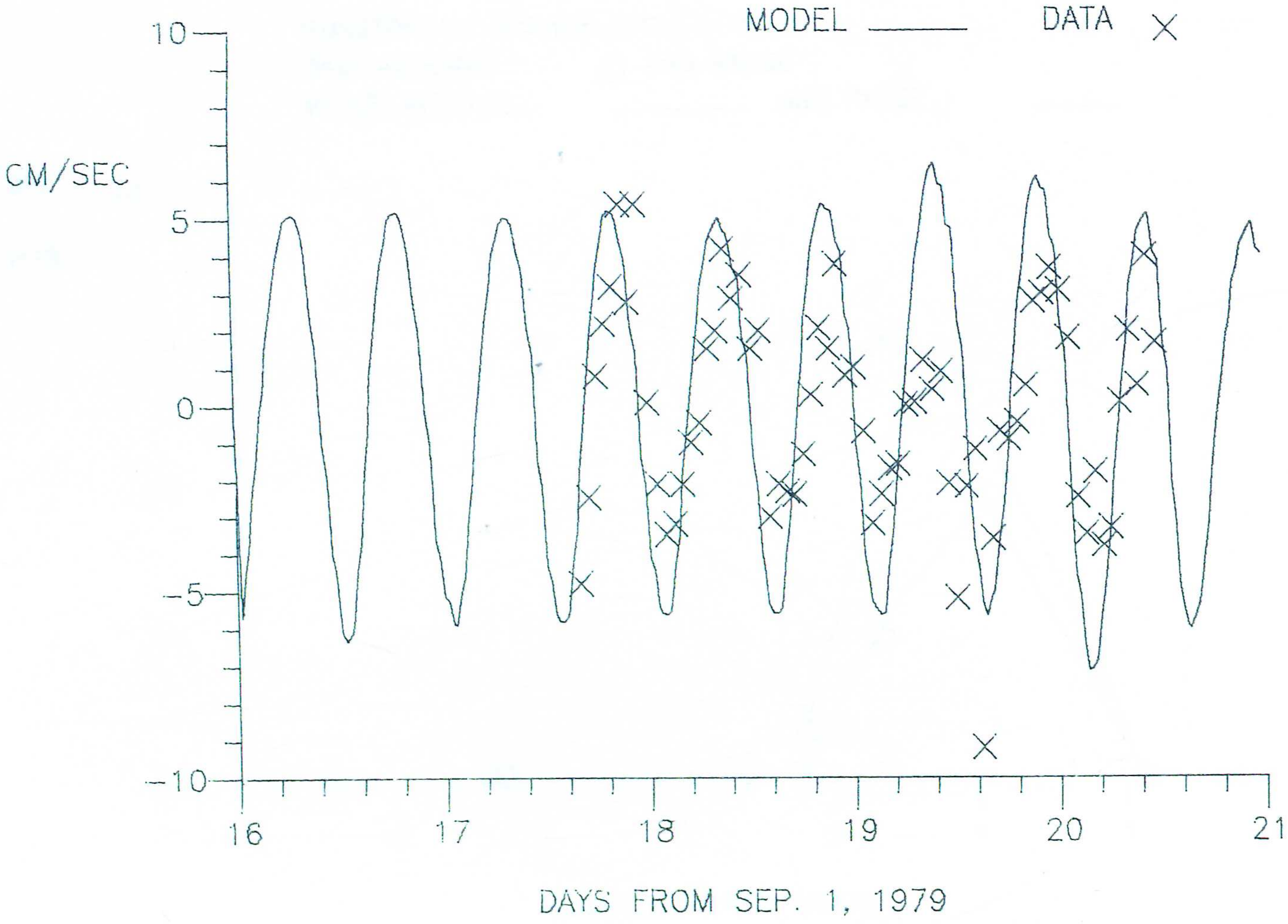


Figure 5-8. Open-Mouth Boundary - September, 1979.



PREDICTED AND MEASURED CURRENT AT STATION 4

Figure 5-9. Verification of Current - September, 1979.

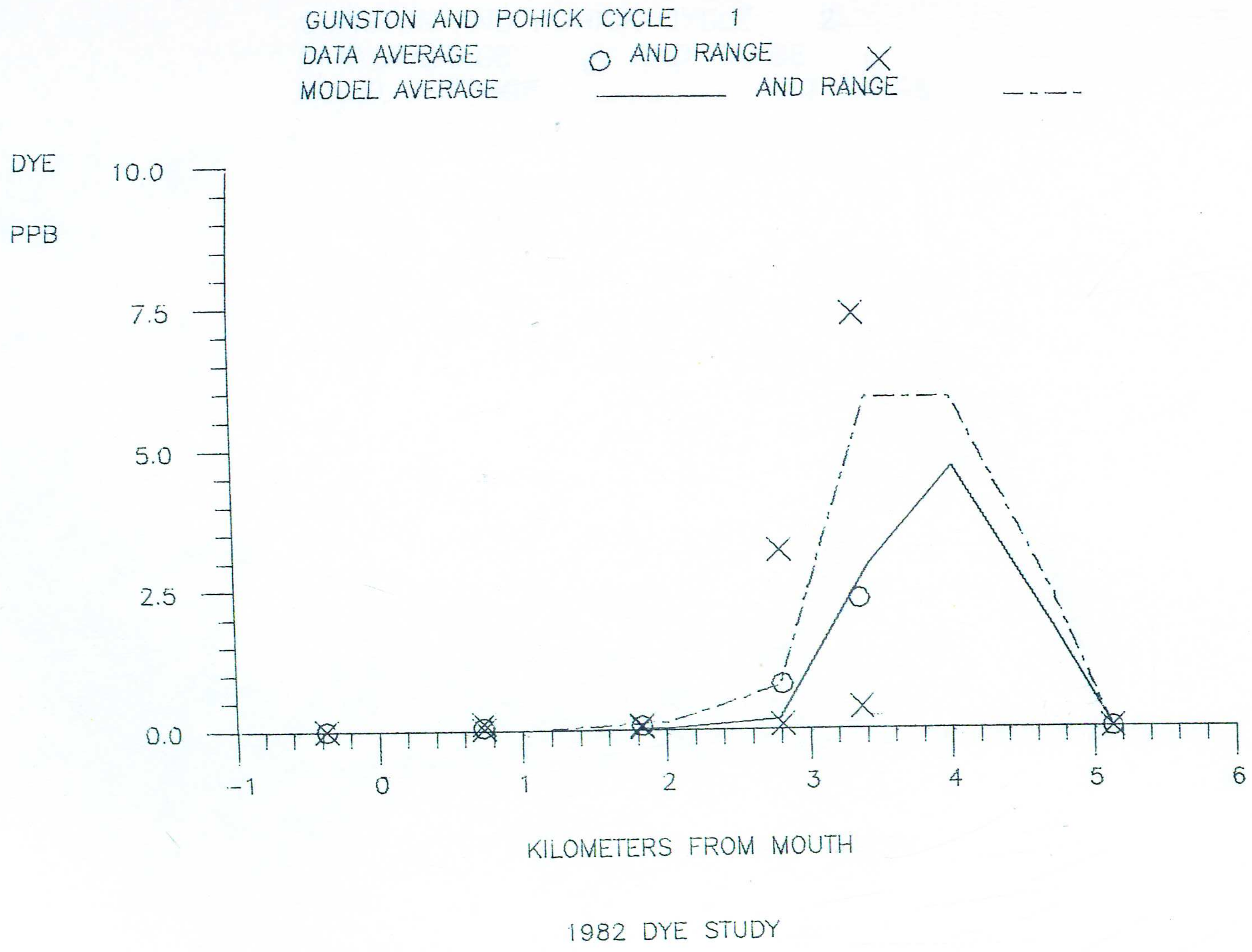


Figure 5-10. Calibration of Dye Dispersion, August, 1982.

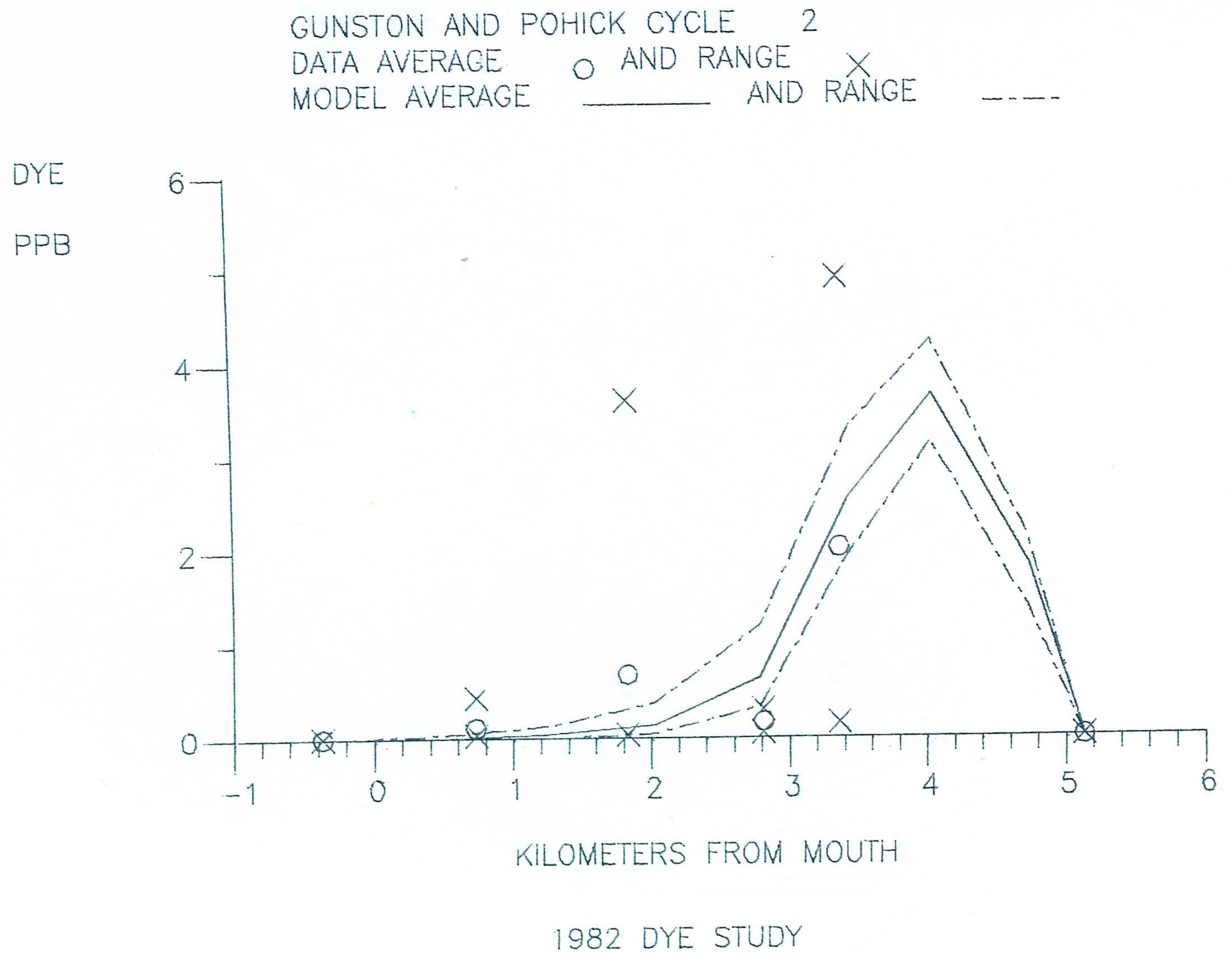
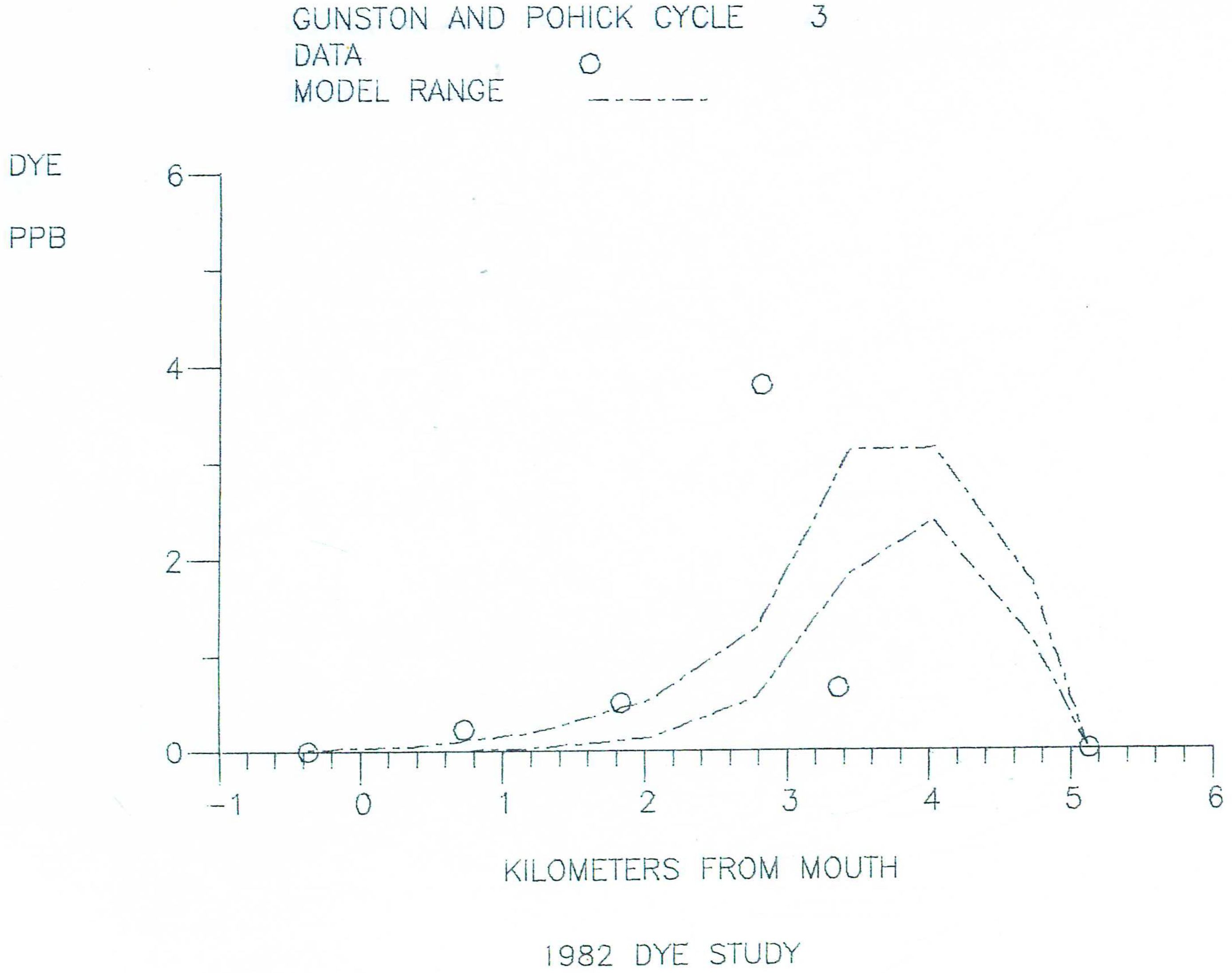


Figure 5-10. (Continued)



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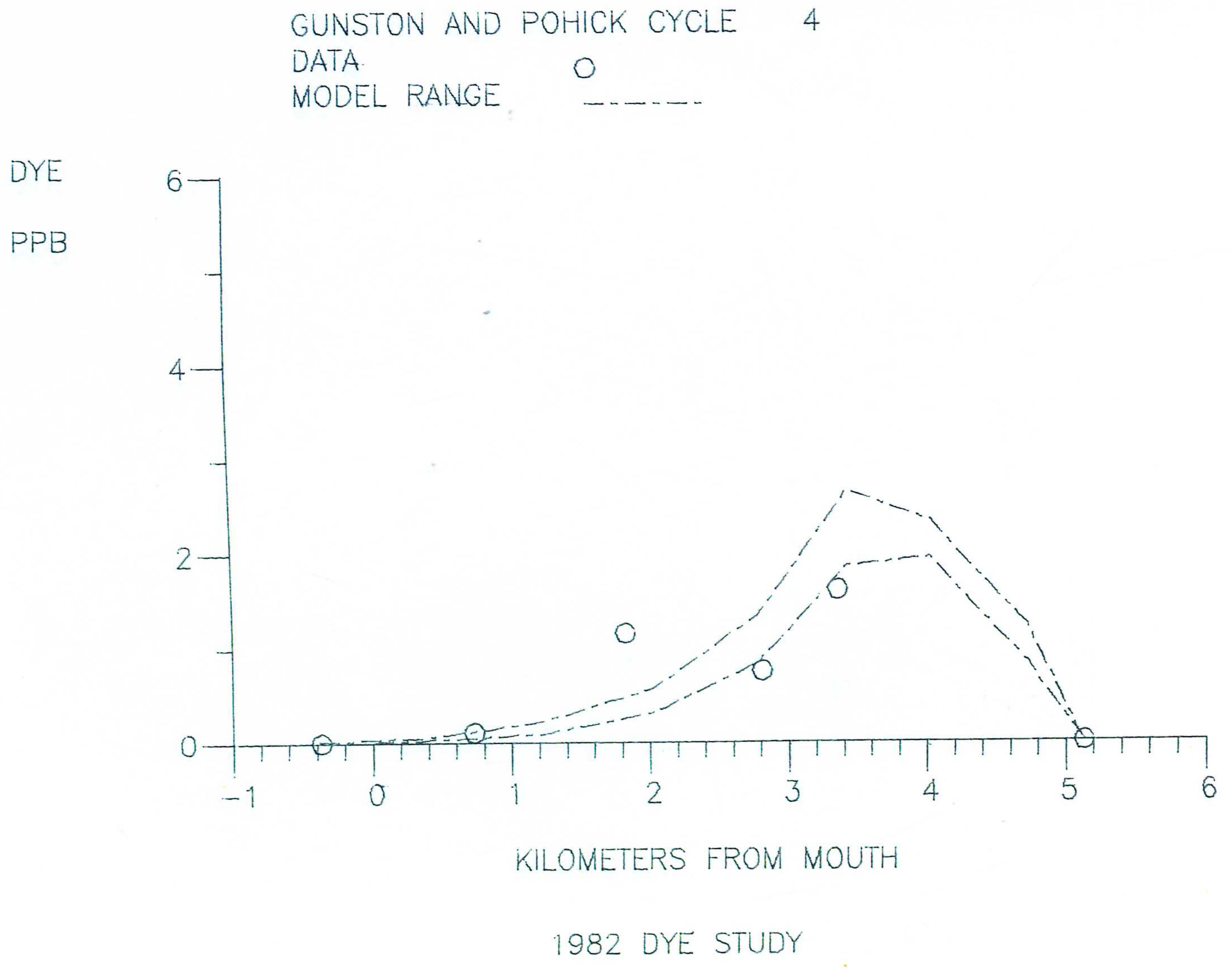

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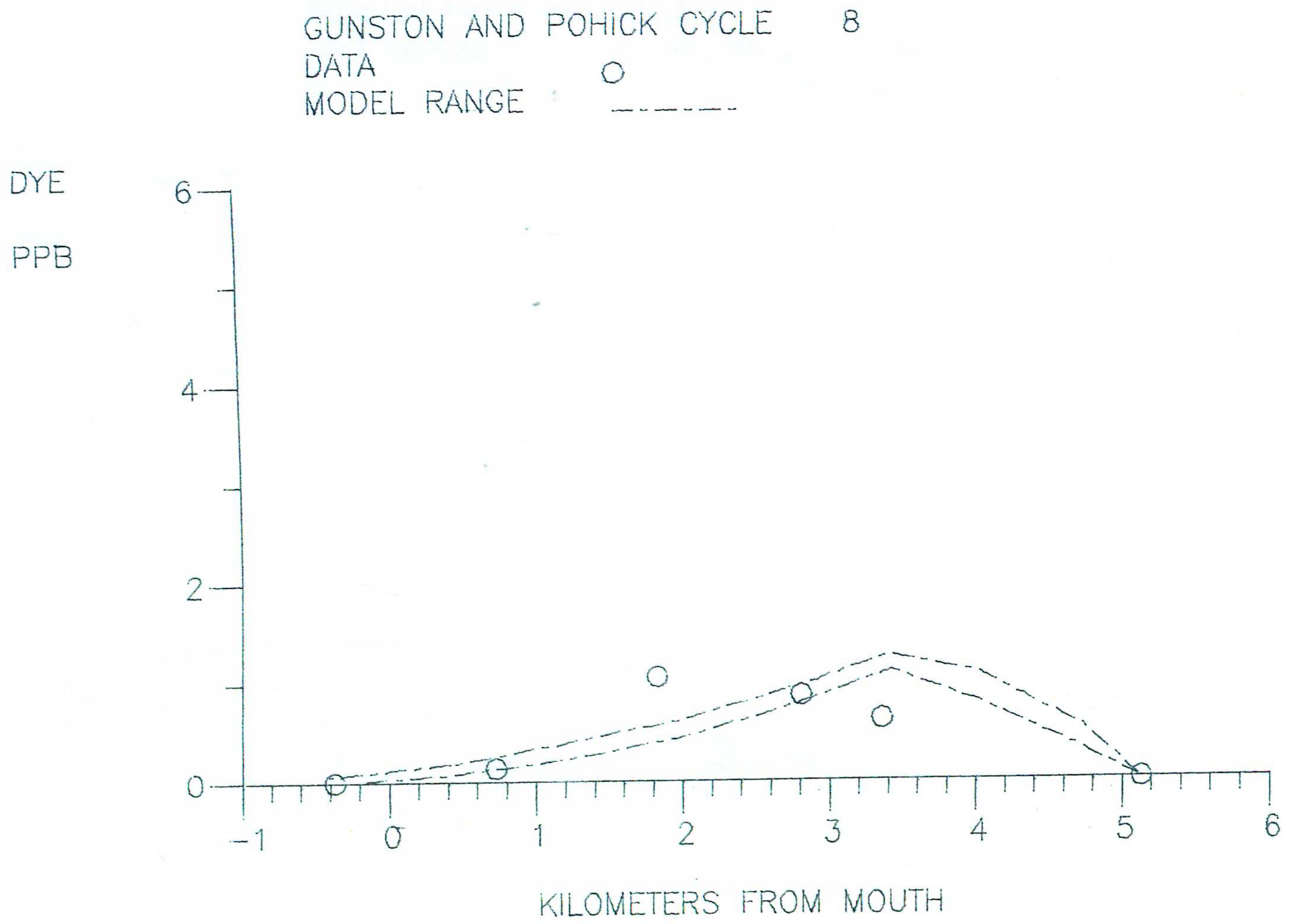


1982 DYE STUDY

Figure 5-10. (Continued)

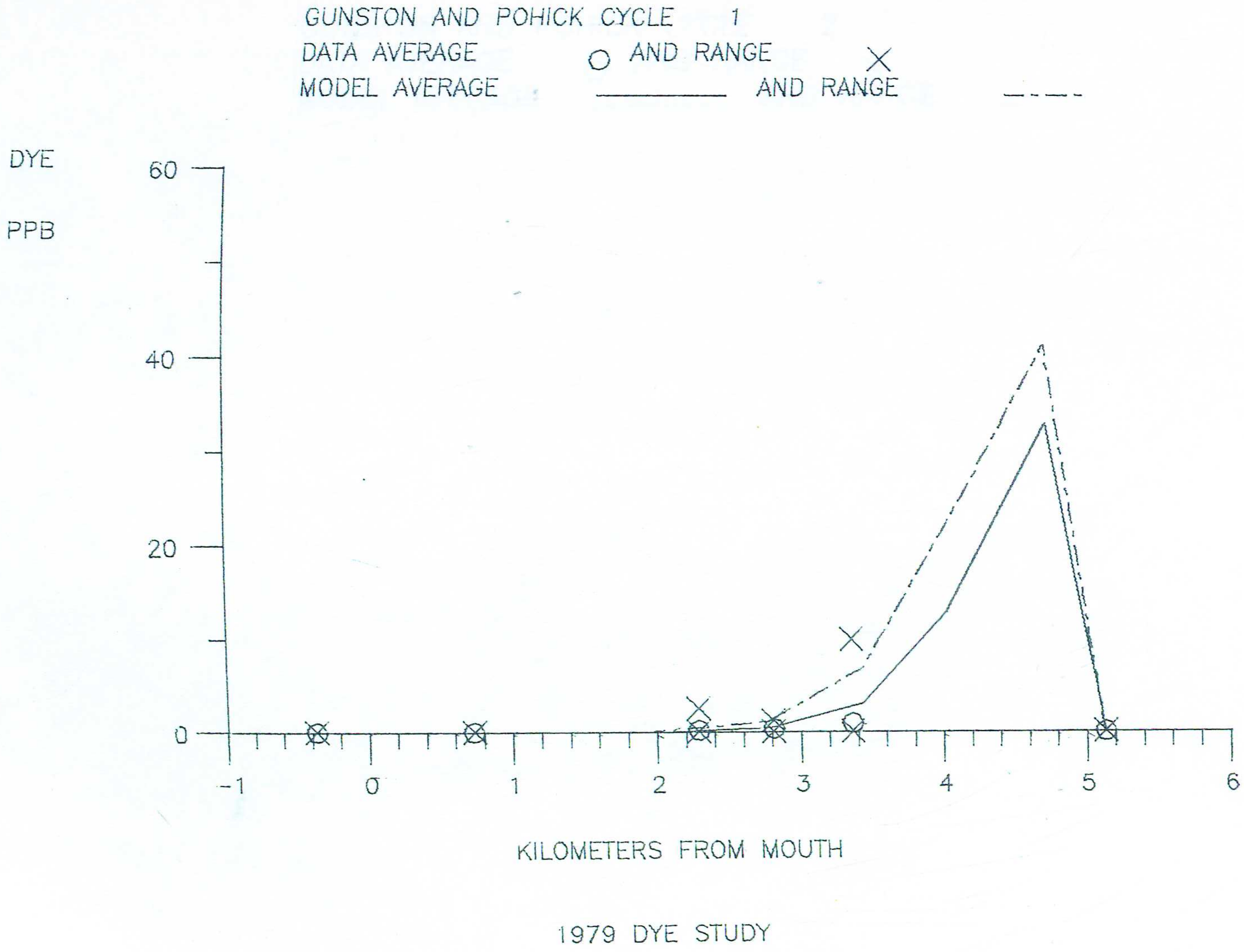
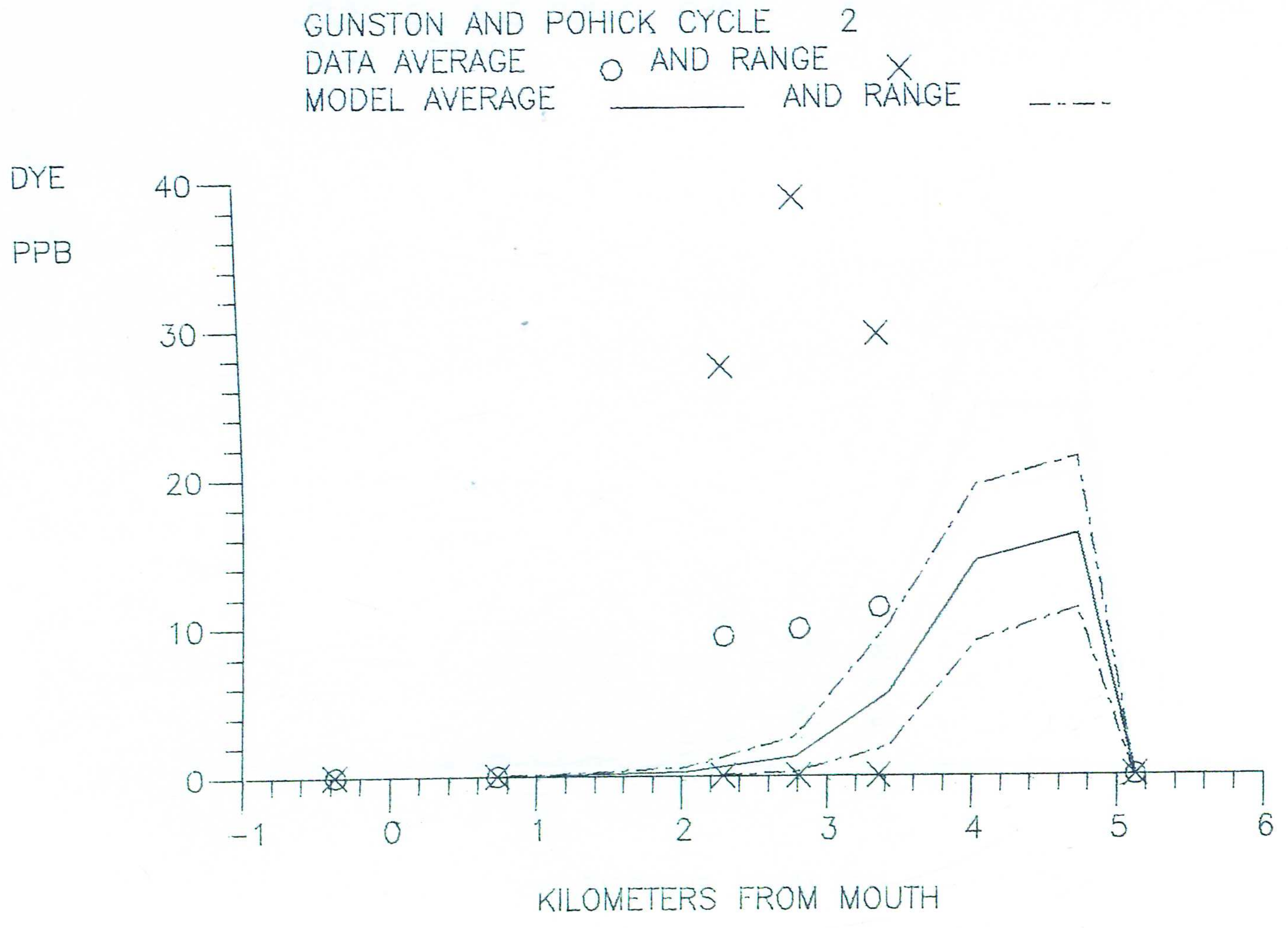


Figure 5-11. Verification of Dye Dispersion, September, 1979.



1979 DYE STUDY

Figure 5-11. (Continued)

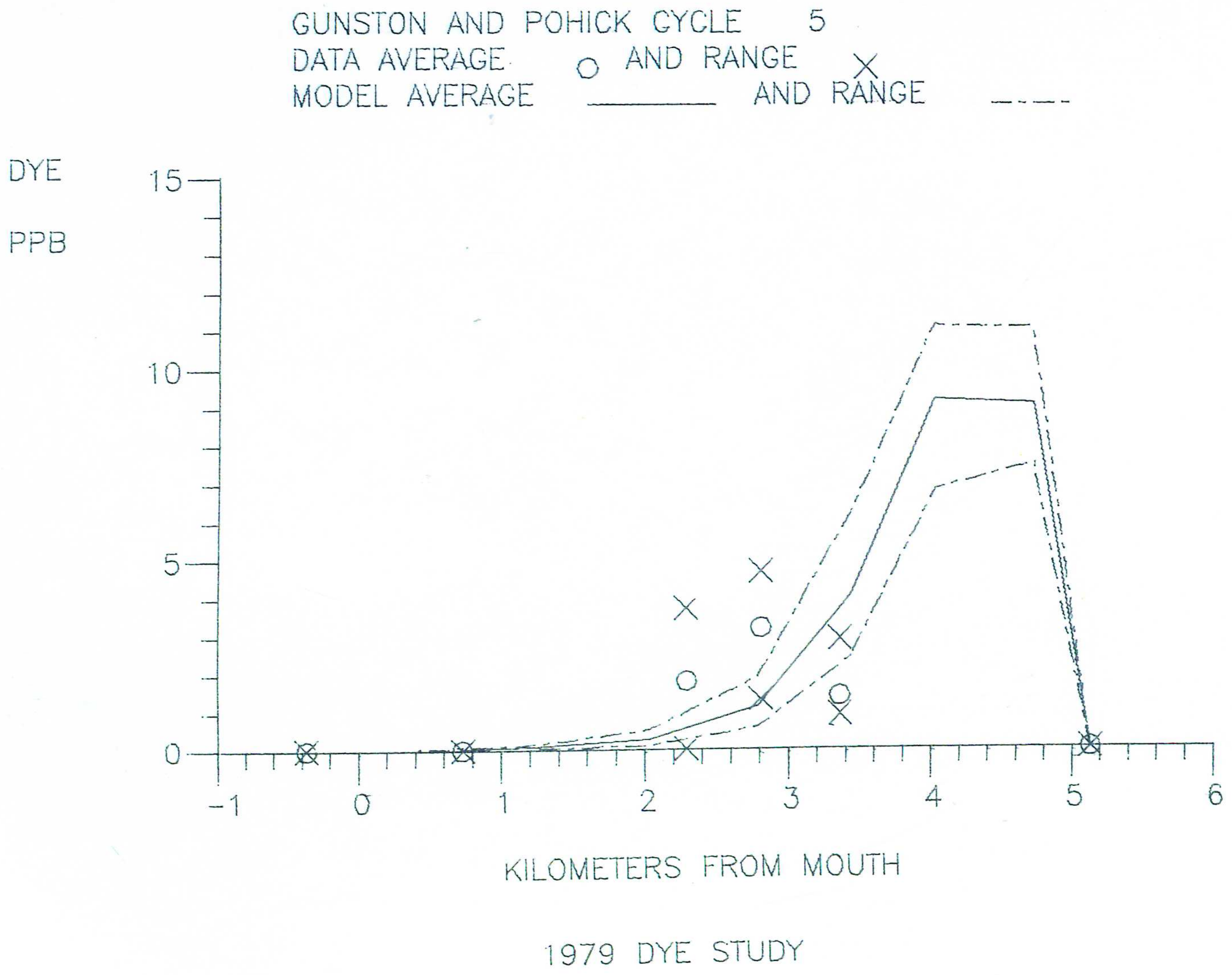


Figure 5-11. (Continued)

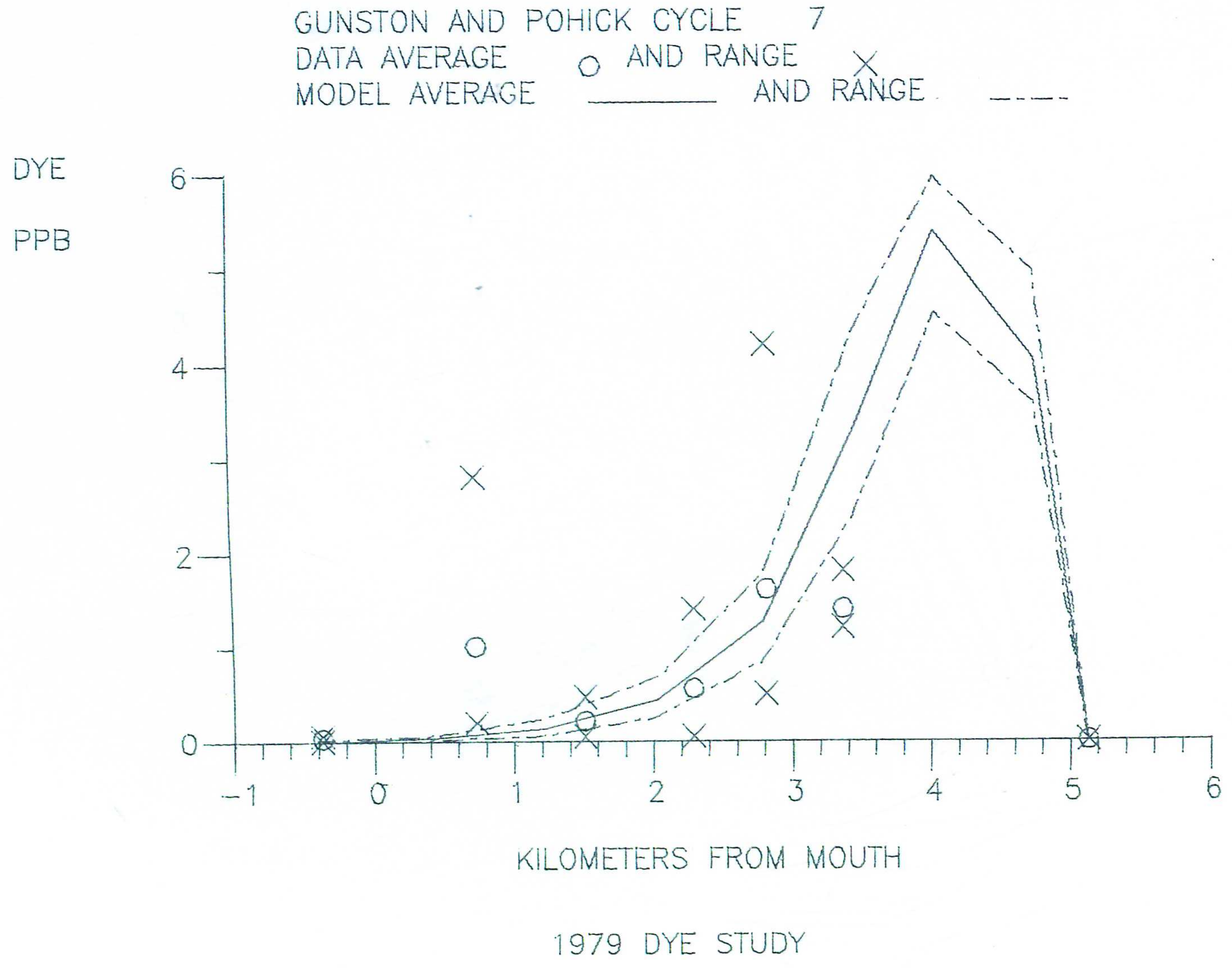


Figure 5-11. (Continued)

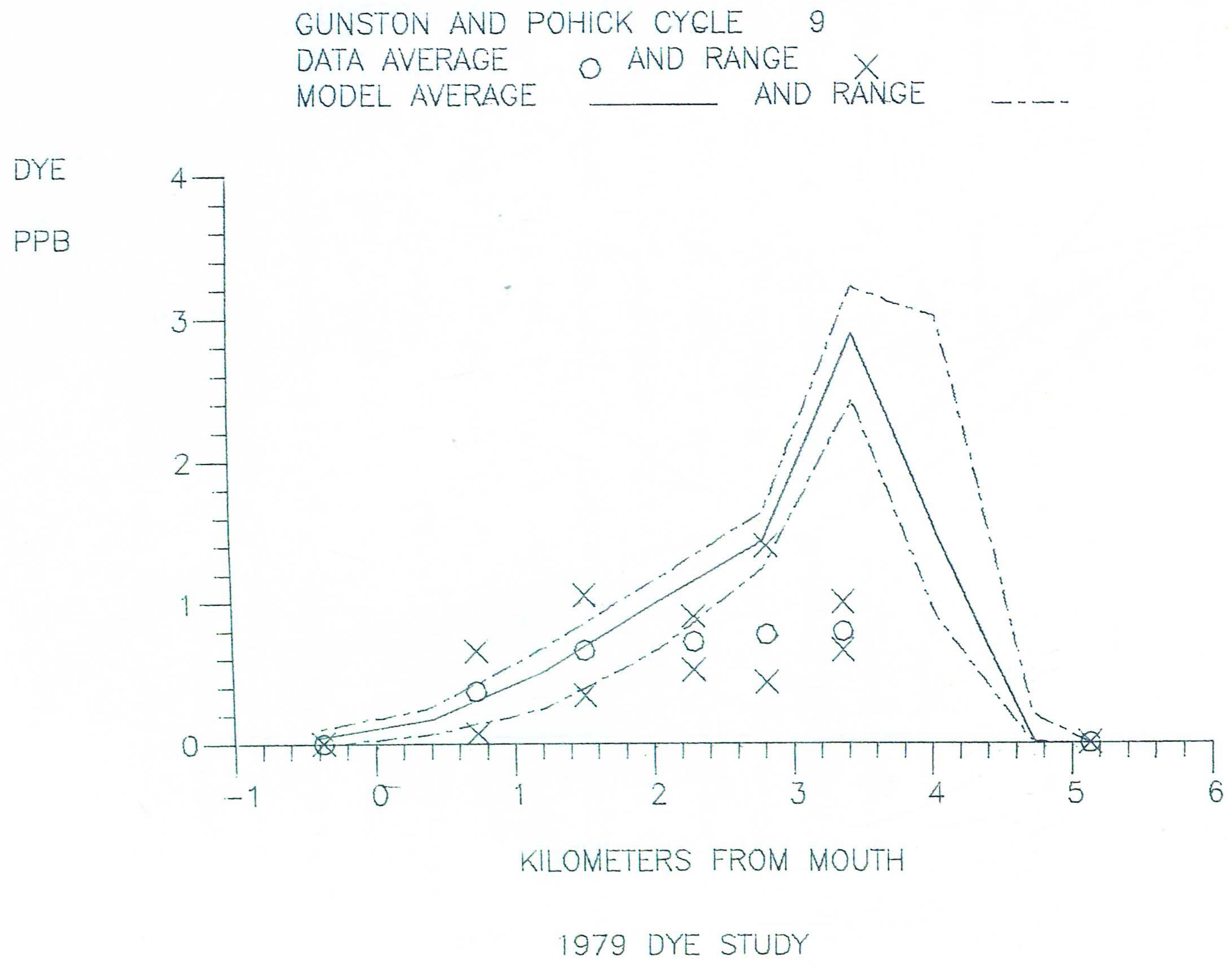


Figure 5-11. (Continued)

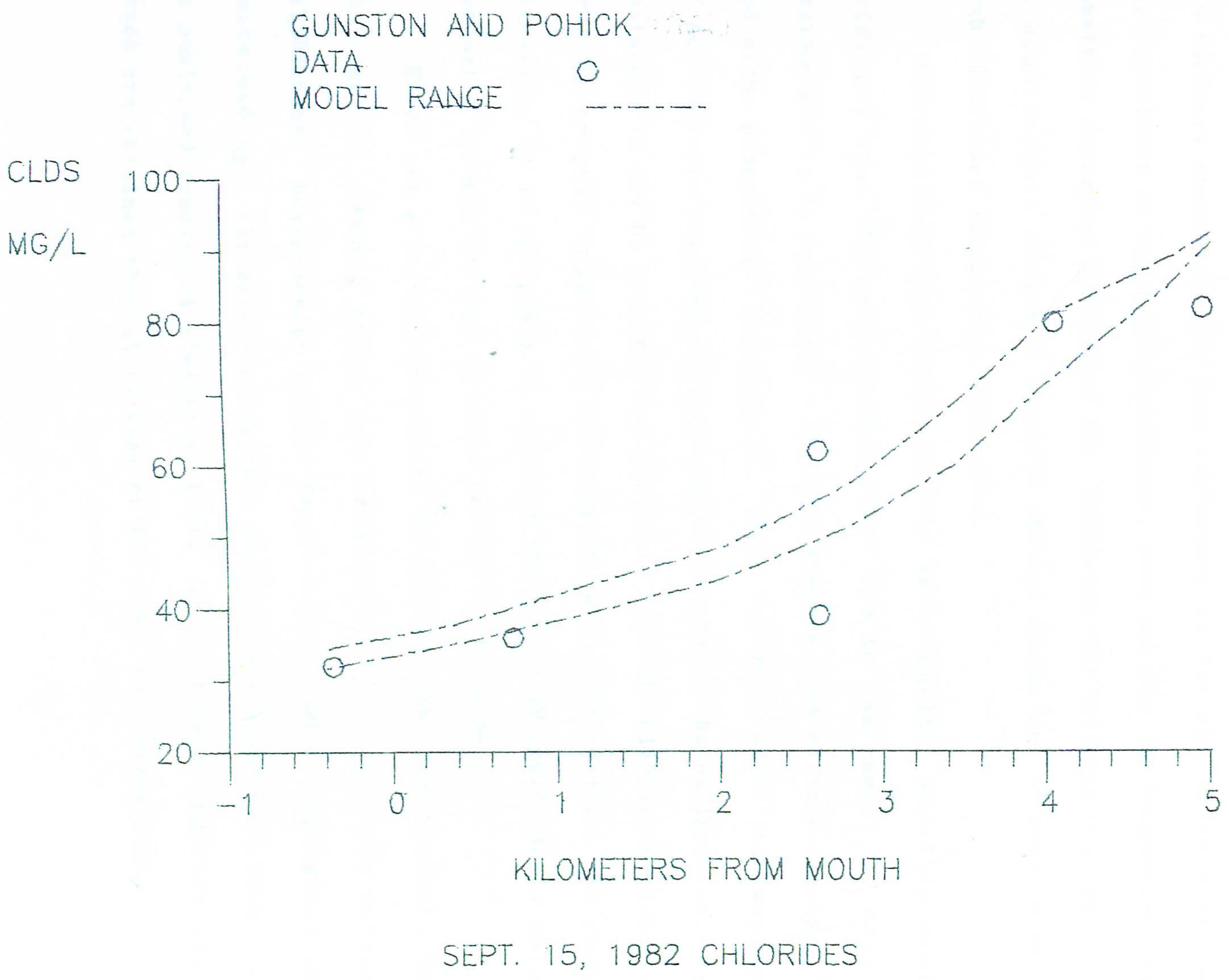


Figure 5-12. Simulation of Chlorides Distribution - September, 1982.

CHAPTER VI. APPLICATION 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 fit the field data 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 which are evaluated through fitting of model results to field data.

There are a variety of sources for the data and coefficients used in this model. Among these are measurements, literature values, and calibration. Measurements include inputs such as water temperature and STP wasteloading. Literature values are coefficients which have been evaluated in published studies of similar systems. Calibration parameters are those which are obtained through fitting of the model to 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 transferable 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 selection of coefficients 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 of natural processes rather than indicative solely of shortcomings in the model.

C. The Calibration and Verification Data Bases

From the data described in Chapter III, three independent data sets were determined to be suitable for model use. These are the August, 1982, intensive survey, the September, 1979, intensive survey, and the June to August, 1979, series of slackwater surveys. Initial calibration is achieved using the 1982 intensive survey with verifications conducted employing the 1979 intensive and slackwater surveys.

D. Calibration of the August, 1982, Intensive Survey

The calibration is conducted by using the observations collected in the August 19 slackwater survey as initial conditions in a model simulation of the period from August 19 through August 25. Model predictions for the period 18:30 hrs August 24 to 20:30 hrs August 25 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 in determining calibration is agreement between predicted and observed daily-average longitudinal distributions of the eight water-quality parameters included in the model. It is also considered desirable to qualitatively reproduce the large diurnal fluctuations of dissolved oxygen apparent in the prototype.

To conduct the simulation, the model requires data on ambient conditions and external inputs to the system, and evaluation of 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 - External inputs to the Gunston Cove system and ambient conditions within the cove during the simulation period are presented in Table 6-1. The majority of values employed are the result of direct measurements and require little comment.

The STP flow rate and phosphorus wasteloading are the average of values obtained from daily records kept by the plant. Wasteloadings of remaining substances and effluent DO are obtained from the average of grab and composite samples collected during the survey.

At the time of calibration, daily solar radiation observations were not yet available. Instead, an empirical relationship of daily solar radiation and cloud cover was employed. Observations of radiation, collected at Rockville, Md., in the interval August 15 to 30, 1979 to 1981, are shown plotted against cloud cover, concurrently observed at D. C. National Airport, in Figure 6-1. Daily totals of solar radiation for use in the model were obtained from this graph, based on cloud cover observed at D. C. National Airport in the interval August 19 to 25, 1982.

Daylength, the quantity td-tu in Equation 4-12, is computed via an equation derived from observations of sunrise and sunset at Rockville, Md. The equation is

$$td-tu = 12.3 + 2.6 \sin \left[\frac{2\pi}{365} * (D-80)\right] \qquad 6\text{-}1$$

in which

td-td = daylength (hours)

D = Julian day of year

Light extinction, as calculated from secchi depth observations via Eq. 3-4 and as employed in the calibration is shown in Figure 6-2. Values employed in the model are at the upper end of the range of observations. Relatively high light extinction is necessary, however, in order to maintain algal growth rates and other plankton-related parameters within conventional limits. This adjustment of the model value upwards from the central tendency of the observations is justified in view of the uncertainty in the disk visibility measurement and in the conversion of disk visibility to light extinction.

It should be noted that Pohick Creek was sampled upstream of the STP which discharges approximately 1.8 km above Pohick Bay. Based on the assumption that substance transformations between the STP and the embayment are negligible, the STP and the freeflowing stream are treated as direct inputs to model segment 2.

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

3) Nitrogen-Related Coefficients - The nitrogen-related coefficients employed in the calibration are presented in Table 6-3.

The benthic fluxes of ammonia and nitrate nitrogen are based on the field measurements described in Chapter III. Due to the variability of natural systems and to the difficulty of conducting the measurements, the field data present a range of fluxes rather than single, deterministic values. The final fluxes employed in the model are calibrated values based on the range of observations and are shown in Figures 6-3 and 6-4 for ammonia and nitrate, respectively.

4) Phosphorus-Related Coefficients - The phosphorus-related coefficients employed in the calibration are presented in Table 6-4. As with the nitrogen fluxes, the benthic flux of ortho phosphorus is obtained through calibration within the range of observations. Observed phosphorus fluxes and the values employed in the model are shown in Figure 6-5.

5) CBOD- and DO-Related Coefficients - The coefficients related to CBOD and DO and employed in the calibration are presented in Table 6-5. The coefficient Kro = 3.93 is the metric equivalent of Kro = 12.9 given by Thomann (1972).

As with the previous benthic fluxes, sediment oxygen demand, BENDO, is obtained via calibration within the range of measurements. Observations and model values are shown in Figure 6-6.

