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Sediment oxygen demand in Hunting Creek and the Potomac River

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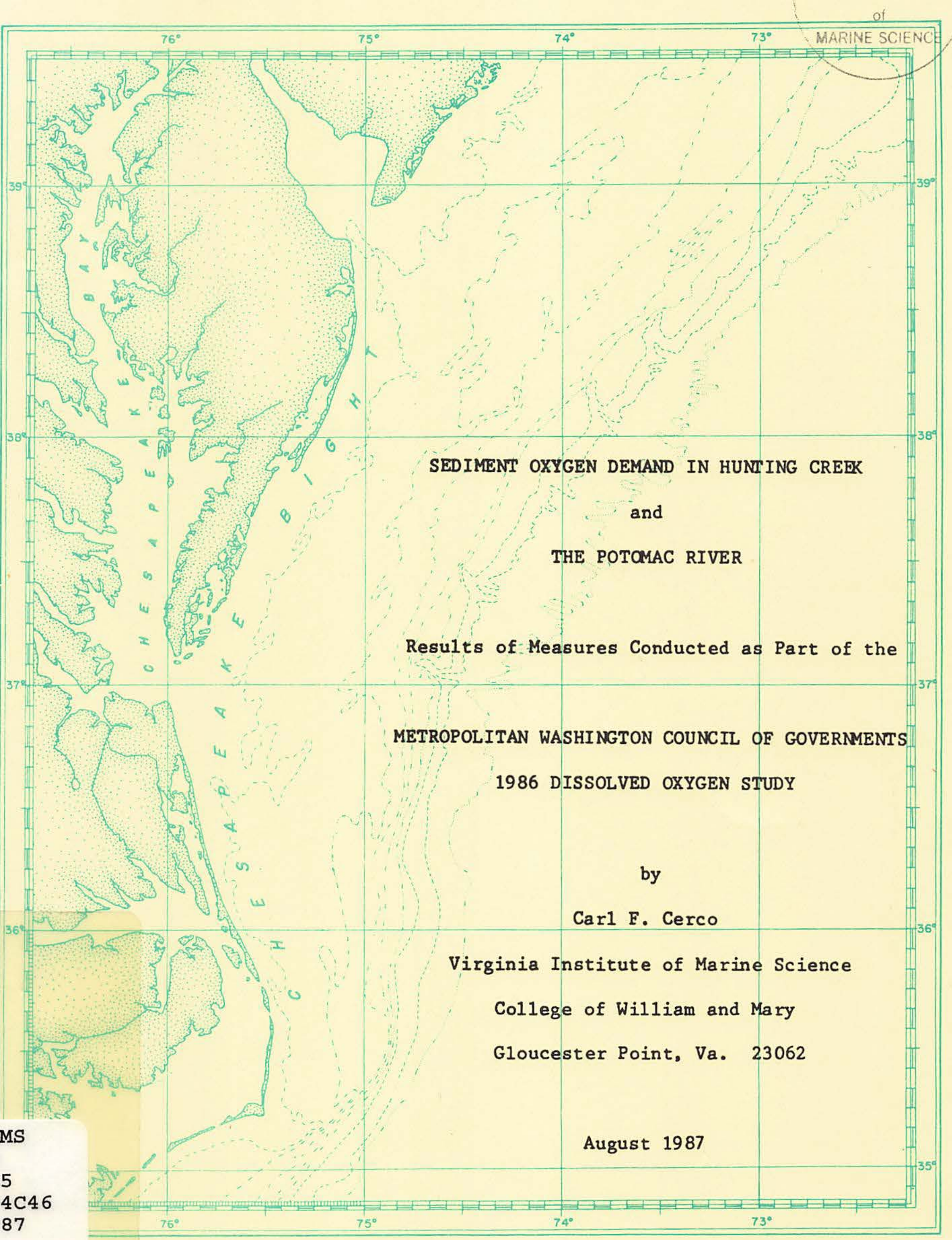

SEDIMENT OXYGEN DEMAND IN HUNTING CREEK

and

THE POTOMAC RIVER

Results of Measures Conducted as Part of the

METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS
1986 DISSOLVED OXYGEN STUDY

by

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August 1987

SEDIMENT OXYGEN DEMAND IN HUNTING CREEK

Final Report

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Samuel Wilson, Karl Dydak and Mark Worrall of the VIMS technical staff spent long hours in the laboratory and in the sun conducting sediment oxygen demand measures. This report would not have been possible without their endeavors.