In order to achieve calibration, augmentation of the measured sources of CBOD with an additional distributed source was necessary. The origin of this additional CBOD cannot be ascertained although detritus from the aquatic and marsh vegetation within Gunston Cove is a likely source. A second hypothesis is the resuspension of bottom sediments. A distributed source of 2.7 gm CBODu/m^2/day is employed in Pohick (segments 2,3,4) and Accotink (segment 10) Bays. Justification for the inclusion of this source will be presented in the chapter on sensitivity analysis.

6) Calibration Results - Field data and model predictions for the August, 1982, intensive survey are plotted against distance from the cove mouth in Figures 6-7 through 6-14. The mean and range of observations and predictions along the Gunston-Pohick axis are shown for organic nitrogen, ammonia nitrogen, nitrite+nitrate nitrogen, ortho phosphorus, total phosphorus, chlorophyll'a', CBODu, and dissolved oxygen. As only one station was located within Accotink Bay, results for this portion of the system are not suited for graphical presentation. Quantitative comparisons of observations and predictions within Accotink are presented in a forthcoming chapter, however.

Qualitative agreement is achieved between predictions and observations. In particular, chlorohyll concentrations in the range 50 to

75 µg/l and supersaturated DO concentrations occur in both the model and prototype, although discrepancies between predictions and observations of these and other parameters do exist. In most cases, the discrepancies can be reduced or eliminated through appropriate adjustment of calibration parameters. Predictions of CBODu would be improved, for example, by increasing the magnitude of the distributed source. These adjustments detract from the comparisons of predictions and observations in the verification process, however. Reasonable discrepancies between predictions and observations must be accepted or else alteration of some calibration parameters between model runs is required.

One large difference between predictions and observations which cannot be remedied through calibration exists in the vicinity of station P1 (km 4.6). At this location (Fig. 3-4), the model overpredicts concentrations of chlorophyll and dissolved oxygen. These discrepancies are largely due to the nature of numerical models which are unable to represent spatial concentration gradients which are steep in comparison to the segment length. A difference of 70 ugm/l chlorophyll'a' exists in the 1.2 km between stations 8 and P1. The model, employing segment lengths of 0.6 to 0.8 km, cannot resolve this gradient since each segment is considered well-mixed along its entire length. The model can only represent the concentrations in the area of this gradient in an average sense. Since a primary goal of this study is to investigate elevated algal concentrations, which are well-represented by the model, lack of agreement between minimum predicted and observed chlorophyll concentrations at the extreme upstream end of the embayment is not considered critical. If representation of this minimum is desirable, then the embayment must be resegmented at a much finer scale.

E. Verification with the September, 1979, Intensive Survey

The objective of verification is not to fit the model to the data through evaluation of various coefficients. Rather, the purpose of verification is to test that previously-evaluated coefficients are correct and consistent. This is done by comparing model predictions with observations collected independently of the calibration survey and under different ambient conditions and external loads.

This verification model run was conducted in a manner similar to the calibration. Initial conditions were obtained from the September 13 slack-water survey and employed in a simulation of the period from September 13 through September 20. Model predictions for the period 1900 hrs. September 19 through 2100 hrs. September 20 were then compared with intensive survey data collected in the same interval.

1) External Inputs and Ambient Conditions - External inputs to the Gunston Cove system and ambient conditions within the cove during the verification period are presented in Table 6-6. The simulation was conducted in a time-variable mode in which background loads, obtained from the Northern Virginia Planning District Commission nonpoint-source model, were allowed to vary from day-to-day. Use of this mode was necessitated by a 0.36 cm rainfall on September 14.

Average values for the simulation period of STP flow rate and wasteloading were obtained from plant records and from samples collected during the intensive survey.

Light extinction, as converted from secchi depth and as employed in the model is shown in Fig. 6-15.

Daily total solar radiation, as measured at Rockville, Md., was input directly to the model. Daylength was again computed by equation 6-1.

2) Constants and Coefficients - All constants and coefficients utilized in the calibration and listed in Tables 6-2 through 6-5 were employed in the verification as well.

3) Verification Results - Field data and model predictions for the September, 1979, intensive survey are plotted against distance from the cove mouth in Figures 6-16 through 6-23. The mean and range of observations and predictions along the Gunston-Pohick axis are shown for organic nitrogen, ammonia nitrogen, nitrite-nitrate nitrogen, ortho phosphorus, total phosphorus, chlorophyll'a', CBODu, and dissolved oxygen.

During the 1979 intensive survey, no data was collected between station 8 and the head of Pohick Bay (Fig. 3-1). An indication of water quality at the extreme end of this embayment is provided by plotting as the uppermost data point (km 5) the flow-weighted average concentration of the STP flow and the free-flowing portion of Pohick Creek. Thus the data at km 5 of Gunston and Pohick represent estimates rather than measurements of prototype conditions.

Qualitative agreement is achieved between predictions and observations of most parameters. In particular, the observed chlorohyll concentrations in the range 50 to 100 μg/l and the observed supersaturated dissolved oxygen concentrations are well-replicated in the model.

As with the calibration, the verification can be improved but improvement requires alteration of calibration parameters between model runs. For example, addition of a distributed source of organic nitrogen to accompany the source of CBODu would produce agreement between predictions of the nitrogen parameter and observations. Inclusion of this nitrogen source in all model runs would adversely affect the calibration, however. Therefore, for the sake of consistency, the source is omitted.

Due to variability in the treatment plant effluent, there is apparent disagreement between predicted and observed phosphorus at km. 5. The observation is based on an anomalously low effluent phosphorus concentration of 0.3 mg/l on September 19 to 20. Effluent characteristics in the model are based on the average reported phosphorus concentration of 1.1 mg/l for the simulation period September 13 to 20. Thus, the model predictions are more representative than the data indicate of the quantity of phosphorus discharged during the verification surveys.

F. Verification with the June to August, 1979, Slackwater Surveys

The calibration and preceding verification were based upon model runs of seven to eight days which provided predictions for comparison with intensive observations collected in a one-day interval. In this verification, the long-term predictive ability of the model is tested through comparisons of model predictions with observations collected in the June 5 through August 29 series of slackwater surveys. The model simulates the summer season in a single, three-month run using the June 5 observations as initial conditions and providing predictions for comparison with data collected in the seven subsequent slackwater surveys (Table 3-2). Details of the verification procedure and results are presented in the remainder of this chapter.

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 temperature and downstream boundary conditions observed in the slackwater surveys to be

constant during the interval beginning one week prior to the survey and extending one week after. That is, temperature and downstream boundary conditions are modelled as step functions with the duration between steps equal to the interval between surveys.

STP wasteloading is also modelled as a step function. Flow rate and effluent phosphorus concentration are taken as the average of daily values reported by the STP for the appropriate interval. Concentrations of the remaining substances in the effluent are based on grab samples collected during the slackwater runs.

Step-function duration, temperature, downstream boundary conditions, and wasteloads employed in the seasonal model run are presented in Tables 6-7 to 6-9.

Background flows and loads from freeflowing Pohick and Accotink Creeks were obtained from the NVPDC model and are shown in Appendix C. As noted previously, the predicted chlorophyll concentrations at the upstream boundary are unsatisfactory. Instead, a constant concentration of 3 µg/l is employed in the model.

Daily total solar radiation, as measured at Rockville, Md., is employed in the model run. Daylength is computed via equation 6-1.

Constant values of light extinction, obtained by calibration within the range of observations are employed in the model and are shown in Figure 6-24. Use of temporally-varying light extinction is preferable, and would yield improved model results, but the observations of disk visibility collected during the slackwater runs are too scanty and variable to provide reliable evaluation of light extinction during the two-week step intervals.

2) Constants and Coefficients - All constants and coefficients employed in the 1979 seasonal verification are identical to the values

employed in the 1982 intensive calibration and the 1979 intensive verification.

3) Verification Results - Results of the seasonal verification, presented as plots of predictions and observations along the Gunston-Pohick axis, are shown in Figures 6-25 through 6-32. The figures indicate the instantaneous data points and the range of predicted concentrations in the twenty-four-hour interval centered on the time of the survey.

A second view of the seasonal verification is presented in the time-series plots of Figures 6-33 through 6-40 which illustrate embayment-average conditions throughout the season for each water-quality parameter. Data points are the average of all embayment samples collected in each survey while the model output is the daily-average of all model segments. These plots are advantageous in that temporal trends in the predictions and observations are readily distinguished.

In evaluating the verification results, consideration must be given to the sparcity 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 manifests 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 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.

One notable deviation of the predictions from the observations is in the chlorophyll prediction for August 6 (day 67). The model predicts an algal bloom with peak chlorophyll concentrations in the 50 to 75 μgm/l range. The observations, however, indicate a decline in chlorophyll from the preceding survey. Chlorophyll concentrations are typically in the 10 to 25 μgm/l range.

The prediction provided by the model is not unreasonable. Chlorophyll concentrations approaching or exceeding 100 μgm/l were observed in the 1979 intensive survey, the 1982 intensive survey, and the 1980 slackwater surveys. Thus attention is focused on what prototype processes acted to prevent a bloom for which conditions were apparently ripe. Two possibilities are suggested. The first is that an alteration in ambient conditions, e.g. a drastic increase in turbidity, occurred between the July 18 and August 6 surveys and thus was not observed. The second is that a process not included in the model framework, e.g. a change in phytoplankton speciation, was active.

Predictions of dissolved oxygen tend to be low, compared to the observations, particularly on June 19 (day 19), July 5 (day 35), August 16 (day 77), and August 28 (day 89). Some discrepancy is unavoidable since the observations are grab samples collected in daylight and thus are representative of the peak of the diurnal DO fluctuations. The model cannot fully replicate these diurnal maxima.

Discrepancies are also attributable to the link between algal production and dissolved oxygen. Any errors in the prediction of chlorophyll concentration will produce errors in the prediction of DO as well.

Table 6-1. External Inputs and Ambient Conditions - August, 1982

External Inputs (Measured)

	Flow	Org N	NH_4	NO_3	Tot P	PO_4	Chl	CBODu	DO
	(m^3/sec)	(kg/day)	(kg/day)	(kg/day)	(kg/day)	(kg/day)	(μgm/1)	(kg/day)	(mg/1)
STP	1.1	0	1000	677	97	87	0	697	8.3
Pohick Ck	0.1	0.9	0.9	0.7	0.3	0.3	1.4	21	8.1
Accotink Ck	0.2	1.7	1.7	3.5	0.5	0.5	2.9	29	8.0

Open-Mouth Boundary Concentrations (Measured)

Org N	NH_4	NO_3	Tot P	PO_4	Chl	CBODu	DO
(mg/1)	(mg/1)	(mg/1)	(mg/1)	(mg/1)	(μgm/1)	(mg/1)	(mg/1)
0.3	0.1	1.1	0.04	0.03	26.	2.0	8.5

Temperature (Measured) 26.5 C^o

Daily Solar Radiation (calculated) 280 to 535 Langleys

Daylength (calculated) 13.4 to 13.7 hours

Light Extinction Coefficient (measured, calibrated) 3 to 6/meter

Table 6-2. Phytoplankton-Related Coefficients

Coefficient	Value	Source
aC	0.050 mg/μgm	calibration
an	0.007 mg/μgm	''
ap	0.0008 mg/μgm	''
PQ	1.4 mole/mole	''
RQ	1.0 mole/mole	''
Kmn	0.025 mg/l	Thomann and Fitzpatrick
Kmp	0.001 mg/l	''
Kgr	2.0/day	''
a	0.09/day	calibration
Is	250 Langleys/day	Cerco and Kuo
Ksch	0.1 m/day	Thomann and Fitzpatrick
P	0.02/day	''
θgr	1.087	Williams and Murdoch
θr	1.150	Calibration

Table 6-3. Nitrogen-Related Coefficients

Coefficient	Value	Source
Kn12	0.075 mg/l/day	Thomann and Fitzpatrick
Kh12	1.0 mg/l	Cerco and Kuo
Kn11	0.1 m/day	Calibration
BENN1	0.0 gm/m^2/day	
Kn23	0.100 mg/l/day	Thomann and Fitzpatrick
Kh23	1.0 mg/l	Cerco and Kuo
BENN2	0.0 to 0.35 gm/m^2/ day	Measured, Calibration
BENN3	-0.1 gm/m^2/day	Measured, Calibration
θn12	1.04	Calibration
θn23	1.04	Calibration

Table 6-4. Phosphorus-Related Coefficients

Coefficient	Value	Source
Kp12	0.22/mg/1/day	Thomann and Fitzpatrick
Kp11	0.1 m/day	Calibration
Khp	1.0 mg/1	,,
BENP1	0.0 $gm/m^2/day$	
Kp22	0.0 m/day	
BENP2	0.0 to 0.02 $gm/m^2/day$	Measured, Calibration
θp12	1.04	Calibration

Table 6-5. CBOD- and DO-Related Coefficients

Coefficient	Value	Source
Kc(20)	0.1/day	Calibration
Ksc	0.1 m/day	Calibration
areal source	0.0 to 2.7 $gm/m^2/day$	Calibration
Kro	3.93	Thomann
BENDO	-2.0 to -2.5	
θ bod	1.04	Calibration
θ do	1.025	ASCE

Table 6-6. External Inputs and Ambient Conditions - September, 1979

STP Discharge (Measured)

Flow (m^3/sec)	Org N (kg/day)	NH_4 (kg/day)	NO_3 (kg/day)	Tot P (kg/day)	PO_4 (kg/day)	CBODu (kg/day)	DO (mg/1)
0.8	96.	1047	96	7	68	787	8.5

Pohick Background Loads (NVPDC)

	Flow (m^3/sec)	Org N (kg/1)	NH_4 (kg/1)	NO_3 (kg/1)	Tot P (kg/1)	PO_4 (kg/1)	Chl (µgm/1)	CBODu (kg/day)	DO (mg/1)
Sept 13	0.4	9.5	2.6	13.5	2.3	0.6	3.0	70	9.0
Sept 14	0.4	19.5	3.6	16.2	4.0	1.0	3.0	150	8.6
Sept 15	0.4	30.7	4.4	19.0	6.0	1.6	3.0	165	9.3
Sept 16	0.3	8.4	2.1	10.2	2.0	0.5	3.0	56	9.4
Sept 17	0.3	6.5	1.7	9.0	1.5	0.4	3.0	47	9.1
Sept 18	0.2	5.9	1.6	8.8	1.4	0.4	3.0	43	9.1
Sept 19	0.2	5.5	1.5	7.6	1.4	0.4	3.0	40	9.4
Sept 20	0.2	5.2	1.5	7.0	1.3	0.3	3.0	39	9.8

Accotink Background Loads (NVPDC)

Sept 13	0.7	9.9	2.3	19.3	3.3	1.3	3.0	66	8.9
Sept 14	0.7	41.5	6.6	32.1	9.1	2.4	3.0	414	8.6
Sept 15	0.8	36.7	5.7	34.7	8.7	2.8	3.0	300	8.9
Sept 16	0.5	13.0	2.4	19.0	3.6	1.4	3.0	79	9.1
Sept 17	0.4	10.0	1.9	16.9	3.0	1.2	3.0	60	9.0
Sept 18	0.4	8.4	1.6	15.8	2.6	1.1	3.0	50	9.0
Sept 19	0.4	7.3	1.5	14.8	2.4	1.0	3.0	44	9.2
Sept 20	0.4	6.4	1.4	13.8	2.2	1.0	3.0	40	9.5

Table 6-6 (Continued)

Open-Mouth Boundary Conditions (Measured)

Org N (mg/1)	NH_4 (mg/1)	NO_3 (mg/1)	Tot P (mg/1)	PO_4 (mg/1)	Chl (μgm/1)	CBODu (mg/1)	DO (mg/1)
0.37	0.27	1.3	0.08	0.07	12.7	2.0	7.6

Temperature (Measured) 22.9°C

Daily Solar Radiation (Klein and Goldberg) 225 to 495 Langleys

Daylength (calculated) 12.3 to 12.6 hours

Light Extinction Coefficient (Measured, Calibrated) 3 to 7

Table 6-7. Model Input Periods for Seasonal Verification

This table shows the intervals in which temperature, boundary conditions, and point-source loads were assumed to be constant and the slackwater surveys from which these data were derived.

Period	Survey
June 5 - June 11	June 5
June 12 - June 26	June 19
June 27 - July 11	July 5
July 12 - July 28	July 18
July 29 - August 11	August 6
August 12 - August 22	August 16
August 23 - August 29	August 28,29

Table 6-8. Temperature and Open-Mouth Boundary Concentrations for Seasonal Verification

	Temp C	Org N mg/l	NH4 mg/l	NO3 mg/l	PO4 mg/l	Tot P mg/l	Chl µgm/l	CBOD mg/l	DO mg/l
June 5	21.2	.53	.30	1.18	.07	.08	3	2.8	7.4
June 12	23.1	.38	.45	.95	.04	.05	10	3.6	7.6
June 27	22.7	.28	.75	.65	.05	.06	17	1.7	8.3
July 12	28.5	.37	.45	.66	.01	.02	26	2.6	7.3
July 29	29.6	.59	.15	.95	.04	.05	17	6.2	8.2
August 12	22.2	.33	.25	1.30	.01	.02	25	3.5	7.9
August 23	26.4	.29	.13	1.00	.02	.03	30	3.9	6.7

Table 6-9. Point-Source Loads for Seasonal Verification

	Q cms	Org N kg/dy	NH4 kg/dy	NO3 kg/dy	PO4 kg/dy	Tot P kg/dy	CBOD kg/dy	DO mg/l
June 5	0.8	0.	1300.	12.	196.	218.	660.	8.5
June 12	0.8	190.	1020.	10.	306.	340.	1748.	8.3
June 27	0.8	460.	1130.	14.	296.	328.	775.	8.4
July 12	0.8	110.	1332.	20.	195.	214.	695.	8.2
July 29	0.8	0.	1209.	13.	176.	196.	1196.	7.3
August 12	0.8	254.	1137.	3.	227.	254.	1685.	7.8
August 23	0.8	194.	1314.	17.	187.	208.	775.	7.5

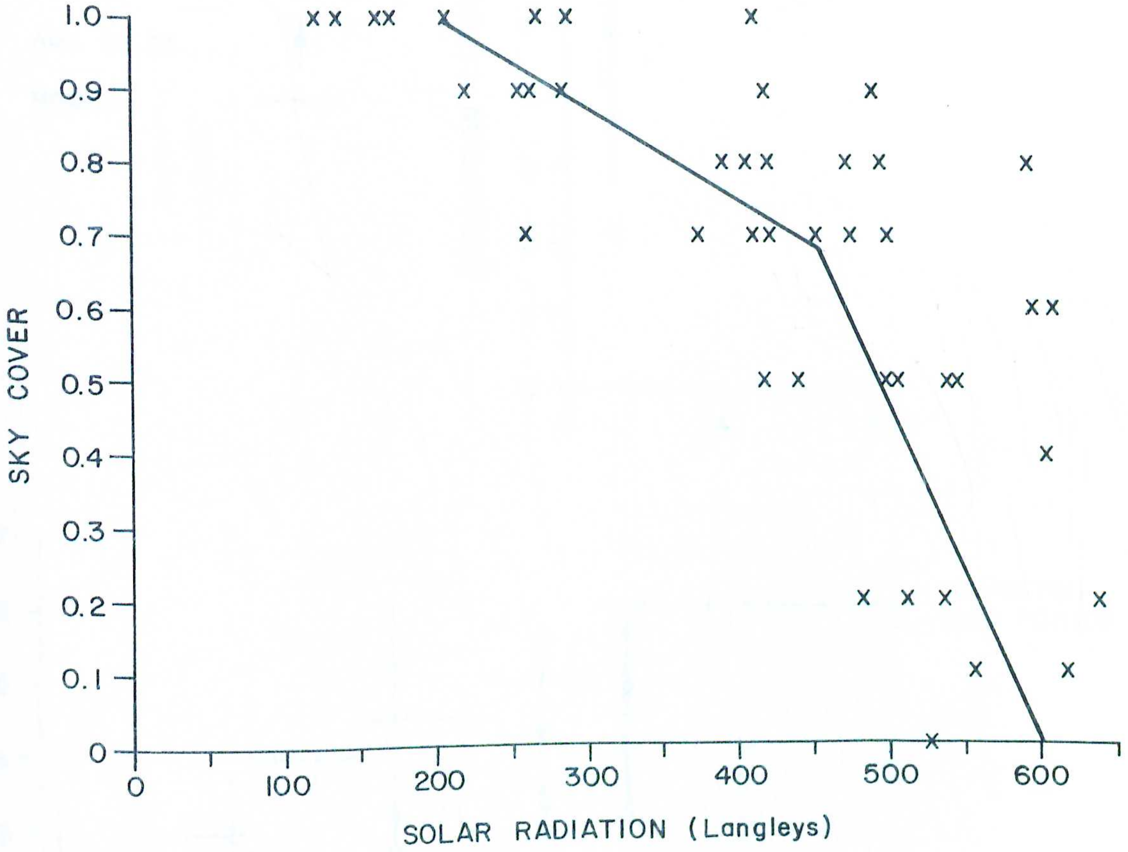


Figure 6-1. Solar radiation as a function of sky cover.

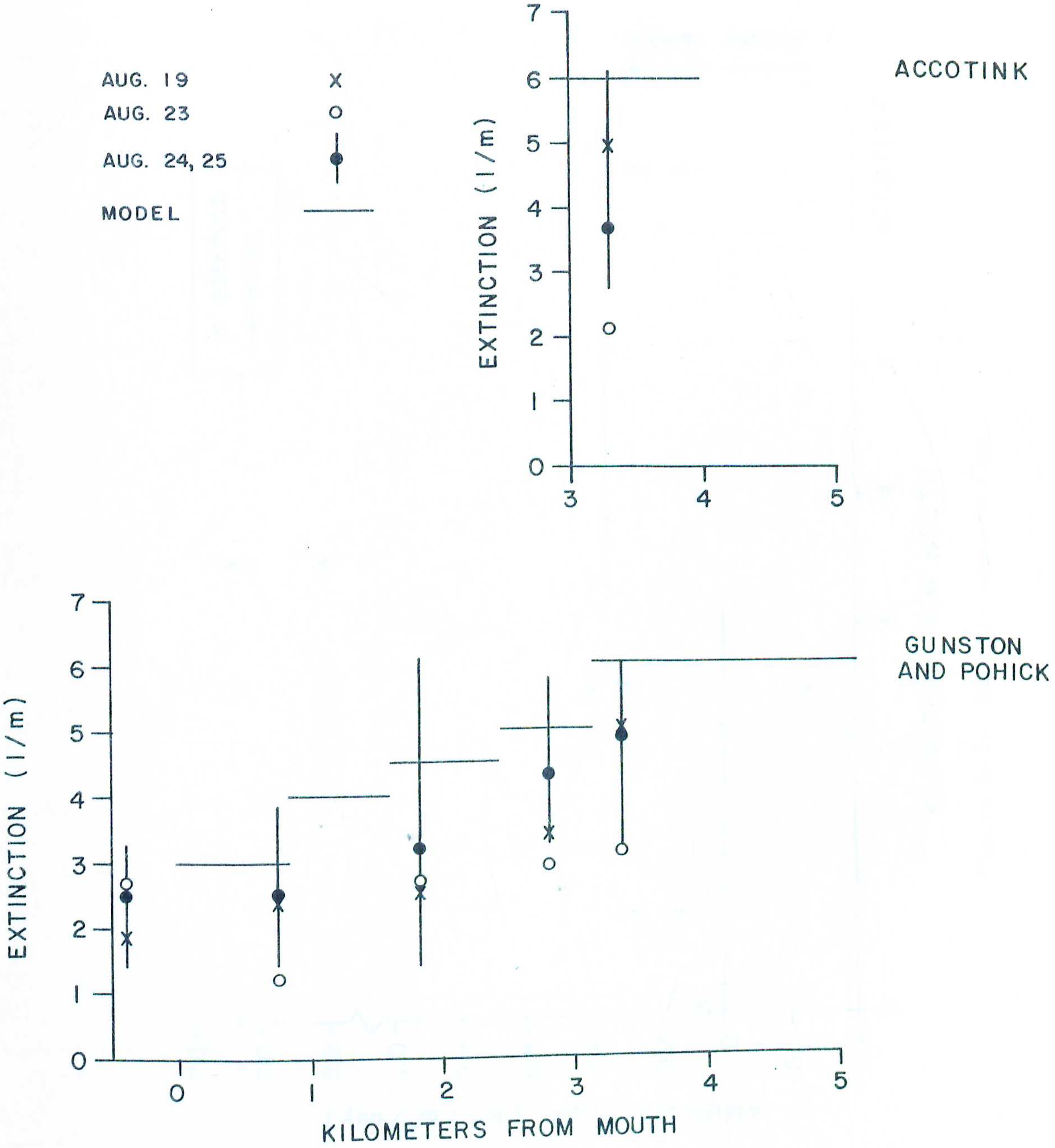


Figure 6-2. Light extinction - August, 1982 surveys.

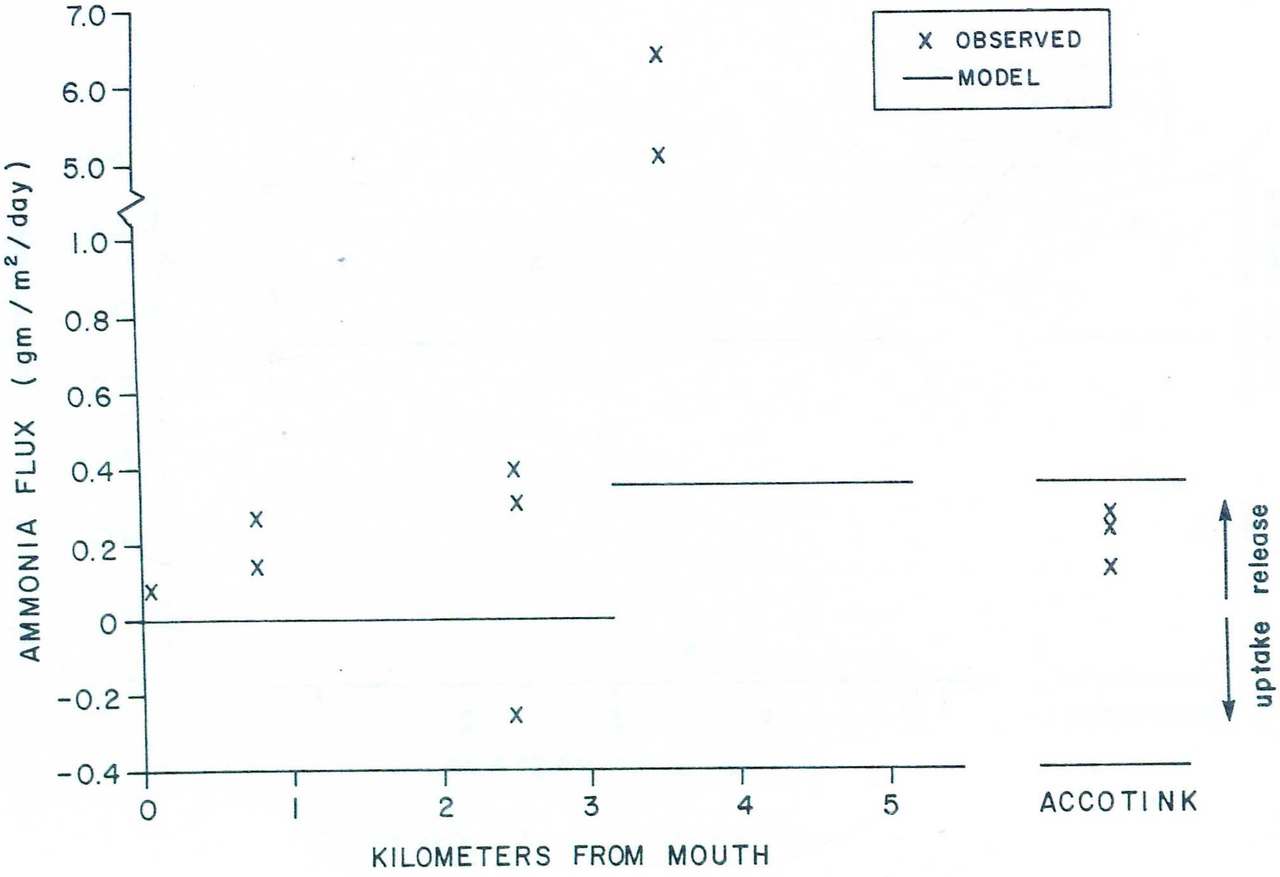


Figure 6-3. Benthic ammonia flux.

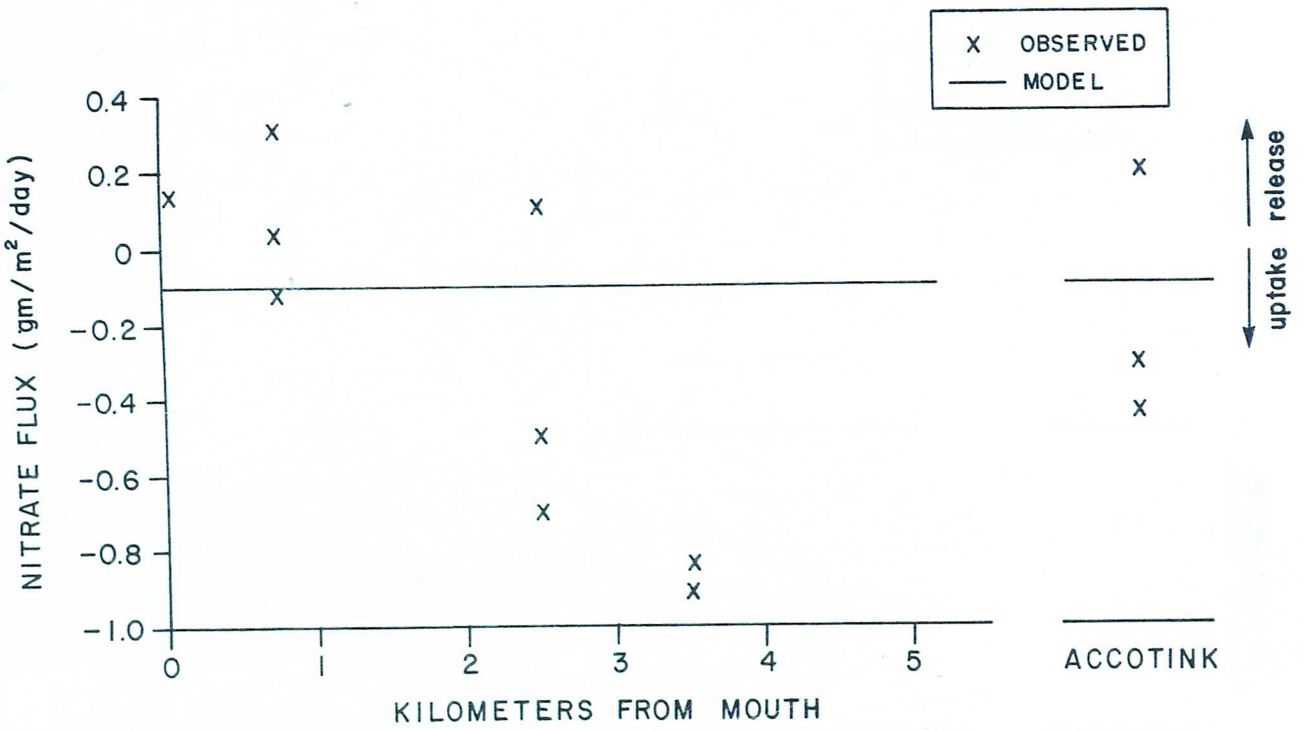


Figure 6-4. Benthic nitrate flux.

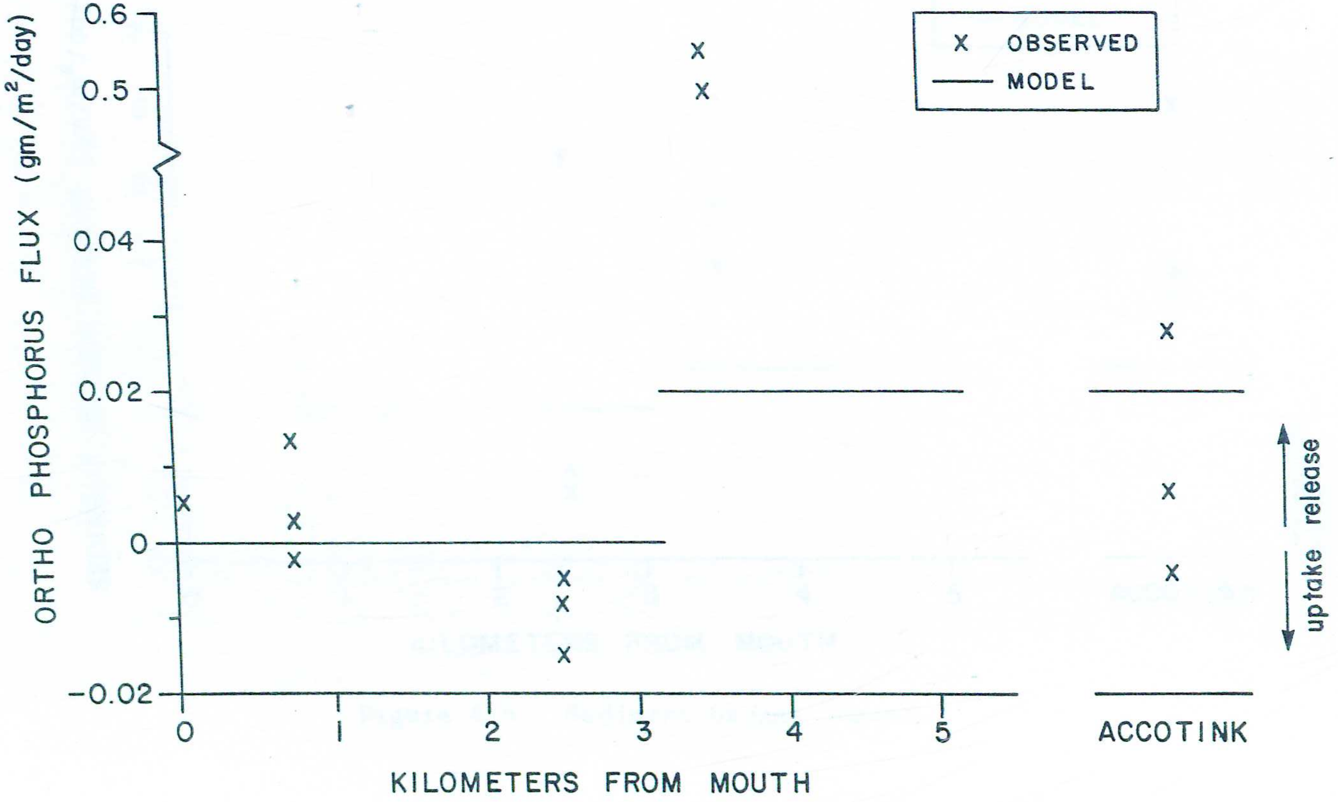


Figure 6-5. Benthic phosphorus flux.

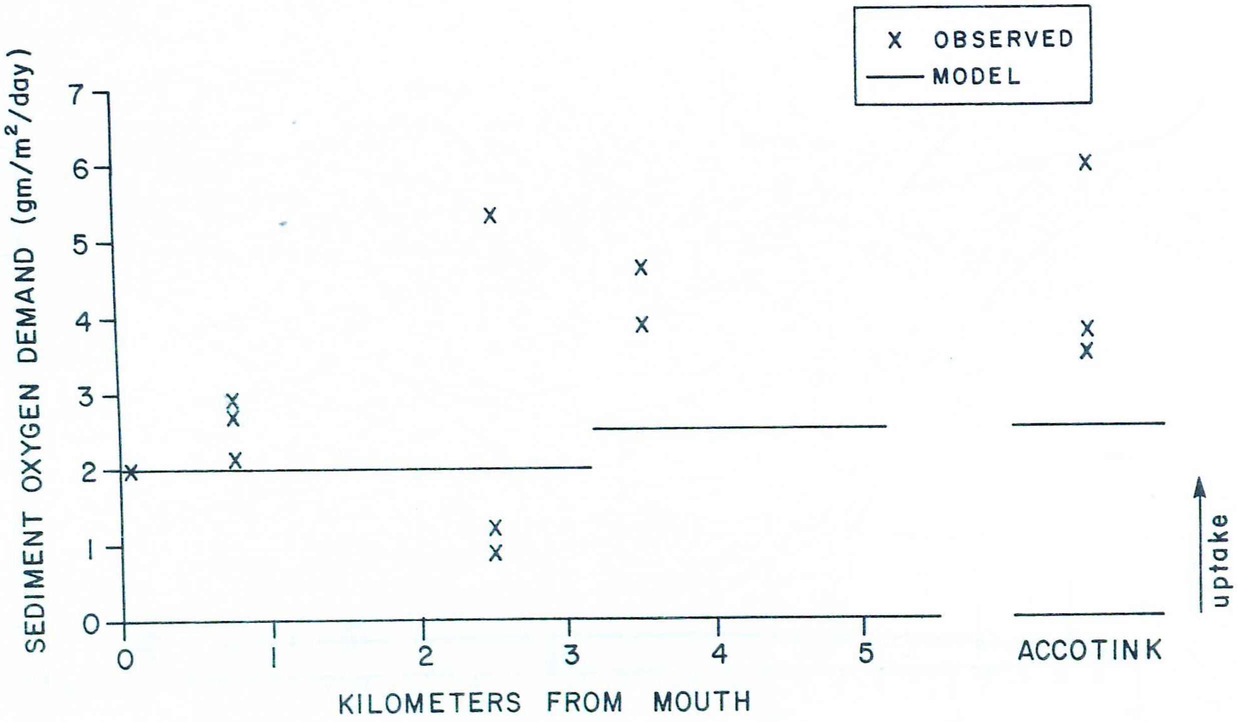


Figure 6-6. Sediment oxygen demand.

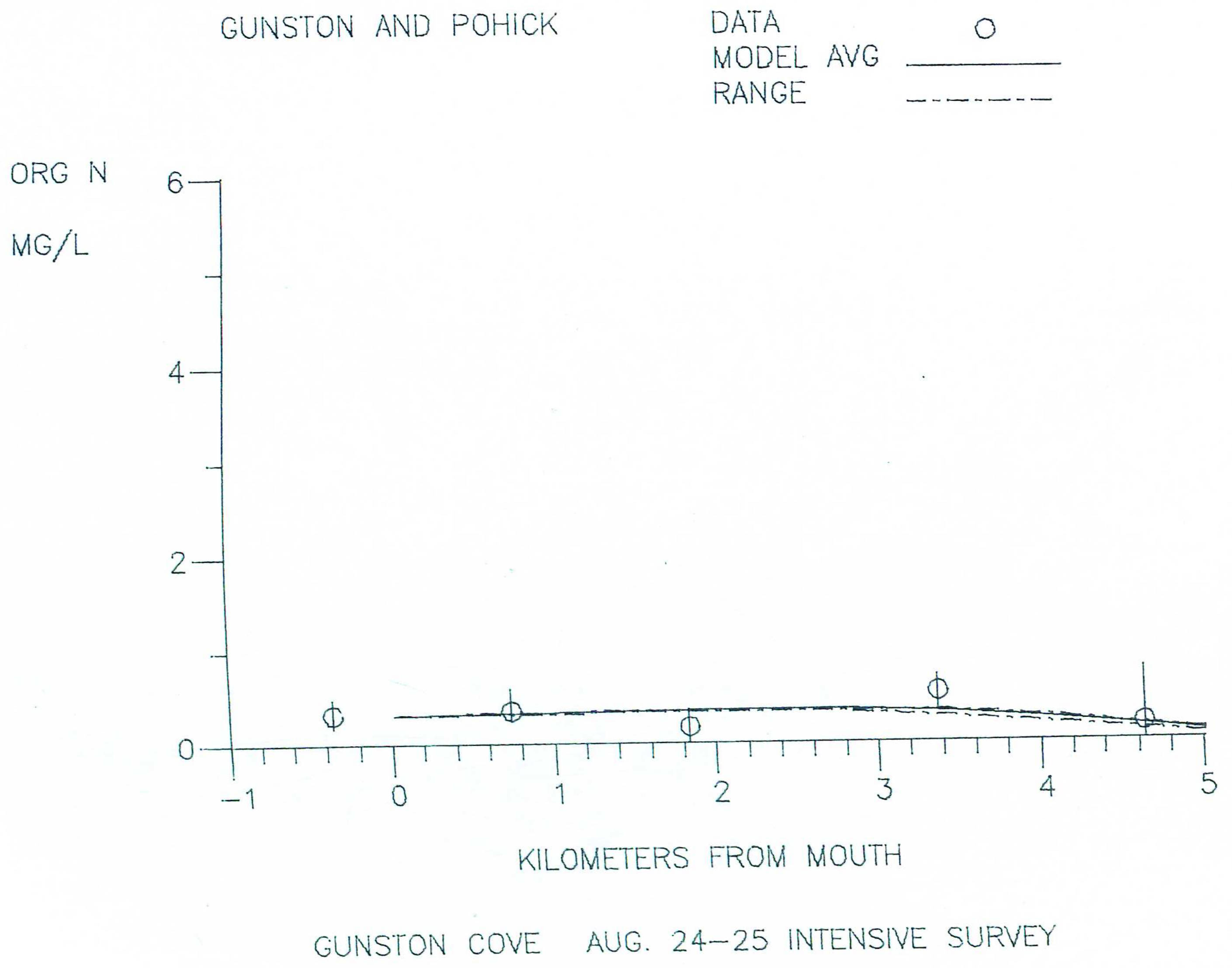


Figure 6-7. Calibration of Organic Nitrogen.

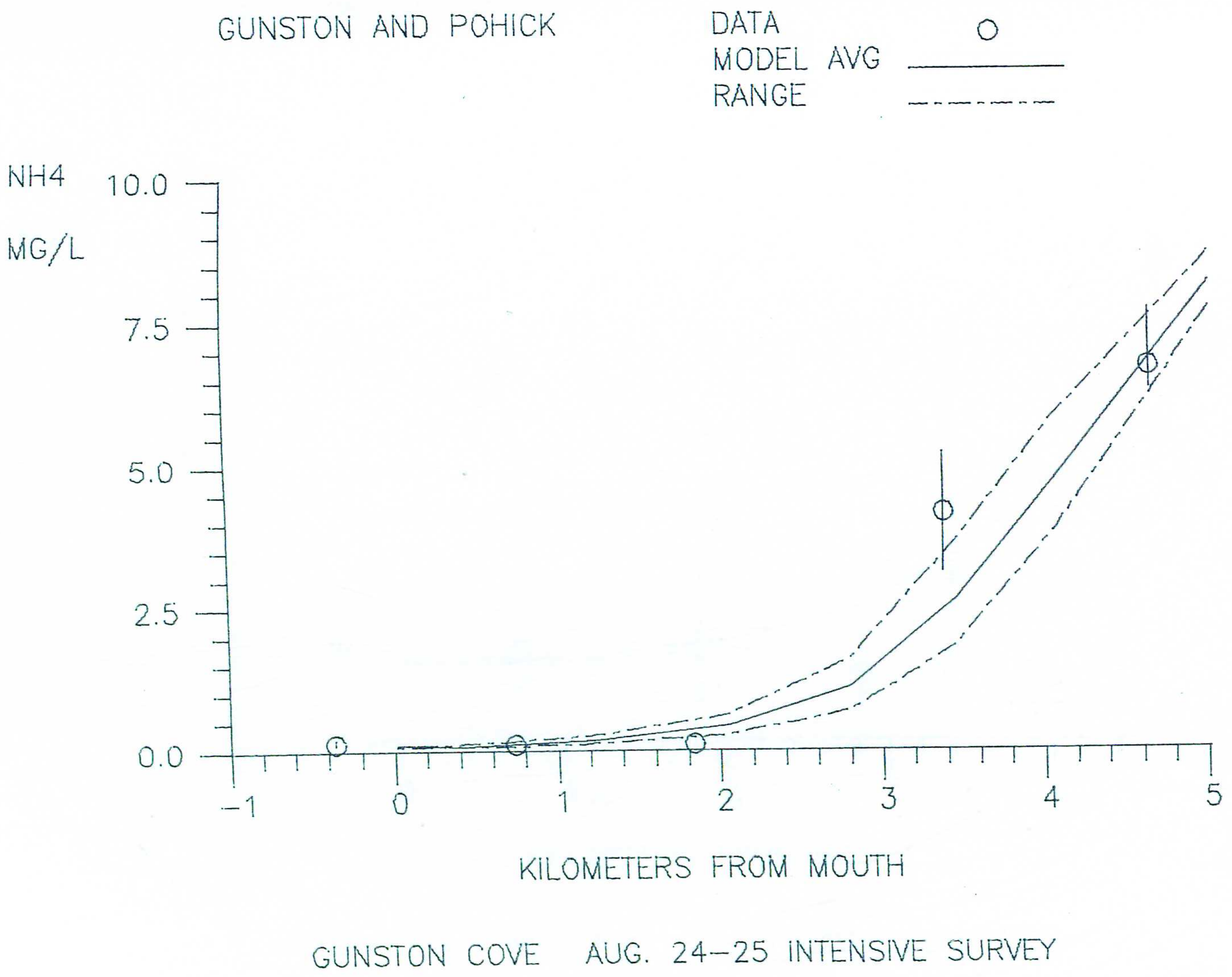


Figure 6-8. Calibration of Ammonia Nitrogen.

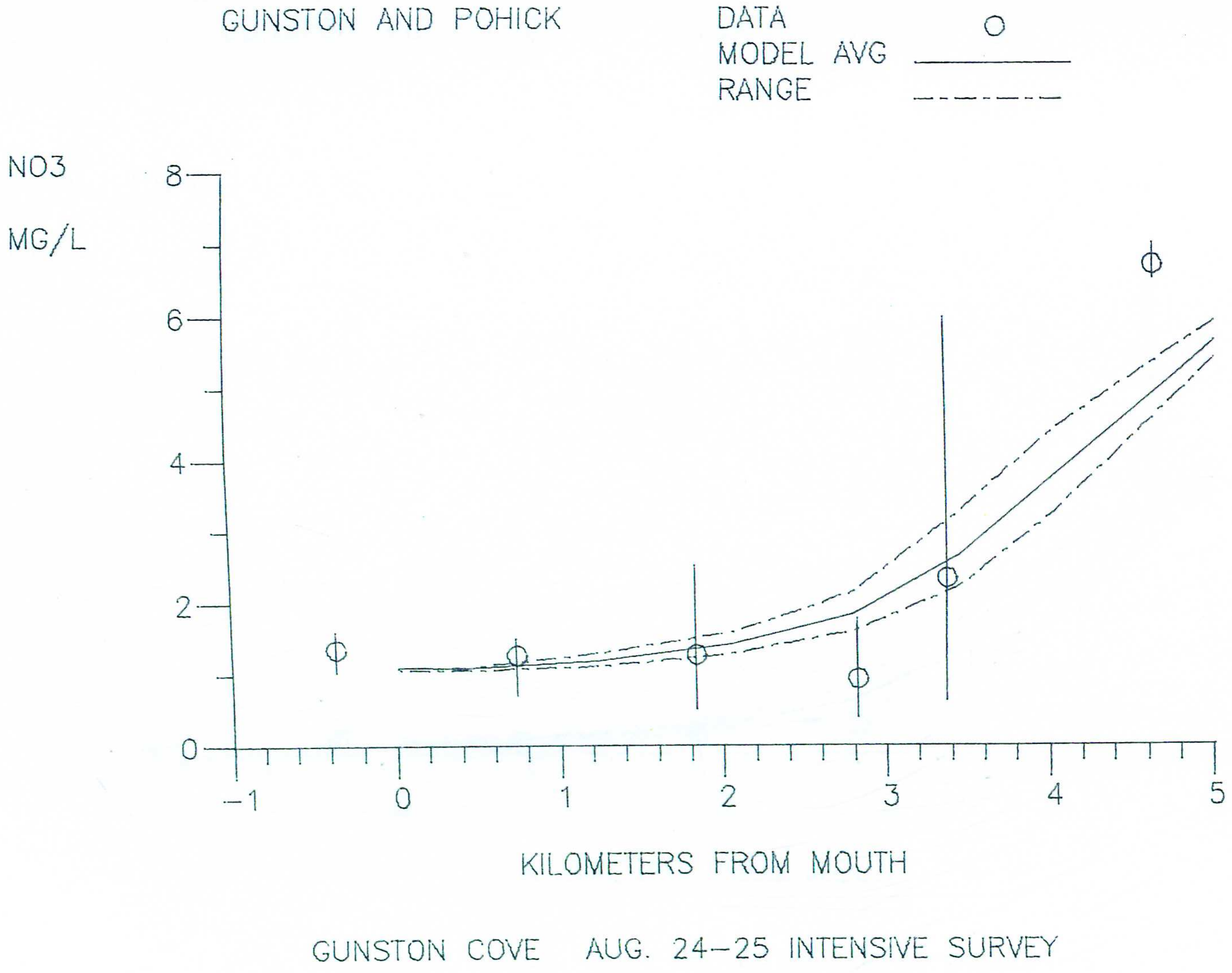


Figure 6-9. Calibration of Nitrate Nitrogen.

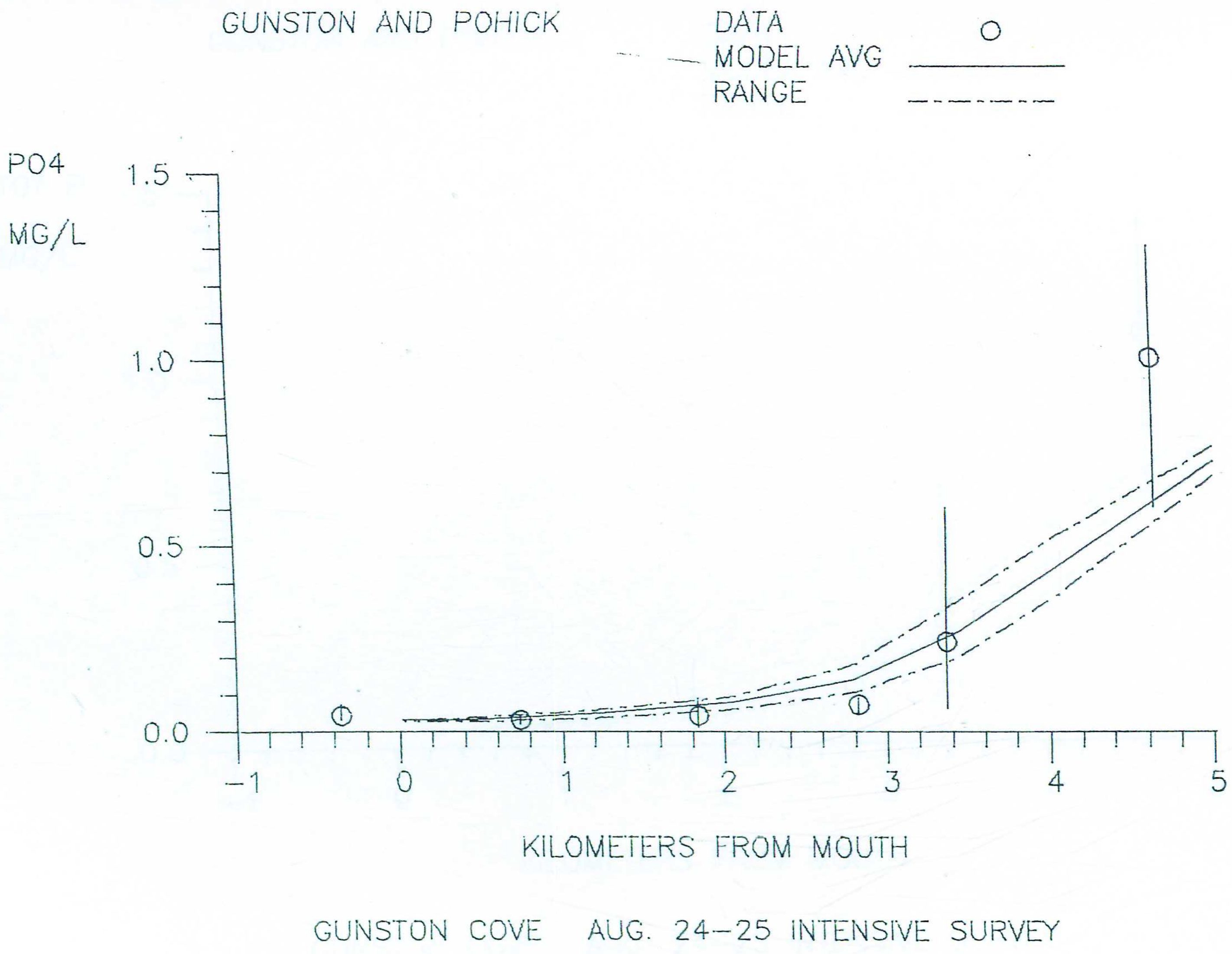


Figure 6-10. Calibration of Ortho Phosphorus.

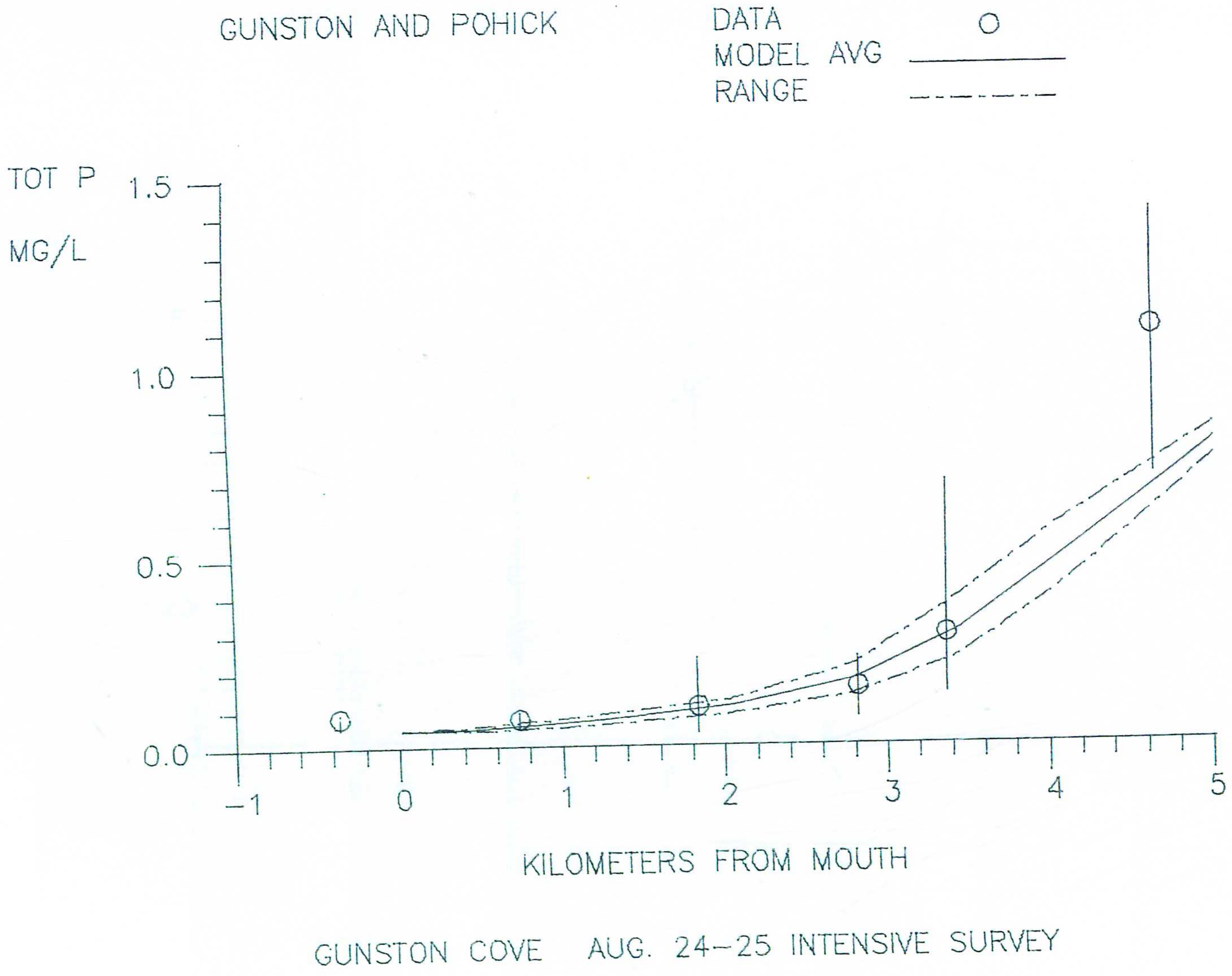


Figure 6-11. Calibration of Total Phosphorus.

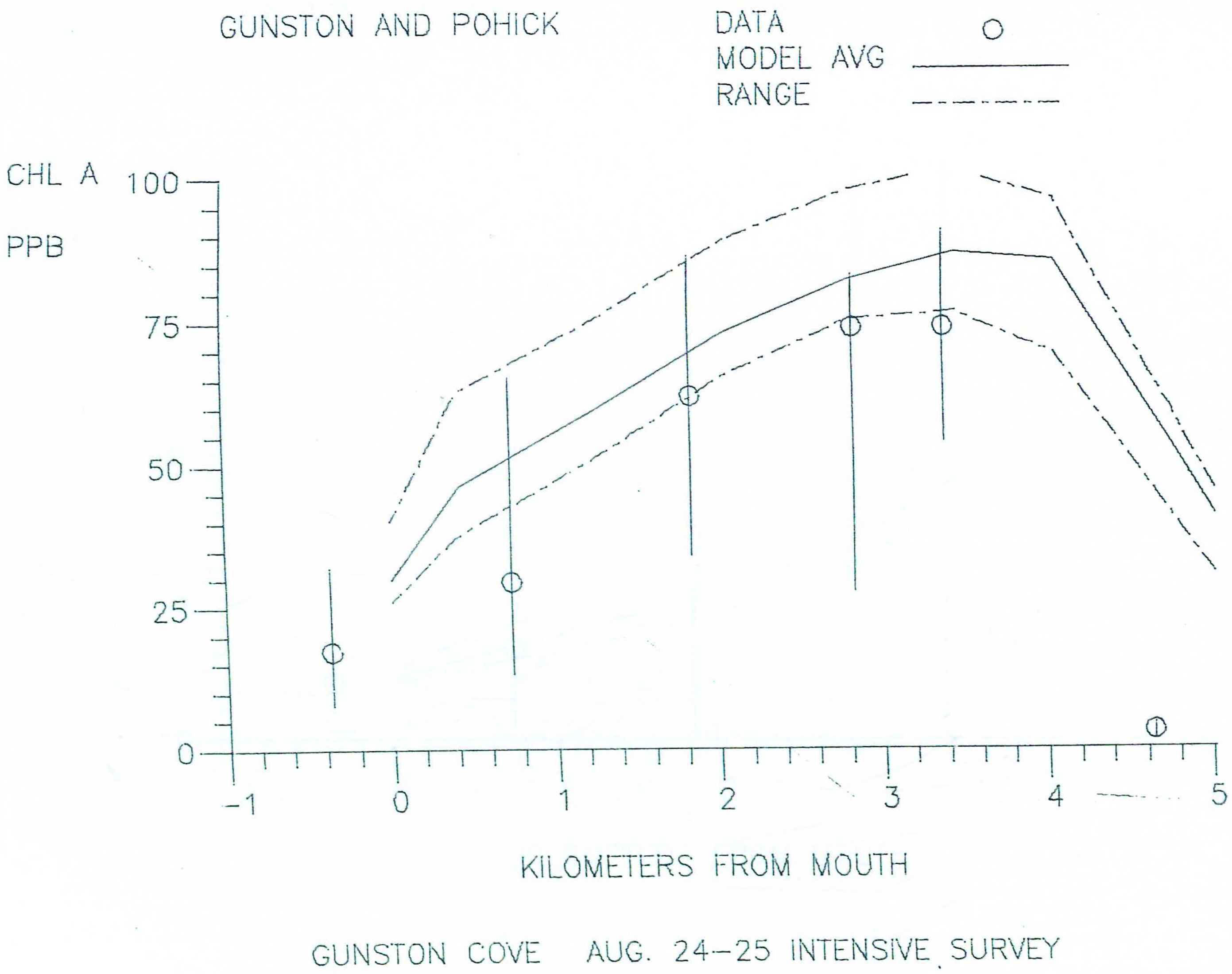


Figure 6-12. Calibration of Chlorophyll 'a'.

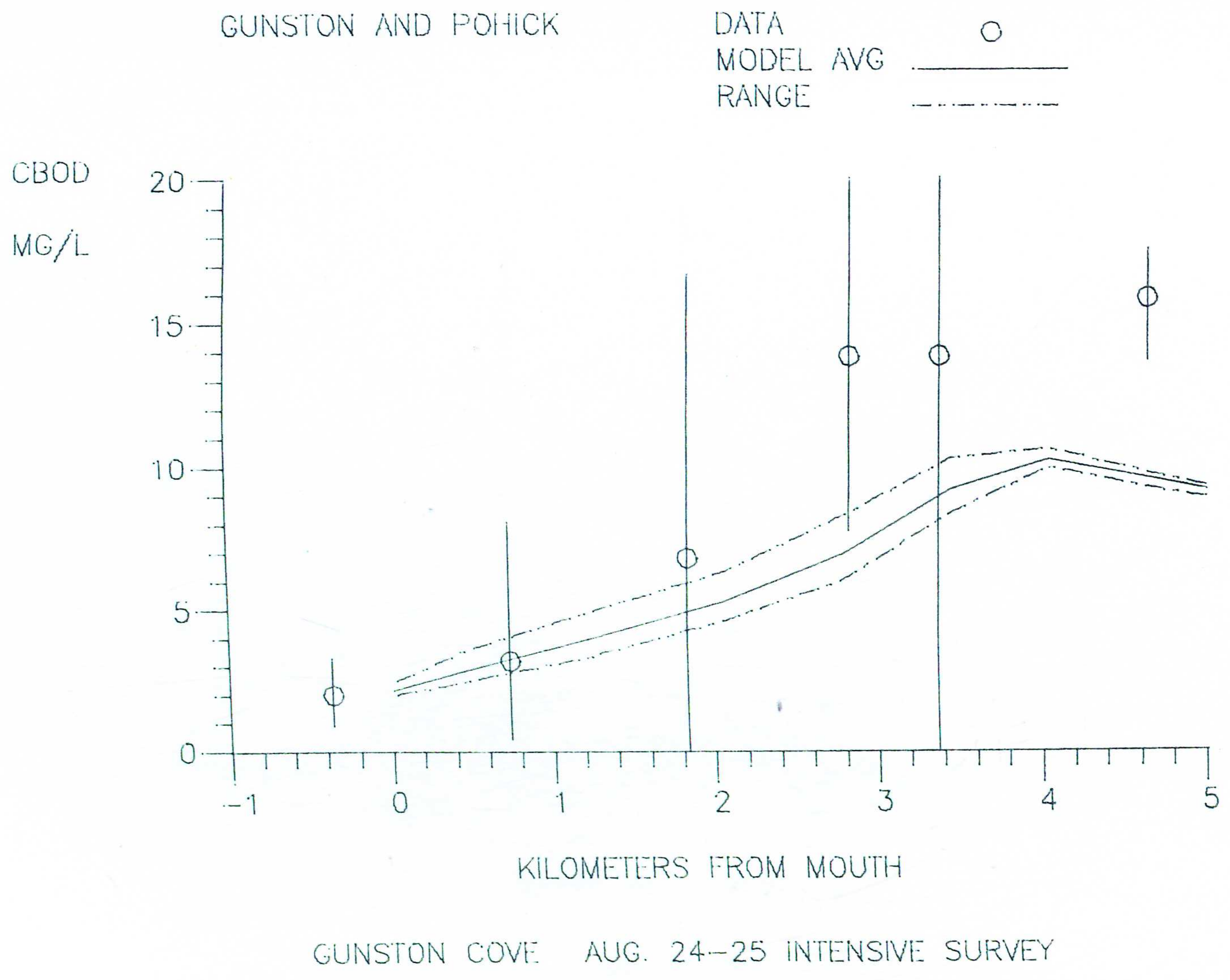


Figure 6-13. Calibration of CBODU.

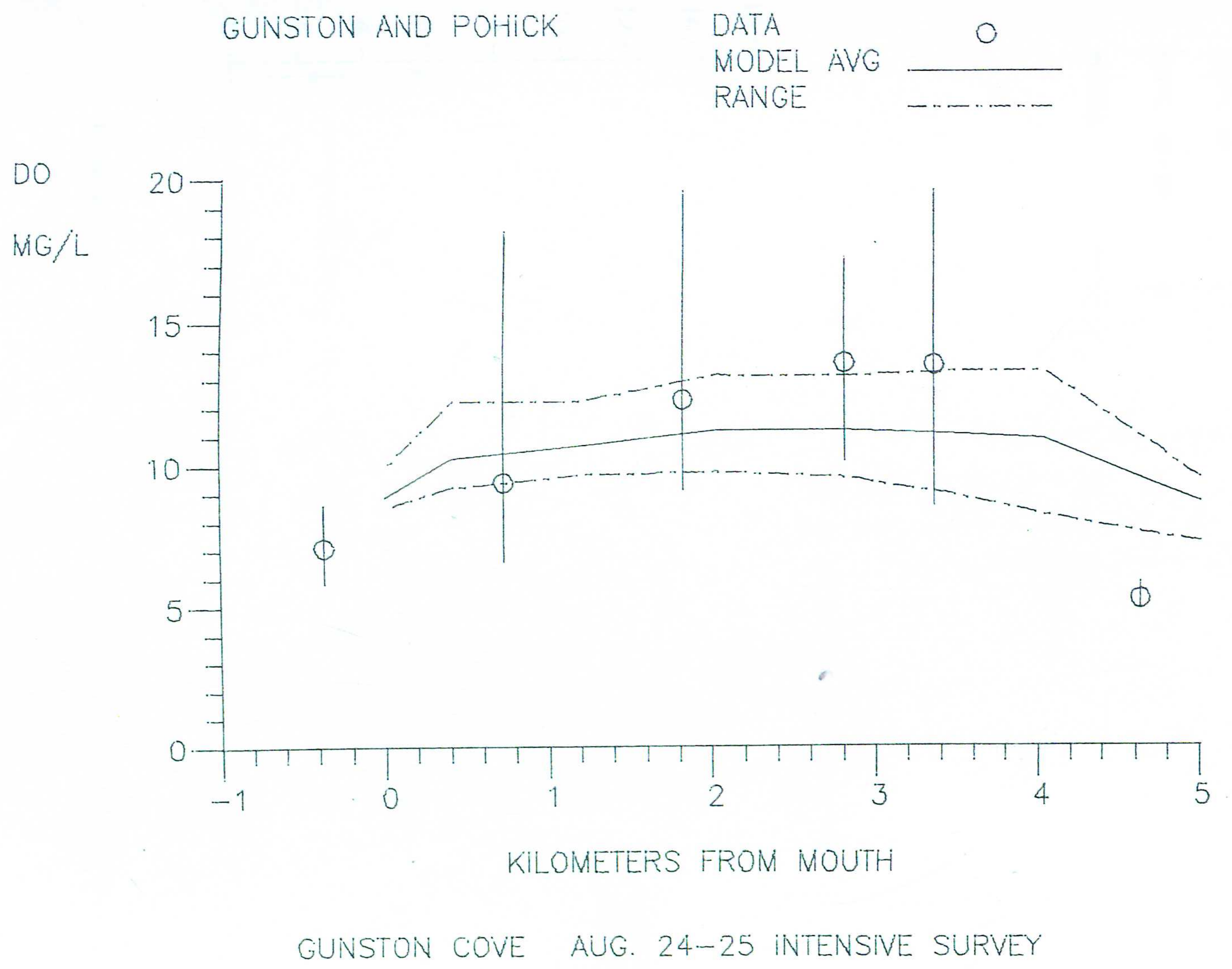


Figure 6-14. Calibration of Dissolved Oxygen.

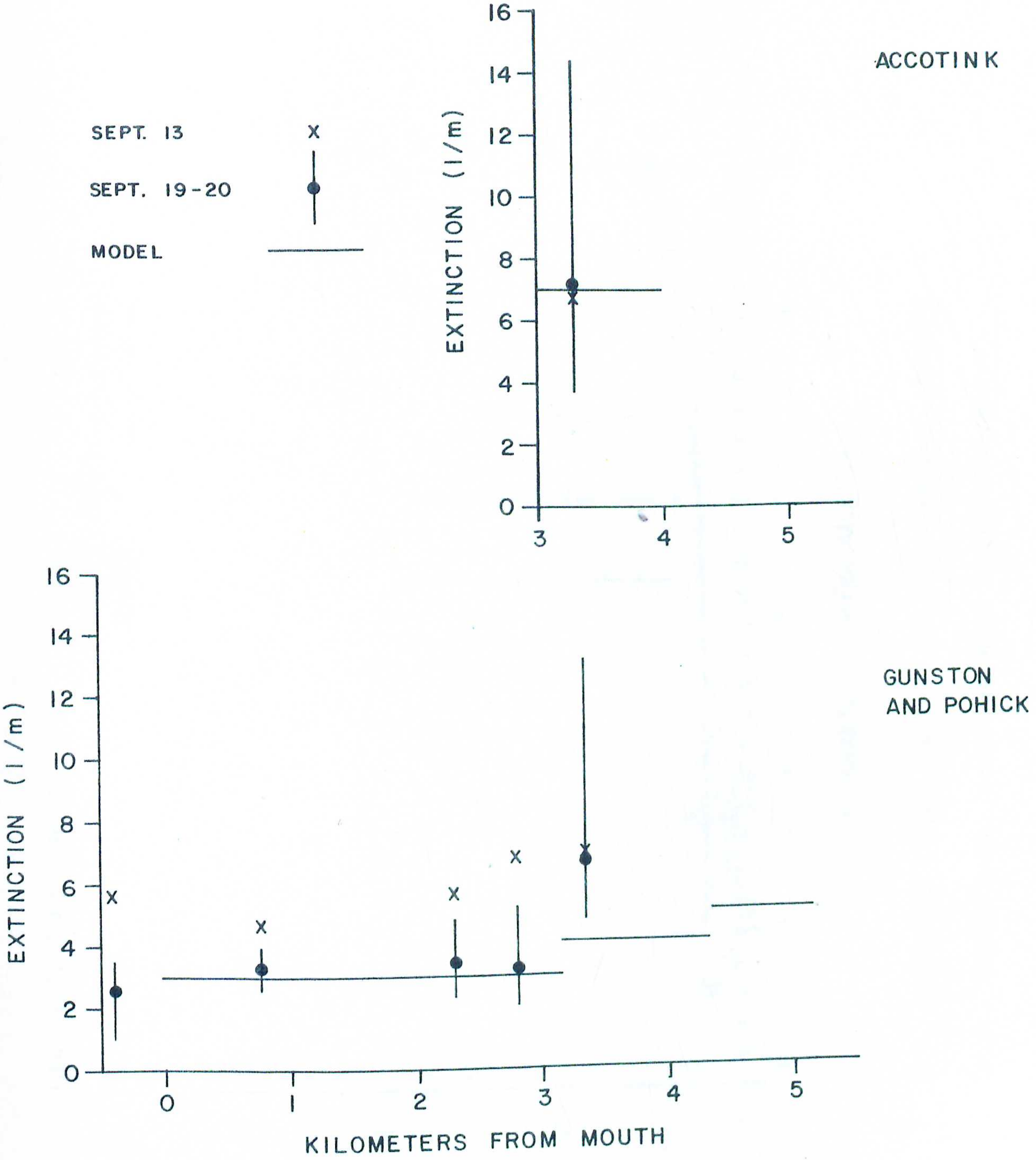


Figure 6-15. Light extinction - September, 1979, surveys.

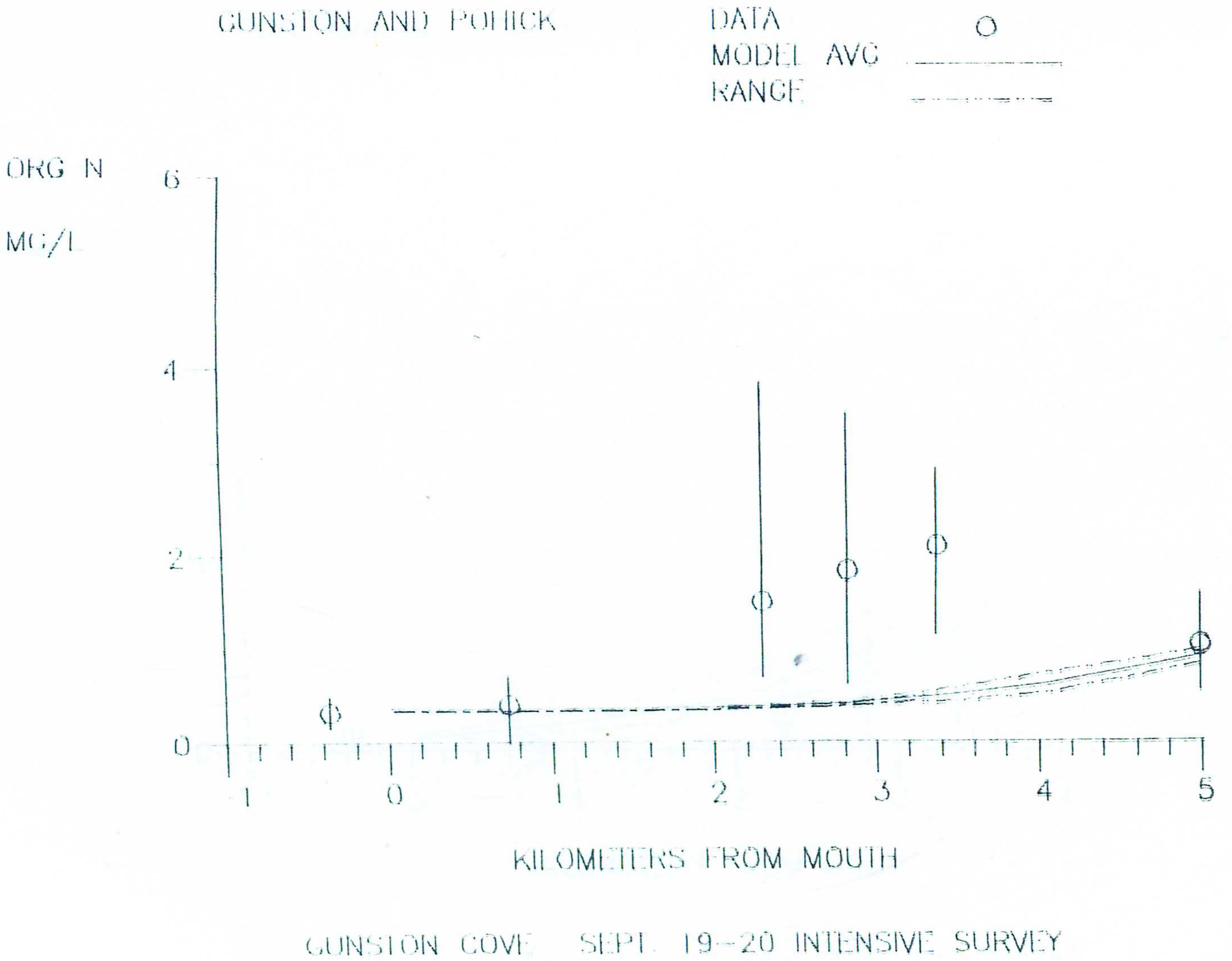
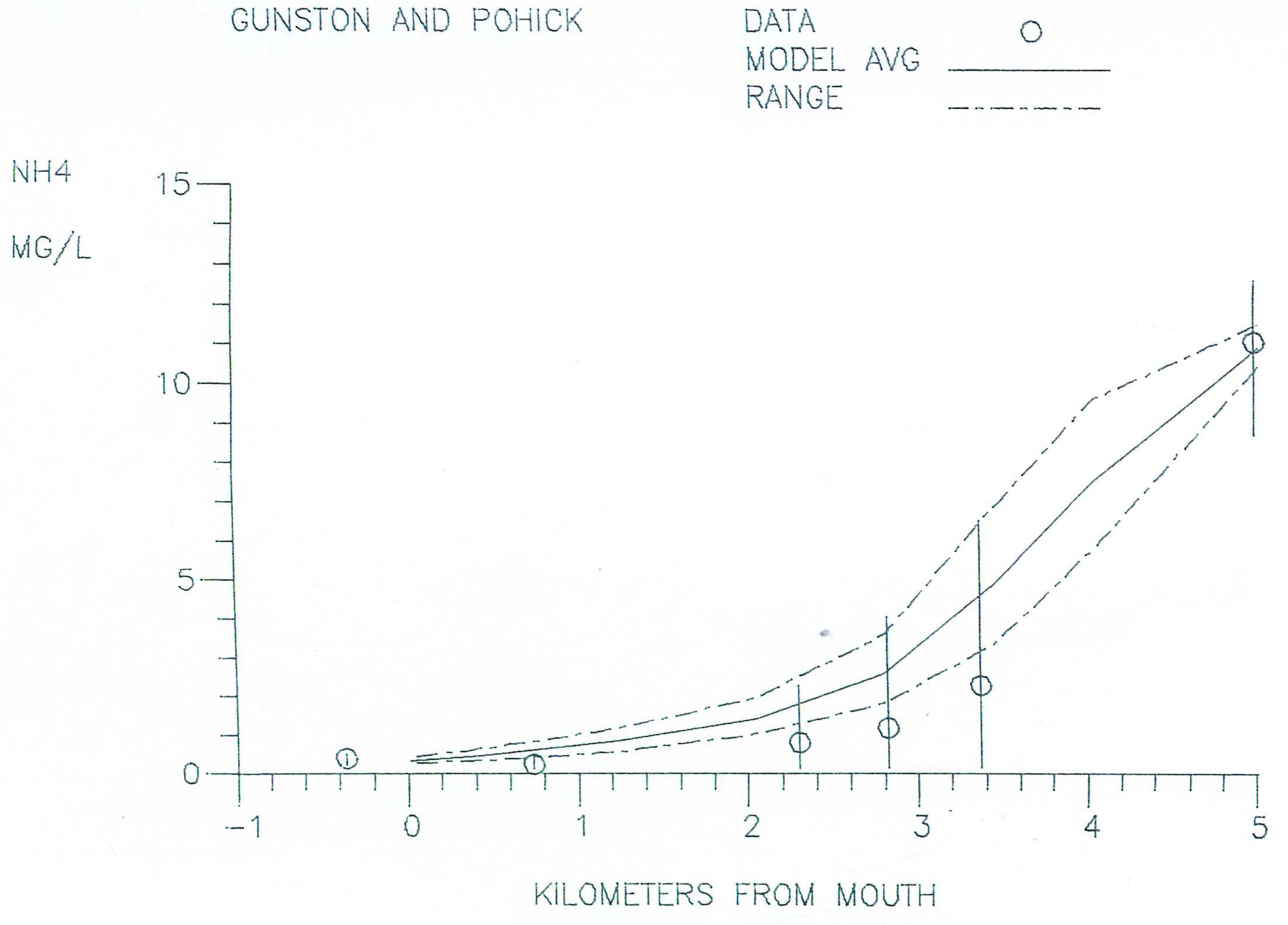


Figure 6-16. Verification of Organic Nitrogen.



GUNSTON COVE SEPT. 19–20 INTENSIVE SURVEY

Figure 6-17. Verification of Ammonia Nitrogen.

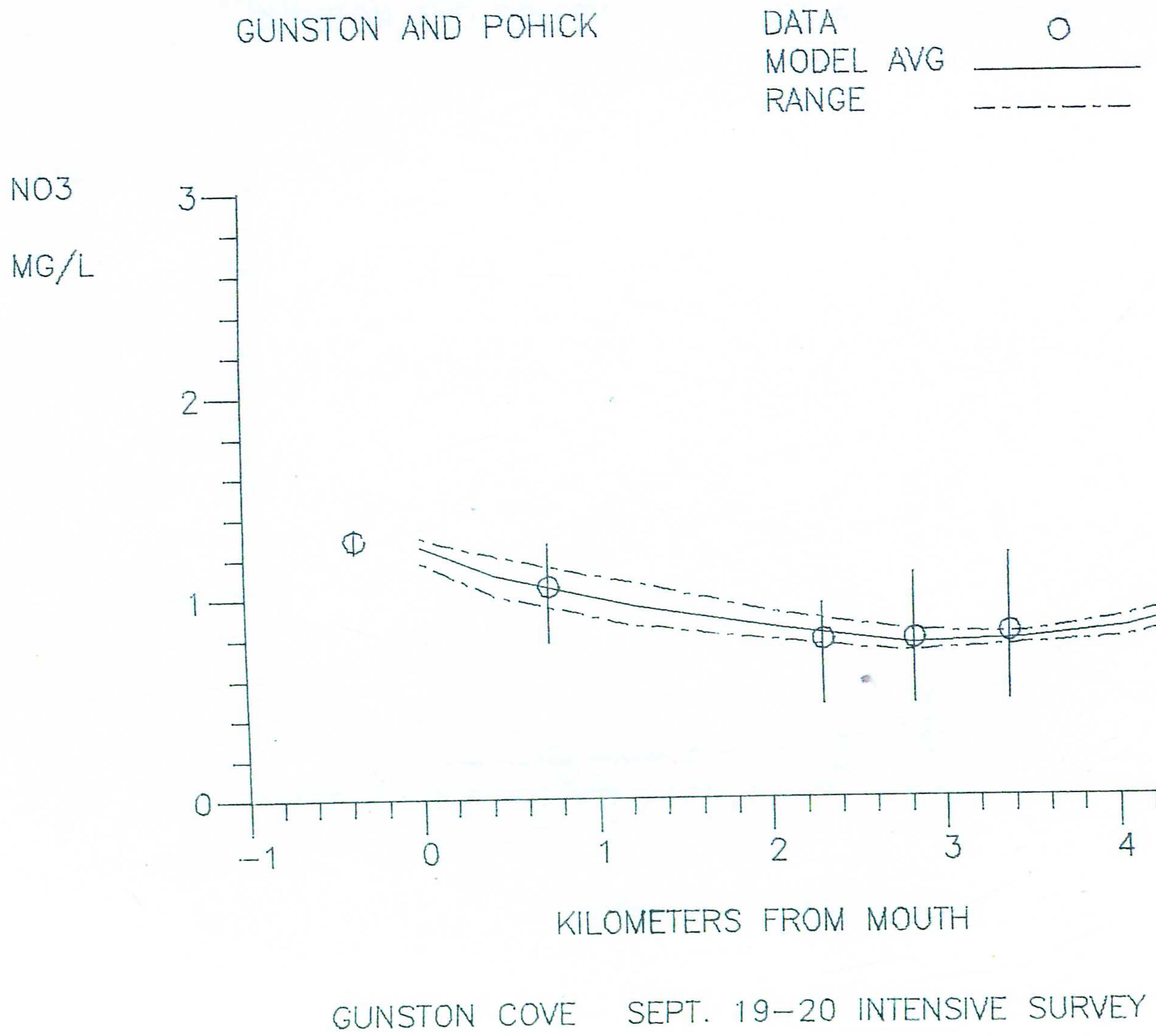


Figure 6-18. Verification of Nitrate Nitrogen.

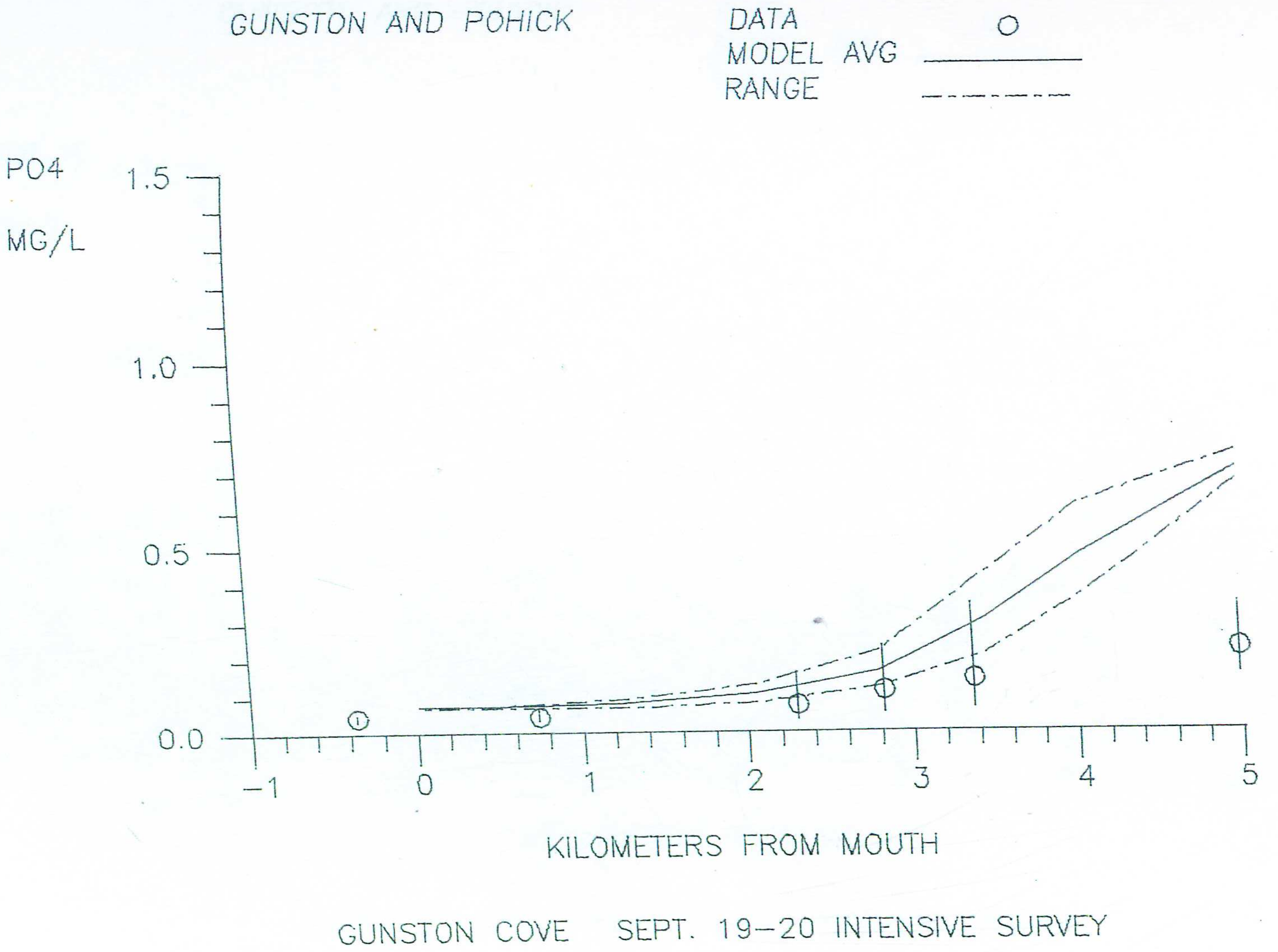


Figure 6-19. Verification of Ortho Phosphorus.

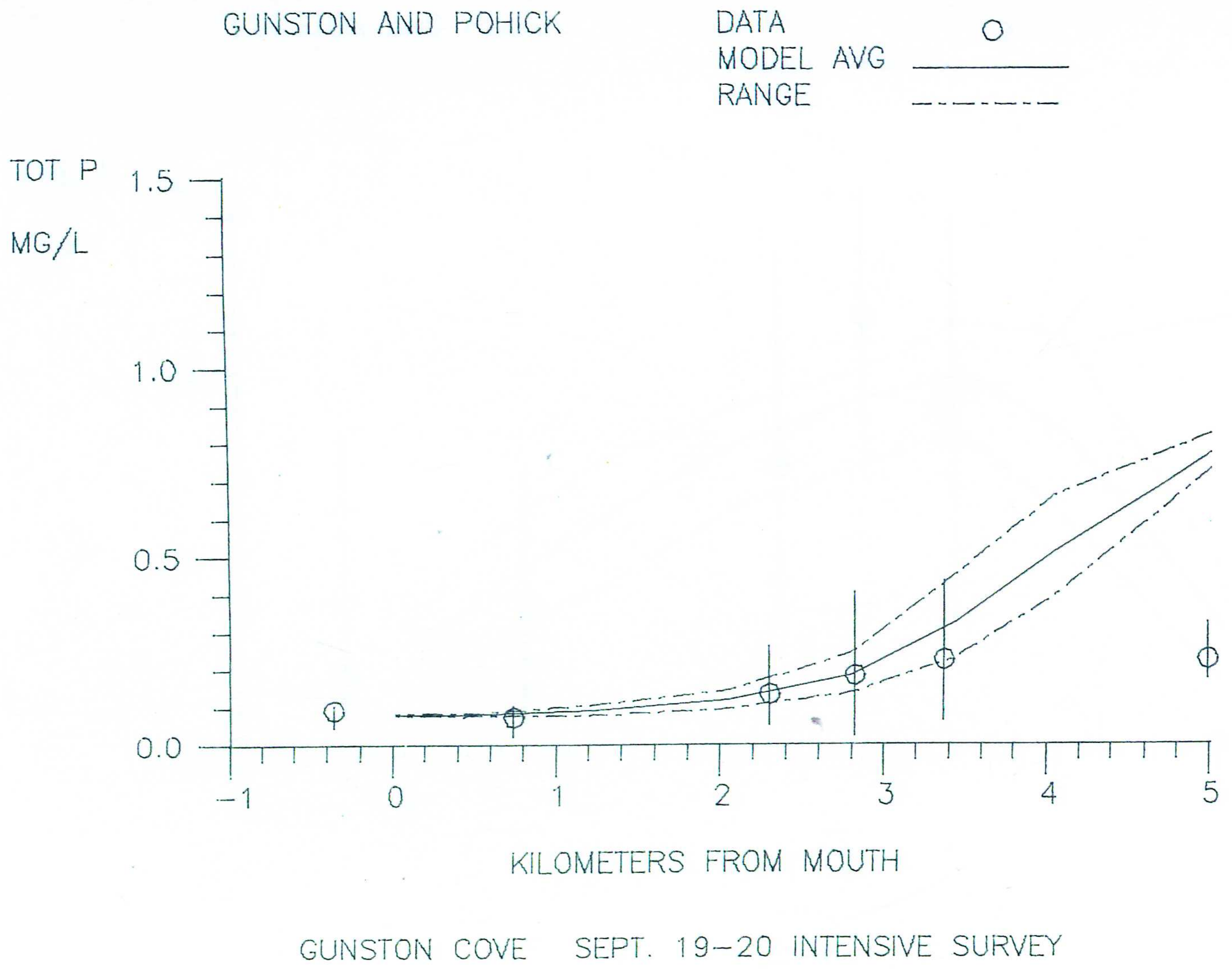


Figure 6-20. Verification of Total Phosphorus.

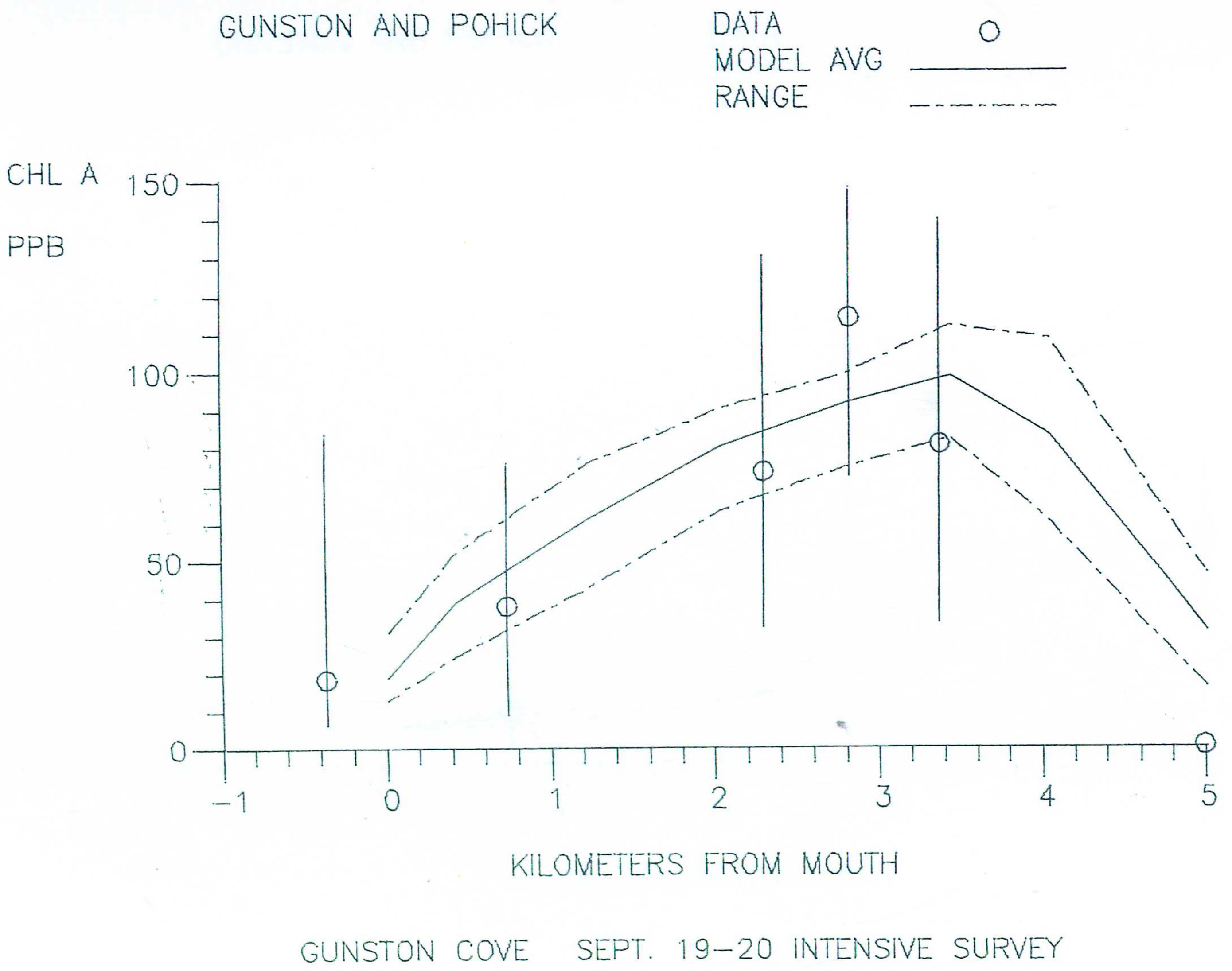


Figure 6-21. Verification of Chlorophyll 'a'.

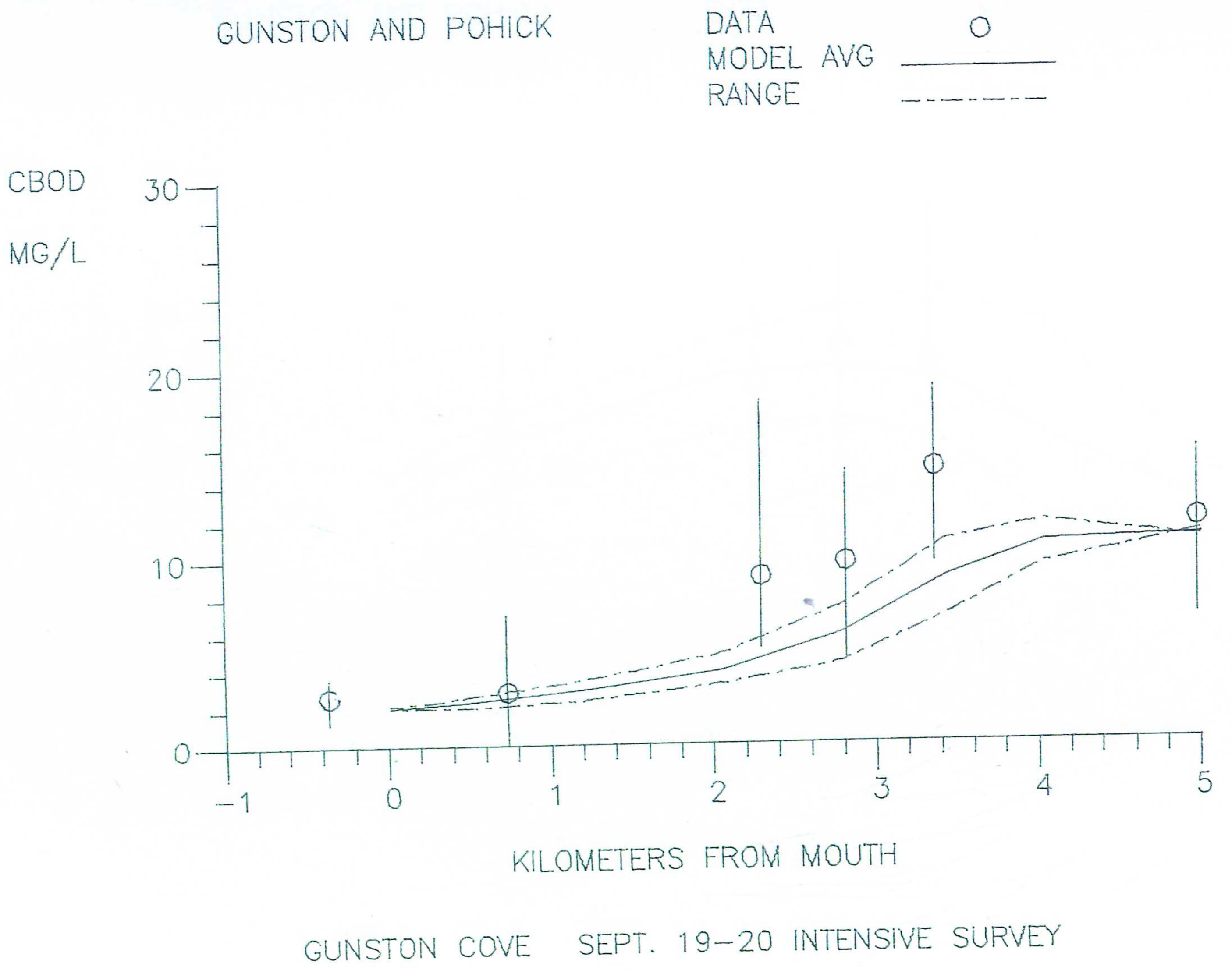


Figure 6-22. Verification of CBODU.