SUMMARY AND CONCLUSIONS

Sediment oxygen demand measures were conducted in Hunting Creek during the period June 17 to August 19, 1986. A total of 25 measures were conducted in-situ using benthic respirometers (SOD cylinders) and 11 measures were conducted in the laboratory on intact sediment cores. The mean of the in-situ measures was 3.1 $gm/m^2/day$ and the range was 1.3 to 7.2 $gm/m^2/day$. The mean of the laboratory measures was 1.9 $gm/m^2/day$ and the range was 0.6 to 4.8 $gm/m^2/day$.

A comparison of in-situ and laboratory measures, which took into account spatial and temporal variations in SOD and the influence of ambient dissolved oxygen concentration, indicated SOD measured in situ exceeded SOD measured in the laboratory by an average factor of 4. Analysis linked the discrepancy in results to different velocities inside the types of measurement devices. Sediment oxygen demand increased as velocity increased. Velocity in the SOD cylinders was nearest ambient velocity in Hunting Creek and for that reason the in-situ measures are preferred over the laboratory measures.

Experiments conducted on sediment cores indicated disturbance of the sediment surface could increase sediment oxygen demand by a factor of 2 or 3. Evidence that deployment of in-situ measurement devices disturbed the sediments sufficiently to induce sediment resuspension was inconclusive, however. No evidence was found that deployment of in-situ devices induced release of oxygen-demanding materials from the sediments. Investigation of this issue was limited, however, and additional investigation is suggested.

Sediment oxygen demand measured in-situ at Stations 1 to A was linearly dependent on ambient dissolved oxygen concentration. SOD increased approximately 0.7 $gm/m^2/day$ for every 1 mg/L increase in DO. Laboratory measures at Station 3 indicated a decline in sediment oxygen demand from June to August. This decline was qualitatively associated with a decline in bioturbation. Macroinvertibrates were present at the sediment-water interface during the earlier measures but absent during the later measures.

Mean sediment oxygen demand measured in-situ during 1986 was almost identical to the mean of measures conducted during 1980 to 1982. More detailed analysis, which took into account spatial and temporal variations in SOD and the influence of ambient dissolved oxygen concentration, suggested SOD declined from 1982 to 1986 by approximately 0.5 $gm/m^2/day$ at Stations 1, 2 and 3. The significance of this decline is doubtful, however, in view of the precision of the methodology and limitations of the analysis. Observations conducted at Station 4 suggested SOD increased at that station from 1981 to 1982 and has remained at the higher value.

INTRODUCTION

Hunting Creek is a freshwater tidal embayment tributary to the Potomac River. The embayment is located on the border between the city of Alexandria and Fairfax County, Virginia, and receives waste discharges from a treatment facility operated by the Alexandria Sanitation Authority (ASA). Water quality surveys were conducted in Hunting Creek during the summer of 1979 and 1980 and a mathematical model based on the 1979 observations has been applied to the embayment (Cerco and Kuo, 1983). The surveys showed that during July and August 1979 and August 1980 dissolved oxygen (DO) downstream of the plant outfall was in the range 2 to 5 mg/L. Measurements of sediment oxygen demand (SOD) and model sensitivity analysis indicated that SOD was a major contributor to the DO deficit downstream of the outfall. At the time of this writing, the model is being used to examine alternatives for managing water quality in Hunting Creek. Sediment oxygen demand in the model is based on observations conducted during 1979 and 1980. The question arises whether these measures are respresentative of the present SOD in the embayment. Improvements implemented since 1979 at the ASA facility, notably a reduction in total suspended solids (TSS) concentration in the effluent, lead to the hypothesis that SOD is now less than previously measured. The primary purpose of this study was to measure the present sediment oxygen demand in Hunting Creek.

Sediment oxygen demand measures were conducted in Fourmile Run, another Potomac embayment, during July 1981. A secondary purpose of this study was to re-examine SOD in Fourmile Run.