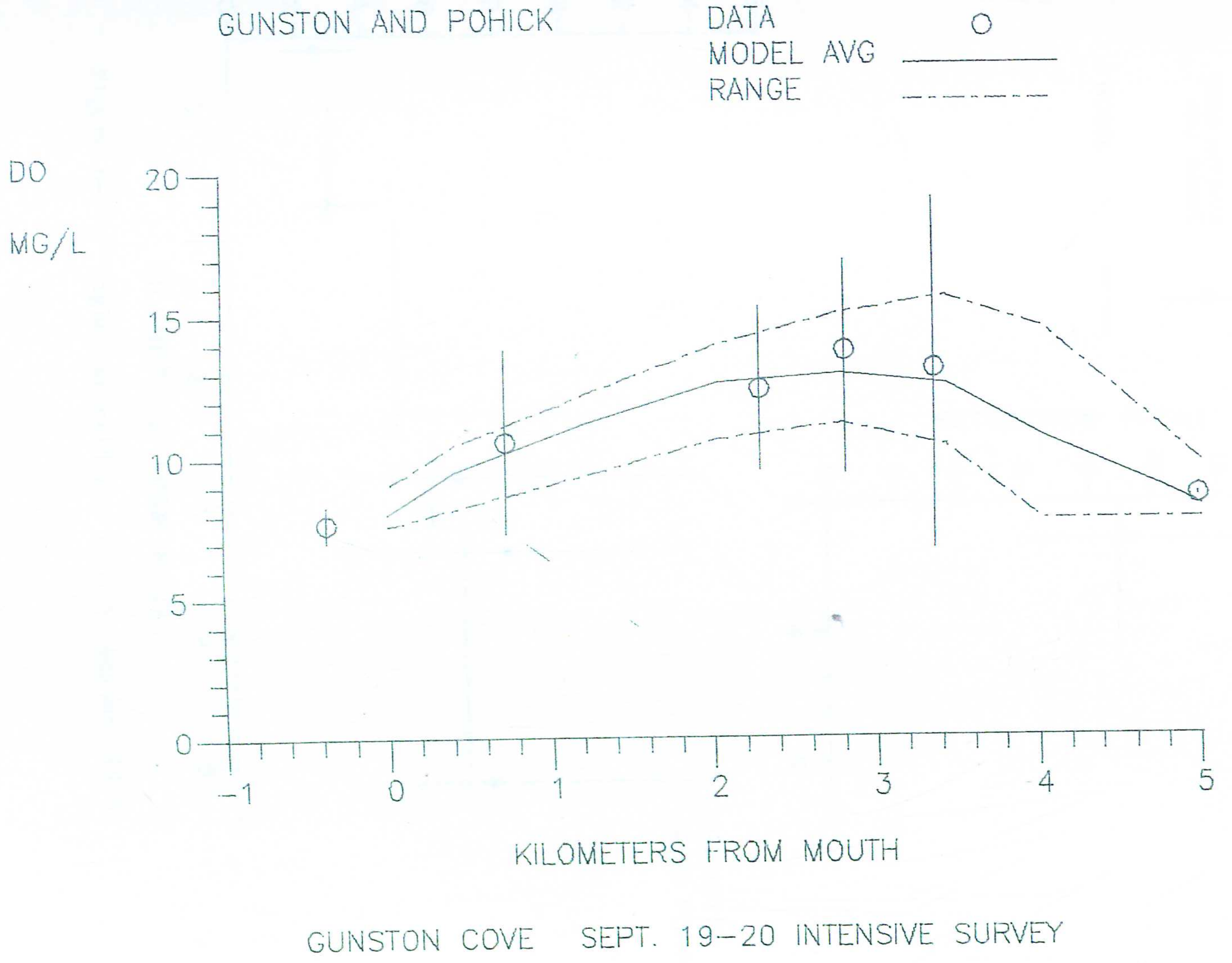


Figure 6-23. Verification of Dissolved Oxygen.

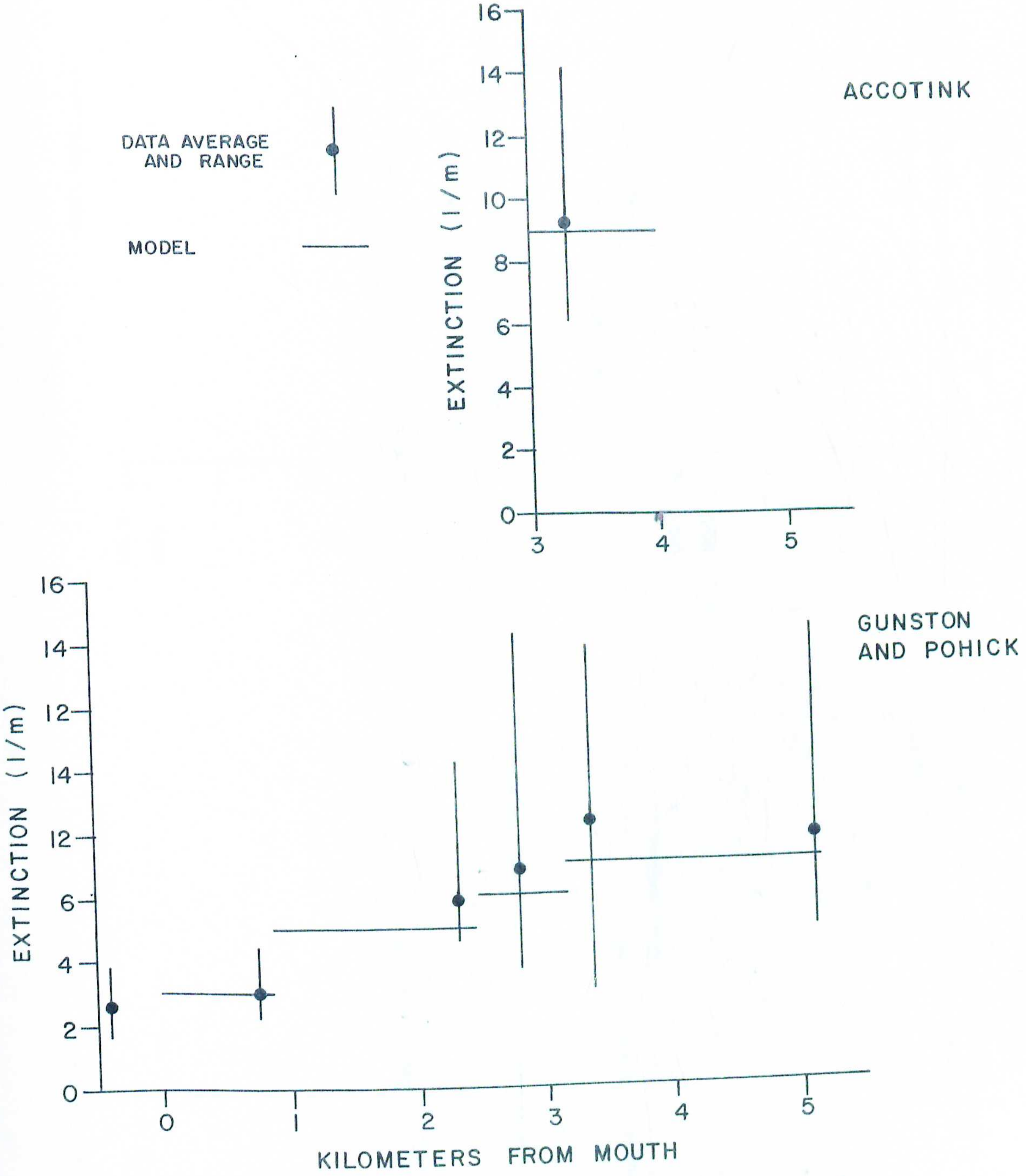


Figure 6-24. Light extinction - June to August, 1979.

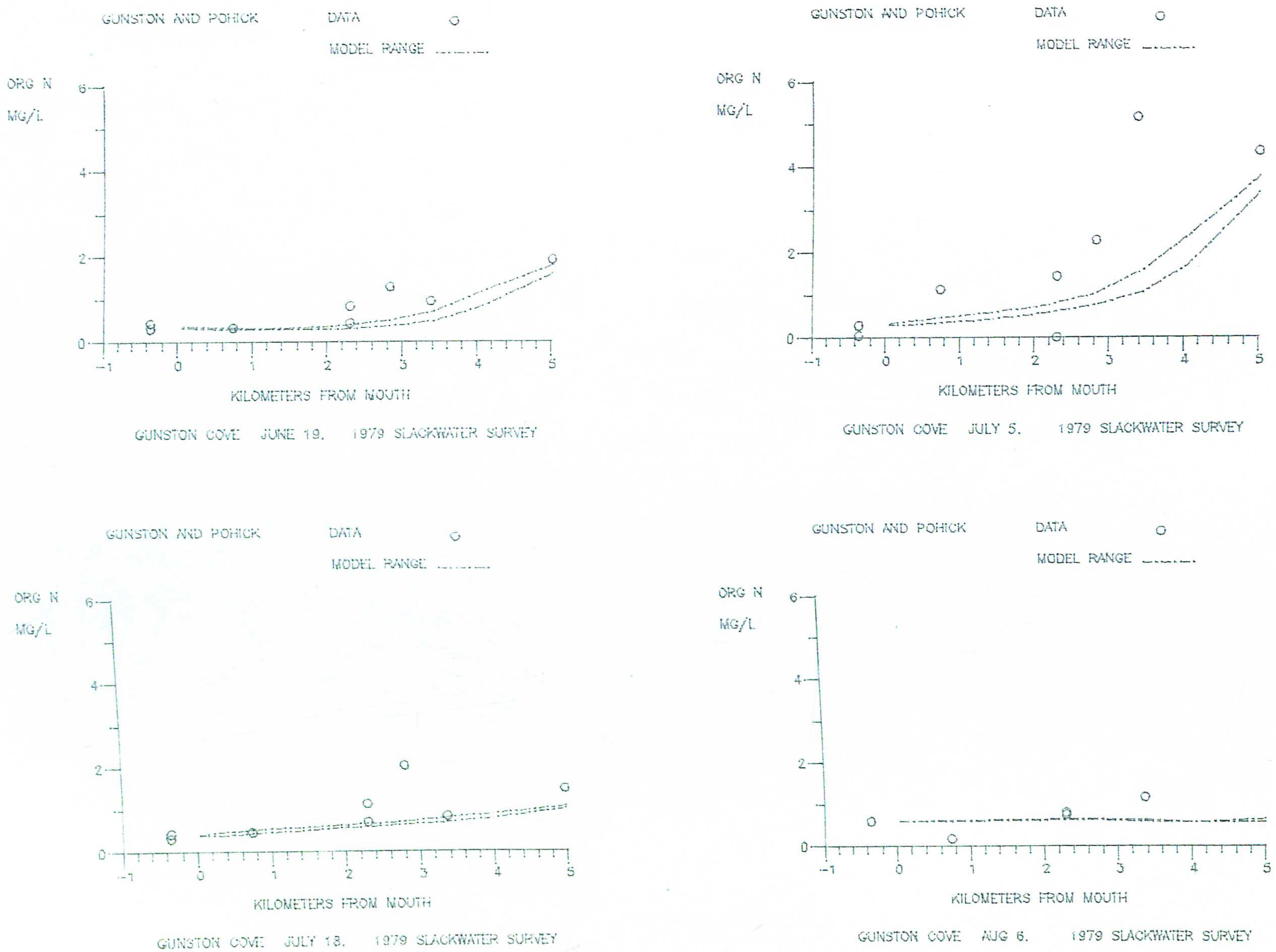
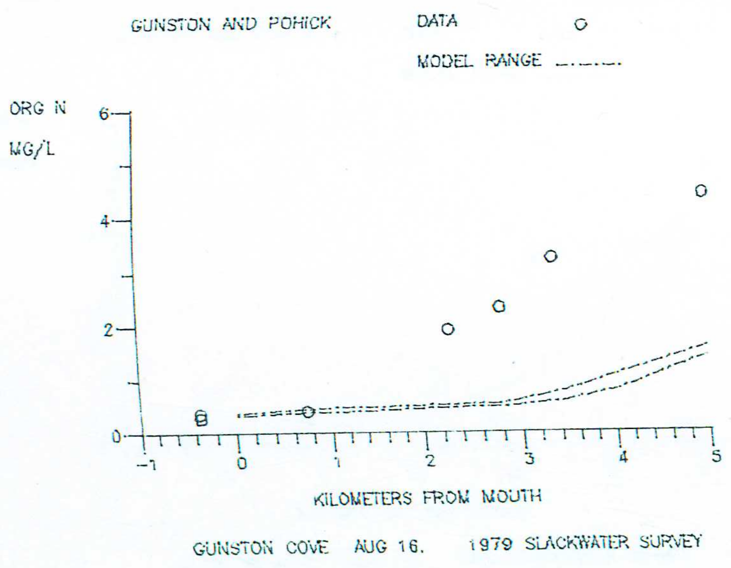
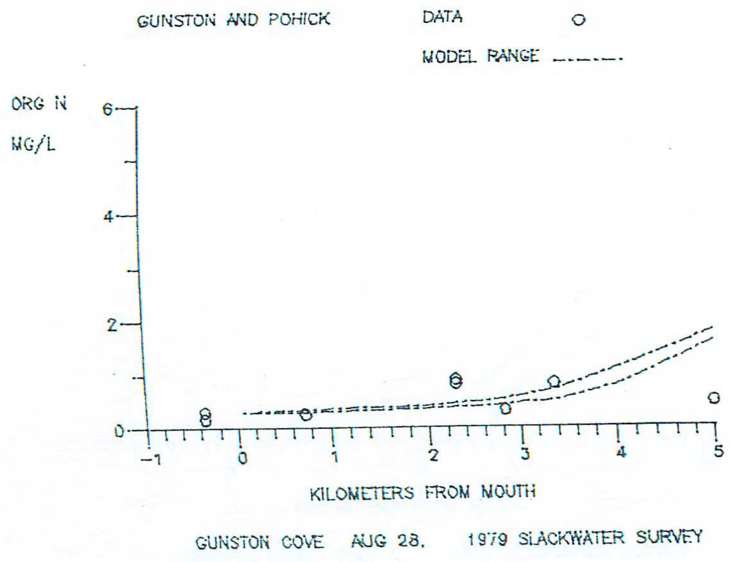


Figure 6-25. Long-Term Verification of Organic Nitrogen.





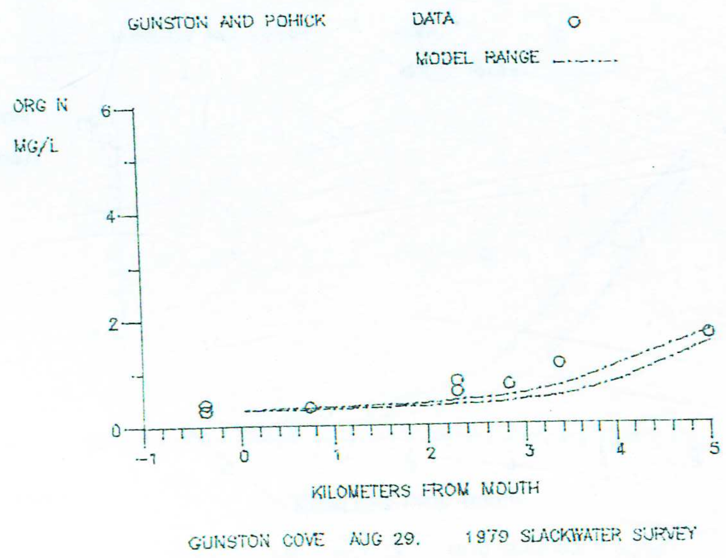
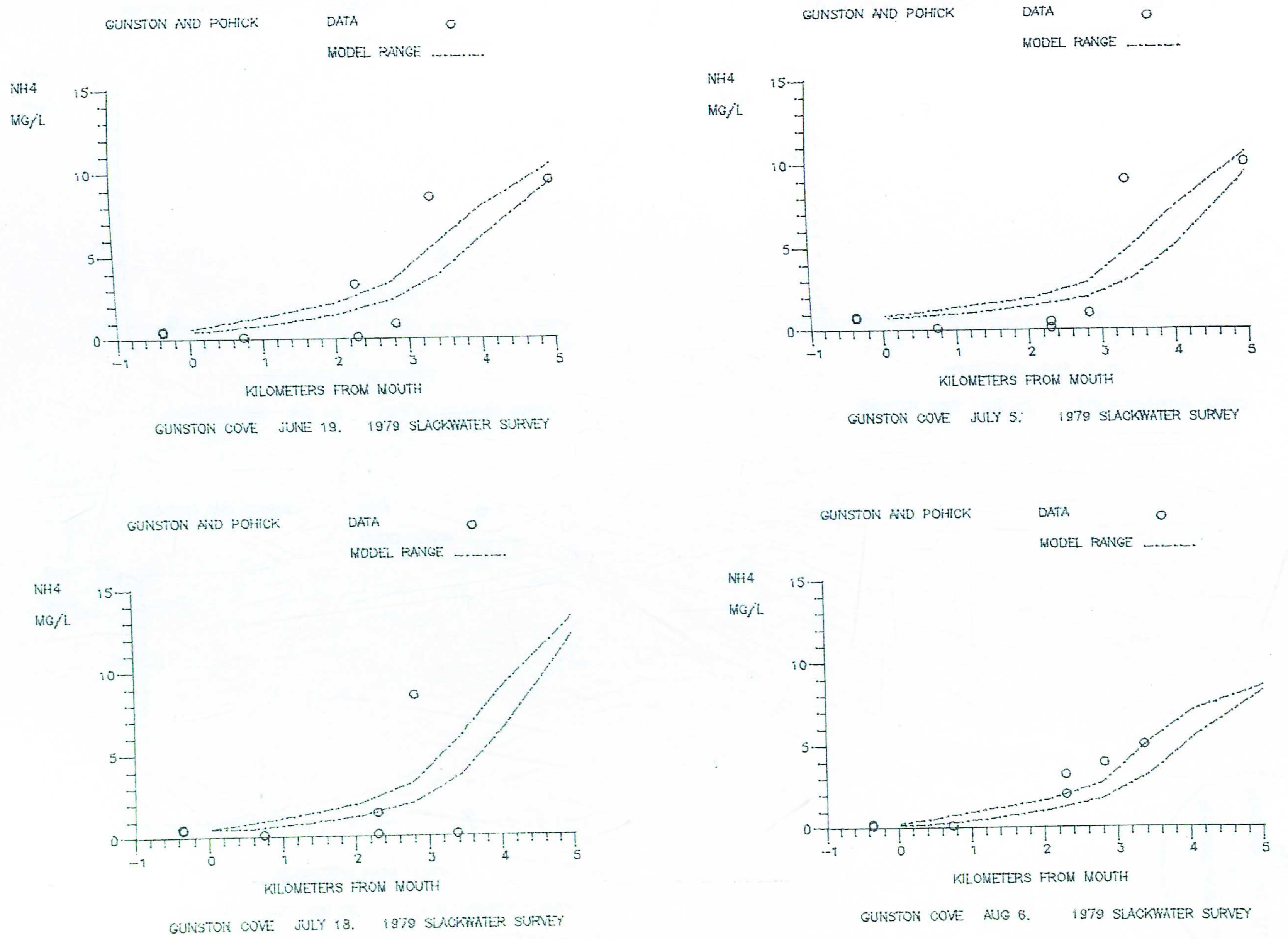


Figure 6-25. (Continued)



GUNSTON COVE JUNE 19. 1979 SLACKWATER SURVEY

GUNSTON COVE JULY 5. 1979 SLACKWATER SURVEY

GUNSTON COVE JULY 18. 1979 SLACKWATER SURVEY

GUNSTON COVE AUG 6. 1979 SLACKWATER SURVEY

Figure 6-26. Long-Term Verification of Ammonia Nitrogen.

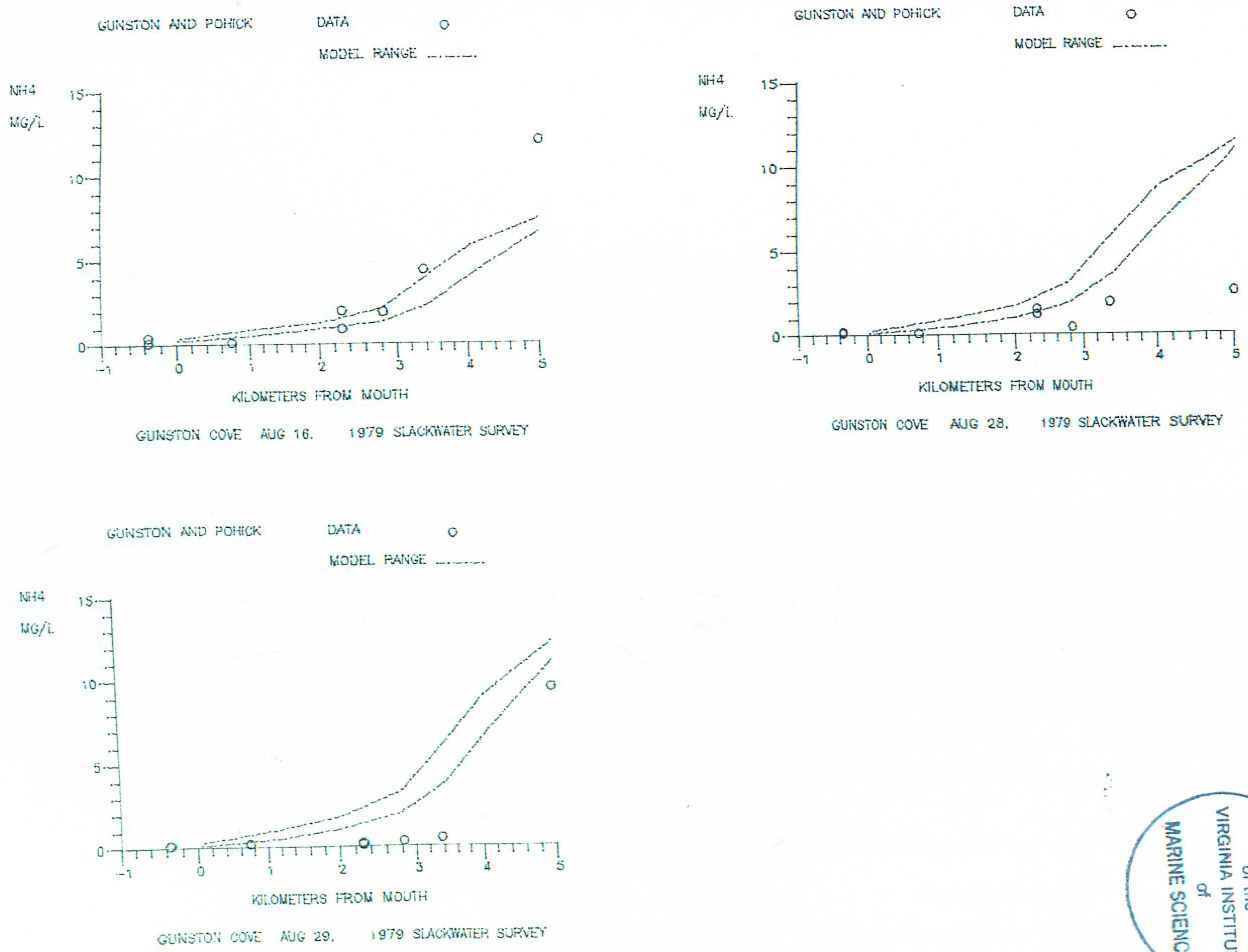


Figure 6-26. (Continued)

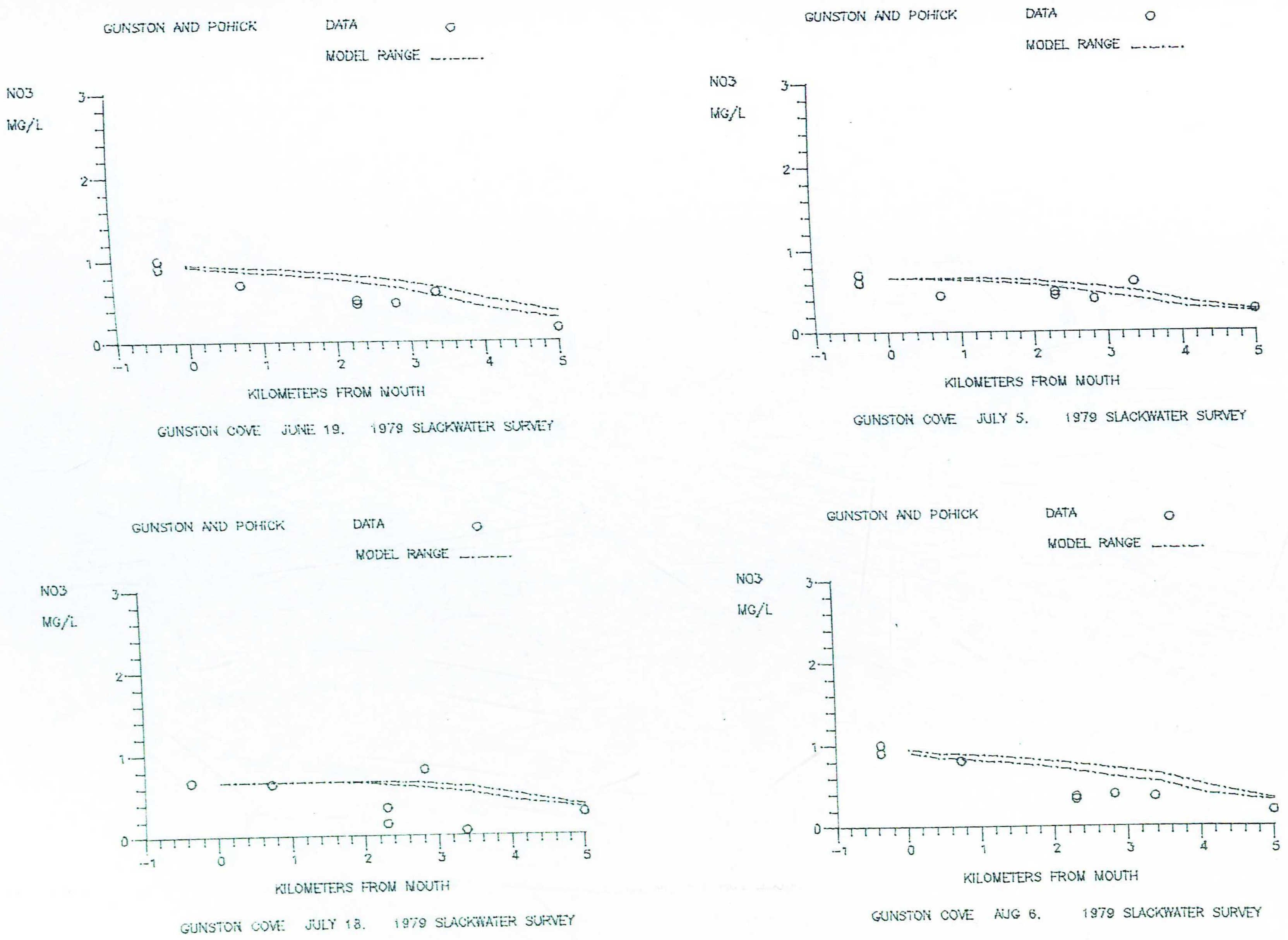
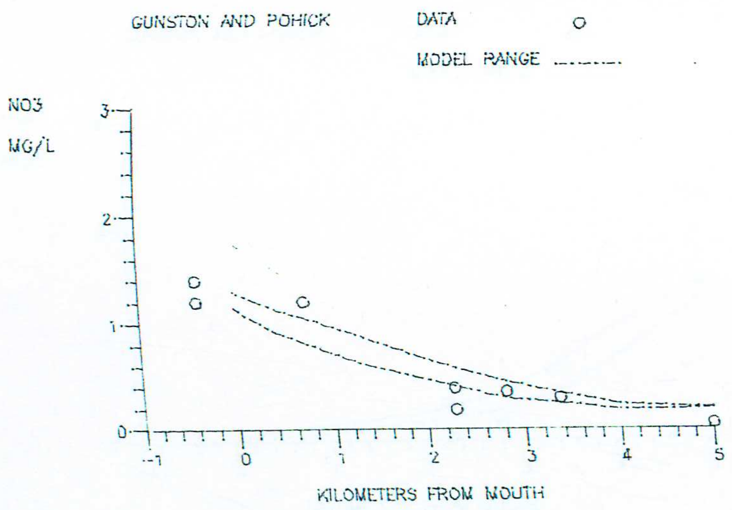
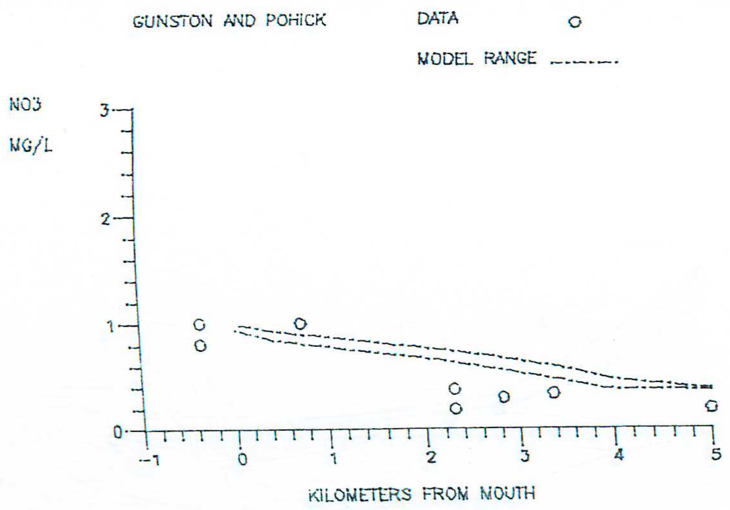


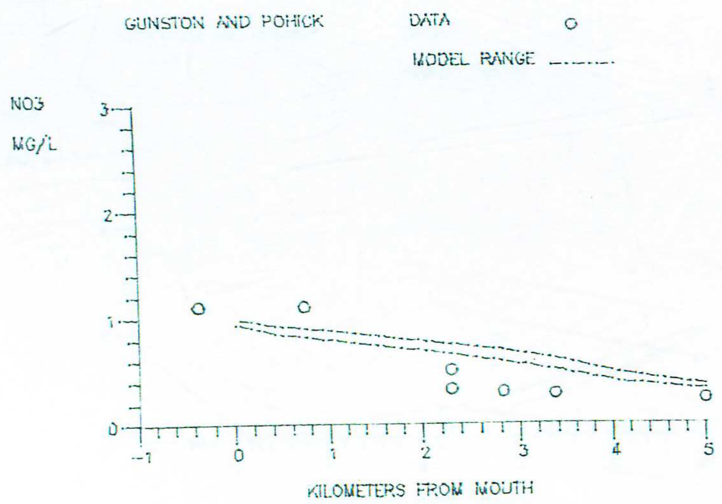
Figure 6-27. Long-Term Verification of Nitrate Nitrogen.



GUNSTON COVE AUG 16. 1979 SLACKWATER SURVEY



GUNSTON COVE AUG 28. 1979 SLACKWATER SURVEY



GUNSTON COVE AUG 29. 1979 SLACKWATER SURVEY

Figure 6-27. (Continued)

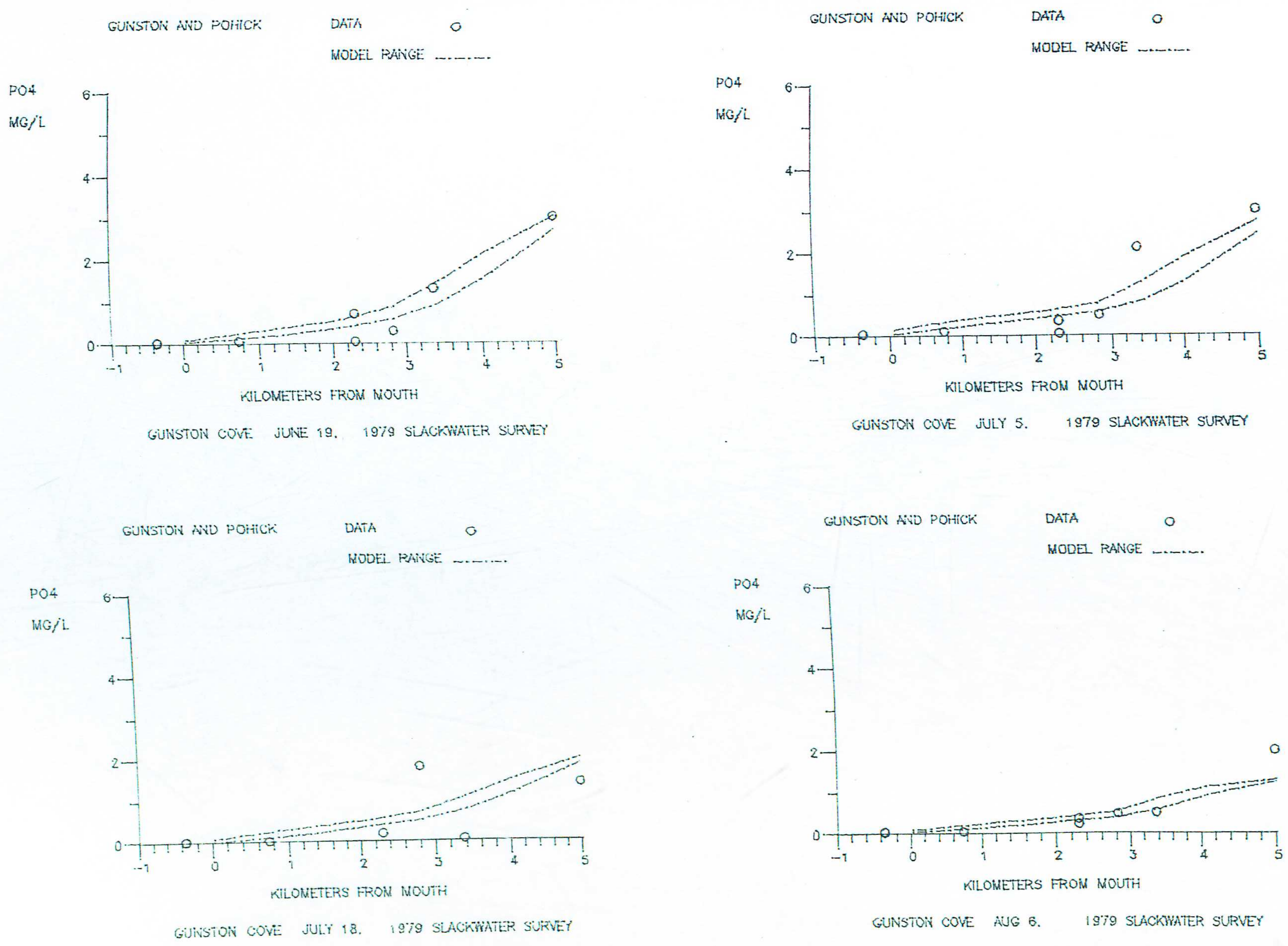
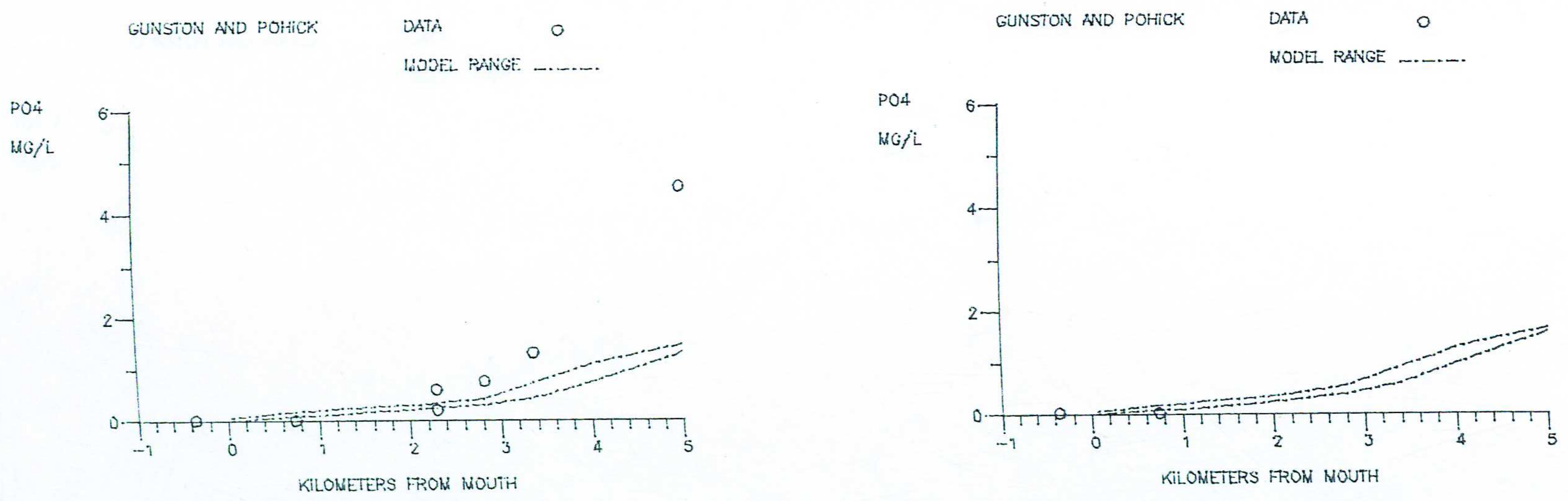
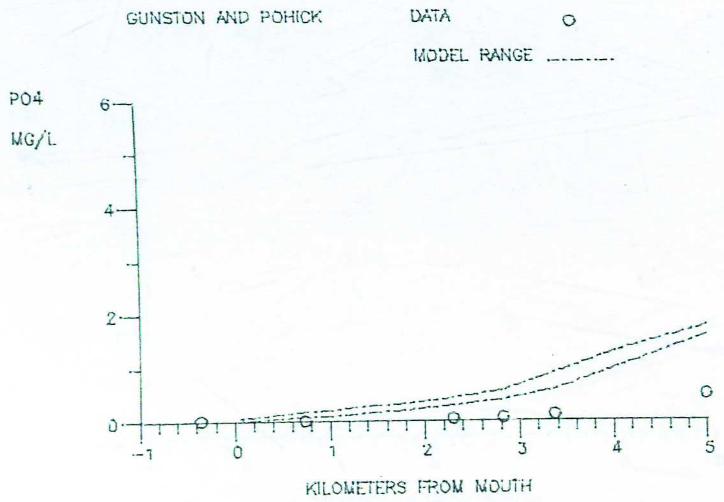


Figure 6-28. Long-Term Verification of Ortho Phosphorus.



GUNSTON COVE AUG 16. 1979 SLACKWATER SURVEY

GUNSTON COVE AUG 28. 1979 SLACKWATER SURVEY



GUNSTON COVE AUG 29. 1979 SLACKWATER SURVEY

Figure 6-28. (Continued)

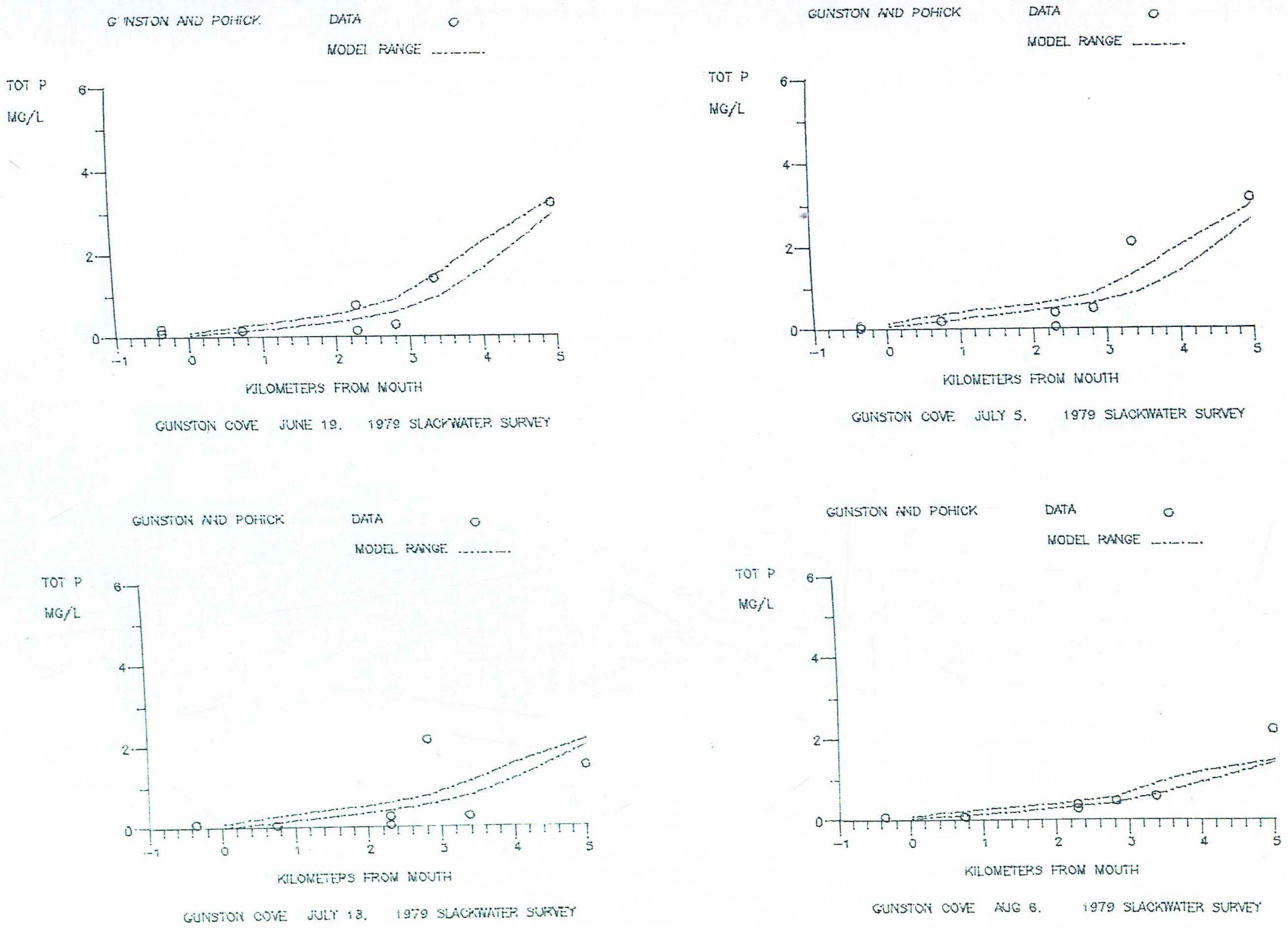
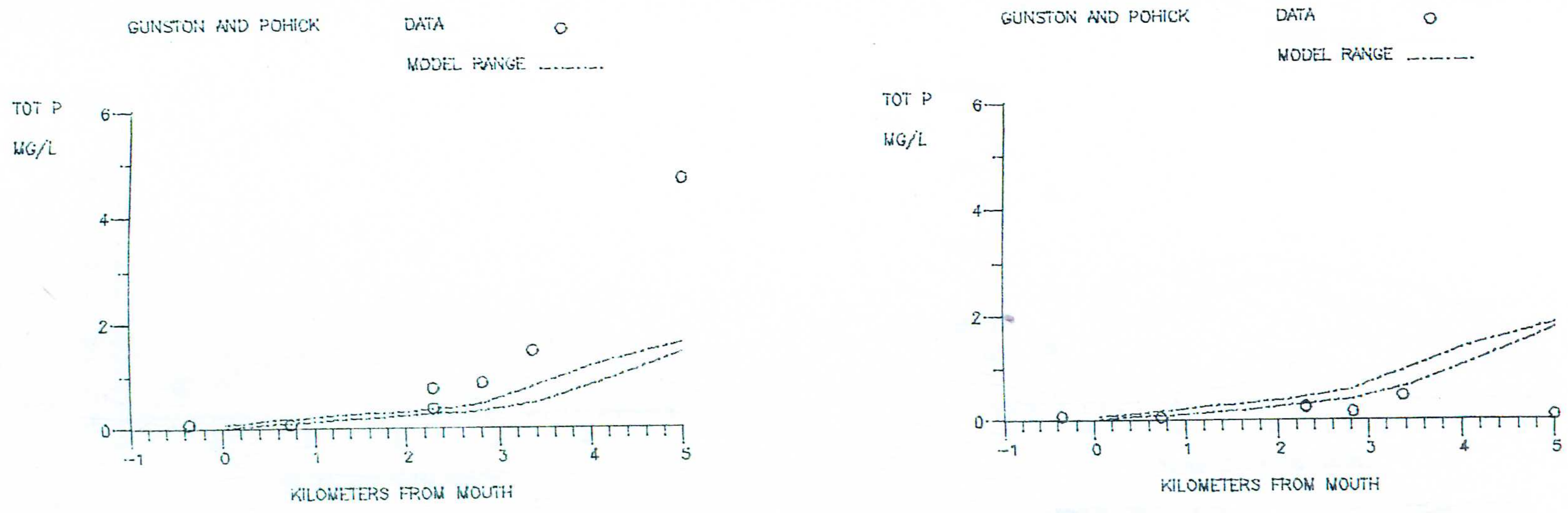
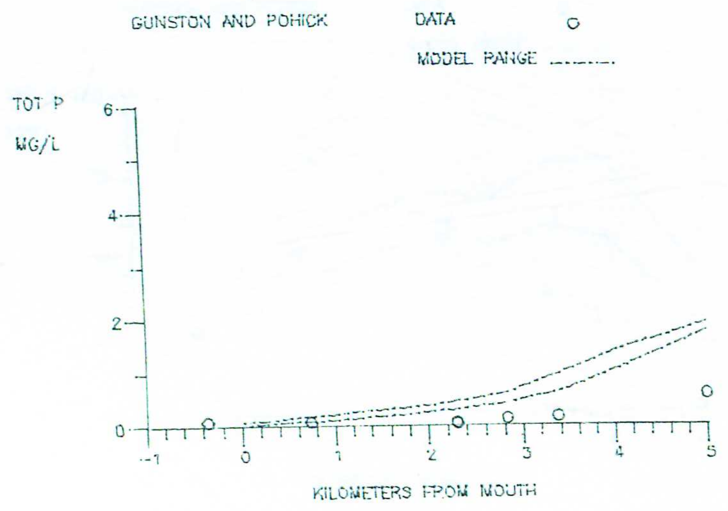


Figure 6-29. Long-Term Verification of Total Phosphorus.



GUNSTON COVE AUG 16. 1979 SLACKWATER SURVEY

GUNSTON COVE AUG 28. 1979 SLACKWATER SURVEY



GUNSTON COVE AUG 29. 1979 SLACKWATER SURVEY

Figure 6-29. (Continued)

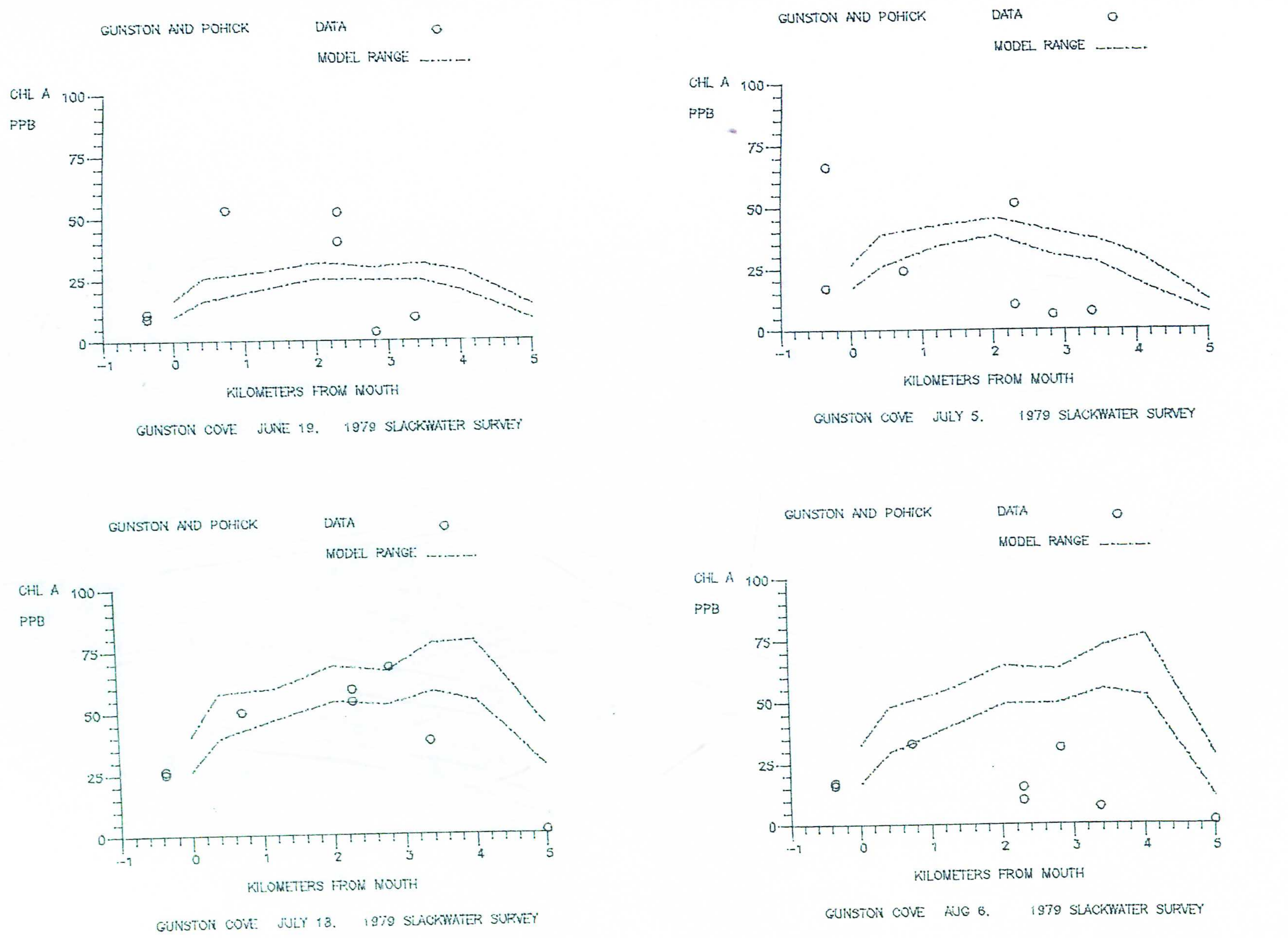


Figure 6-30. Long-Term Verification of Chlorophyll 'a'.

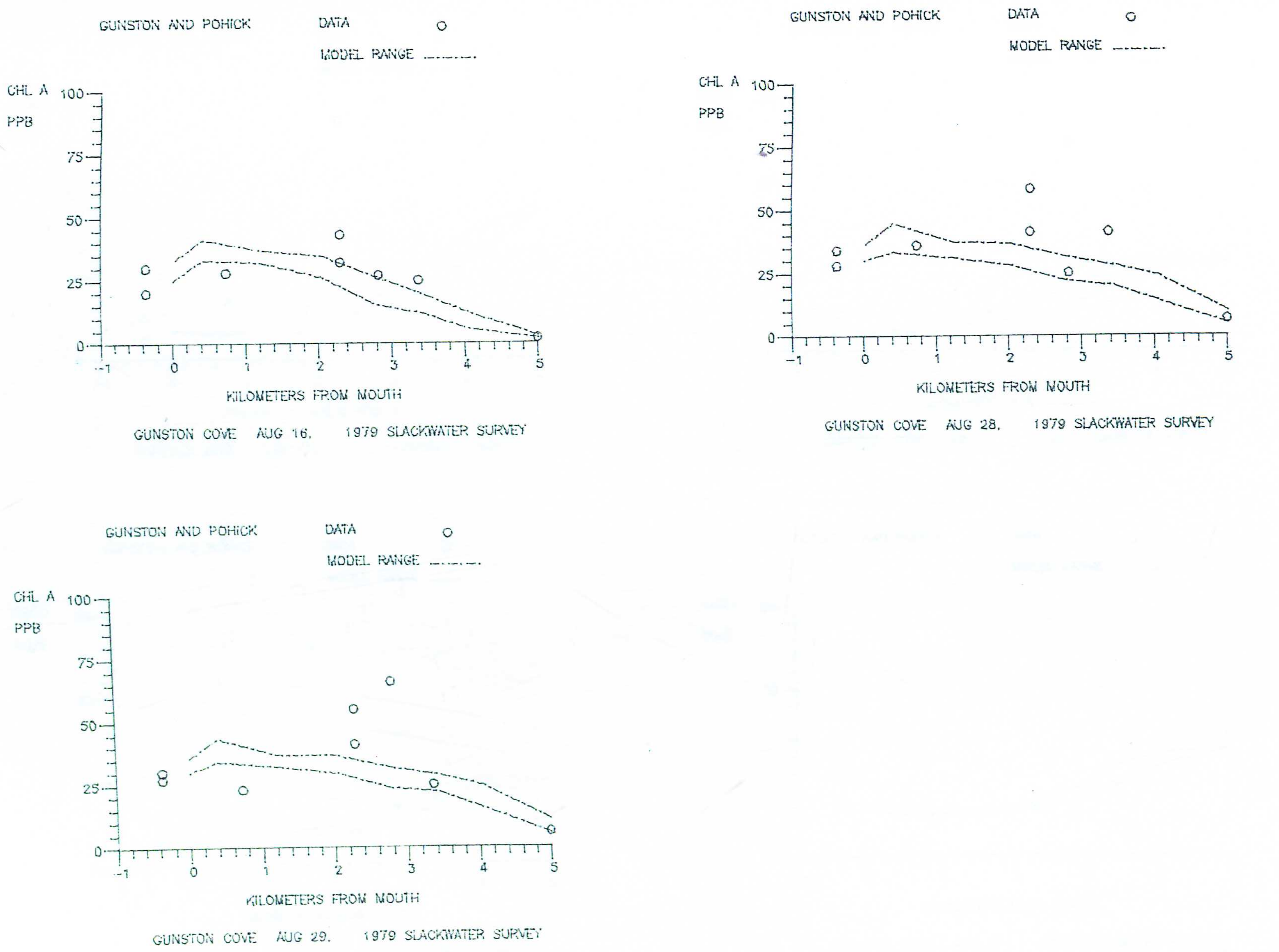


Figure 6-30. (Continued)

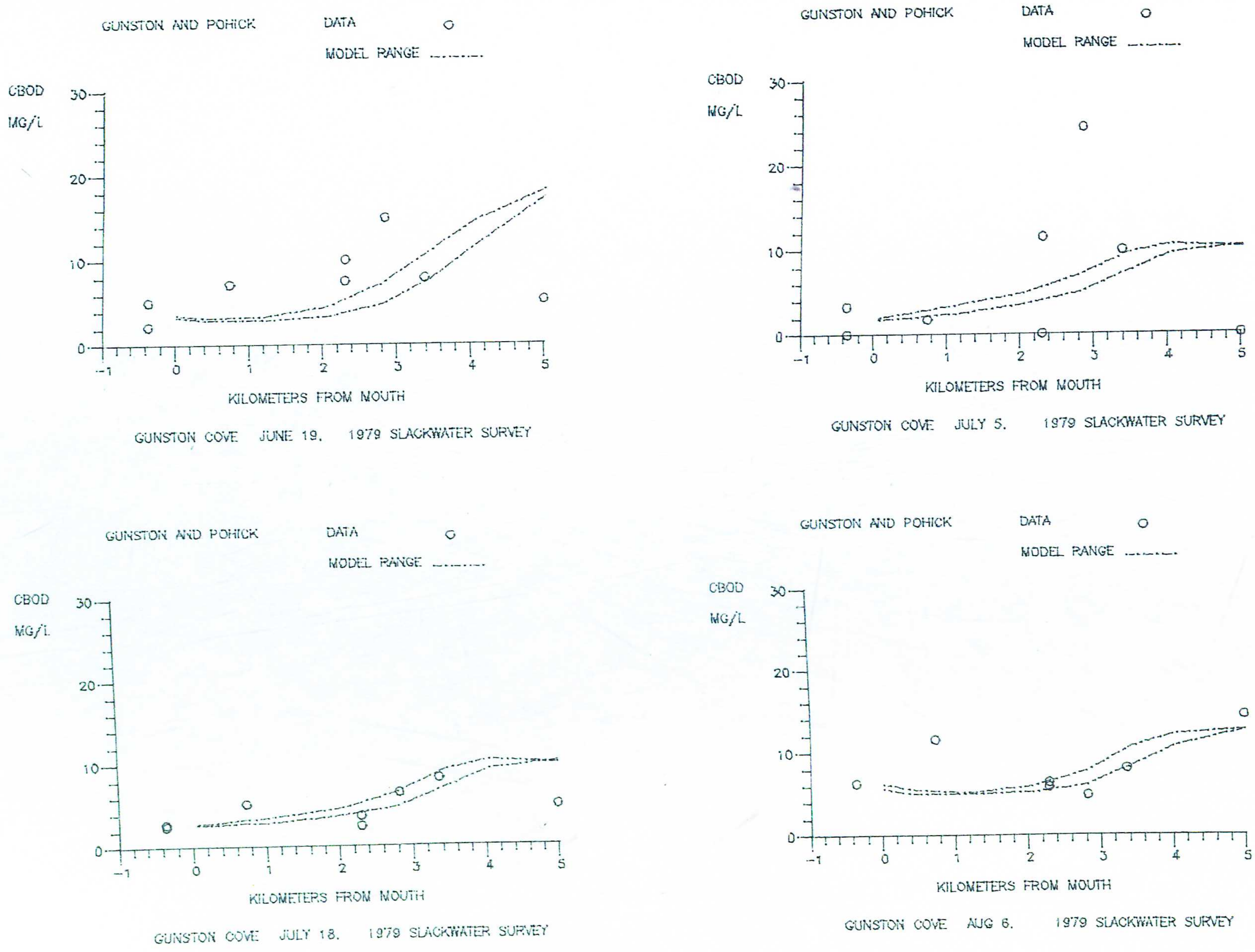
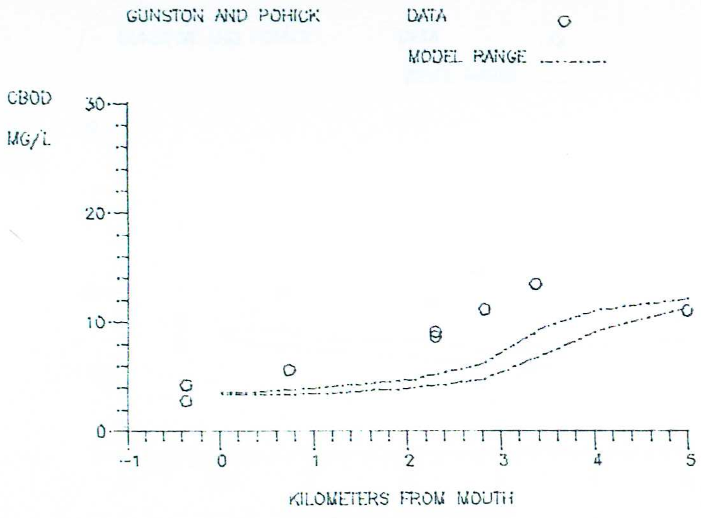
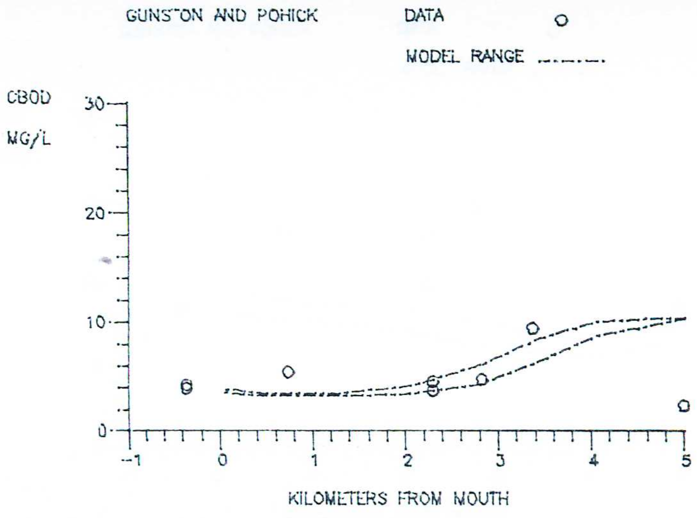


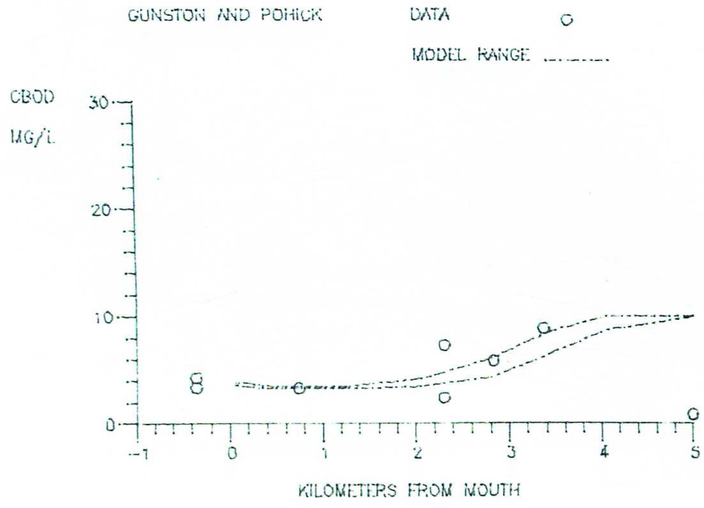
Figure 6-31. Long-Term Verification of CBODU.



GUNSTON COVE AUG 16. 1979 SLACKWATER SURVEY

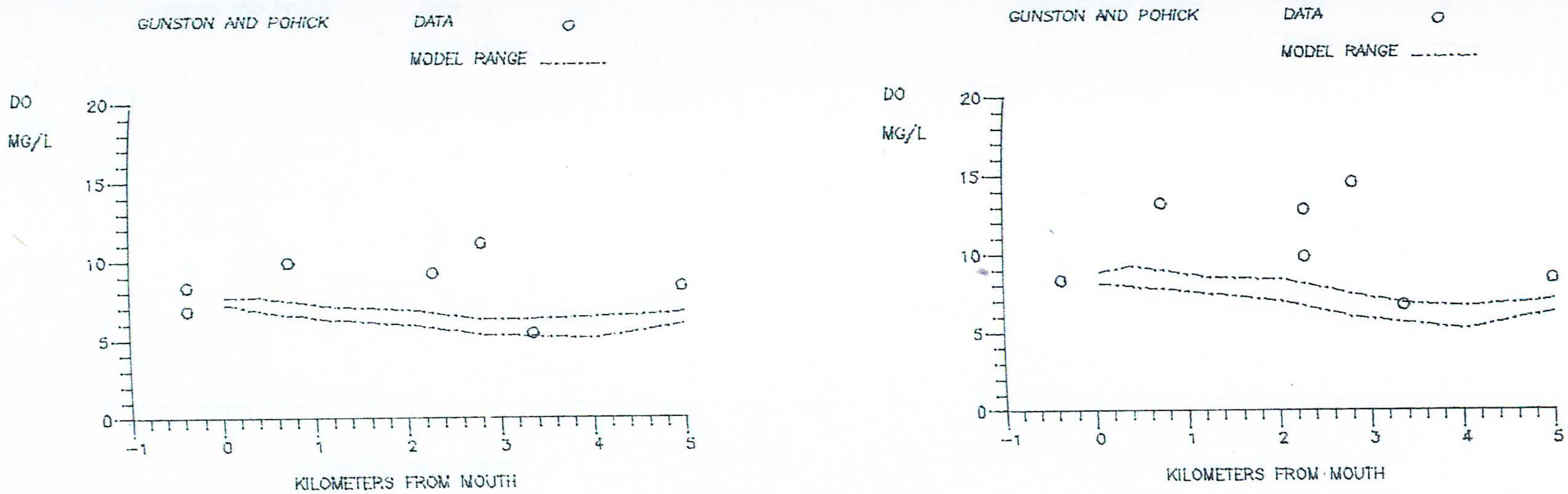


GUNSTON COVE AUG 28. 1979 SLACKWATER SURVEY



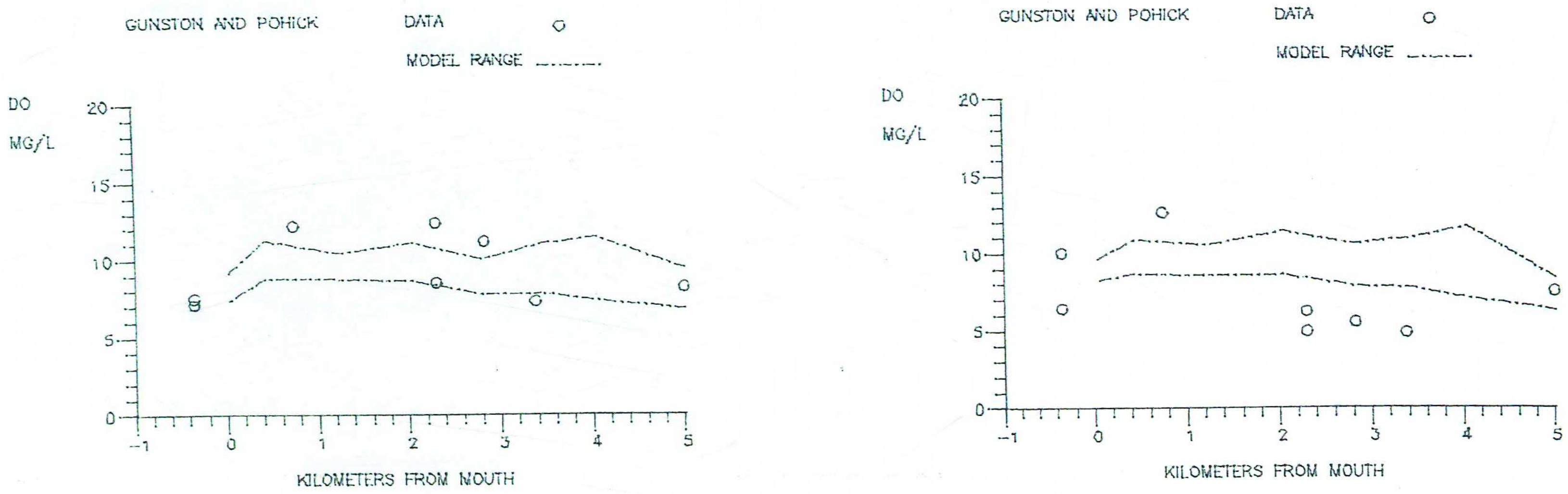
GUNSTON COVE AUG 29. 1979 SLACKWATER SURVEY

Figure 6-31. (Continued)



GUNSTON COVE JUNE 19. 1979 SLACKWATER SURVEY

GUNSTON COVE JULY 5. 1979 SLACKWATER SURVEY



GUNSTON COVE JULY 18. 1979 SLACKWATER SURVEY

GUNSTON COVE AUG 6. 1979 SLACKWATER SURVEY

Figure 6-32. Long-Term Verification of Dissolved Oxygen.

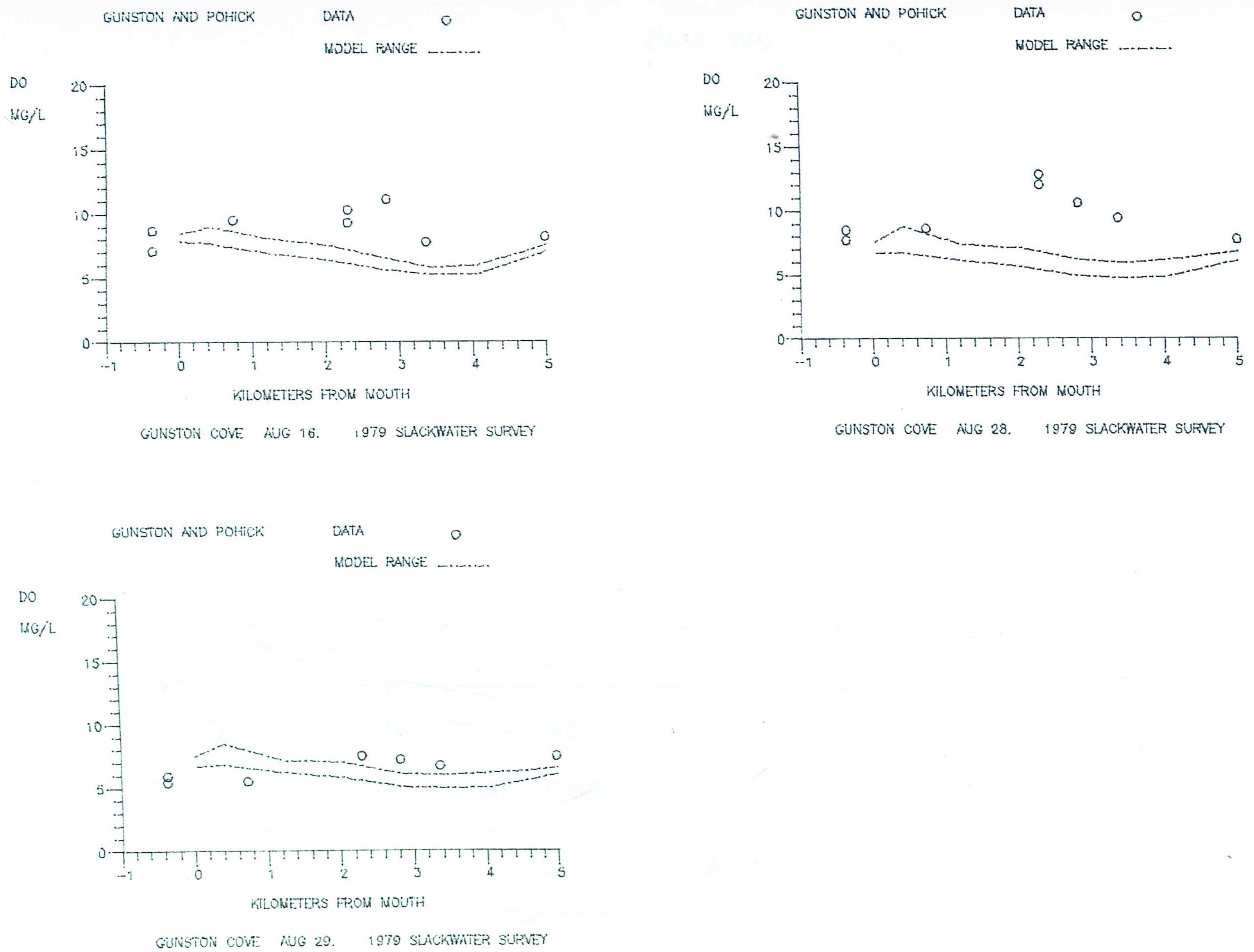


Figure 6-32. (Continued)

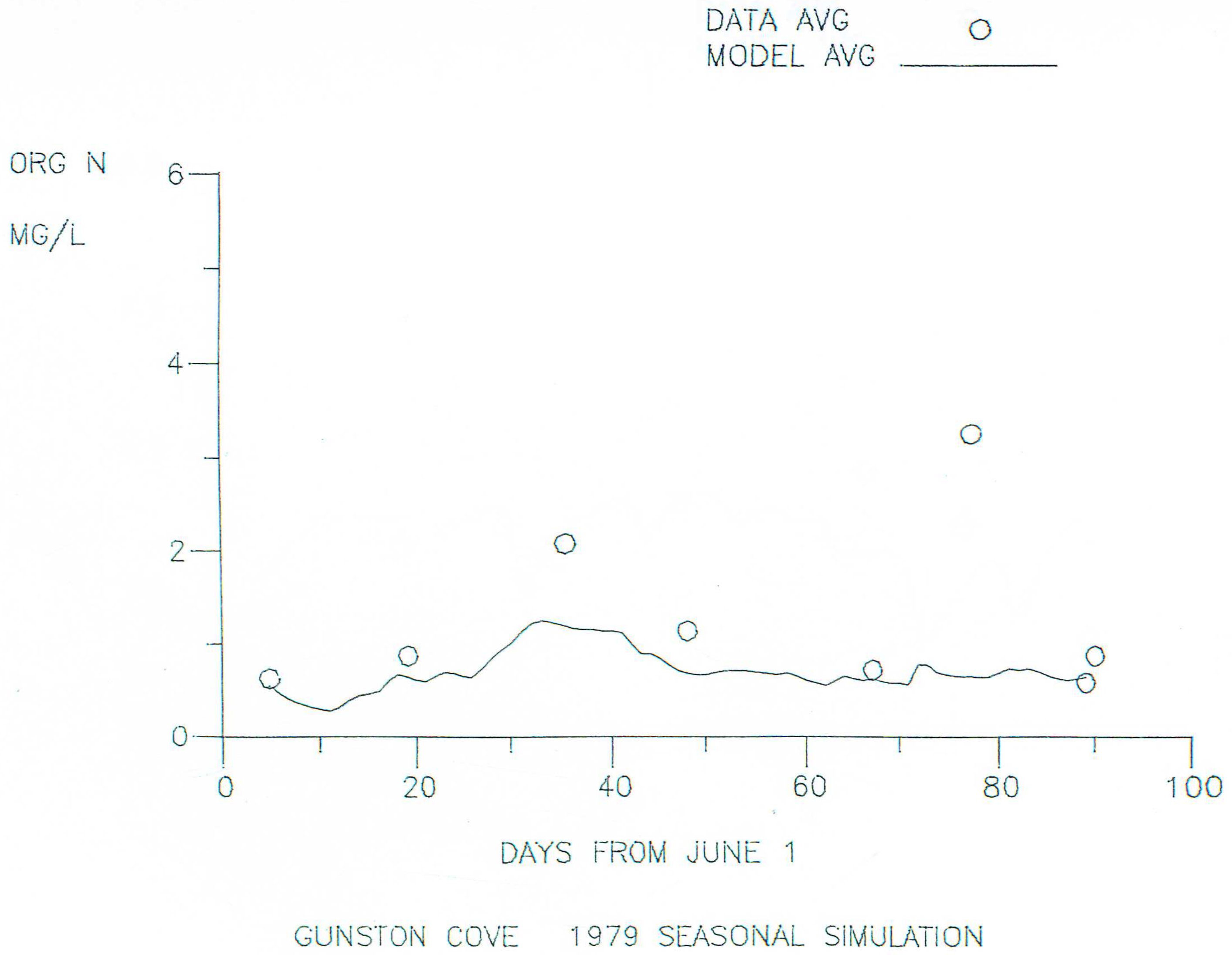


Figure 6-33. Time Series of Organic Nitrogen.

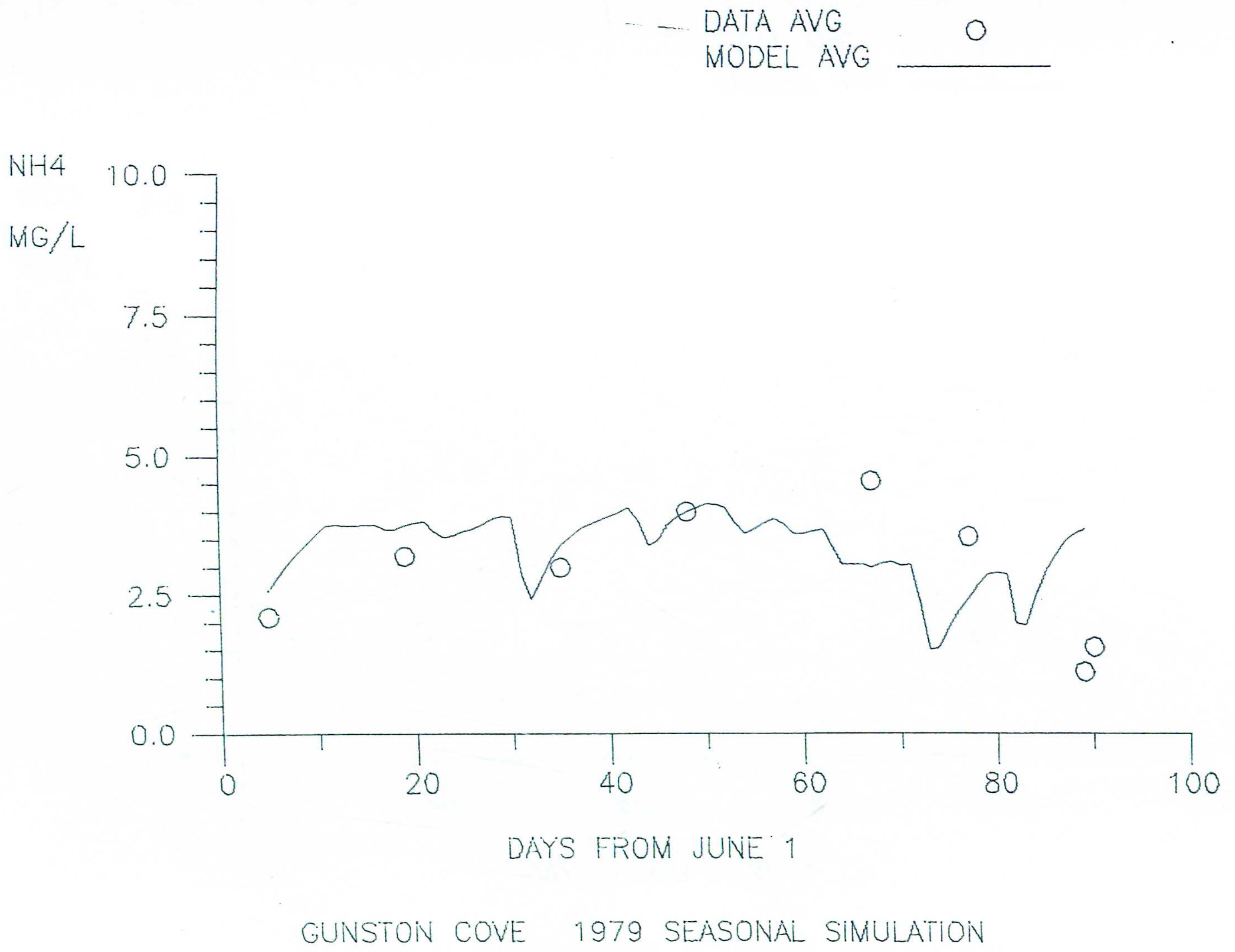


Figure 6-34. Time Series of Ammonia Nitrogen.

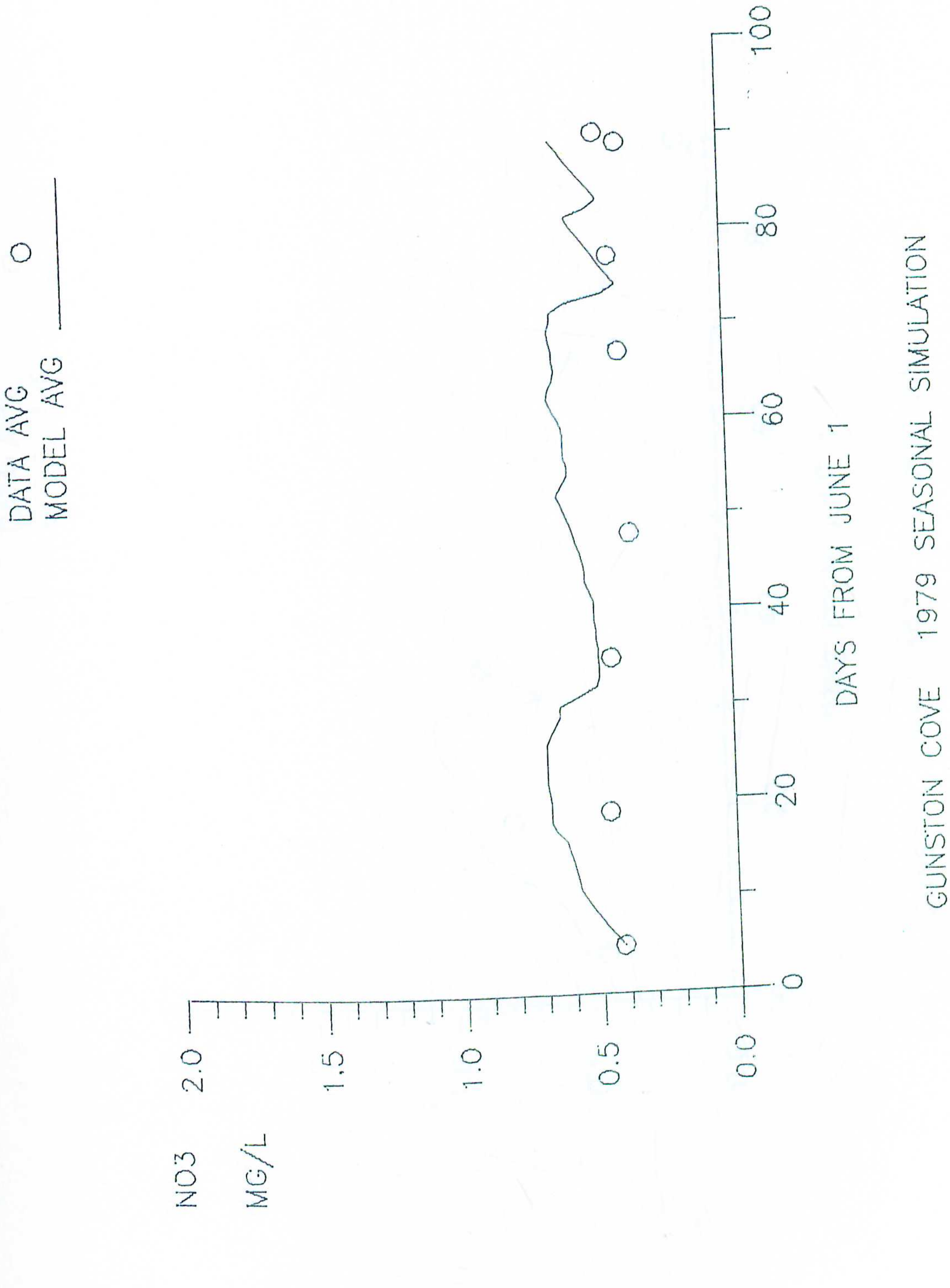


Figure 6-35. Time Series of Nitrate Nitrogen.

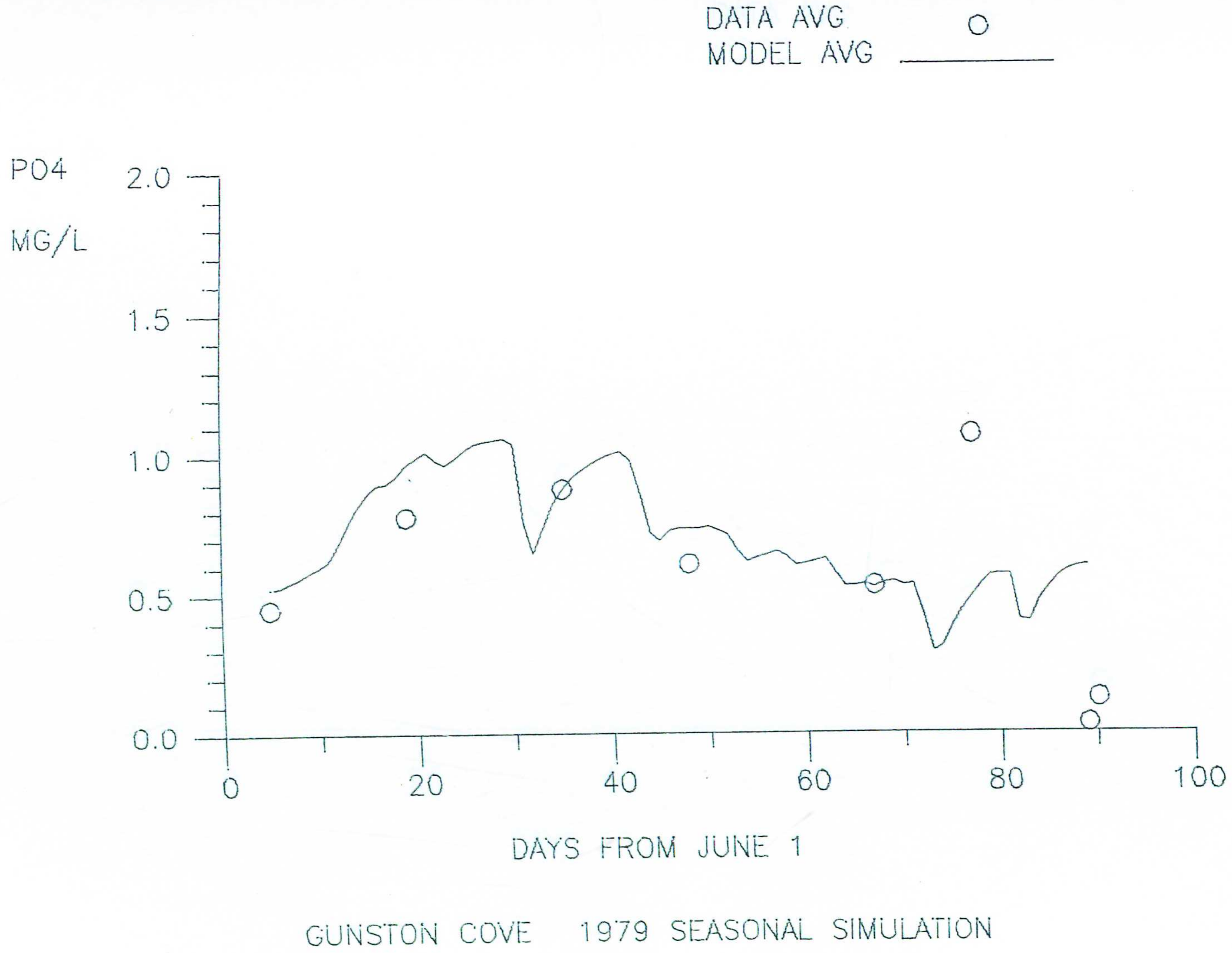


Figure 6-36. Time Series of Ortho Phosphorus.

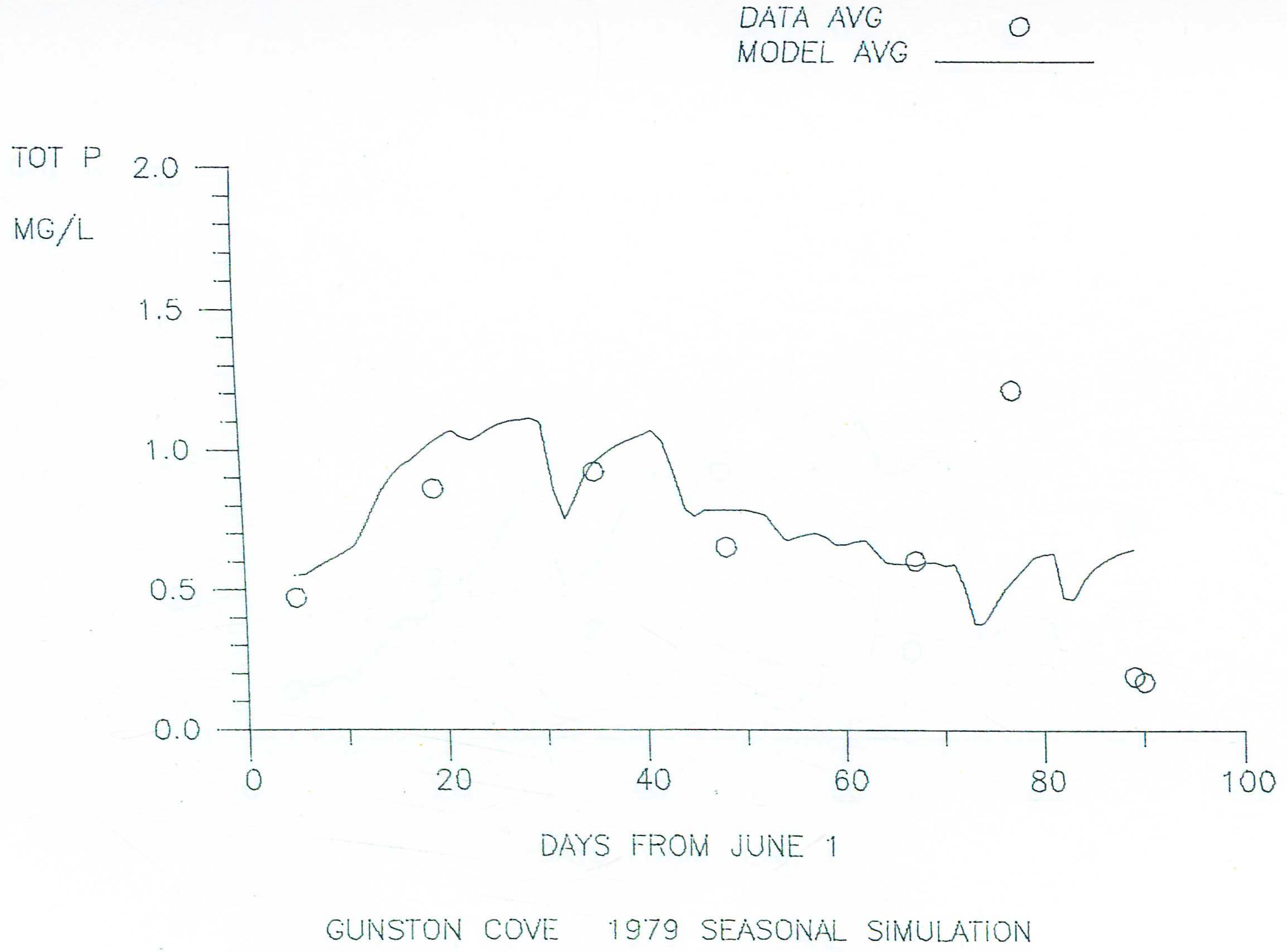


Figure 6-37. Time Series of Total Phosphorus.

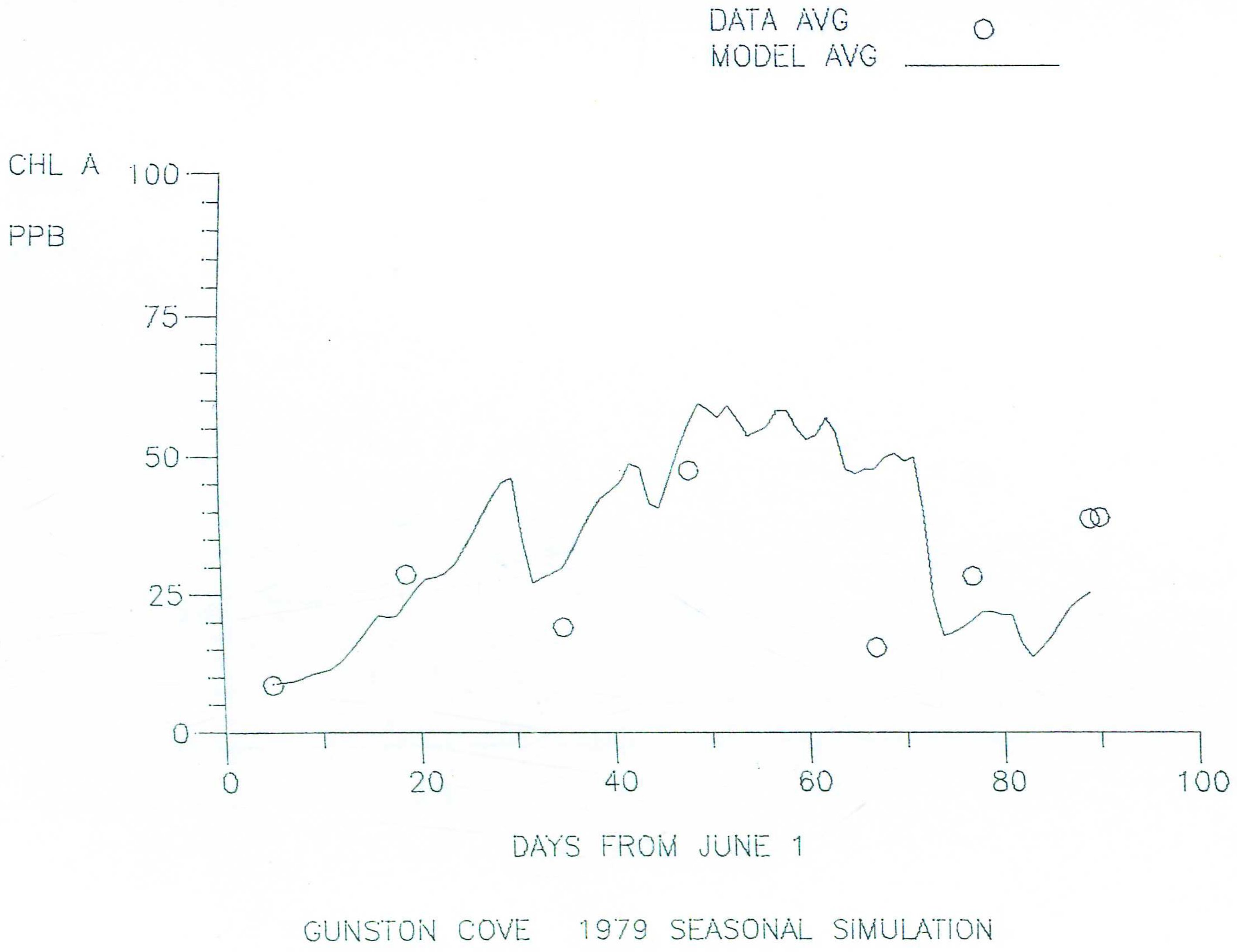


Figure 6-38. Time Series of Chlorophyll 'a'.

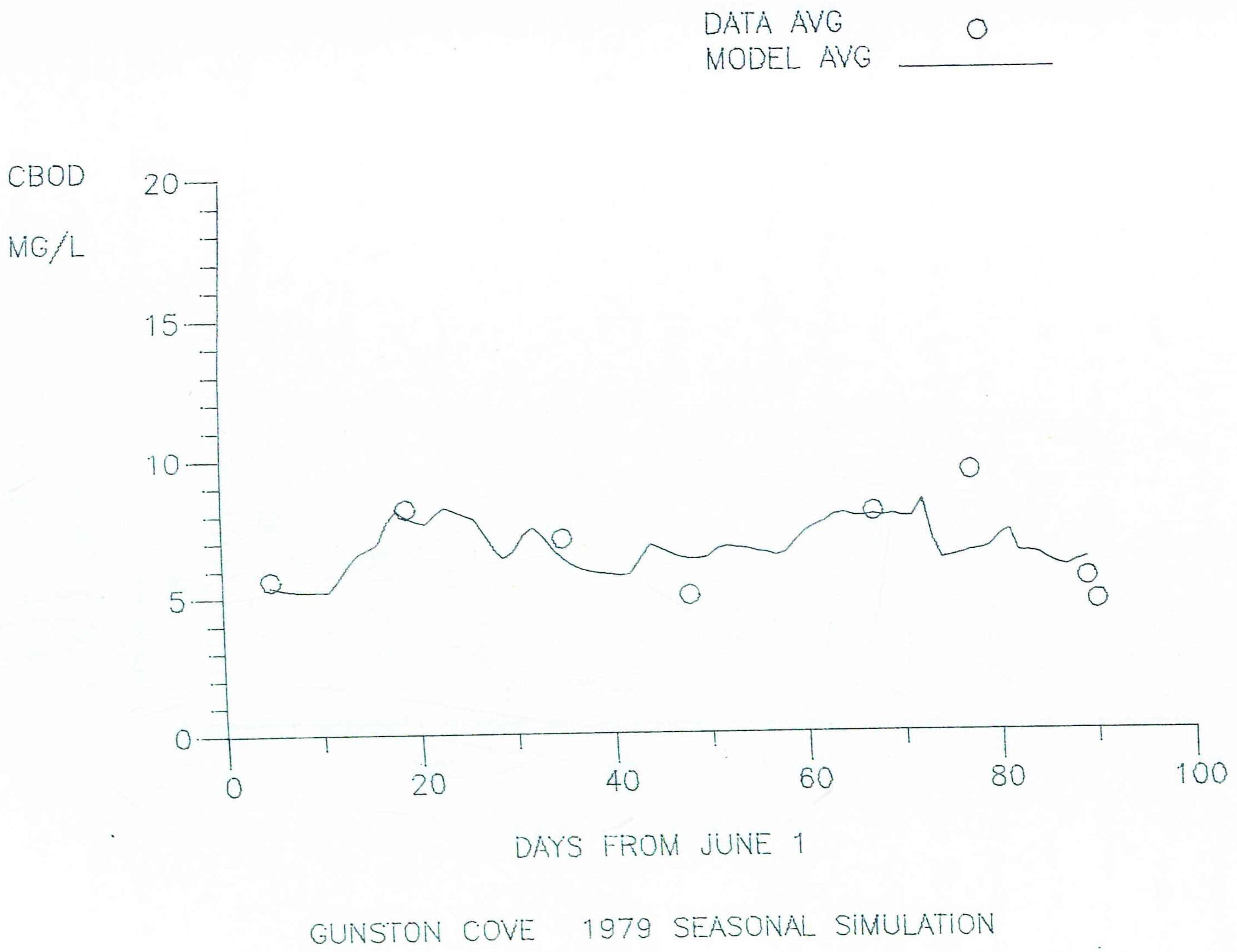


Figure 6-39. Time Series of CBODU.

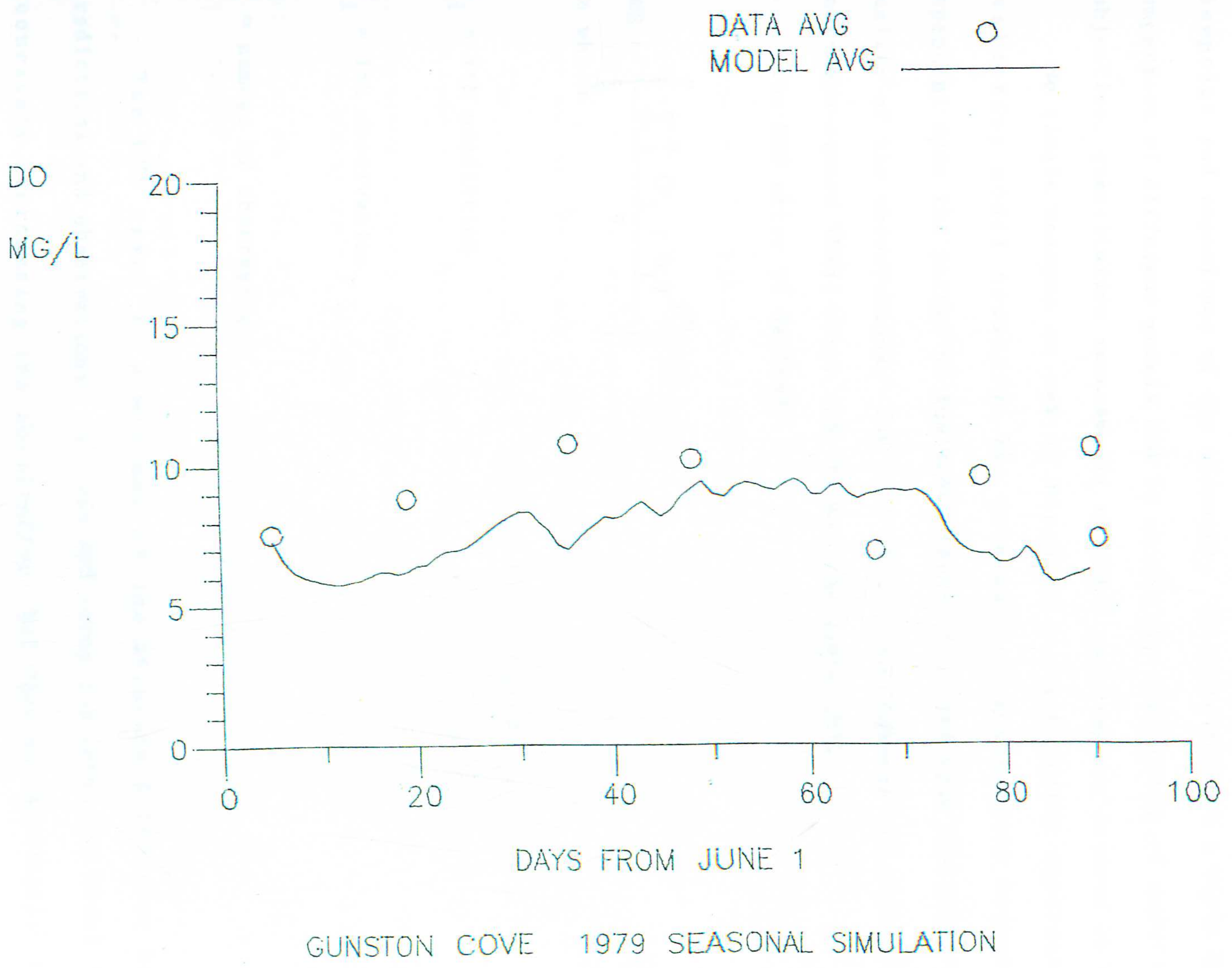


Figure 6-40. Time Series of Dissolved Oxygen.