METHODOLOGY

Sediment oxygen demand was measured by isolating an area of sediment in contact with an overlying parcel of water. Sediment uptake of oxygen was indicated by the decline in DO concentration in the water. In some instances, the measures were conducted in-situ by placing a chamber at the sediment-water interface. Alternately, measures were conducted on intact sediment cores removed to a laboratory. The devices and methods employed are described in more detail below.

SOD Cylinder

The primary device employed in this study is an in-situ benthic respirometer. The device is referred to as an "SOD cylinder" due to its purpose and shape. The cylinder is constructed of opaque PVC pipe closed at one end and open at the other. The pipe is 30 cm in diameter and 21 cm long. In operation, the pipe is lowered into the sediments, open end first, so that a fixed volume of water is entrapped in contact with a sediment surface of known area. Weights on the device ensure that it penetrates the sediments while a flange around the circumference ensures that it does not penetrate too far. Installed, the cylinder has a height of 13 cm and encloses 700 cm^2 of sediment in contact with 9200 cm^3 of water. Water is circulated through the device at a rate of 470 cm^3/sec by a bilge pump mounted on top. Water is pumped from the chamber past a Yellow Springs Instruments (YSI) model 5739 DO probe and returned to the chamber. The return jet is directed towards the cap of the cylinder to avoid erosion of the sediment surface.

The SOD cylinder measures the total oxygen consumption in the enclosed sediment and water. In order to isolate the oxygen consumption of the sediment alone, the oxygen consumption of the water must be measured separately and subtracted from the total. Oxygen consumption in the water is measured in a cylinder called a "control". The control cylinder is identical to the SOD cylinder except that it is sealed at the bottom so it contains water not in contact with the sediments.

A typical SOD measure was conducted in the following manner. A johnboat was anchored at the station and the depth and current direction were noted. Measures or samples for analysis of ambient temperature, DO concentration, pH, and conductivity were collected at one to three depths. DO probes were air calibrated according to manufacturers instructions and installed in two SOD cylinders and one control. The cylinders were slowly lowered to the creek bottom from opposite ends of the boat in order to obtain two simultaneous SOD measures conducted five meters apart. In locations at which Hydrilla was present, cylinders were lowered over patches of bottom free of rooted plants. After the cylinders were installed, the control was filled with ambient water and lowered to the bottom. DO concentration in each device was monitored at two to five-minute intervals on a YSI Model 54A Dissolved Oxygen Meter. Measures lasted aproximately 90 minutes during which DO declined roughly 2 mg/L in the SOD cylinders and less than 0.2 mg/L in the control. After the devices were recovered, the calibration of the probes was checked and the magnitude of any drift recorded.

The SOD cylinders employed in 1986 differ in two regards from the devices employed in the earlier study. The older cylinders were 10 cm in height and were mixed by a stirrer rather than a pump-driven circulation system. In order to compare the performance of the older and newer cylinders, an old and new cylinder were deployed side by side on one occasion.

Nutrient Dome

On one occasion, a different set of respirometers was employed. These devices are primarily intended to measure the exchange of nutrients between sediments and overlying water but can be used to measure SOD as well. The "nutrient domes" are hemispherical chambers 46 cm in diameter. They enclose 25000 cm^3 of water and 1640 cm^2 of sediment. The primary difference in the nutrient domes and SOD cylinders is in the circulation system. The circulation system of the nutrient domes may be operated in an open or closed mode. In the closed mode, internal water is circulated, at a rate of 150 cm^3/sec, out one side of the dome and returned through the opposite side. In the open mode, internal water is pumped to the outside environment while fresh ambient water is drawn in the opposite side of the dome. The circulation system is also designed to allow removal of water samples from inside the dome.

The nutrient dome emplacement was conducted in the following manner. Two nutrient domes, open to the sediments at the bottom, were lowered from opposite sides of the johnboat. A third dome, closed at the bottom and not in contact with sediments, was used as a control. Immediately after the installation, samples for analysis of TSS and immediate oxygen demand (IOD) were removed from the domes. Following collection of the initial samples, the circulation system was opened and the domes were flushed with external water for 20 minutes. This procedure was intended to flush out any dissolved or particulate matter which may have been released from the sediments when the domes were installed. Next, samples for analysis of DO, TSS, and IOD were removed from the domes and the circulation systems closed. Subsequent DO samples were removed at hours 1.0, 2.5, 4.0, and 5.5 after collection of the initial sample. Removal of a TSS sample at hour 5.5 completed the nutrient dome emplacement. During the 5.5 hour period, DO in the domes open to the sediments declined roughly 2 mg/L.