CHAPTER VII. ANALYSIS OF MODEL ACCURACY

Traditional assessments of model accuracy, the agreement between predictions and observations, are usually qualitative and dependent upon the viewpoint and experience of the assessor. In order to form a basis for the comparison of different models and to render the evaluation of models less subjective, quantitative assessments of model accuracy are desired as well.

No single measure or set of measures is universally applicable in evaluating model accuracy. The selection of appropriate measures is dependent upon the nature of the model predictions and upon the quantity and quality of the observations. For this study, two measures are reported: the root-mean-square (RMS) error and the average error (E).

The RMS error is defined

$$\mathrm{RMS} = \left[\frac{\sum_i^n (P_i - 0_i)^2}{n} \right]^{1/2} \qquad (7\text{-}1)$$

in which

P_i = ith prediction

0_i = ith observation

n = number of observations

The RMS error is a measure of the absolute difference between predictions and observations. A large RMS error indicates the model is not accurately reproducing the observations but does not distinguish between predictions which are consistently high, predictions which are consistently low, or predictions which are centrally located within widely scattered data. Thus, a second measure, the average error, is desirable.

The average error is defined

$$E = \frac{\sum_i^n (P_i - 0_i)}{n} \tag{7-2}$$

An average error which is large and positive indicates the model overpredicts the observations. An average error which is large and negative indicates the model underpredicts the observations. An average error which is near zero indicates the model closely reproduces the observations in an average sense although the data may be widely scattered.

The use of these measures in evaluating the calibration and verification of the model is detailed in the remainder of this chapter.

A. Accuracy of the August, 1982, Calibration

The accuracy of the calibration is evaluated through comparison of the daily-mean observations and predictions at each station for each parameter. Differences between the predicted and observed means are then used to compute embayment-wide RMS and average errors for each parameter, as presented in Table 7-1.

B. Accuracy of the September, 1979, Verification

The accuracy of the September, 1979, verification is computed in the same manner as that of the calibration. Results are presented in Table 7-2.

C. Accuracy of the June-August, 1979, Verification

The accuracy of the June-August, 1979, verification is evaluated by comparison of the embayment-mean observations from each survey with the predicted mean for the same day. Differences between the predicted and observed means are then used to compute seasonal RMS and average errors for each parameter. Results of the analysis are presented in Table 7-3.

Table 7-1. Accuracy of August, 1982, Calibration

Station		3	4	7	8	P1	6	RMS Error	Average Error
Org N	(o)	.35	.17	–	.52	.18	.35		
	(p)	.35	.35	.35	.33	.17	.35	.12	.00
NH4	(o)	.10	.10	–	4.15	6.71	.10		
	(p)	.12	.37	1.09	2.59	6.86	1.06	.83	–.03
NO3	(o)	1.25	1.25	0.92	2.33	6.71	.41		
	(p)	1.12	1.35	1.83	2.64	4.94	1.62	.96	.11
PO4	(o)	.03	.04	.07	.24	1.00	.05		
	(p)	.04	.07	.14	.26	.62	.13	.16	–.03
Tot P	(o)	.07	.10	.15	.29	1.09	.08		
	(p)	.06	.09	.17	.30	.67	.16	.17	–.06
Chl'a'	(o)	30	62	74	74	3	64		
	(p)	52	70	82	87	58	94	28	23
CBODu	(o)	3.2	6.8	13.8	13.8	15.8	6.7		
	(p)	3.3	4.9	7.0	9.1	9.6	9.4	4.4	-2.8
DO	(o)	9.4	12.3	13.6	13.5	5.2	13.2		
	(p)	10.5	11.2	11.3	11.1	9.5	11.7	2.4	-0.3

All concentrations in mg/l except chlorophyll 'a' in μgm/l

o = observed mean
p = predicted mean

Table 7-2. Accuracy of September, 1979, Verification

Station		3	4,5	7	8	9	6	RMS Error	Average Error
Org N	(o)	.39	1.48	1.82	2.07	1.02	.84		
	(p)	.34	.38	.39	.48	.95	.33	1.00	-.79
NH4	(o)	.22	.80	1.16	2.26	11.02	.10		
	(p)	.61	1.79	2.56	4.85	11.34	2.20	1.54	1.30
NO3	(o)	1.05	.78	.78	.81	1.07	.24		
	(p)	1.05	.81	.76	.77	1.06	.60	.15	.05
PO4	(o)	.04	.07	.11	.14	.22	.04		
	(p)	.07	.12	.16	.30	.74	.14	.23	.15
Tot P	(o)	.07	.13	.18	.22	.22	.10		
	(p)	.08	.13	.18	.32	.80	.16	.24	.13
Chl'a'	(o)	38	74	114	81	1	52		
	(p)	47	84	92	99	24	72	18	10
CBODu	(o)	2.8	8.9	9.7	14.6	11.8	12.6		
	(p)	2.5	4.6	5.8	8.8	10.9	7.3	4.0	-3.4
DO	(o)	10.6	12.4	13.7	13.1	8.5	11.2		
	(p)	10.2	12.7	12.9	12.5	7.9	9.8	0.8	- .6

All concentrations in mg/l except chlorophyll 'a' in µgm/l

o = observed mean
p = predicted mean

Table 7-3. Accuracy of June-August, 1979, Verification

Survey		June 19	July 5	July 18	Aug 6	Aug 16	Aug 28	Aug 29	RMS Error	Average Error
Org N	(o)	.86	2.05	1.12	.71	3.22	.57	.85		
	(p)	.62	1.19	.68	.61	.64	.61	.63	1.05	-.63
NH4	(o)	3.21	3.00	3.99	4.54	3.55	1.10	1.56		
	(p)	3.75	3.39	4.00	2.99	2.46	3.60	3.67	1.45	.27
NO3	(o)	.46	.44	.36	.38	.41	.37	.45		
	(p)	.67	.49	.57	.63	.46	.59	.61	.18	.16
PO4	(o)	.78	.88	.61	.53	1.07	-	.12		
	(p)	.96	.88	.74	.52	.49	.60	.60	.32	.03
Tot P	(o)	.86	.92	.65	.60	1.21	.19	.17		
	(p)	1.03	.95	.79	.58	.54	.64	.64	.36	.08
Chl'a'	(o)	29	196	48	16	28	39	39		
	(p)	24	30	56	48	20	24	26	16	1.
CBODu	(o)	8.2	7.1	5.0	8.0	9.4	5.6	4.7		
	(p)	7.9	6.4	6.4	7.9	6.5	6.1	6.2	1.4	-0.1
DO	(o)	8.8	10.7	10.2	6.8	9.4	10.5	7.2		
	(p)	6.2	7.0	9.1	8.9	6.7	6.0	6.2	2.8	-1.9

All concentrations in mg/l except chlorophyll 'a' in µgm/l

o = observed mean
p = predicted mean

Chapter VIII. Sensitivity Analysis

Sensitivity analysis is the process in which the effects on model predictions of alterations in calibration or input parameters are examined. The analysis herein is largely directed toward examining the sensitivity of the model to alterations in the values of calibration parameters for which the magnitudes are only approximately known or which vary in an unpredictable manner in the natural system.

The sensitivity analysis is conducted by first creating a standard set of model predictions based on the ambient conditions and calibration parameters of the August, 1982, simulation. In creating the standard predictions, steady ambient conditions are assumed and the model is run for twenty tidal cycles. In successive model runs, a calibration parameter is altered and the resulting predictions are compared to the standard set. Unless otherwise noted, results are presented as longitudinal plots of daily-average water-quality constituents.

Parameters towards which the sensitivity of the model is tested include

algal growth rate
dependence of algal growth on temperature
light extinction
algal carbon-to-chlorophyll ratio
benthic nutrient release
distributed source of CBOD
sediment oxygen demand
chlorophyll concentration of freeflowing streams
decay rate of CBOD

nitrification rate of ammonium

diurnal variability of open-mouth boundary conditions

macrophyte oxygen production

A. Algal Growth Rate

The model employs a base algal growth rate, Kgr, which is varied in a deterministic manner as a function of temperature and the availability of light and nutrients. The sensitivity of model results to the evaluation of the base rate and to natural fluctuations about the base is examined in a pair of runs in which the algal growth rate is altered by plus or minus ten percent. The effects on the predicted chlorophyll concentration, after twenty tidal cycles, are presented in Figure 8-1. It can be seen that the ten-percent alteration in base growth rate produces a maximum 45 μgm/1 alteration in predicted daily-average chlorophyll. The most significant implication of this test is that small, natural fluctuations in the base growth rate can produce algal populations which diverge widely from the model predictions.

It is also illustrative to examine the effects of alterations in the algal population on several water-quality constituents. Organic nitrogen predictions from the growth-rate sensitivity tests are shown in Figure 8-2a. It can be seen that the 45 μgm/1 change in the chlorophyll concentration produces less than 0.2 mg/1 change in organic nitrogen. The same alteration in chlorophyll produces approximately 0.5 mg/1 change in ammonium (Figure 8-2b) and 0.2 mg/1 change in nitrate + nitrite (Figure 8-2c).

Ortho phosphorus changes by approximately 0.05 mg/1 when chlorophyll changes 45 μgm/1 (Fig 8-2d) and CBOD changes of approximately 1 mg/1 are produced (Fig. 8-2e).

The most significant effect is on dissolved oxygen (Fig 8-2f). The 45 µgm/l change in chlorophyll results in a maximum 4 mg/l change in daily-average dissolved oxygen. Thus, the DO predictions are also sensitive to algal growth rate and departures of observations from predictions can be expected due to the natural variability of the base growth rate.

B. Dependence of Algal Growth Rate on Temperature

Two parameters, θgr and θr, are used in the model to determine the effect of temperature on algal growth and respiration. The values employed, $\theta gr = 1.087$ and $\theta r = 1.15$, are selected from a range of possible values. To test the sensitivity of model results to this selection, alternate values $\theta gr = 1.068$ and $\theta r = 1.045$, obtained from the Potomac Estuary Model, are employed. The effect on the predicted chlorophyll concentration is shown in in Figure 8-3. It can be seen that predicted chlorophyll concentrations rise from a maximum of approximately 140 µgm/l to over 200 µgm/l based on the alternate values of θ. This effect is largely due to the reduction of respiration at high temperatures.

The sensitivity test indicates the selected values are suited to the model as presently calibrated. Employment of alternate values of would require adjustment of one or more additional calibration parameters in order to maintain reasonable chlorophyll predictions.

C. Light Extinction

Algal growth is dependent upon the availability of light which is a function of the rate of light extinction in the water column. The magnitude of light extinction in Gunston Cove is only approximately known and is highly variable in space and time due to the influences of wind mixing, storm runoff and other processes which increase or decrease water-column turbidity.

The sensitivity of chlorophyll predictions to the magnitude of light extinction is examined in model runs in which extinction is altered by plus-or-minus ten percent of the August, 1982, calibration values. Results are shown in Figure 8-4. It can be seen that the ten-percent change in extinction produces a maximum 30 µgm/l change in daily-average chlorophyll concentration. The implication of this test is that discrepancies between predictions and observations of chlorophyll can be expected unless the temporal and spatial distribution of light extinction is well-known.

D. Algal Carbon-to-Chlorophyll Ratio

The algal carbon-to-chlorophyll ratio employed in this study, aC = 0.05 mg C/µgm chl 'a', is selected largely on the basis of experience with models of similar systems. To test the sensitivity of the model to the evaluation of this parameter, model runs with aC = 0.04 and aC = 0.06 are performed. The selection of aC does not affect the chlorophyll predictions but rather influences dissolved oxygen and CBOD. The results of the sensitivity test for these two constituents are presented in Figure 8-5. It can be seen that a change in aC of 0.01 mgC/µgm chl produces a maximum change of approximately 2.5 mg/l in dissolved oxygen but less than 1 mg/l change in CBOD. Thus, the evaluation of aC is seen to be an important factor in the prediction of dissolved oxygen in the system.

E. Benthic Nutrient Releases

Benthic nutrient fluxes in Gunston Cove are variable and difficult to evaluate. Based on measurements and upon model runs, net releases of ammonium and ortho phosphorus in Pohick and Accotink Bays have been employed in the model. The sensitivity of model results to these releases is tested in a model run in which the releases are eliminated. Results for ammonium and phosphorus are shown in Figure 8-6a and for chlorophyll in Figure 8-6b. It can be seen the benthic releases contribute over 1 mg/l ammonium and approximately 0.08 mg/l ortho phosphorus to the upper three kilometers of Gunston and Pohick. These fluxes have negligible influence on the chlorophyll predictions, however.

The results of this test should be interpreted with caution. The fluxes have little effect on the chlorophyll concentration because sufficient nutrients are available from alternate sources, particularly the sewerage treatment plant, during the calibration period selected for analysis. If the alternate sources were not available, however, the benthic fluxes would play a more significant role in maintaining the algal population. Attention should be directed towards the magnitude and role of the benthic fluxes in any management use of the model.

F. Distributed Source of CBOD

A distributed source of CBOD has been employed in Pohick and Accotink Bays in order to bring predictions of CBOD into the same range as observations. The sensitivity of the model to the distributed source is tested in a series of runs in which the source is changed by plus-or-minus fifty percent. In Figure 8-7, it can be seen that the alteration in the source produces a maximum 3 mg/l change in daily-average CBOD concentration but that the predicted DO concentration is little-affected. Thus, the approximation involved in assuming the distributed source does not exert an important influence on the predictions of dissolved oxygen.

G. Sediment Oxygen Demand

As with the other benthic fluxes, sediment oxygen demand (SOD) is variable and difficult to measure. SOD in the range 2.0 to 2.5 gm/m^2/day has been employed in the model. Sensitivity to this SOD is tested in model runs in which SOD is altered by plus-or-minus fifty percent. Results are shown in Figure 8-8 in which it can be seen that the fifty-percent change in SOD produces an approximately 1.5 mg/l change in daily-average dissolved oxygen.

As long as DO remains in the supersaturated range due to algal production, SOD is an insignificant part of the DO budget. In the event that algal productivity is reduced, however, due to natural events or management strategy, then SOD will play a more important role and attention should be devoted to evaluating its magnitude and the effects of natural variability.

H. Chlorophyll Concentration in Freeflowing Streams

Due to lack of agreement between the nonpoint-source model predictions and observations, a constant chlorophyll concentration of 3 µgm/l has been employed in the freeflowing streams for the 1979 seasonal simulation. Observed chlorophyll concentrations have been in the 1 to 8 µgm/l range while nonpoint-source model predictions are as high as 20 µgm/l.

In order to test the sensitivity to the boundary condition employed, three model runs are performed. In the first, a chlorophyll concentration of 3 µgm/l is specified. In the second, this concentration is tripled to 9 µgm/l, approximately the upper limit of observed concentrations. In the third run, the initial chlorophyll concentration is increased ten-fold to 30 µgm/l, a value in excess of the largest concentration predicted by the nonpoint-source model. Results are shown in Figure 8-9. It can be seen that the predicted chlorophyll concentrations in Gunston Cove are virtually identical for all three boundary conditions. This lack of sensitivity of model results to the boundary condition occurs because the flow rate of the incoming streams is negligible compared to the volume and tidal prism of the embayment.

I. CBOD Decay Rate

The CBOD decay rate, Kc = 0.1/day, is obtained through calibration of model results to observations and has a large degree of uncertainty associated with it. The sensitivity of the model to the decay rate employed is tested in sensitivity runs in which Kc is varied by plus-or-minus fifty percent. The effects on CBOD and dissolved oxygen are shown in Figure 8-10. The fifty-percent change in decay rate produces a maximum 2 mg/l change in predicted CBOD. Daily-average dissolved oxygen predictions are altered by less than 1 mg/l, however.

J. Ammonium Nitrification Rate

As with the CBOD decay rate, the nitrification rate, Kn23 = 0.1 mg/l/day, is subject to uncertainty. The sensitivity of the model to the nitrification rate employed is tested in sensitivity runs in which Kn23 is varied by plus-or-minus fifty percent. The effects on ammonium and dissolved oxygen are shown in Figure 8-11. It can be seen that the fifty-percent change in the nitrification rate produces only negligible changes in predicted daily-average ammonium and dissolved oxygen concentrations indicating that specification of the nitrification rate is not crucial to the model results.

K. Diurnal Variations at Open Mouth

Observations in Gunston Cove indicate large diurnal fluctuations in chlorophyll and dissolved oxygen. It may be hypothesized that these fluctuations are driven by diurnal variations of chlorophyll and DO in the Potomac River. This hypothesis is tested in a model run in which diurnally-varying boundary conditions are employed at the open mouth of Gunston Cove. The amplitude of the diurnal variability, typical of observations collected in this study, is 10 µgm/l for chlorophyll and 1 mg/l for DO. Mean downstream boundary conditions and initial concentrations within Gunston Cove are 20 µgm/l chlorophyll and 8.05 mg/l DO (saturation concentration.). All internal sources and sinks of chlorophyll and dissolved oxygen are rendered inoperative and constituent concentrations in the inflows to Gunston Cove are set to maintain the initial conditions within the embayment. Thus the sole source of any departure of chlorophyll or DO from the steady initial conditions is the diurnal variability at the mouth. Results are shown in Figure 8-12.

It can be seen that the effects of diurnal fluctuations of chlorophyll and dissolved oxygen at the mouth of Gunston Cove are limited to the lower kilometer of the embayment. Thus it may be concluded that diurnal fluctuations within the embayment, especially fluctuations observed within Pohick and Accotink Bays, are the result of internal rather than external processes.

L. Macrophyte Productivity

A second process which might account for the large diurnal fluctuations of dissolved oxygen in Gunston Cove is the photosynthesis/respiration of the rooted aquatic plants which proliferate in the upper portions of Pohick and Accotink Bays. To test this hypothesis, a model run similar to the previous one is performed. Again, initial dissolved oxygen within Gunston Cove is set to the steady saturation concentration of 8.05 mg/1 and all sources and sinks of DO are rendered inoperative. Macrophyte productivity and respiration within Pohick and Accotink Bays are represented as areal sources and sinks similar to sediment oxygen demand. Photosynthesis, a source of dissolved oxygen, is represented by a half sine wave with maximum amplitude at mid-day. Respiration is represented as a continuous, steady sink of DO. Based on observations in the South River, a free-flowing Piedmont stream (M. D. Phillips, Va SWCB), and in Delaware Bay, a coastal-plain estuary (J. Fitzpatrick, HydroQual, Inc.), an amplitude of 8.28 gm/m^2/day is specified for photosynthesis and a respiration rate of -3.0 gm/m^2/day is employed.

Results of this model run are shown in Figure 8-13. It can be sen that macrophyte production/respiration produces a diurnal fluctuation in dissolved oxygen with an amplitude of approximately 1 mg/1. Thus it is unlikely that macrophytes are largely responsible for the diurnal dissolved oxygen fluctuations observed in Gunston Cove.

Run 1 - Calibration growth rate
Run 2 - Calibration rate plus ten percent
Run 3 - Calibration rate minus ten percent

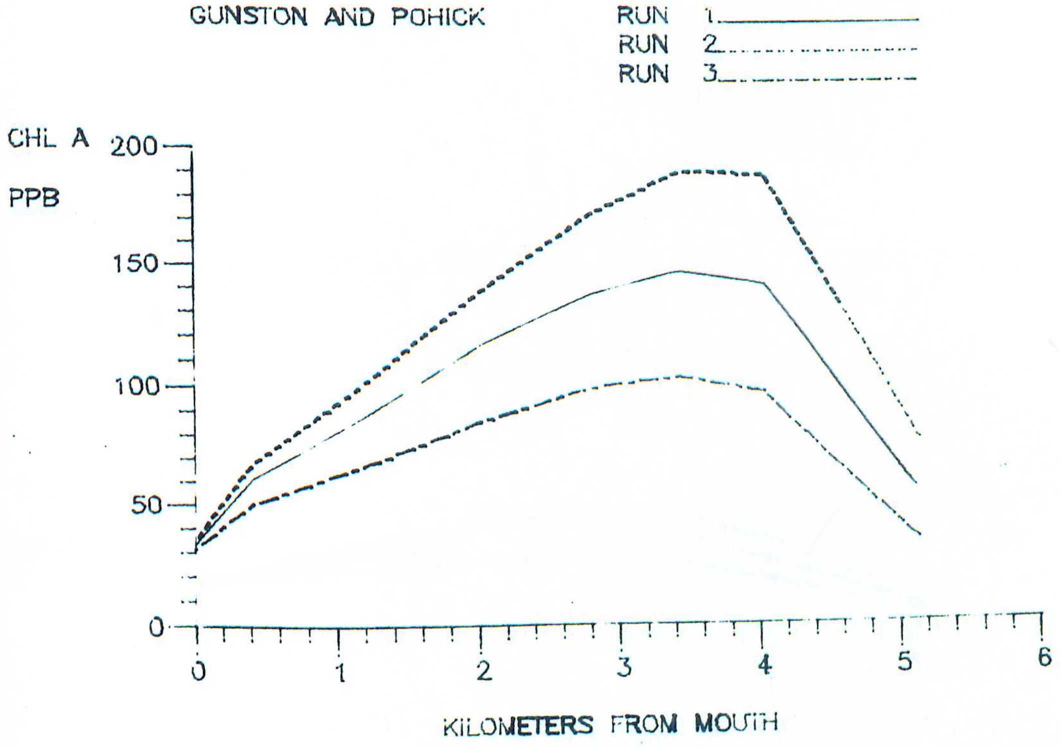


Figure 8-1. Sensitivity of Chlorophyll to Algal Growth Rate.

Run 1 Calibration growth rate

Run 2 Calibration rate plus ten percent

Run 3 Calibration rate minus ten percent

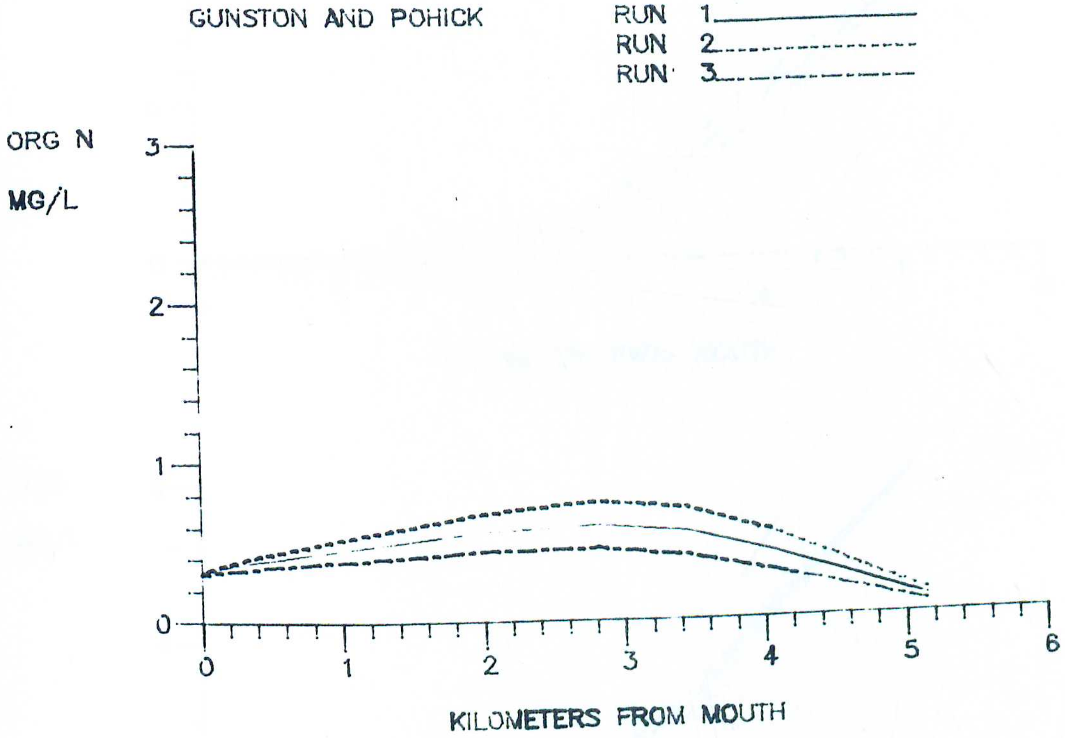


Figure 8-2. Sensitivity of Nitrogen, Phosphorus, CBOD, and Dissolved Oxygen to Algal Growth Rate.

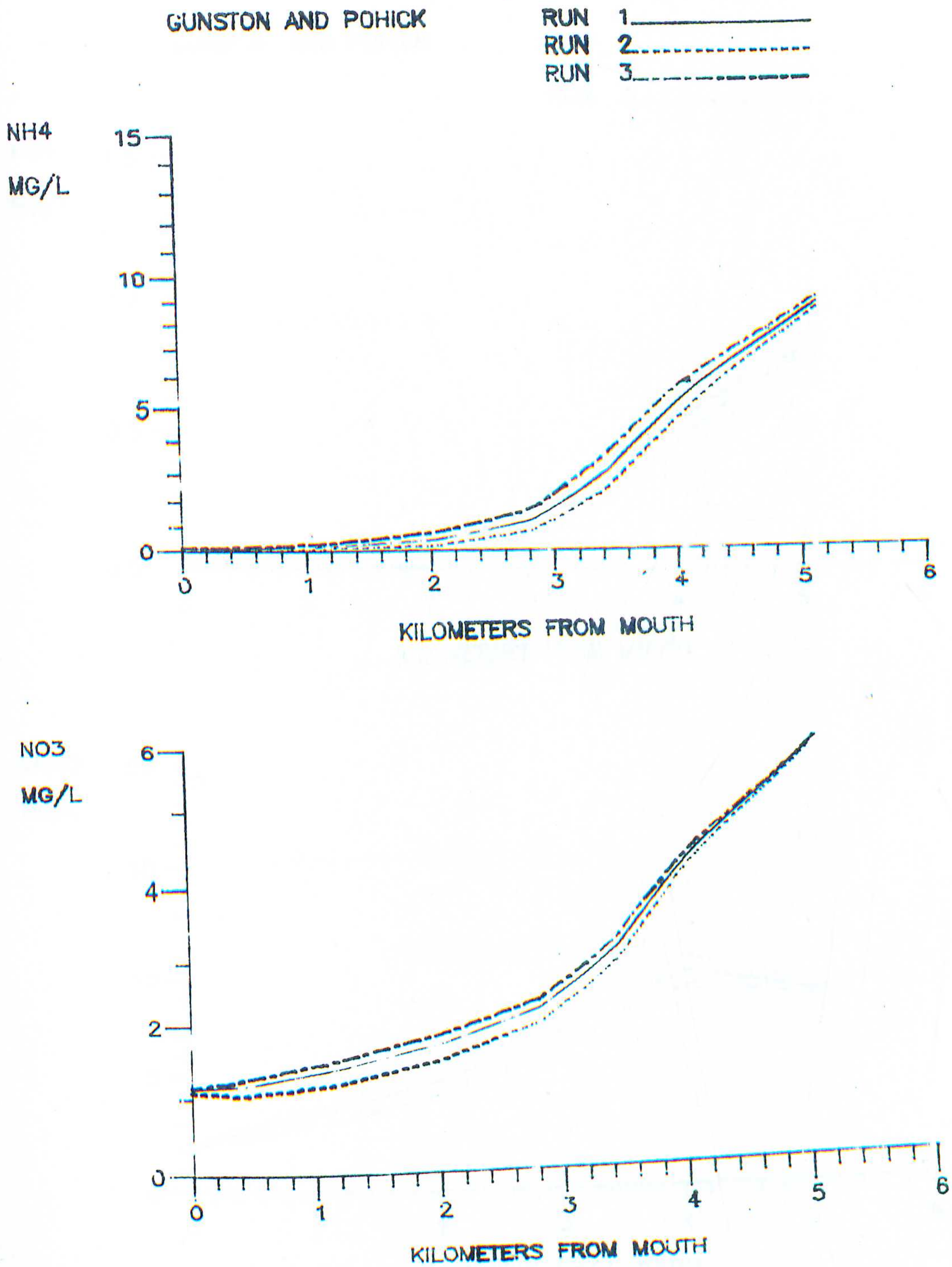


Figure 8-2. (Continued)

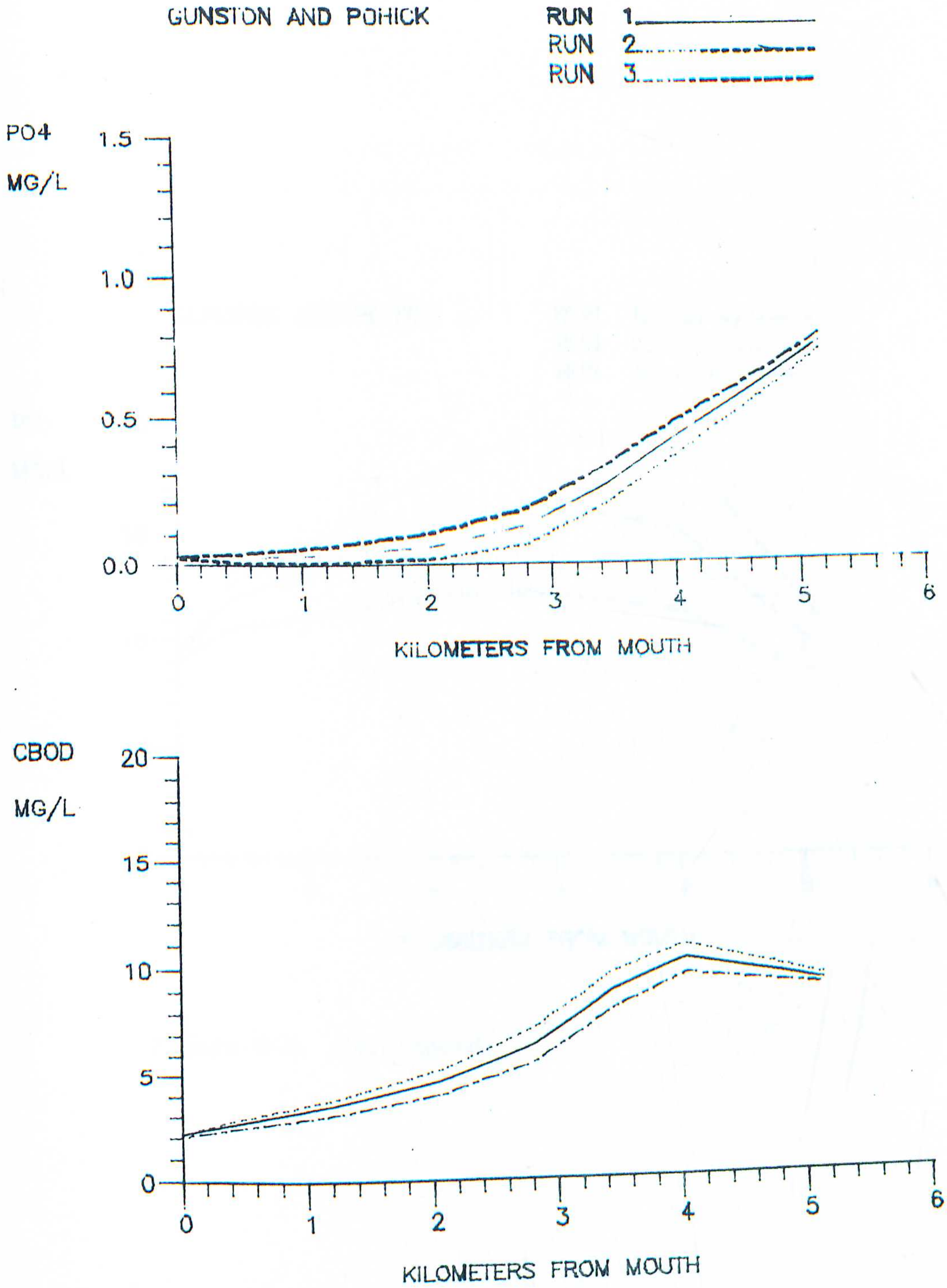


Figure 8-2. (Continued)

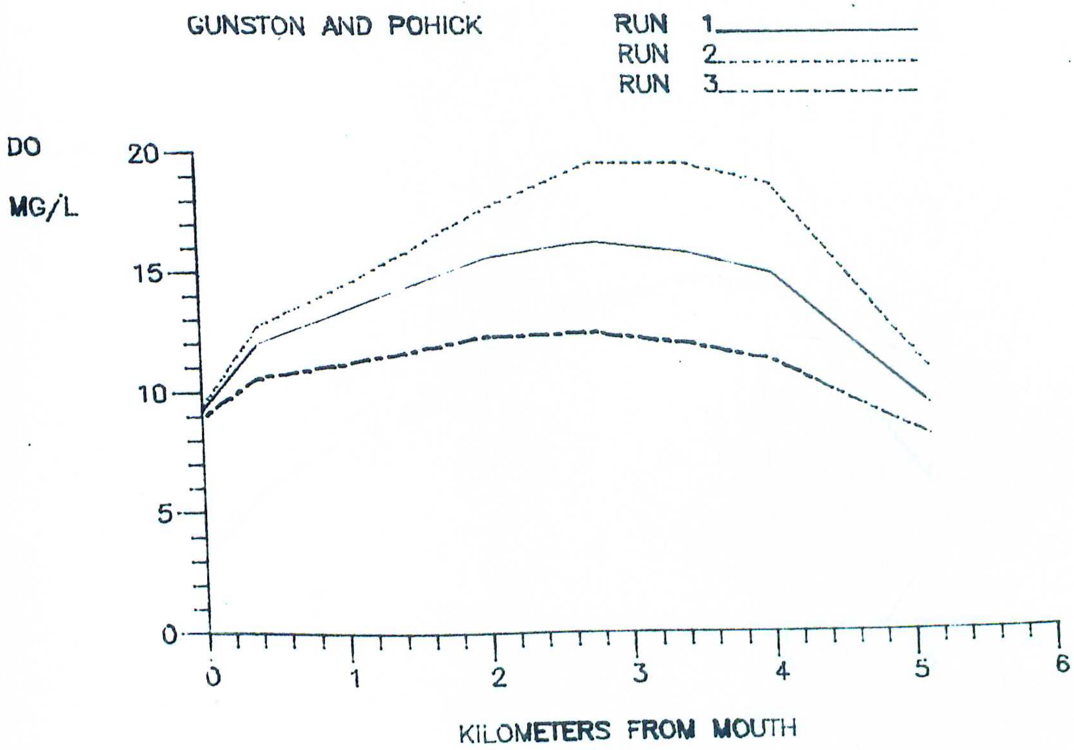


Figure 8-2. (Continued)

Run 1 Calibration Values

Run 2 Alternate Values

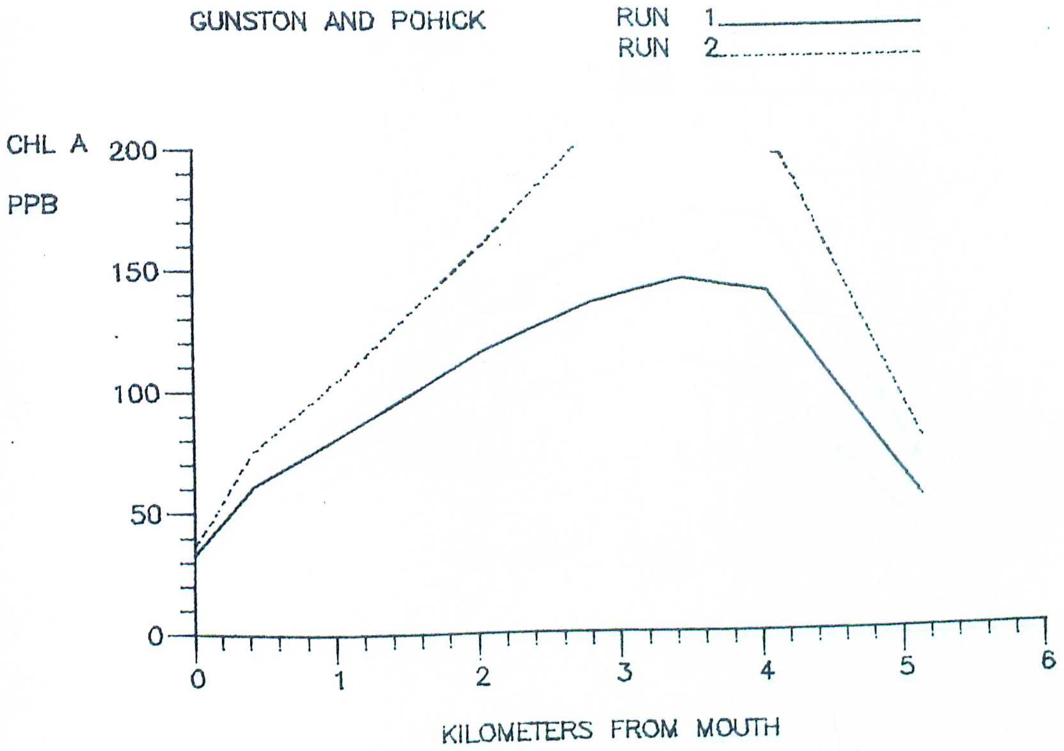


Figure 8-3. Sensitivity of Chlorophyll to Temperature Coefficients.

Run 1 Calibration Light Extinction

Run 2 Calibration Extinction Plus Ten Percent

Run 3 Calibration Extinction Minus Ten Percent

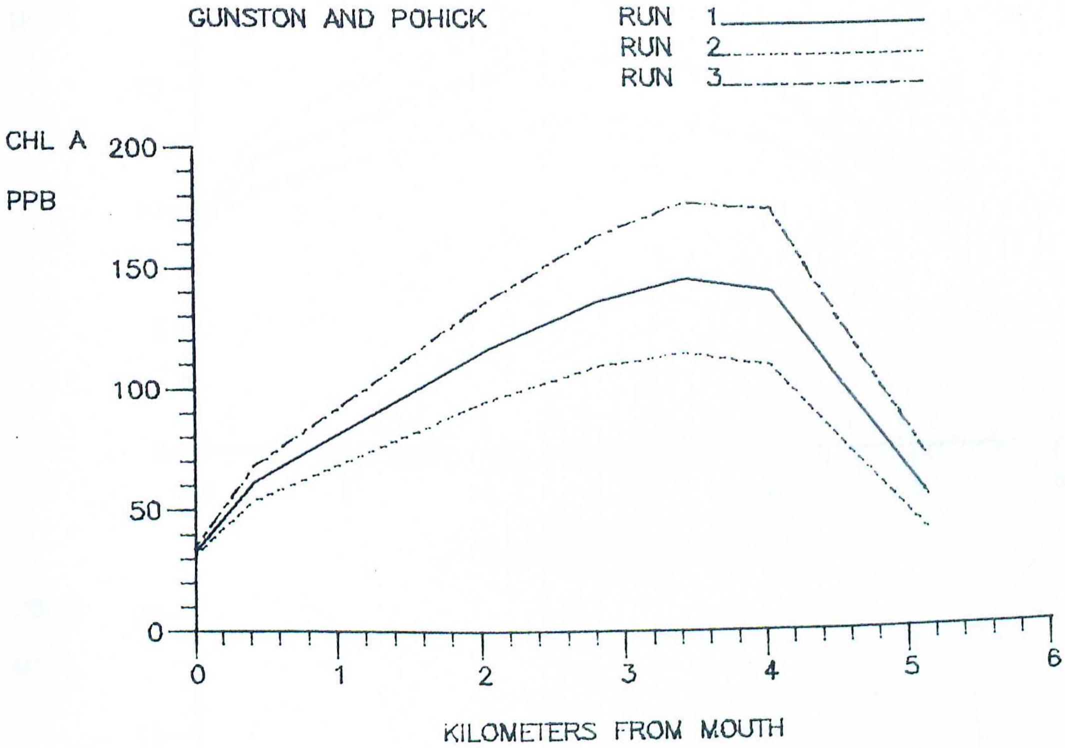


Figure 8-4. Sensitivity of Chlorophyll to Light Extinction.

Run 1 aC = 0.05

Run 2 aC = 0.06

Run 3 aC = 0.04

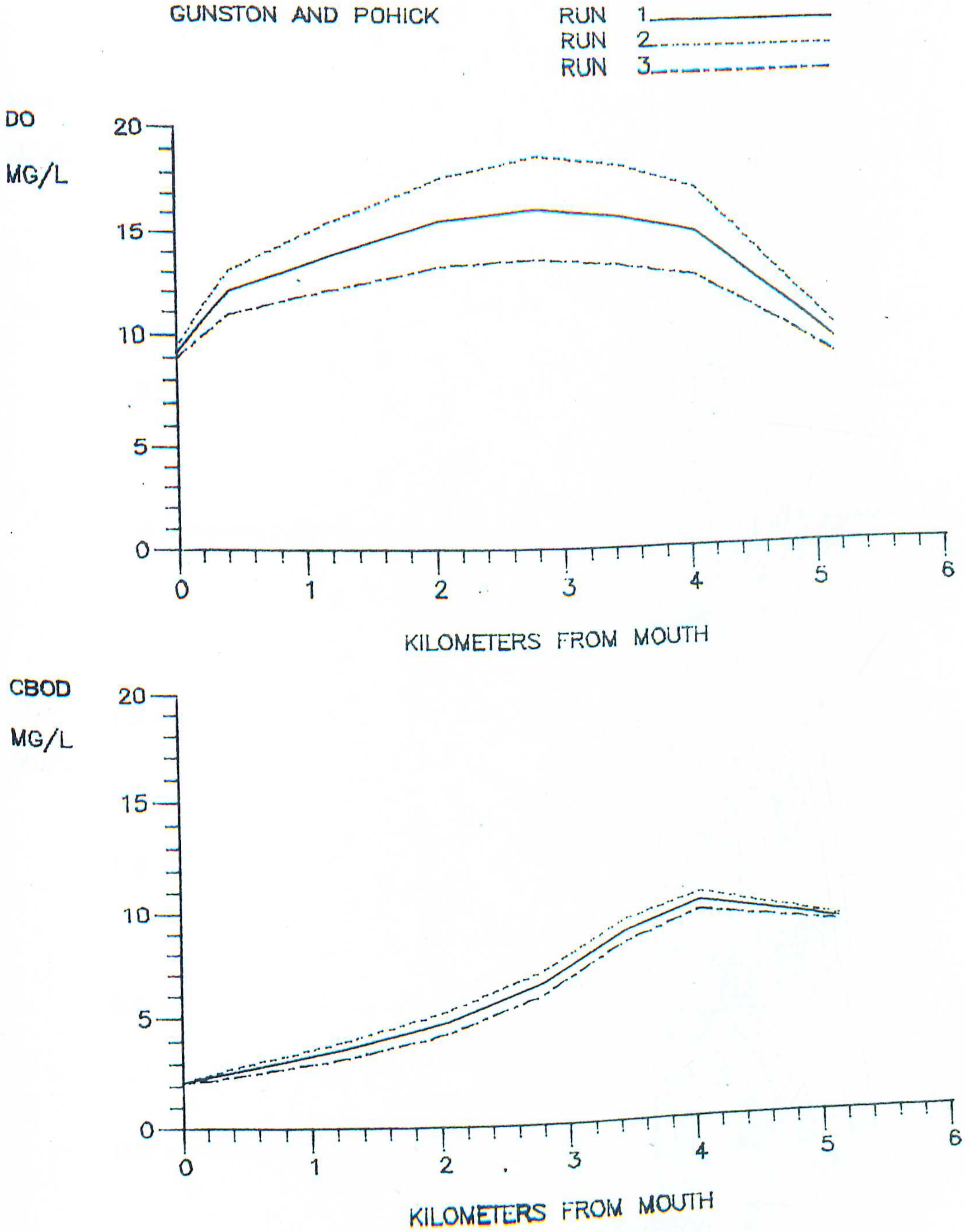


Figure 8-5. Sensitivity of DO and CBOD to Algal Carbon-to-Chlorophyll Ratio.

Run 1 Benthic Nutrient Releases

Run 2 No Benthic Releases

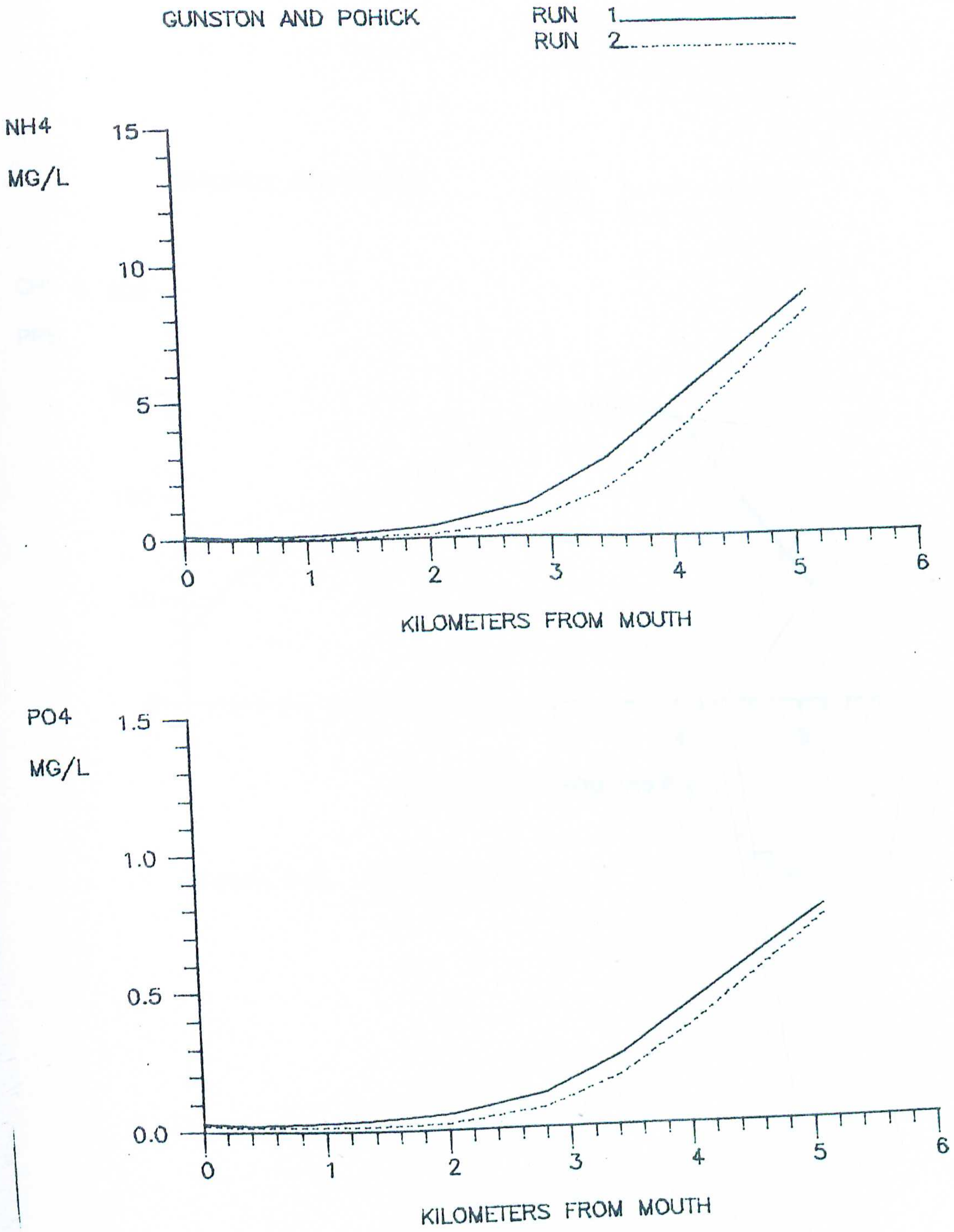


Figure 8-6. Sensitivity of Ammonium, Phosphorus, and Chlorophyll to Benthic Nutrient Releases.