Laboratory Cores

Laboratory measures of sediment oxygen demand were conducted on intact sediment cores removed from Hunting Creek and Fourmile Run. A diver collected cores and overlying water in transparent acrylic tubes 40 cm long and 10 cm in diameter. Sediment occupied roughly half the length of the tube. Following collection of the cores, ambient water was pumped into a carboy and the cores and carboy were transported to a laboratory. At the lab, a description of each sediment core was noted and depth of water overlying each core was measured at 4 places around the circumference of the column. Water in the carboy was pumped though a series of one-micron string filters in order to remove the majority of particulate matter. Water overlying the sediment cores was siphoned off and replaced with the filtered water. This procedure removed material which may have been released from the sediments during collection of the cores and reduced respiration and oxidation of particulates in the ambient water. A control column, identical to the sediment columns except it contained only water, was set up. This column measured residual oxygen consumption in the filtered water. Each column was fitted with an air-tight cap into which was inserted a YSI Model 5720A Self-Stirring BOD Bottle Probe. The probe continuously stirred the water and measured DO concentration during the course of the SOD measure. A baffle was placed around the stirrer so that water overlying the sediments was in motion but no resuspension of particulates occurred. The BOD probes were air calibrated immediately before and after each measure and any drift which occurred during the course of the measure was noted.

SOD measures were primarily conducted in a lab at the ASA treatment facility and were initiated within six hours of collection of the cores. In one instance, cores were transported to the VIMS lab at Gloucester Point and SOD measures initiated 24 hours after core collection. For purposes of comparison, several cores were collected on the same day or the day following an in-situ SOD measure. Laboratory SOD measures lasted 2 to 4 hours during which DO concentration was recorded at 15 to 30 minute intervals. DO usually declined 1 to 2 mg/L in the sediment cores and less than 0.4 mg/L in the controls.

Great care was taken not to disturb the sediment surface during collection of the cores or during subsequent SOD measures. In one instance, a core was knocked to the floor causing sediment resuspension and noticeable turbidity in the overlying water. An SOD measure on this core indicated enhanced sediment oxygen demand. This incident prompted several additional measures of the effect of sediment disturbance on SOD. Following SOD measures on undisturbed cores, the cores were turned horizontal and shaken until noticeable sediment was resuspended into the overlying water. In one instance, sediment resuspension was accompanied by release of gas from the sediments. The cores were returned to the vertical and SOD measures conducted as detailed above. Control columns were not run simultaneously with the disturbed cores. Oxygen consumption in the filtered water which initially overlay the cores was determined to be negligible during measures conducted simultaneously with the undisturbed cores.

Analysis of SOD Data

Raw data from both in-situ and laboratory SOD measures consisted of a time series of dissolved oxygen concentrations. Linear regression was used to fit a line to the series and obtain the slope, in mg/L/hour. The slope was multiplied by the volume of the overlying water, divided by the sediment area, and multiplied by a conversion factor to yield sediment oxygen demand in gm/m^2/day. The decline of DO with time in the lab cores, the nutrient domes, and some SOD cylinders was roughly linear (Fig 1). Numerous SOD cylinders, however, indicated a break in the DO vs. time curve approximately 15 minutes into the measure (Fig 2). Dissolved oxygen declined steeply at first and then declined less steeply. The initial steep decline was interpreted as a transient effect perhaps induced during installation of the devices. Therefore, the first 15 minutes DO observations in the SOD cylinders were neglected in the linear regression.

An apparent SOD was computed for each of the control devices and subtracted from the combined sediment and water-column oxygen demand in the sediment devices. In rare instances, DO in the control devices increased rather than decreased. The increase may have been caused by photosynthethic oxygen production or by seepage of oxygen into the control devices.