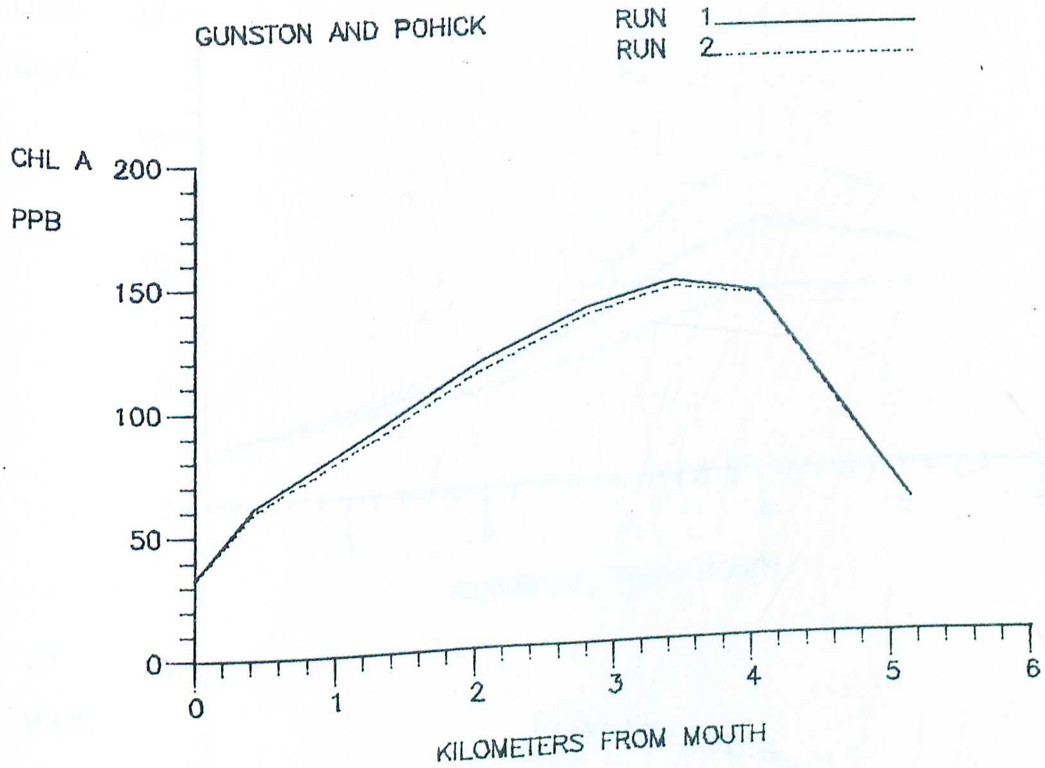


Figure 8-6. (Continued)

Run 1 Calibration Distributed Source

Run 2 Calibration Source Plus Fifty Percent

Run 3 Calibration Source Minus Fifty Percent

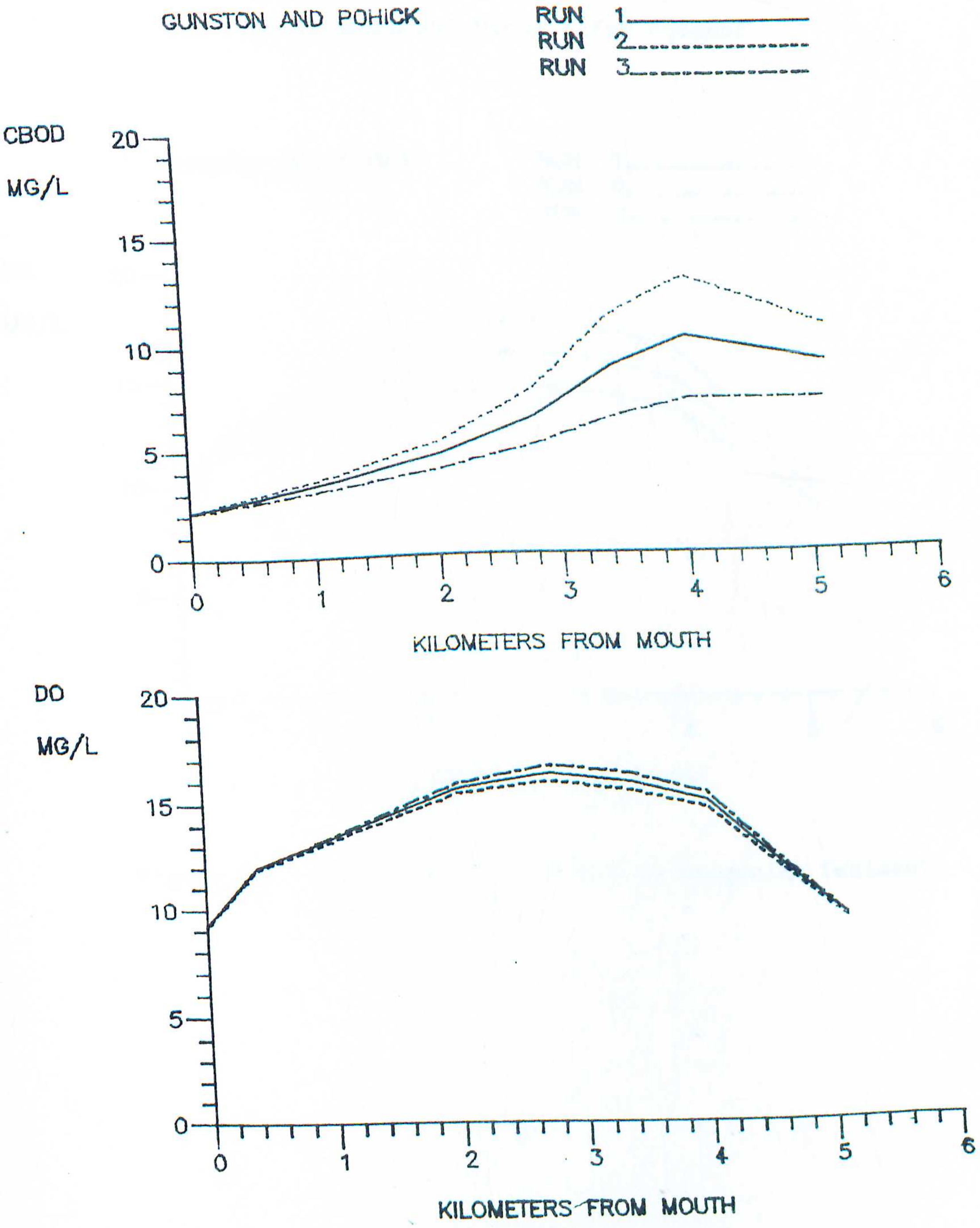


Figure 8-7. Sensitivity of CBOD and DO to Distributed Source of CBOD.

Run 1 Calibration SOD

Run 2 Calibration SOD Plus Fifty Percent

Run 3 Calibration SOD Minus Fifty Percent

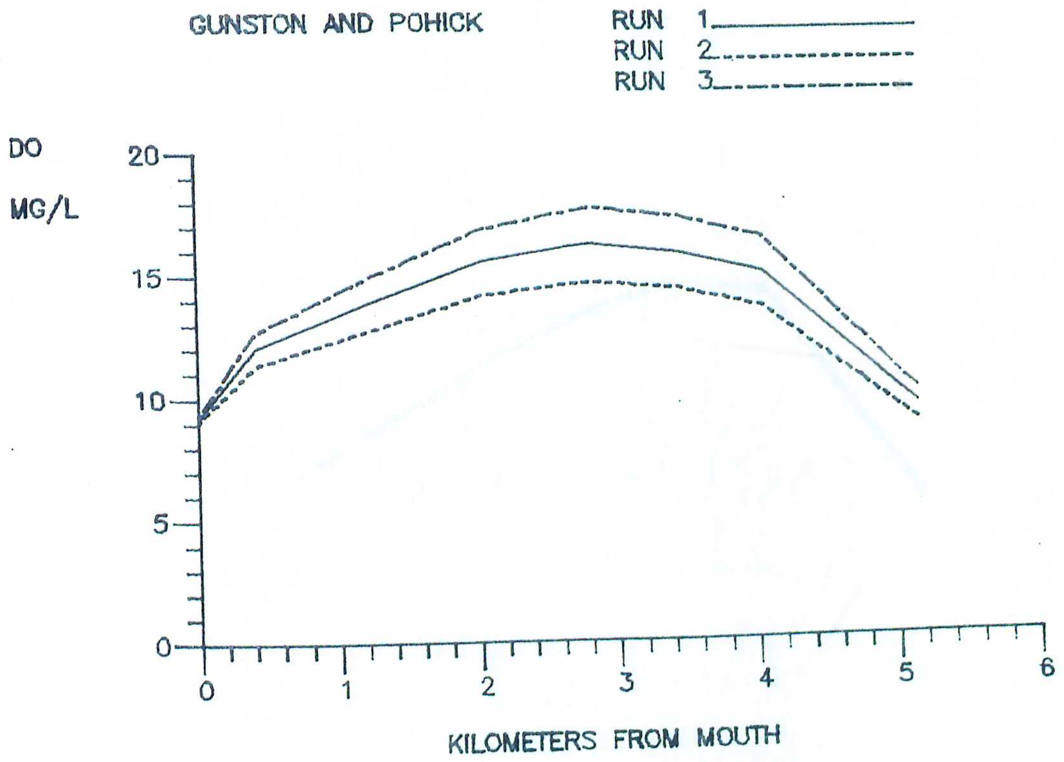


Figure 8-8. Sensitivity of Dissolved Oxygen to Sediment Oxygen Demand.

Run 1 Boundary Concentration = 3 μgm/l

Run 2 Boundary Concentration = 9 μgm/l

Run 3 Boundary Concentration = 30 μgm/l

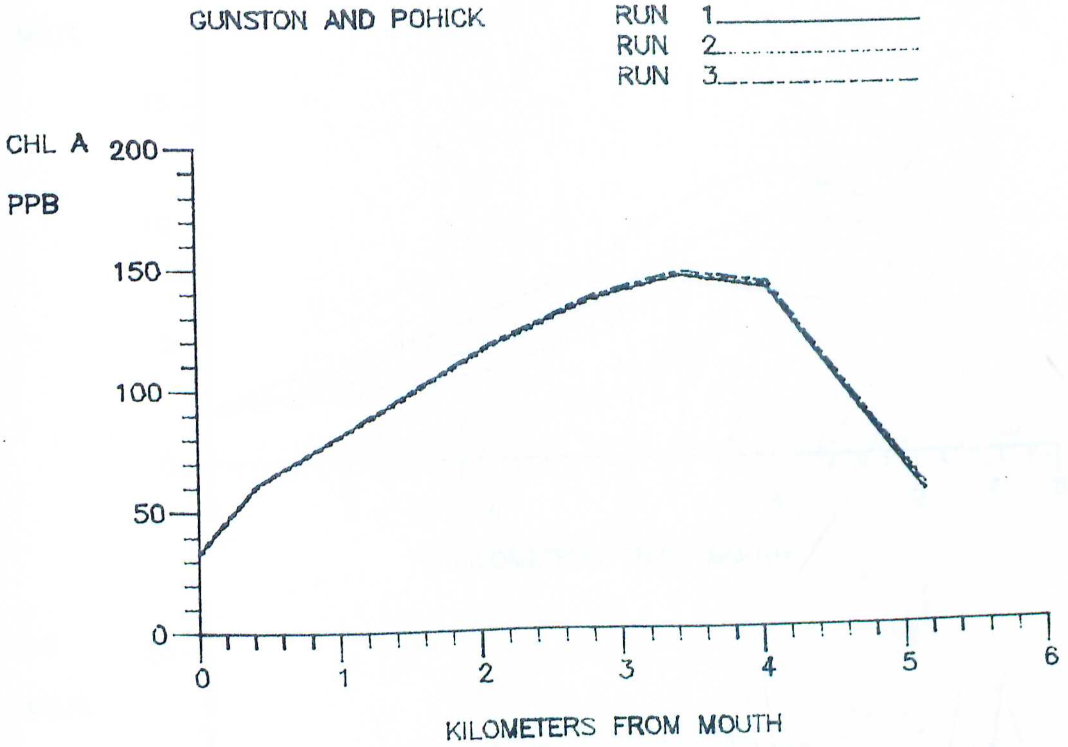


Figure 8-9. Sensitivity of Chlorophyll to Upstream Boundary Concentration.

Run 1 Calibration Decay Rate

Run 2 Calibration Rate Plus Fifty Percent

Run 3 Calibration Rate Minus Fifty Percent

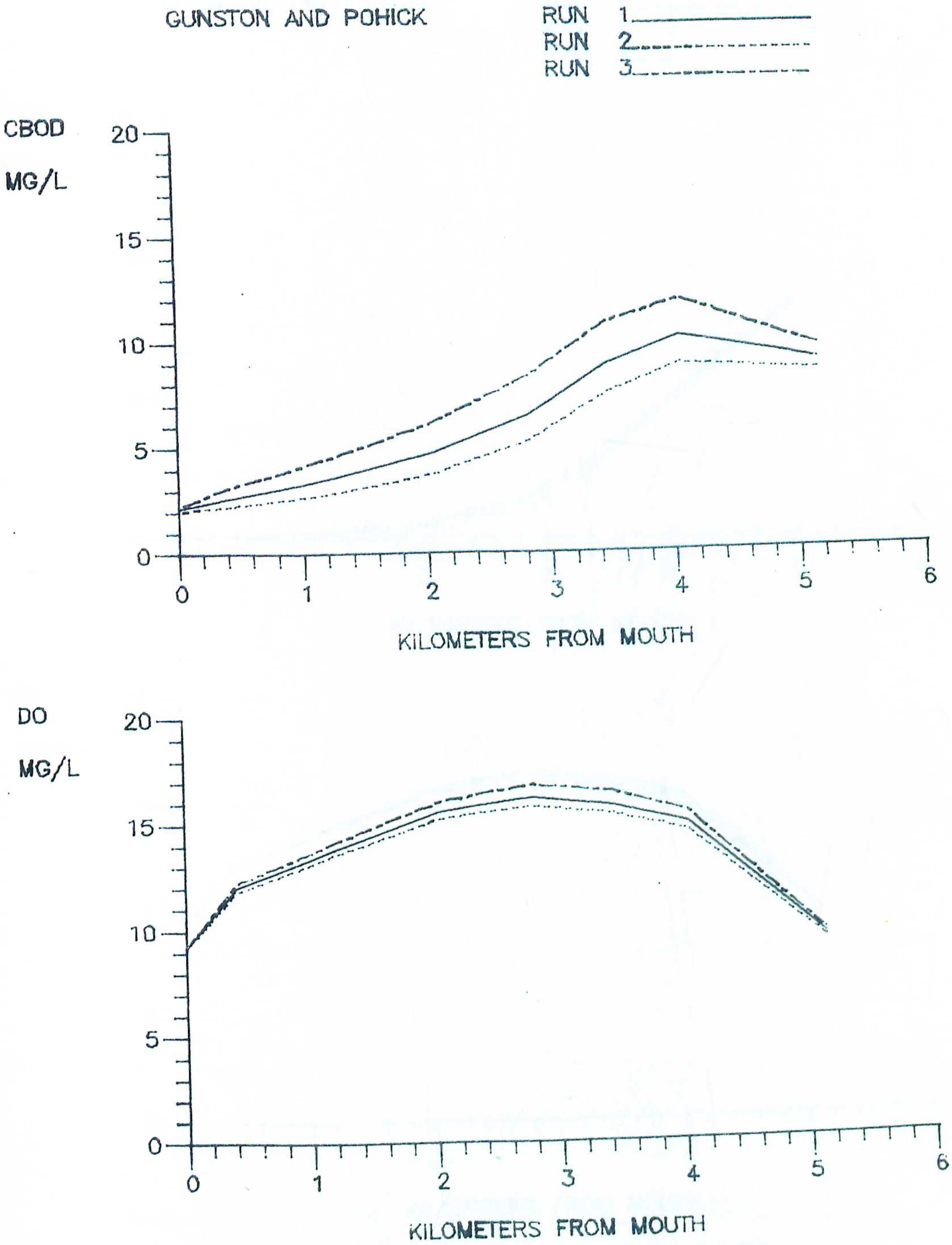


Figure 8-10. Sensitivity of CBOD and DO to CBOD Decay Rate.

Run 1 Calibration Nitrification Rate

Run 2 Calibration Rate Plus Fifty Percent

Run 3 Calibration Rate Minus Fifty Percent

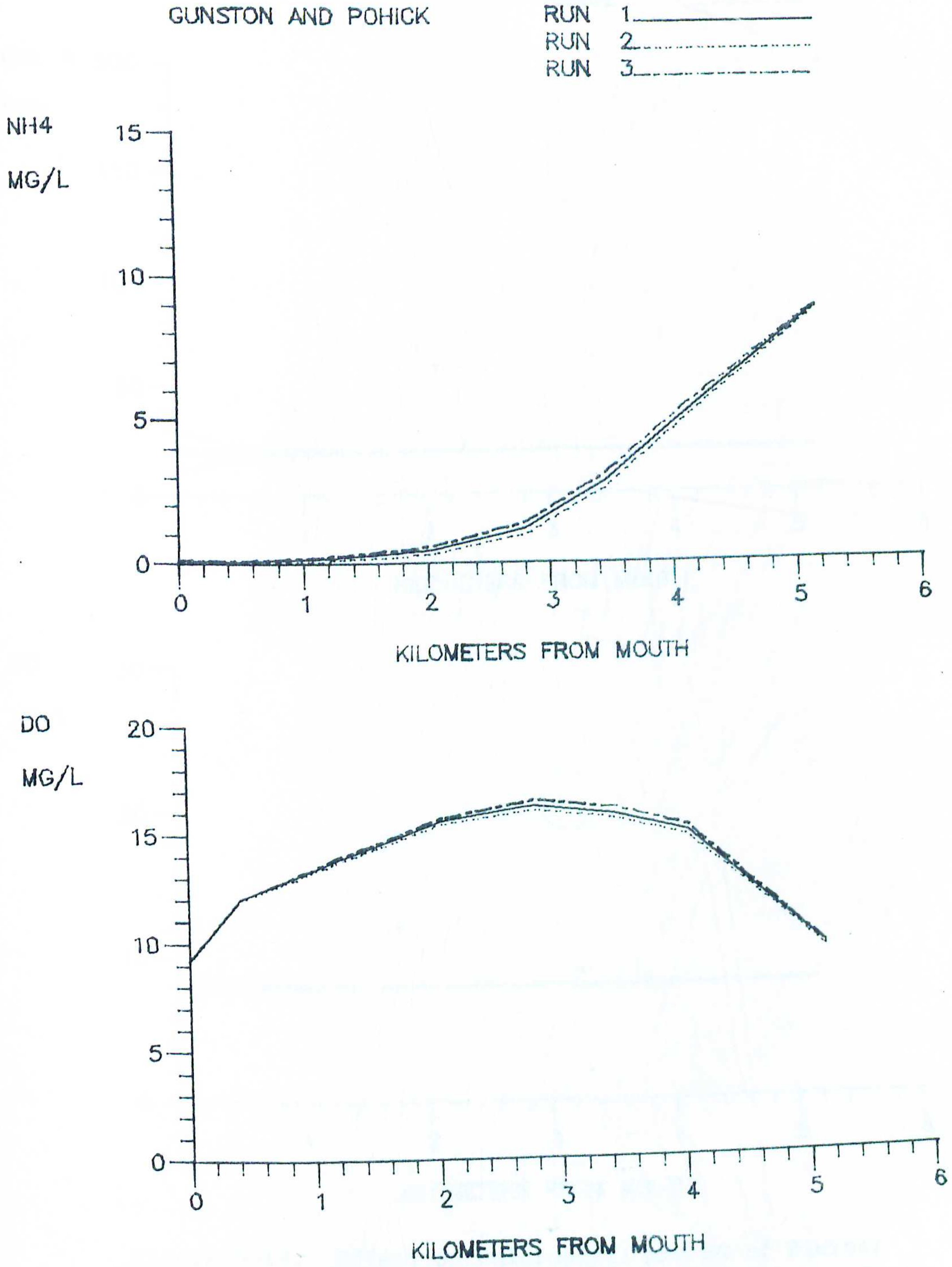


Figure 8-11. Sensitivity of Ammonium and DO to Nitrification Rate.

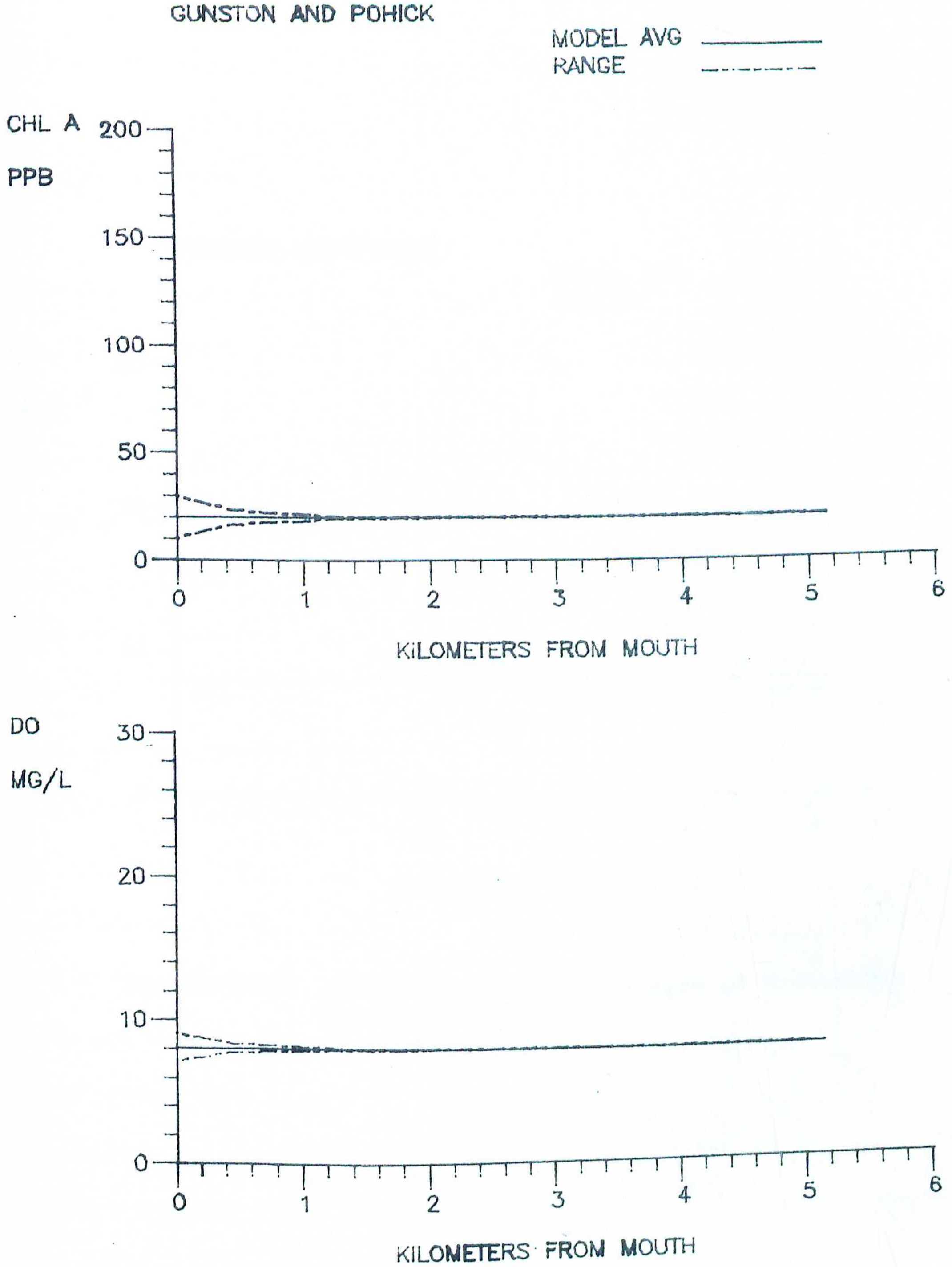


Figure 8-12. Effect on Chlorophyll and DO of Diurnal Fluctuations at the Mouth of Gunston Cove.

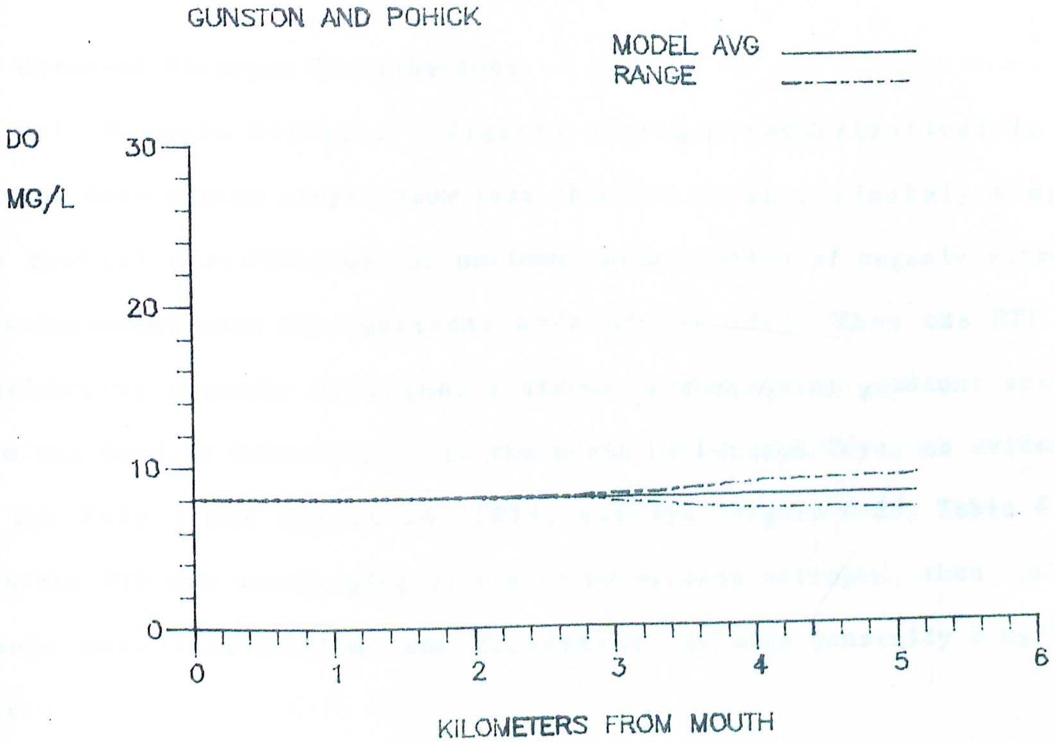


Figure 8-13. Effect on Dissolved Oxygen of Macrophyte Productivity.

CHAPTER IX. DISCUSSION

This chapter is devoted to an overview of water-quality conditions observed in Gunston Cove during the 1979 to 1982 survey period, to a review of the model application, and to some suggestions for its use.

A. Observed Nitrogen Distributions

1) Organic Nitrogen - Organic nitrogen concentrations in the Gunston Cove system ranged from less than 0.1 to approximately 6 mg/1. The spatial distribution and maximum concentration of organic nitrogen were dependent upon the operating mode of the STP. When the STP was discharging organic nitrogen, a strong concentration gradient existed from the head of Pohick Creek to the mouth of Gunston Cove, as evidenced by the July 5 and August 16, 1979, surveys (Figure 6-25, Table 6-9). When the STP was discharging little or no organic nitrogen, then spatial trends were less evident and concentrations were generally 2 mg/1 or less.

Although the STP influences the distribution of organic nitrogen, it is not the sole source of this substance. An additional major source is through the excretion and death of phytoplankton. A secondary sporadic source of organic nitrogen may also exist. Organic nitrogen observations in the September, 1979, intensive survey could not be reproduced on the basic of measured external inputs and computed phytoplankton turnover (Figure 6-16). A distributed source of organic nitrogen, presumably marsh detritus or resuspended bottom sediments, was likely active at that time.

2) Ammonia Nitrogen - Ammonia nitrogen concentrations in the Gunston Cove system ranged from 0.1 to approximately 10 mg/1. A decline in ammonia concentration from the head of Pohick to the mouth of Gunston was a persistent feature of the embayment and the elevated ammonia concentrations were due to the STP which typically discharged ammonia in the 10-20 mg/1 range.

The STP is not the sole source of ammonia to the system, however. Measurements indicate an additional source to be the flux of ammonium out of the bottom sediments and into the water column.

3) Nitrate Nitrogen - Nitrate nitrogen is the only water-quality parameter which showed a decreasing trend away from the Gunston mouth towards the head of Pohick. Typically, nitrate was approximately 1 mg/1 at the juncture with the Potomac and declined to approximately 0.2 mg/1 at the opposite end of the embayment. This trend was subject to reversal, however, in the event of the discharge of significant quantities of nitrate by the STP, as evidenced by the August, 1982, intensive survey (Figure 6-9).

B. Observed Phosphorus Distributions

Total phosphorus concentrations in Gunston Cove ranged from approximately 0.05 mg/1 to more than 2 mg/1. Based on the observations in the intensive surveys, 40-100% of the total phosphorus was in mineral form with the mineral fraction declining from the head of Pohick towards the mouth of Gunston.

The magnitude and spatial distribution of phosphorus in the embayment was variable and depended upon the operational mode of the point source. The predominant trend in the observations, however, was a decline of phosphorus from the head of Pohick to the mouth of Gunston.

Measurements indicate the bottom sediments may act as either a source or sink of phosphorus. The sediments are considered, in the model, to be a net source of mineral phosphorus, but the magnitude and direction of this source are not known with certainty.

C. Observed Chlorophyll Distributions

Daily-average chlorophyll concentrations in Gunston Cove ranged from less than 5 to more than 100 µgm/l. Concentrations in the 75 µgm/l range were common, recurrent phenomena and extremes of 150 µgm/l were observed.

Peak chlorophyll concentrations usually were found at the juncture of Pohick Bay and Gunston Cove (Station 7 in Figure 3-1) with the algal population declining in either direction towards the mouth of Gunston Cove or the head of Pohick Bay. Concentrations in the vicinity of the embayment mouth were influenced by the adjacent Potomac River and were typically 20 µgm/l. Concentrations at the head of Pohick Bay were typically less than 5 µgm/l.

D. Observed CBOD Distributions

Ultimate carbonaceous biochemical oxygen demand in Gunston Cove ranged widely between 0-20 mg/l reflecting both the natural variability of the system and the imprecise analyses which determine this parameter. Frequently, CBOD concentrations were observed to increase downstream of the STP and to peak at Station 7 (Figs 6-22 and 6-31). This trend in the data suggests the existence of a CBOD source other than external loading or the internal cycling of phytoplankton detritus. Likely sources of the additional CBOD are detritus from rooted aquatic plants and resuspension of bottom sediments.

E. Observed Dissolved Oxygen Distributions

Dissolved oxygen in Gunston Cove is generally in the saturated or supersaturated state. Maximum concentrations in the central portion of the embayment reach 15-20 mg/1 and daily average concentrations attain 9-14 mg/1. Lesser concentrations prevail only at the head and mouth of the embayment where conditions are affected by Pohick Creek and the Potomac River. Even at these extremes, DO exceeds 5 mg/1. Indeed, 5 mg/1 was the approximate minimum observation throughout the course of the field program.

Saturated DO concentrations are the result of an excess of algal photosynthesis over respiration. At times when the algal productivity is low (e.g. Aug. 6, 1979, Fig. 6-30), dissolved oxygen concentrations are low as well (Fig. 6-32) and approach the 5 mg/1 minimum observation. When algal productivity is high (e.g. September 1979, Fig. 6-21), then oxygen concentrations are elevated also (Fig. 6-23).

F. The Hydrodynamic Model

The hydrodynamic model used in this study is a one-dimensional, time-variable model based on the principles of conservation of volume, momentum, and mass. The model provides real-time predictions of surface level, current, and transport and dispersion of a conservative substance. The model is applied along the axis of Gunston Cove and Pohick Bay and treats Accotink Bay as a well-mixed storage area.

Calibration and verification analyses show that the model provides near-perfect predictions of surface level within the embayment (Figures 5-4 and 5-7). This is demonstrative of both the applicability of the model and of the unified response of Gunston Cove to tidal fluctuations at the mouth.

The calibration and verification of current (Figures 5-5 and 5-9) are less ideal than tide but are still more than sufficient for the purposes of this study. Discrepancies between predictions and observations are attributable to the collection and nature of the observations rather than to shortcomings in the model.

The ability of the model to predict mass transport and dispersion has been verified in both the steady and time-variable modes. The model has simulated the steady-state longitudinal distribution of chlorides (Figure 5-12) and the nonsteady-state longitudinal and temporal distribution of dye (Figures 5-10 and 5-11).

The ability of the model to predict time-variable mass transport and dispersion has been verified only at the intertidal rather than intratidal time scale. That is, the model has been used to predict the change in dye concentration from tidal cycle to tidal cycle but not within a tidal cycle. Lack of real-time verification is due to the nature of the dye distribution which is patchy and not subject to deterministic modelling. Only by averaging the dye samples over a sufficient time period can smooth temporal and spatial patterns be discerned.

In view of the capabilities enumerated above, the hydrodynamic model is deemed sufficient and suitable for employment as a management tool.

G. The Water Quality Model

The water-quality model provides one-dimensional, real-time predictions of eight water-quality constituents via solution of an equation identical to the mass-conservation equation in the hydrodynamic model except that appropriate source and sink terms are included. The eight water-quality constituents are:

organic nitrogen
ammonia nitrogen
nitrite+nitrate nitrogen
organic phosphorus
ortho phosphorus
chlorophyll 'a'
CBOD
dissolved oxygen

The water-quality model has been calibrated and verified against several independent data sets and in different modes of operation. These are

Calibration of approximately steady-state longitudinal distribution of all constituents. August, 1982, intensive survey.

Verification of approximately steady-state longitudinal distribution of all constituents. September, 1979, intensive survey.

Verification of long-term predictive ability through simulation of intertidally varying longitudinal distributions of all constituents. June to August, 1979, slackwater surveys.

The agreement between predictions and observations has been reported in both qualitative and quantitative terms. In general, the predictive ability of the model is dependent upon the quality and quantity of the input data upon which the model run is based. Agreement between predictions and observations is dependent upon both the input data and the nature and number of observations. Thus, the results of the simulations of the intensive survey periods are more satisfactory than the results of the seasonal simulation.

The water-quality model results are commensurate with the data available to this study. It is unlikely that adopting a more sophisticated model would provide significantly improved predictive capability without the collection of additional and comprehensive data. Even then, discrepancies between predictions and observations would still persist due to the random variability inherent in natural systems.

An additional cause of the discrepancies which exist between predictions and observations is the goal of consistency which motivated the calibration and verification procedures. The objective of these procedures was to find a single set of model constituents which would provide satisfactory predictions in all cases rather than to employ survey-specific constituents in an effort to obtain the best fit to the data.

The water-quality model is deemed suitable for employment as a management tool but care should be exercised in its usage and in interpretation of model results.

Water quality in Gunston Cove is influenced by a number of naturally-variable and, occasionally, unpredictable biological and environmental factors. Model results obtained will depend upon the values of those constituents specified as model inputs.

It has been shown, for example, that chlorophyll and dissolved oxygen concentrations are sensitive to light extinction in the water column. The magnitude of light extinction in Gunston Cove is neither well-known nor predictable, however. Therefore it is recommended that management runs be performed based on several alternate sets of light extinction data rather than on a single set.

Benthic fluxes pose a similar problem. Measurements indicate the magnitude of ammonia and dissolved oxygen fluxes and the magnitude and direction of the phosphorus flux are all variable. Since these factors exert, or potentially exert, a large influence on water quality, it is recommended that management runs be performed based on several alternate values of benthic flux.

To summarize, chlorophyll concentrations and other water-quality conditions in Gunston Cove are dependent upon naturally-variable biological processes and random events as well as upon deterministic processes such as wasteloading. The model is a valid and useful tool for the management of water quality within the embayment but the model results are partially-dependent upon the assumed values of the variable and random processes. Thus, a number of model runs should be made based upon alternate scenarios of temperature, light extinction, etc., before irrevocable management decisions are made.

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APPENDIX A. RAW FIELD DATA

KEY TO RAW FIELD DATA

Field	Parameter
1- 5	TKN (mg/1)
6-10	NH_4 (mg/1)
11-15	$NO_3 + NO_2$ (mg/1)
16-20	Ortho P (mg/1)
21-25	Total P (mg/1)
26-30	Chl 'a' (μgm/1)
31-35	$CBOD_5$ (mg/1)
36-40	D.O. (mg/1)
41-45	Temp. (C^o)
46-50	Disk Visibility (cm)
51-55	Flow (ft^3/sec)
56-60	pH
61-65	CBODu (mg/1)
66-70	TOC (mg/1)
71-75	Standard Time (hr:min)
76-77	Station
78-85	Date (day-mo-yr)

Missing data indicated by 999.

1979 Slackwater Surveys

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1979 Intensive Survey

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999. 999. 999. 999. 999. 999. 9.7317.8024.90 20.0 999.10.10 999. 999.15:48G819-09-79
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 999. 999. 999. 999. 999. 999. 999.11.4021.70 20.0 999. 8.80 999. 999. 7:48G820-09-79
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  .10  .10  .15  .07  .10 1.00 1.10 8.9019.50 80.0 999. 7.40 2.7812.0011:421119-09-79
  .20  .10  .15  .06  .10 1.40 1.50 8.5018.80 999. 999. 6.70 3.08 8.0017:001119-09-79
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1980 Slackwater Surveys

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 1.00 0.60 0.75 0.01 0.10 20.1 3.00 8.3025.30 32.5 999. 8.00 999.11.0014:50G125-06-80
 0.90 0.40 0.66 0.04 0.10 22.9 3.00 8.9025.20 30.0 999. 8.70 999.11.0014:37G225-06-80
 1.20 0.10 0.49 0.01 0.10 53.5 999.11.4026.80 35.0 999. 9.70 999.16.0014:25G325-06-80
 1.50 0.30 0.36 0.04 0.10 63.3 5.0012.6028.00 30.0 999. 9.80 999.15.0014:08G425-06-80
 2.30 0.30 0.33 0.06 0.20 74.214.0011.2028.80 37.5 999. 9.80 999.22.0013:50G525-06-80
 1.30 0.10 0.05 0.01 0.10 45.9 8.00 6.1026.90 15.0 999. 9.20 999.17.0013:40G625-06-80
 4.20 1.90 0.71 0.18 0.30 86.313.0010.1027.90 30.0 999. 9.40 999.30.0013:30G725-06-80
 6.50 4.20 1.30 0.20 0.30 43.7 8.00 7.6027.80 30.0 999. 8.90 999.23.0013:20G825-06-80
 2.30 2.10 0.48 0.03 0.10  1.3 2.00 8.0023.10 24.0 999. 8.40 999. 9.0011:00G925-06-80
13.0011.50 3.50 0.11 0.20 999. 7.00 6.3026.00 999.31.00 8.80 999.17.0014:151025-06-80
 0.20 0.10 0.11 0.01 0.10  1.0 1.00 8.2022.10 999.33.12 8.40 999. 8.0010:451125-06-80
 0.20 0.10 0.25 0.01 0.10  2.8 1.00 9.0025.50 24.013.66 8.90 999. 8.0015:001225-06-80
  .90  .20 2.37  .01  .10 19.7 2.00 6.7028.20 73.0 999. 7.50 999. 9.0011:55G104-09-80
 1.00  .30 2.37  .01  .10 10.0 2.00 6.3028.00 63.0 999. 7.30 999.10.0011:45G204-09-80
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 7.50 2.90 0.50  .90 1.20130.117.5510.2027.40 21.0 999. 9.5038.7029.0011:00G704-09-80
14.20 7.00 1.40  .80  .80 29.5 6.00 4.4025.90 36.0 999. 7.70 999.17.0010:50G804-09-80
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18.0010.00 1.70  .17  .20 999. 6.03 8.0026.30 999.34.10 7.9013.7014.0015:151004-09-80
 3.10 3.10 0.35  .05  .10  6.8 0.65 8.6025.00 999. 0.00 7.20 3.47 8.0015:151104-09-80
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1982 Slackwater Surveys

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 0.5   0.2 1.64 0.05   0.1   8.6   2.0   6.1 27.2 75.2 999.   7.5 999.    6.14:52G119-08-82
 0.5   0.3 1.65 0.02   0.1   8.2   2.0   5.8 27.2 63.6 999.   7.6 999.    4.15:10G219-08-82
 1.5  999. 0.90 0.04   0.2  59.0   8.3  14.7 28.2 40.6 999.   9.5 16.7   13.15:30G319-08-82
 1.9   0.1 1.10 0.07   0.3  73.8  10.8  16.0 28.4 33.1 999.   9.7 23.5   17.15:45G419-08-82
 1.3   0.1 0.23 0.04   0.2  40.1   7.7  15.0 28.9 25.4 999.   9.4 18.2   12.16:04G619-08-82
 2.8   1.1 2.35 0.11   0.4  72.8  15.2  16.4 28.4 30.5 999.   9.3 26.6   14.16:15G719-08-82
 3.7   2.4 3.40 0.22   0.3  39.0  10.0  11.5 26.9 25.4 999.   8.4 999.   11.16:30G819-08-82
 7.9   6.2 6.00 0.49   0.6   0.9   3.0   8.4 24.5 999. 999.   1.6 999.    5.13:55G919-08-82
 8.9   8.9 4.70 0.55   0.7  999.   1.5   8.8 25.1 999. 43.4   7.2  5.0    5.13:401019-08-82
 0.3   0.1 0.19 0.01   0.1   1.6   1.0   9.6 23.0 90.0  5.4   7.0 999.    4.13:301119-08-82
 0.4   0.1 0.46 0.02   0.1   3.8   1.0   8.6 23.0 999. 15.8   7.4 999.    5.12:151219-08-82
 0.8   0.1 0.80 0.03   0.1  29.5   4.0  10.0 25.9 45.0 999.   8.7 999.    8.11:00G123-08-82
 0.7   0.1 1.18 0.03   0.1  44.7   2.0   8.7 26.0 45.0 999.   7.6 999.    5.11:25G223-08-82
 0.6   0.1 1.28 0.03   0.1  60.1   2.1   8.2 26.0 63.5 999.   7.5  4.7    6.11:40G323-08-82
 2.0   0.1 0.90 0.07   0.2  79.1   8.4  11.3 25.4 35.6 999.   9.4 18.8   13.12:00G423-08-82
 1.2   0.1 0.41 0.04   0.1  82.2   5.0  11.6 24.9 40.6 999.   9.0 999.   10.12:15G623-08-82
 1.5   0.1 0.33 0.05   0.2  27.0   8.0  12.0 25.3 43.2 999.   9.4 999.   12.12:33G723-08-82
 2.9   0.6 2.70 999.   0.3  73.8   9.0  14.5 25.2 33.0 999.   9.5 999.   14.12:53G823-08-82
999.  999. 999. 999.  999.  999.  999.  999. 999. 999. 999.  999. 999.  999.13:00G923-08-82
10.4  10.4 7.50 1.3    1.3  999.   2.0   8.9 25.2 999. 40.8   7.5  7.0    5.13:101023-08-82
 0.1   0.1 0.07 0.01   0.1   1.4   1.0   9.4 21.0 999.  3.1   7.1 999.    3.12:501123-08-82
 0.2   0.1 0.26 0.01   0.1   1.4   1.0   8.5 21.3 999.  8.5   7.1 999.    4.10:251223-08-82
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1982 Intensive Survey

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 0.6   0.1 1.51 0.04  0.1 10.3   1.0  6.0 26.8 90.0 999.  7.0 999.   4.18:44G124-08-82
999. 999. 999. 999. 999. 55.9 999.  5.4 26.7 999. 999.  7.0 999. 999.20:41G124-08-82
 0.6   0.1 1.05 0.03  0.1 28.5   3.0  9.3 27.0 999. 999.  7.9 999.   6.22:48G124-08-82
999. 999. 999. 999. 999. 24.9 999.  8.4 26.4 999. 999.  7.4 999. 999.00:43G125-08-82
 0.9   0.1 1.05 0.04  0.1 22.2   2.0  7.9 26.2 999. 999.  7.1 999.   3.02:40G125-08-82
999. 999. 999. 999. 999. 19.0 999.  7.1 26.0 999. 999.  7.0 999. 999.04:35G125-08-82
 0.5   0.1 1.51 0.05 0.06  7.0   0.9  6.1 26.2 60.0 999.  6.7  2.5   6.06:43G125-08-82
999. 999. 999. 999. 999.  8.4 999.  6.0 26.4 70.0 999.  6.8 999. 999.08:45G125-08-82
 0.5   0.1 1.38 0.04  0.1 15.2   2.0  6.9 26.4 55.0 999.  6.7 999.   5.10:50G125-08-82
 0.5   0.1 0.90 0.03 0.12 32.9   2.1  8.7 26.2 40.0 999.  7.9  4.2   7.12:51G125-08-82
 0.4   0.1 1.28 0.04  0.1 18.6   1.0  7.8 26.9 45.0 999.  7.2 999.   5.14:55G125-08-82
999. 999. 999. 999. 999. 20.2 999.  7.6 26.5 40.0 999.  7.1 999. 999.16:51G125-08-82
 0.5   0.2 1.61 0.10  0.1 10.1   1.0  6.5 26.3 55.0 999.  6.7 999.   6.18:42G125-08-82
999. 999. 999. 999. 999.  8.3 999.  6.0 26.1 999. 999.  6.7 999. 999.20:57G125-08-82
 0.6   0.1 1.39 0.04  0.1 16.0   3.0  8.6 27.3 60.0 999.  7.5 999.   6.18:38G224-08-82
999. 999. 999. 999. 999.  8.0 999.  6.2 26.7 999. 999.  7.0 999. 999.20:37G224-08-82
 0.6   0.1 1.31 0.04  0.1 11.0   2.0  6.6 27.0 999. 999.  7.2 999.   6.22:42G224-08-82
999. 999. 999. 999. 999. 25.3 999.  8.6 26.3 999. 999.  7.3 999. 999.00:38G225-08-82
 0.6   0.1 1.16 0.03  0.1 23.6   2.0  7.9 26.2 999. 999.  7.1 999.   6.02:35G225-08-82
999. 999. 999. 999. 999. 21.3 999.  7.7 26.3 999. 999.  7.0 999. 999.04:32G225-08-82
 0.6   0.1  1.5 0.04 0.07 11.8   0.9  6.2 26.2 50.0 999.  6.8  2.8   6.06:38G225-08-82
999. 999. 999. 999. 999. 14.8 999.  6.6 26.3 60.0 999.  6.9 999. 999.08:39G225-08-82
 0.5   0.2 1.62 0.04  0.1 10.3   2.0  6.3 26.6 50.0 999.  6.8 999.   7.10:44G225-08-82
 0.4   0.1 1.17 0.03 0.11 20.9   2.3  8.6 26.6 55.0 999.  7.0  5.1   6.12:45G225-08-82
 0.5   0.1 1.50 0.03  0.1 13.7   2.0  7.5 26.8 50.0 999.  7.0 999.   7.14:48G225-08-82
999. 999. 999. 999. 999.  8.9 999.  5.9 26.5 45.0 999.  6.7 999. 999.16:45G225-08-82
 0.5   0.2 1.61 0.04  0.1 10.1   1.0  6.2 26.3 55.0 999.  6.7 999.   6.18:37G225-08-82
999. 999. 999. 999. 999.  7.2 999.  5.9 25.8 999. 999.  6.7 999. 999.20:51G225-08-82
 1.0   0.1 0.90 0.04  0.1 45.8   6.0 18.2 27.8 50.0 999.  9.7 999.   9.18:35G324-08-82
999. 999. 999. 999. 999. 65.4 999. 16.8 26.2 999. 999.  9.8 999. 999.20:30G324-08-82
 0.5   0.1 1.50 0.04  0.1 13.3   2.0  7.8 27.1 999. 999.  7.2 999.   6.22:33G324-08-82
999. 999. 999. 999. 999. 21.1 999.  7.4 26.4 999. 999.  6.9 999. 999.00:34G325-08-82
 0.6   0.1 1.41 0.04  0.1 17.1   2.0  6.6 26.3 999. 999.  6.8 999.   6.02:47G325-08-82
999. 999. 999. 999. 999. 17.7 999.  7.2 26.3 999. 999.  6.9 999. 999.05:40G325-08-82
 0.6   0.1 1.41 0.04 0.08 17.7   1.1  6.8 26.1 80.0 999.  6.9  3.2   6.06:32G325-08-82
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 999. 999. 999. 999. 999. 19.0 999.  7.1 26.0 50.0 999.  7.0 999. 999.08:34G325-08-82
  0.5  0.1 1.50 0.03  0.1 21.3  2.0  7.0 26.3 55.0 999.  7.0 999.   6.10:38G325-08-82
  0.6  0.1 1.29 0.02 0.11 34.2  2.5  9.0 26.7 45.0 999.  7.3  4.6   7.12:39G325-08-82
  0.6  0.1 1.29 0.02  0.1 33.8  3.0  8.9 26.7 50.0 999.  7.8 999.   7.14:42G325-08-82
 999. 999. 999. 999. 999. 21.5 999.  8.4 26.7 45.0 999.  7.4 999. 999.16:41G325-08-82
  0.7 999. 0.70 0.03  0.1 53.8  5.0 11.2 26.5 30.0 999.  8.7 999.   9.18:32G325-08-82
 999. 999. 999. 999. 999. 31.0 999.  9.6 25.9 999. 999.  8.0 999. 999.21:10G325-08-82
  2.1 999. 1.52 0.08  0.3 65.4  9.0 19.6 27.8 20.0 999. 10.2 999.  13.18:30G424-08-82
 999. 999. 999. 999. 999. 79.1 999. 18.2 27.3 999. 999. 10.0 999. 999.20:35G424-08-82
  1.4 999. 0.70 0.05  0.2 67.5  9.0 13.8 27.0 999. 999.  9.5 999.  13.22:28G424-08-82
 999. 999. 999. 999. 999. 999. 999. 12.3 26.3 999. 999.  9.0 999. 999.00:26G425-08-82
  0.7  0.1 1.09 0.02  0.1 34.0  4.0 10.0 26.3 999. 999.  7.7 999.   8.02:27G425-08-82
 999. 999. 999. 999. 999. 46.4 999. 11.6 26.2 999. 999.  9.0 999. 999.04:25G425-08-82
  1.2 999. 0.50 0.05 0.20 65.4  4.7 11.3 26.0 40.0 999.  9.3 12.7  11.06:24G425-08-82
 999. 999. 999. 999. 999. 59.0 999. 10.7 25.9 35.0 999.  9.4 999. 999.08:27G425-08-82
  0.6  0.1 1.07 0.02  0.1 39.0  4.0 10.0 26.3 40.0 999.  8.2 999.   7.10:31G425-08-82
  0.5  0.1 1.29 0.01 0.10 43.2  2.6  9.6 27.3 50.0 999.  7.3  4.6   7.12:32G425-08-82
  0.5  0.1 1.28 0.02  0.1 66.4  3.0  9.1 26.8 55.0 999.  7.7 999.   7.14:36G425-08-82
 999. 999. 999. 999. 999. 75.9 999. 12.1 27.0 30.0 999.  9.1 999. 999.16:35G425-08-82
  2.1 999. 2.52 0.09  0.2 86.5 12.0 12.4 26.7 25.0 999.  9.2 999.  14.18:27G425-08-82
 999. 999. 999. 999. 999. 78.0 999. 11.4 26.3 999. 999.  9.3 999. 999.20:32G425-08-82
  1.2 999. 0.06 0.06  0.1 999.  9.0 16.5 28.8 20.0 999.  9.5 999.  14.18:50G624-08-82
 999. 999. 999. 999. 999. 55.3 999. 15.0 27.6 999. 999.  9.6 999. 999.20:46G624-08-82
  1.7 999. 0.60 0.07  0.2 73.8  9.0 13.8 26.7 999. 999.  9.8 999.  15.22:41G624-08-82
 999. 999. 999. 999. 999. 71.7 999. 12.8 26.6 999. 999.  9.7 999. 999.00:32G625-08-82
  1.2 999. 0.42 0.05  0.1 61.2  8.0 12.8 26.3 999. 999.  9.6 999.  13.02:45G625-08-82
 999. 999. 999. 999. 999. 65.4 999. 11.0 25.8 999. 999.  9.5 999. 999.04:47G625-08-82
  1.2 999. 0.22 999. 0.20 60.1  5.4  8.8 25.3 999. 999.  8.9 12.3  13.06:36G625-08-82
 999. 999. 999. 999. 999. 66.4 999.  8.8 25.2 20.0 999.  9.3 999. 999.08:32G625-08-82
  0.8  0.1 0.50 0.04  0.1 53.8  7.0 10.4 25.7 40.0 999.  9.3 999.  11.10:35G625-08-82
  0.9  0.1 0.60 0.04 0.15 59.0  5.6 12.5 26.2 35.0 999.  9.5 12.0  10.12:33G625-08-82
  1.0 999. 0.50 0.04  0.1 61.2  8.0 14.8 26.9 38.0 999.  9.7 999.  11.14:39G625-08-82
 999. 999. 999. 999. 999. 67.5 999. 16.1 27.2 27.0 999.  9.8 999. 999.16:33G625-08-82
  1.0 999. 0.40 0.04  0.1 999.  8.0 17.1 27.1 24.0 999.  9.8 999.  12.18:26G625-08-82
 999. 999. 999. 999. 999. 70.6 999. 14.9 26.0 999. 999.  8.8 999. 999.20:30G625-08-82
```

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999. 999. 999. 999. 999.  2.9 999. 999. 999. 999. 999. 999. 999. 999.20:351A24-08-82
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999. 999. 999. 999. 999. 30.2 999. 999. 999. 999. 999. 999. 999. 999.00:301A25-08-82
 0.5   0.1 0.08 0.04  0.1  4.6  3.4  8.1 25.8 999. 999.  7.8  6.0  6.02:301A25-08-82
999. 999. 999. 999. 999.  2.6 999. 999. 999. 999. 999. 999. 999. 999.04:301A25-08-82
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999. 999. 999. 999. 999.  4.6 999. 999. 999. 999. 999. 999. 999. 999.08:351A25-08-82
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999. 999. 999. 999. 999. 14.8 999. 999. 999. 999. 999. 999. 999. 999.12:351A25-08-82
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999. 999. 999. 999. 999.  7.2 999. 999. 999. 999. 999. 999. 999. 999.16:351A25-08-82
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999. 999. 999. 999. 999. 78.0 999. 17.3 27.0 999. 999.  9.7 999. 999.20:54G724-08-82
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999. 999. 999. 999. 999. 999. 999. 13.6 26.6 999. 999.  9.9 999. 999.00:41G725-08-82
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999. 999. 999. 999. 999. 80.2 999. 12.6 26.2 999. 999.  9.6 999. 999.04:57G725-08-82
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999. 999. 999. 999. 999. 77.0 999. 17.2 27.0 999. 999.  9.7 999. 999.21:04G824-08-82
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999. 999. 999. 999. 999. 80.2 999. 13.5 26.5 999. 999.  9.6 999. 999.00:47G825-08-82
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 1.5 999. 0.70 0.06 0.29 75.9  7.9 10.9 26.4 23.0 999.  9.3 17.1  14.12:52G825-08-82
 4.3  3.1 4.50 0.40  0.6 70.6 13.0 14.9 26.8 20.0 999.  8.9 999.  13.15:02G825-08-82
999. 999. 999. 999. 999. 53.8 999. 15.3 27.4 25.0 999.  8.3 999. 999.16:48G825-08-82
 2.4 999. 3.00 999.  0.3 90.7 17.0 19.6 27.3 21.0 999.  9.6 999.  14.18:42G825-08-82
999. 999. 999. 999. 999. 70.6 999. 14.9 26.4 999. 999. 999. 999. 999.20:43G825-08-82
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999. 999. 999. 999. 999.  4.0 999. 999. 999. 999. 999.  6.8 999. 999.20:351P24-08-82
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999. 999. 999. 999. 999.  3.2 999. 999. 999. 999. 999. 999. 999. 999.00:351P25-08-82
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999. 999. 999. 999. 999.  1.4 999. 999. 999. 999. 999. 999. 999. 999.04:301P25-08-82
 6.5  6.5 6.50 0.90  1.0 999.  5.9  4.9 25.1 999. 999.  6.8 12.1   6.06:301P25-08-82
999. 999. 999. 999. 999.  4.1 999. 999. 999. 999. 999. 999. 999. 999.08:351P25-08-82
 6.5  6.5 6.50 0.90  1.0  1.9  7.5  5.0 26.5 999. 999.  7.1 13.2   6.10:351P25-08-82
999. 999. 999. 999. 999.  2.7 999. 999. 999. 999. 999. 999. 999. 999.12:351P25-08-82
 6.3  6.3 6.50 0.80  0.9  1.3  8.0 999. 999. 999. 999.  7.1 16.6   6.14:351P25-08-82
999. 999. 999. 999. 999.  3.6 999. 999. 999. 999. 999. 999. 999. 999.16:351P25-08-82
 6.4  6.4 6.50 0.60  0.7  4.3  6.7 999. 999. 999. 999. 999. 13.0   8.18:351P25-08-82
999. 999. 999. 999. 999.  2.5 999. 999. 999. 999. 999. 999. 999. 999.20:351P25-08-82
 9.8  9.8 6.49 1.40 1.40 999.  2.2  8.1 26.7 999. 39.1  7.3  7.0   6.19:451024-08-82
 9.7  9.5 6.00 1.00 1.45 999.  3.6  7.8 26.2 999. 38.6  7.4  6.7   7.19:351025-08-82
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 0.3  0.1 0.16 0.01 0.02  1.4  0.6  8.0 24.8 999.  8.5  7.5  1.6   7.19:351225-08-82
```

Appendix B. Converted Field Data

KEY TO CONVERTED FIELD DATA

Field	Parameter	
1- 5	Organic Nitrogen	(mg/l)
6-10	NH_4	(mg/l)
11-15	$NO_2 + NO_3$	(mg/l)
16-20	Ortho P	(mg/l)
21-25	Total P	(mg/l)
26-30	Chl 'a'	(μgm/l)
31-35	CBUDu	(mg/l)
36-40	D.O.	(mg/l)
50-55	Standard Time	(hr:min)
56-57	Station	
58-65	Date	(da-mo-yr)

Missing data indicated by 999.

1979 Slackwater Data

```
 0.58 0.30 1.23 0.06 0.10  3.2  2.5  7.4         9:42G105-06-79
 0.48 0.30 1.13 0.07 0.10  2.7  3.1  7.4        10:00G205-06-79
 0.72 1.00 0.61 0.32 0.29 12.0  7.0  7.8        10:30G305-06-79
99.99 1.40 0.45 0.30 0.30 99.9 99.9  6.4        10:42G405-06-79
99.99 1.30 0.48 0.27 0.30 99.9 99.9  7.2        11:00G505-06-79
 0.71 1.20 0.46 0.28 0.29 13.0 10.2  7.0        11:18G605-06-79
 0.57 1.30 0.46 0.19 0.20  4.6  2.6  7.8        11:36G705-06-79
 0.57 3.90 0.31 0.90 0.90  4.4  4.7  7.8        11:48G805-06-79
99.99 4.50 0.19 0.90 1.00 99.9 99.9  8.8        13:18G905-06-79
 0.0017.80 0.16 3.00 3.40 99.9  9.0  8.5        13:001005-06-79
 0.20 0.10 0.20 0.03 0.10 99.9  1.7  8.9        13:061105-06-79
 0.00 0.10 0.43 0.03 0.10 99.9 99.9  8.5        13:421205-06-79
 0.44 0.40 1.00 0.03 0.09  9.0  5.0  8.3         9:48G119-06-79
 0.32 0.50 0.90 0.04 0.19 11.0  2.2  6.8        10:00G219-06-79
 0.33 0.10 0.70 0.06 0.15 53.0  7.1  9.9        10:24G319-06-79
 0.82 3.30 0.50 0.70 0.76 40.0  7.5  9.2        10:30G419-06-79
 0.44 0.10 0.46 0.05 0.15 52.0 10.0  9.2        10:48G519-06-79
 0.29 0.10 0.30 0.02 0.08 15.0  4.9  8.3        11:06G619-06-79
 1.28 0.90 0.47 0.30 0.30  3.5 14.9 11.1        11:30G719-06-79
 0.94 8.50 0.60 1.30 1.39  9.2  7.8  5.4        11:48G819-06-79
99.99 9.50 0.16 3.00 3.20 99.9 99.9  8.4        12:12G919-06-79
 2.8015.00 0.14 5.00 5.10 99.9 22.7  8.3        12:001019-06-79
 0.20 0.10 0.07 0.03 0.10 99.9 99.9  9.7        11:301119-06-79
99.9999.99 0.30 0.03 0.10 99.9  2.3  7.4         9:301219-06-79
 0.04 0.70 0.70 0.05 0.03 66.0  0.0  8.3        10:30G105-07-79
 0.28 0.80 0.60 0.04 0.08 17.0  3.3  8.3        10:48G205-07-79
 1.13 0.10 0.44 0.10 0.18 24.0  1.7 13.2        11:12G305-07-79
 1.43 0.50 0.49 0.35 0.39 10.0 11.4 12.8        11:24G405-07-79
 0.00 0.10 0.44 0.05 0.05 51.0  0.0  9.8        11:42G505-07-79
 0.08 0.30 0.43 0.05 0.08 17.0  2.4  9.6        11:48G605-07-79
 2.26 1.00 0.40 0.50 0.49  5.9 24.3 14.5        12:06G705-07-79
 5.15 9.00 0.60 2.10 2.09  6.9  9.8  6.7        12:12G805-07-79
 4.3310.00 0.26 3.00 3.13 67.0  0.0  8.4        12:12G905-07-79
 7.1017.50 0.21 5.00 5.50 99.9 32.1  8.3        12:001005-07-79
 0.18 0.10 0.29 0.05 0.10  3.0  3.0  9.7        11:301105-07-79
 0.48 0.10 0.44 0.03 0.20  3.2  2.1  7.4         9:301205-07-79
 0.42 0.40 0.66 0.01 0.07 26.0  2.5  7.5         9:48G118-07-79
 0.32 0.50 0.66 0.01 0.07 25.0  2.7  7.1        10:00G218-07-79
 0.45 0.10 0.63 0.02 0.05 50.0  5.1 12.2        10:12G318-07-79
 1.12 1.40 0.34 0.18 0.25 54.0  3.6  8.5        10:30G418-07-79
 0.69 0.10 0.1499.99 0.04 59.0  2.4 12.4        10:42G518-07-79
 1.26 1.20 0.29 0.22 0.34 63.0  4.6 11.4        10:48G618-07-79
 2.02 8.50 0.80 1.80 2.13 68.0  6.4 11.2        11:00G718-07-79
 0.83 0.10 0.06 0.05 0.26 38.0  8.1  7.3        11:06G818-07-79
 1.4916.50 0.27 1.40 1.50  1.3  4.8  8.2        11:36G918-07-79
 1.7020.50 0.31 1.70 1.80 99.9 12.2  8.2        11:181018-07-79
 0.09 0.10 0.06 0.10 0.10  1.8  0.1  7.9        11:181118-07-79
 0.09 0.10 0.06 0.01 0.10  2.1  0.4  9.8        12:121218-07-79
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 0.73 3.20 0.36 0.35 0.39  9.8  6.3  4.9       14:24G406-08-79
 0.79 2.00 0.33 0.23 0.28 15.0  5.8  6.2       14:30G506-08-79
 0.72 0.60 0.23 0.11 0.19 12.0  5.2  6.4       14:42G606-08-79
99.99 3.90 0.39 0.47 0.47 31.0  4.8  5.5       14:54G706-08-79
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 0.0018.50 0.20 2.20 2.40 99.9 22.4  7.3        9:301006-08-79
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1979 Intensive Survey

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 0.24 0.10 0.92 0.04 0.05 52.0  7.0 13.6        15:00G319-09-79
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0.7017.50 1.30 0.19 0.20 99.9 17.1  8.6      17:001019-09-79
1.3016.50 1.70 0.46 0.40 99.9  8.4  8.4       8:421020-09-79
0.00 0.10 0.15 0.07 0.10  1.0  2.2  8.9      11:421119-09-79
0.09 0.10 0.15 0.06 0.10  1.4  3.0  8.5      17:001119-09-79
0.10 0.10 0.14 0.02 0.10 99.9  2.3  8.8       8:421120-09-79
0.19 0.10 0.20 0.01 0.10  1.4  3.9  8.2      11:421219-09-79
0.10 0.10 0.17 0.01 0.10 99.9  2.7  8.5      17:001219-09-79
0.09 0.10 0.14 0.01 0.10  1.2  2.0  9.1       9:301220-09-79
```

1980 Slackwater Surveys

```
0.26 0.60 0.75 0.01 0.08 20.1  4.6  8.3       14:50G125-06-80
0.34 0.40 0.66 0.04 0.08 22.9  4.3  8.9       14:37G225-06-80
0.73 0.10 0.49 0.01 0.05 53.5 999. 11.4       14:25G325-06-80
0.76 0.30 0.36 0.04 0.04 63.3  4.4 12.6       14:08G425-06-80
1.48 0.30 0.33 0.06 0.13 74.2 23.9 11.2       13:50G525-06-80
0.88 0.10 0.06 0.01 0.05 45.9 13.3  6.1       13:40G625-06-80
1.70 1.90 0.71 0.18 0.21 86.3 20.2 10.1       13:30G725-06-80
1.99 4.20 1.30 0.20 0.26 43.7 13.5  7.6       13:20G825-06-80
0.19 2.10 0.48 0.03 0.10  1.3  4.5  8.0       11:00G925-06-80
1.5011.50 3.50 0.11 0.20 999. 16.1  6.3       14:151025-06-80
0.09 0.10 0.11 0.01 0.10  1.0  2.0  8.2       10:451125-06-80
0.08 0.10 0.25 0.01 0.10  2.8  1.8  9.0       15:001225-06-80
0.56 0.20 2.37 0.01 0.08 19.7  2.4  6.7       11:55G104-09-80
0.63 0.30 2.37 0.01 0.09 10.0  3.5  6.3       11:45G204-09-80
1.66 0.10 0.06 0.11 0.14 63.3 25.1 14.2       11:35G304-09-80
2.13 0.20 0.27 0.35 0.55152.4 17.4 11.9       11:10G404-09-80
2.53 0.20 0.16 0.34 0.52 81.9 18.4  9.7       11:15G504-09-80
2.07 0.10 0.06 0.05 0.25 46.9 24.2 12.4       11:20G604-09-80
3.69 2.90 0.50 0.90 1.07130.1 25.8 10.2       11:00G704-09-80
6.99 7.00 1.40 0.80 0.77 29.5 10.5  4.4       10:50G804-09-80
8.75 9.00 1.70 0.20 0.19  7.4 20.5  8.5       15:30G904-09-80
8.0010.00 1.70 0.17 0.20 999. 13.9  8.0       15:151004-09-80
0.00 3.10 0.35 0.05 0.09  6.8  0.6  8.6       15:151104-09-80
0.28 0.10 0.06 0.01 0.10  2.8  1.8  8.8       16:151204-09-80
```

1982 Slackwater Surveys

```
 0.24 0.20 1.64 0.05 0.09  8.6  3.4  6.1       14:52G119-08-82
 0.14 0.30 1.65 0.02 0.09  8.2  3.5  5.8       15:10G219-08-82
99.9999.99 0.90 0.04 0.14 59.0 11.6 14.7       15:30G319-08-82
 1.28 0.10 1.10 0.07 0.23 73.8 15.5 16.0       15:45G419-08-82
 0.92 0.10 0.23 0.04 0.16 40.1 12.4 15.0       16:04G619-08-82
 1.19 1.10 2.35 0.11 0.33 72.8 25.5 16.4       16:15G719-08-82
 1.03 2.40 3.40 0.22 0.26 39.0 17.6 11.5       16:30G819-08-82
 1.69 6.20 6.00 0.49 0.60  0.9  6.5  8.4       13:55G919-08-82
 0.00 8.90 4.70 0.55 0.70 99.9  4.5  8.8       13:401019-08-82
 0.19 0.10 0.19 0.01 0.10  1.6  2.0  9.6       13:301119-08-82
 0.27 0.10 0.46 0.02 0.10  3.8  1.8  8.6       12:151219-08-82
 0.49 0.10 0.80 0.03 0.07 29.5  5.5 10.0       11:00G123-08-82
 0.29 0.10 1.18 0.03 0.06 44.7  0.0  8.7       11:25G223-08-82
 0.08 0.10 1.28 0.03 0.04 60.1  0.0  8.2       11:40G323-08-82
 1.35 0.10 0.90 0.07 0.12 79.1  9.6 11.3       12:00G423-08-82
 0.52 0.10 0.41 0.04 0.02 82.2  1.8 11.6       12:15G623-08-82
 1.21 0.10 0.38 0.05 0.17 27.0 14.6 12.0       12:33G723-08-82
 1.78 0.60 2.7099.99 0.23 73.8 11.5 14.6       12:53G823-08-82
 0.00 9.64 6.95 1.21 1.21 0.10 5.70 8.93       13:00G923-08-82
 0.0010.40 7.50 1.30 1.30 99.9  6.0  8.9       13:101023-08-82
 0.00 0.10 0.07 0.01 0.10  1.4  2.0  9.4       12:501123-08-82
 0.09 0.10 0.26 0.01 0.10  1.4  2.0  8.5       10:251223-08-82
```

1982 Intensive Survey

```
 0.43 0.10 1.51 0.04 0.09 10.3  1.0  6.0    18:44G124-08-82
99.9999.9999.9999.9999.99 55.9 99.9  5.4    20:41G124-08-82
 0.30 0.10 1.05 0.03 0.07 28.5  3.4  9.3    22:48G124-08-82
99.9999.9999.9999.9999.99 24.9 99.9  8.4    00:43G125-08-82
 0.64 0.10 1.06 0.04 0.08 22.2  1.9  7.9    02:40G125-08-82
99.9999.9999.9999.9999.99 19.0 99.9  7.1    04:35G125-08-82
 0.35 0.10 1.51 0.05 0.05  7.0  1.2  6.1    06:43G125-08-82
99.9999.9999.9999.9999.99  8.4 99.9  6.0    08:45G125-08-82
 0.29 0.10 1.38 0.04 0.08 15.2  2.7  6.9    10:50G125-08-82
 0.17 0.10 0.90 0.03 0.09 32.9  0.9  8.7    12:51G125-08-82
 0.17 0.10 1.28 0.04 0.08 18.6  0.1  7.8    14:55G125-08-82
99.9999.9999.9999.9999.99 20.2 99.9  7.6    16:51G125-08-82
 0.23 0.20 1.61 0.10 0.09 10.1  1.1  6.5    18:42G125-08-82
99.9999.9999.9999.9999.99  8.3 99.9  6.0    20:57G125-08-82
 0.39 0.10 1.39 0.04 0.08 16.0  4.8  8.6    18:38G224-08-82
99.9999.9999.9999.9999.99  8.0 99.9  6.2    20:37G224-08-82
 0.42 0.10 1.31 0.04 0.09 11.0  3.2  6.6    22:42G224-08-82
99.9999.9999.9999.9999.99 25.3 99.9  8.6    00:38G225-08-82
 0.33 0.10 1.16 0.03 0.08 23.6  1.8  7.9    02:35G225-08-82
99.9999.9999.9999.9999.99 21.3 99.9  7.7    04:32G225-08-82
 0.42 0.10 1.50 0.04 0.06 11.8  0.7  6.2    06:38G225-08-82
99.9999.9999.9999.9999.99 14.8 99.9  6.6    08:39G225-08-82
 0.23 0.20 1.62 0.04 0.09 10.3  3.2  6.3    10:44G225-08-82
 0.15 0.10 1.17 0.03 0.09 20.9  2.7  8.6    12:45G225-08-82
 0.30 0.10 1.50 0.03 0.09 13.7  2.9  7.5    14:48G225-08-82
99.9999.9999.9999.9999.99  8.9 99.9  5.9    16:45G225-08-82
 0.23 0.20 1.61 0.04 0.09 10.1  1.1  6.2    18:37G225-08-82
99.9999.9999.9999.9999.99  7.2 99.9  5.9    20:51G225-08-82
 0.58 0.10 0.90 0.04 0.05 45.8  8.1 18.2    18:35G324-08-82
99.9999.9999.9999.9999.99 65.4 99.9 16.8    20:30G324-08-82
 0.31 0.10 1.50 0.04 0.09 13.3  2.9  7.8    22:33G324-08-82
99.9999.9999.9999.9999.99 21.1 99.9  7.4    00:34G325-08-82
 0.38 0.10 1.41 0.04 0.08 17.1  2.5  6.6    02:47G325-08-82
99.9999.9999.9999.9999.99 17.7 99.9  7.2    05:40G325-08-82
 0.38 0.10 1.41 0.04 0.05 17.7  0.4  6.8    06:32G325-08-82
99.9999.9999.9999.9999.99 19.0 99.9  7.1    08:34G325-08-82
 0.25 0.10 1.50 0.03 0.08 21.3  2.0  7.0    10:38G325-08-82
 0.26 0.10 1.29 0.02 0.08 34.2  1.7  9.0    12:39G325-08-82
 0.26 0.10 1.29 0.02 0.07 33.8  2.8  8.9    14:42G325-08-82
99.9999.9999.9999.9999.99 21.5 99.9  8.4    16:41G325-08-82
99.9999.99 0.70 0.03 0.05 53.8  5.0 11.2    18:32G325-08-82
99.9999.9999.9999.9999.99 31.0 99.9  9.6    21:10G325-08-82
99.9999.99 1.52 0.08 0.23 65.4 12.5 19.6    13:30G424-08-82
99.9999.9999.9999.9999.99 79.1 99.9 18.2    20:35G424-08-82
99.9999.99 0.70 0.05 0.13 67.5 12.2 13.8    22:28G424-08-82
99.9999.9999.9999.9999.99 99.9 99.9 12.3    00:26G425-08-82
 0.36 0.10 1.09 0.02 0.07 34.0  5.0 10.0    02:27G425-08-82
99.9999.9999.9999.9999.99 46.4 99.9 11.6    04:25G425-08-82
99.9999.99 0.50 0.05 0.13 65.4  3.0 11.3    06:24G425-08-82
99.9999.9999.9999.9999.99 59.0 99.9 10.7    08:27G425-08-82
 0.23 0.10 1.07 0.02 0.06 39.0  4.4 10.0    10:31G425-08-82
 0.10 0.10 1.29 0.01 0.06 43.2  0.9  9.5    12:32G425-08-82
 0.00 0.10 1.28 0.02 0.03 66.4  0.0  9.1    14:36G425-08-82
99.9999.9999.9999.9999.99 75.9 99.9 12.1    16:35G425-08-82
99.9999.99 2.52 0.09 0.11 86.5 16.7 12.4    18:27G425-08-82
99.9999.9999.9999.9999.99 78.0 99.9 11.4    20:32G425-08-82
```

```
99.9999.99 0.06 0.06 0.10 99.9 99.9 16.5       18:50G624-08-82
99.9999.9999.9999.9999.99 55.3 99.9 15.0       20:46G624-08-82
99.9999.99 0.60 0.07 0.13 73.8 11.5 13.8       22:41G624-08-82
99.9999.9999.9999.9999.99 71.7 99.9 12.8       00:32G625-08-82
99.9999.99 0.42 0.05 0.04 61.2 10.7 12.8       02:45G625-08-82
99.9999.9999.9999.9999.99 65.4 99.9 11.0       04:47G625-08-82
99.9999.99 0.2299.99 0.14 60.1  5.1  8.8       06:36G625-08-82
99.9999.9999.9999.9999.99 66.4 99.9  8.8       08:32G625-08-82
 0.32 0.10 0.50 0.04 0.05 53.8  9.4 10.4       10:35G625-08-82
 0.39 0.10 0.60 0.04 0.09 59.0  5.7 12.5       12:33G625-08-82
99.9999.99 0.50 0.04 0.04 61.2 10.7 14.8       14:39G625-08-82
99.9999.9999.9999.9999.99 67.5 99.9 16.1       16:33G625-08-82
99.9999.99 0.40 0.04 0.09 99.9 99.9 17.1       18:26G625-08-82
99.9999.9999.9999.9999.99 70.6 99.9 14.9       20:30G625-08-82
 0.09 0.10 0.12 0.01 0.10  1.6  2.0  7.6       18:351A24-08-82
99.9999.9999.9999.9999.99  2.9 99.9 99.9       20:351A24-08-82
 0.41 0.10 0.06 0.05 0.17 27.6 12.3 99.9       22:351A24-08-82
99.9999.9999.9999.9999.99 30.2 99.9 99.9       00:301A25-08-82
 0.37 0.10 0.08 0.04 0.10  4.6  7.0  8.1       02:301A25-08-82
99.9999.9999.9999.9999.99  2.6 99.9 99.9       04:301A25-08-82
 0.09 0.10 0.13 0.02 0.10  2.1  3.9  8.1       06:301A25-08-82
99.9999.9999.9999.9999.99  4.6 99.9 99.9       08:351A25-08-82
 0.48 0.10 0.07 0.04 0.05 45.4  8.5  7.6       10:351A25-08-82
99.9999.9999.9999.9999.99 14.8 99.9 99.9       12:351A25-08-82
99.99 0.10 0.14 0.01 0.10 99.9 99.9  7.6       14:351A25-08-82
99.9999.9999.9999.9999.99  7.2 99.9 99.9       16:351A25-08-82
99.99 0.10 0.13 0.02 0.10 99.9 99.9  6.8       18:351A25-08-82
99.9999.9999.9999.9999.99  1.0 99.9 99.9       20:351A25-08-82
99.9999.99 1.75 0.09 0.22 83.3 12.7 15.8       19:03G724-08-82
99.9999.9999.9999.9999.99 78.0 99.9 17.3       20:54G724-08-82
99.9999.99 1.7699.99 0.23 73.8 20.3 13.7       22:54G724-08-82
99.9999.9999.9999.9999.99 99.9 99.9 13.6       00:41G725-08-82
99.9999.99 1.11 0.08 0.12 77.6 13.3 12.9       02:57G725-08-82
99.9999.9999.9999.9999.99 80.2 99.9 12.6       04:57G725-08-82
99.9999.99 0.45 0.07 0.13 70.6  7.7 11.0       06:47G725-08-82
99.9999.9999.9999.9999.99 77.0 99.9 10.2       08:40G725-08-82
99.9999.99 0.39 0.05 0.07 27.4 16.7 10.1       10:44G725-08-82
99.9999.99 0.60 0.05 0.22 99.9 99.9 12.4       12:43G725-08-82
99.9999.99 0.90 0.08 0.12 80.2  8.6 13.9       14:54G725-08-82
99.9999.9999.9999.9999.99 81.2 99.9 15.4       16:41G725-08-82
99.9999.99 0.40 0.08 0.12 80.2 17.4 16.4       18:34G725-08-82
99.9999.9999.9999.9999.99 80.2 99.9 14.7       20:37G725-08-82
99.99 5.20 5.99 0.60 0.69 99.9 99.9 12.3       19:13G824-08-82
99.9999.9999.9999.9999.99 77.0 99.9 17.2       21:04G824-08-82
99.9999.99 1.2499.99 0.23 72.8  0.0 13.6       23:07G824-08-82
99.9999.9999.9999.9999.99 80.2 99.9 13.5       00:47G825-08-82
99.9999.99 1.24 0.08 0.13 70.6  9.7 12.5       03:07G825-08-82
99.9999.9999.9999.9999.99 81.2 99.9 13.0       05:07G825-08-82
99.9999.99 1.3999.99 0.22 81.2 18.2 12.0       07:02G825-08-82
99.9999.9999.9999.9999.99 67.5 99.9  8.5       08:45G825-08-82
99.9999.99 0.60 0.06 0.13 71.7 11.8 10.5       10:50G825-08-82
99.9999.99 0.70 0.06 0.21 75.9  8.9 10.9       12:52G825-08-82
 0.71 3.10 4.50 0.40 0.53 70.6 20.7 14.9       15:02G825-08-82
99.9999.9999.9999.9999.99 53.8 99.9 15.3       16:48G825-08-82
99.9999.99 3.0099.99 0.21 90.7 27.2 19.6       18:42G825-08-82
99.9999.9999.9999.9999.99 70.6 99.9 14.9       20:43G825-08-82
```

```
 0.77 7.20 6.97 1.30 1.40  3.8 30.4  5.8      18:351P24-08-82
99.9999.9999.9999.9999.99  4.0 99.9 99.9      20:351P24-08-82
 0.48 7.70 6.99 1.30 1.40  3.2 17.2 99.9      22:351P24-08-82
99.9999.9999.9999.9999.99  3.2 99.9 99.9      00:351P25-08-82
 0.00 6.40 7.00 1.20 1.30  2.0 13.6  4.9      02:301P25-08-82
99.9999.9999.9999.9999.99  1.4 99.9 99.9      04:301P25-08-82
99.99 6.50 6.50 0.90 0.93 99.9 99.9  4.9      06:301P25-08-82
99.9999.9999.9999.9999.99  4.1 99.9 99.9      08:351P25-08-82
 0.00 6.50 6.50 0.90 1.00  1.9 16.3  5.0      10:351P25-08-82
99.9999.9999.9999.9999.99  2.7 99.9 99.9      12:351P25-08-82
 0.00 6.30 6.50 0.80 0.90  1.3 17.5 99.9      14:351P25-08-82
99.9999.9999.9999.9999.99  3.6 99.9 99.9      16:351P25-08-82
 0.00 6.40 6.50 0.60 0.70  4.3 14.3 99.9      18:351P25-08-82
99.9999.9999.9999.9999.99  2.5 99.9 99.9      20:351P25-08-82
 0.00 9.80 6.49 1.40 1.40 99.9  6.6  8.1      19:451024-08-82
 0.20 9.50 6.00 1.00 1.45 99.9 10.8  7.8      19:351025-08-82
 0.09 0.10 0.08 0.03 0.03  1.7  2.4  7.4      19:301124-08-82
 0.09 0.10 0.08 0.01 0.03  0.8  2.3  7.6      19:351125-08-82
 0.07 0.10 0.19 0.03 0.03  4.8  2.1  7.4      20:001224-08-82
 0.19 0.10 0.16 0.01 0.02  1.4  1.2  8.0      19:351225-08-82
```

Appendix C. Predicted and Observed 1979 Background Inputs

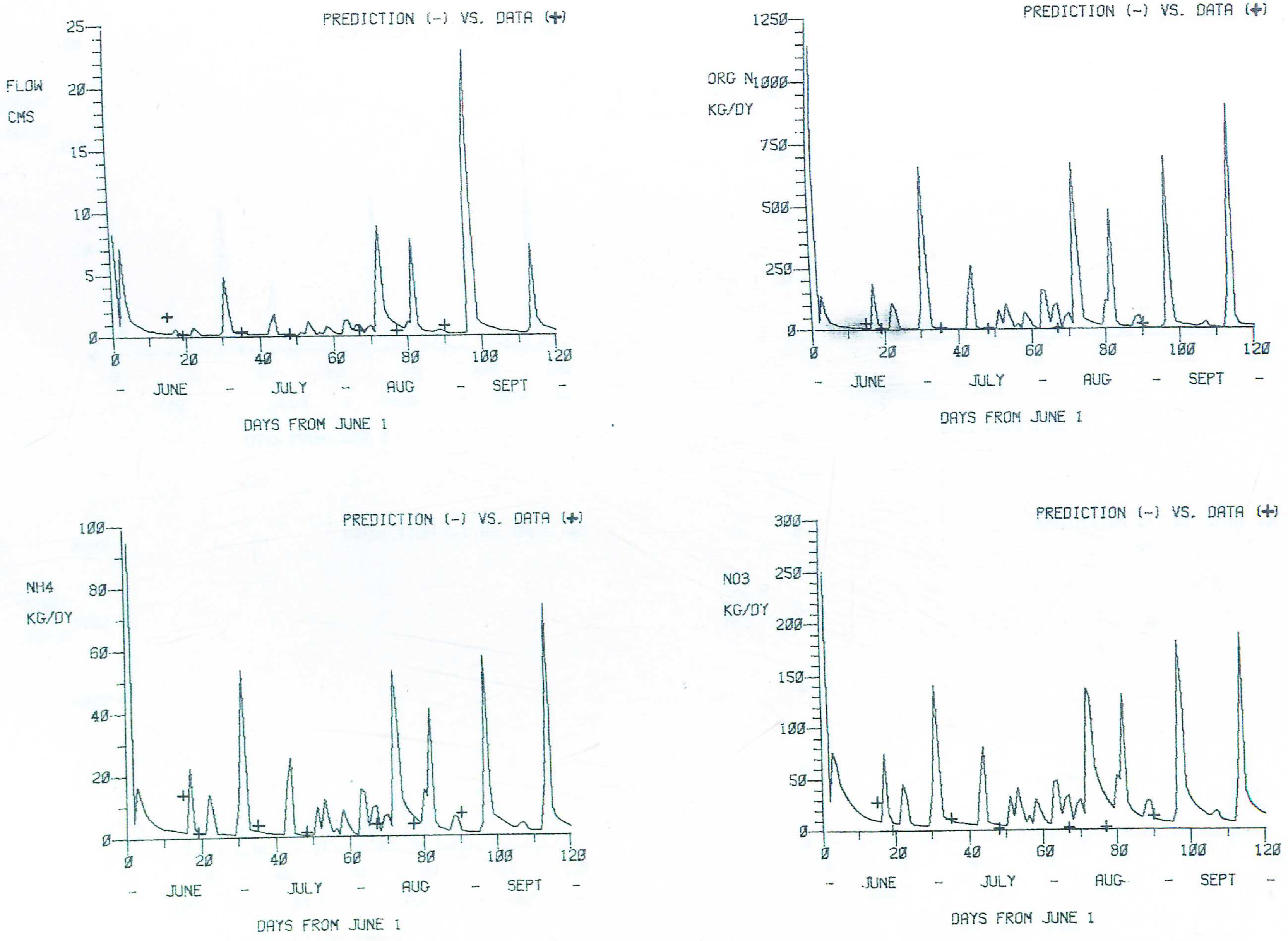

Figure G1. 1979 Background Flows from Pohick Creek.

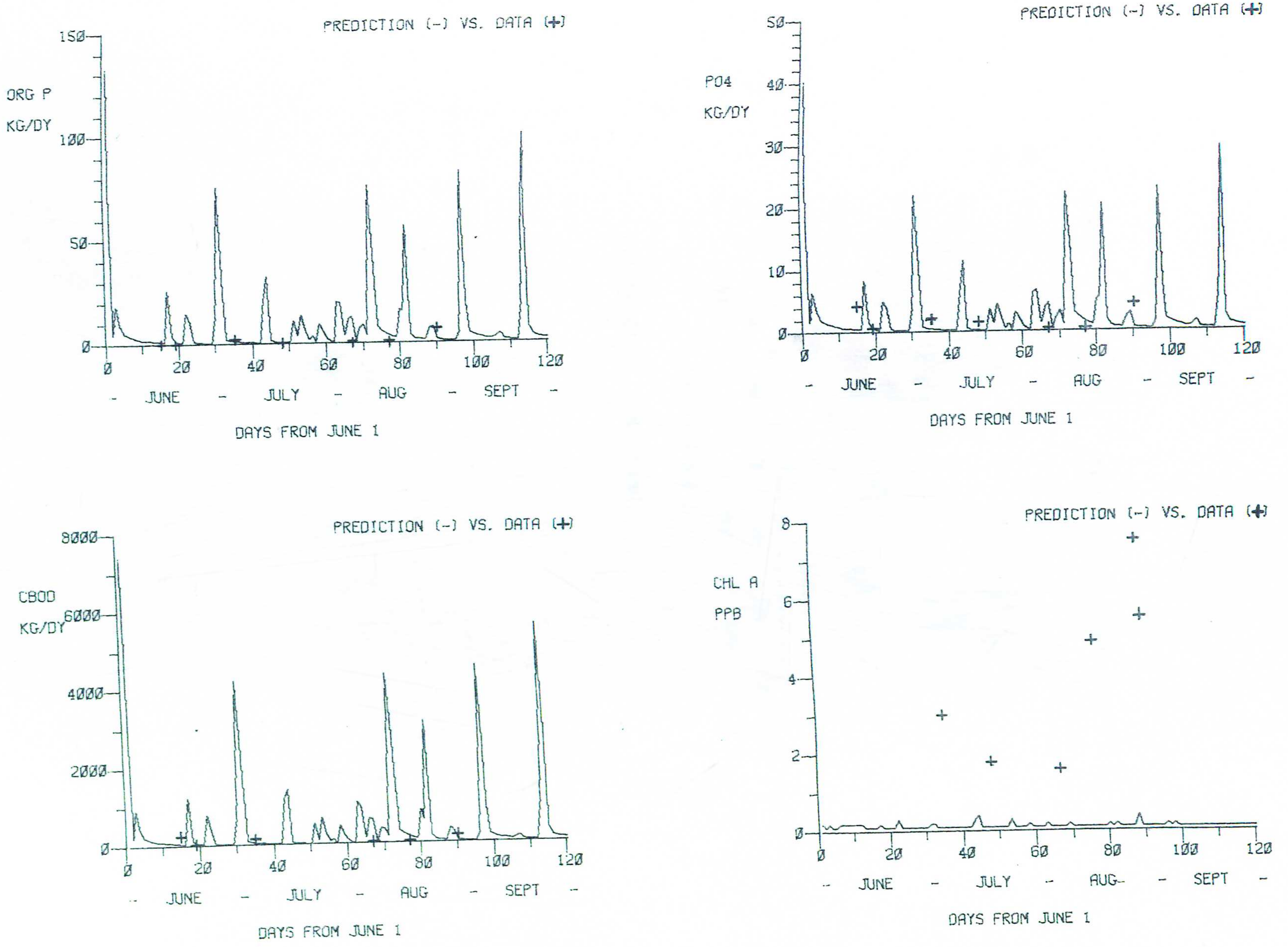

Figure C1. Continued.

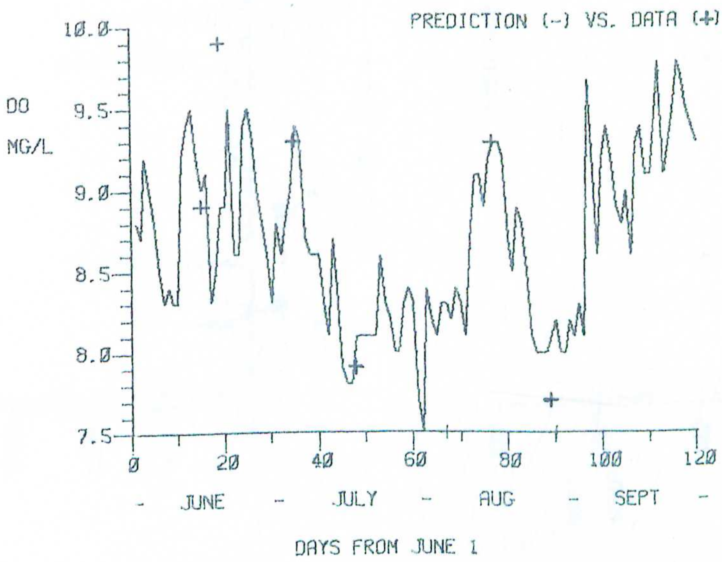

Figure C1. Continued.

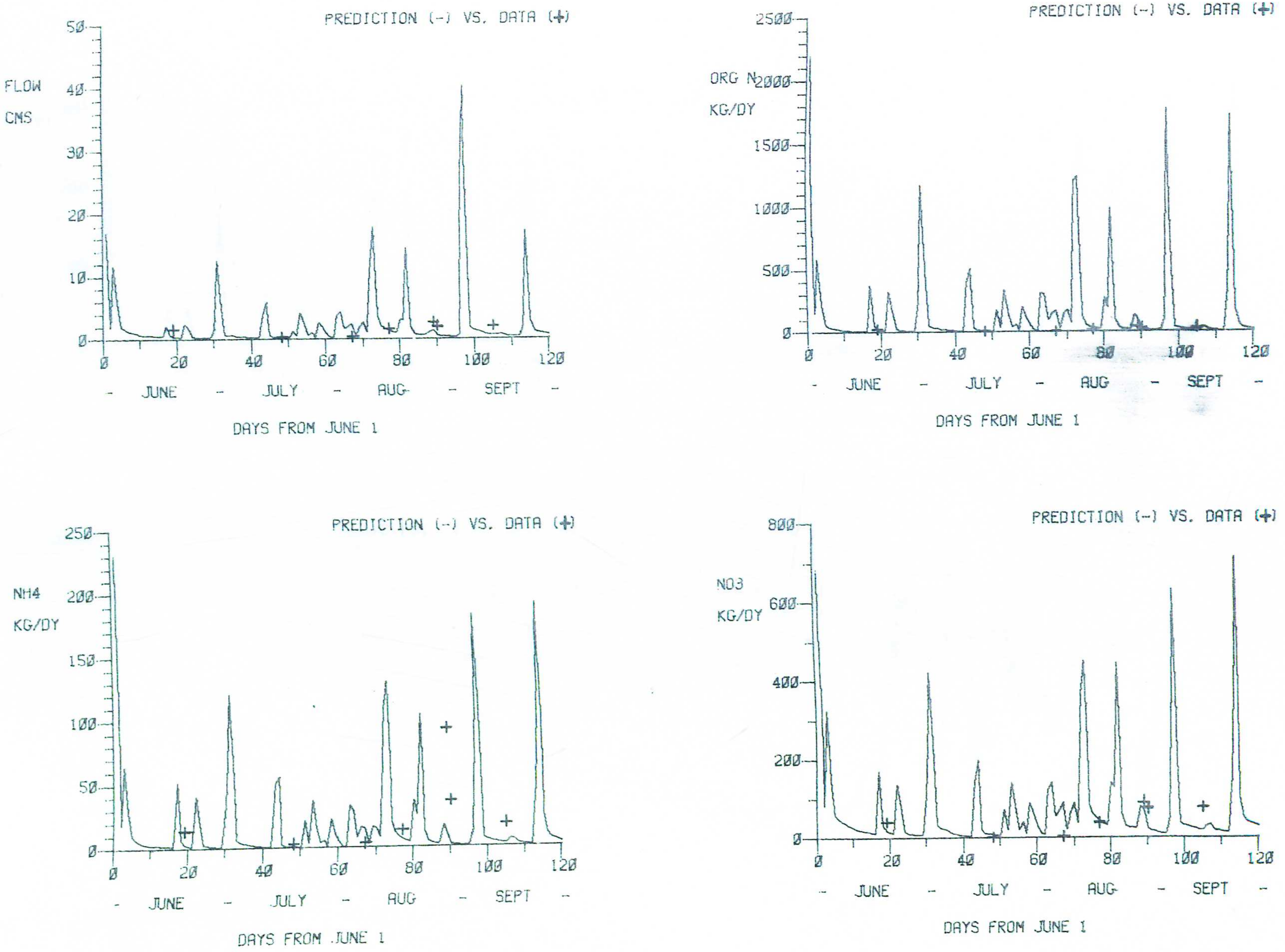

Figure C 2. 1979 Background Flows from Accotink Creek.

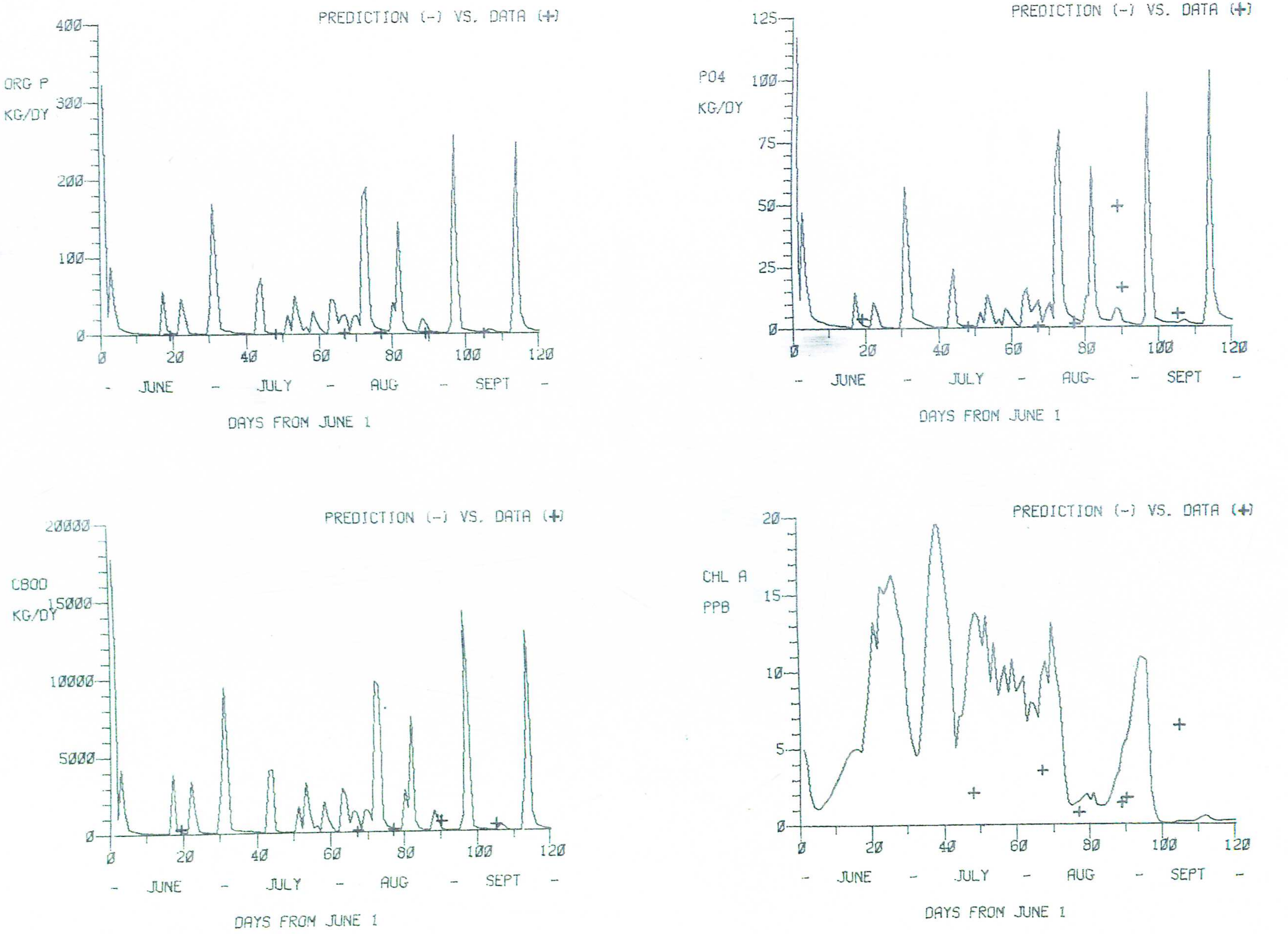

Figure G2. Continued.

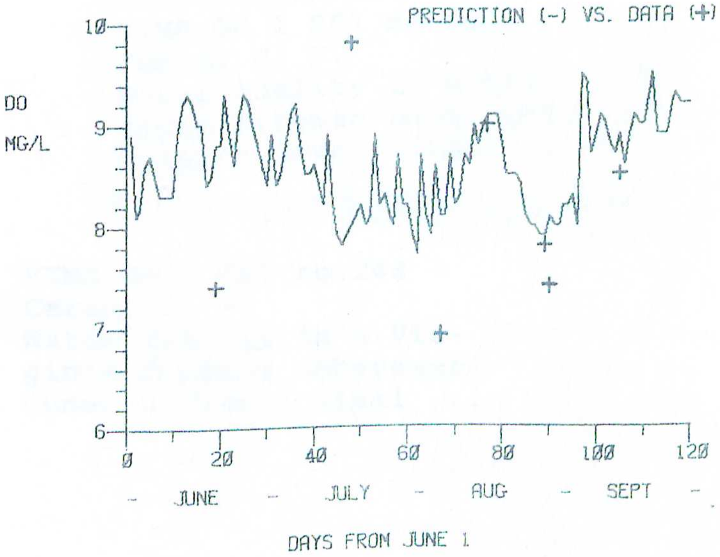

Figure C2. Continued.