Probe drift during both lab and field measures was usually less than + or - 0.2 mg/L although drift in excess of 0.4 mg/L did occur. Drift was negligible compared to the DO consumption in the SOD cylinders. Drift was of the same magnitude as DO consumption in the control cylinders, however, and complicated interpretation of the controls. DO consumption in the control cylinders was considered to be zero unless a distinct trend of greater magnitude than the probe drift was noted. Observations in both sediment and control laboratory columns were corrected for probe drift.

Additional Data Collection and Analysis

Records and measures were made of conditions at the time the in-situ SOD measures were conducted. Weather conditions and depth of water flowing over the broad wier at the head of Hunting Creek were recorded daily. Water depth and current direction at the initiation of each measure were noted. Dissolved oxygen, temperature, pH, and conductivity were measured at mid-depth and occasionally at the top (30 cm below surface) and bottom (30 cm above bottom) of the water column. DO and temperature were usually measured with a YSI Model 5739 Dissolved Oxygen Probe fitted with a Model 5795A Submersible Stirrer. The probe was air calibrated prior to each use. In some instances, water samples were collected, "fixed" in the field, and analyzed for DO via azide-modified Winkler titration according to Standard Methods (American Public Health Association, 1976). The pH was measured by collecting a sample in a 250 mL bottle and immediately inserting an Orion Phi 21 pH probe into the mouth. The probe was calibrated in the field prior to each use. Samples for analysis of conductivity were returned to VIMS and analyzed on a Beckman Model RS7B Induction Salinometer. The salinometer indicated the conductivity ratio of the sample compared to the conductivity of seawater at $22.5\ C^{o}$. Conductivity ratio was converted to conductivity, in mmho/cm, through multiplication by 42.9.

Dissolved oxygen samples from the nutrient domes were fixed in the field and analyzed by Winkler titration. Both the DO titration and the analysis of total suspended solids were according to Standard Methods (American Public Health Association, 1976). IOD samples were collected in 300 mL BOD bottles, kept at ambient temperature, and transported to a lab at the ASA facility. Less than 2 hours elapsed between collection of the sample and measurement of initial DO with a freshly-calibrated Model 5720A

BOD probe. The samples were incubated for 4 hours at room temperature. At the end of the incubation, probe calibration was checked and a final DO measure taken.

SAMPLE PROGRAM

The program of experiments was conducted from June 17 to August 19, 1986. During that period, 25 in-situ SOD cylinder measures were conducted at 9 stations in Hunting Creek. Ambient dissolved oxygen concentration at initiation of the measures ranged from 1.5 to 7.3 mg/L and ambient temperature ranged from 23 to 29 C^{o}. A total of 11 laboratory SOD measures on intact cores and 4 measures on disturbed cores were conducted at 3 stations in Hunting Creek. Dissolved oxygen in the water overlying the cores at initiation of the measurements ranged from 4.3 to 7.3 mg/L and temperature ranged from 25 to 30 C^{o}. Replicate in-situ nutrient domes were installed at a single station at a time when ambient DO was 4.0 mg/L and temperature was 26 C^{o}. The station, date, and nature of measurements are summarized in Table 1.

Hunting Creek sample stations are shown in Figure 3. The figure indicates revisions in station location from the map which accompanied the COG RFP. Station C was moved to an area accessible by boat and free of Hydrilla. A new station, designated E, was inserted between Stations 1 and 2. Measurements at Station A were conducted 50 m upstream of the ASA outfall but downstream of Hooff Run.

A total of 3 in-situ SOD cylinder measures were performed at 2 stations in Fourmile Run. A pair of lab SOD measures were performed on cores removed from a single station. Ambient DO at initiation of the in-situ measures was 5.1 to 5.9 mg/L and temperature was 25 to 26 C^{o}. DO in the water overlying the lab cores was initially 7.5 to 7.6 mg/L and temperature was 26 C^{o}. Fourmile Run stations are shown in Figure 4.

RESULTS

Sediment cores collected in Hunting Creek consisted largely of sand. A longitudinal gradient in sand content was evident. Cores collected near the mouth had a layer of organic matter and/or silt on the surface while cores collected near the head of the creek were exclusively sand. Worms and insects were present in the cores collected in June but no biological activity was initially evident in the cores collected in August. Worms emerged from cores collected in August and held several days but burrows were not present at the time SOD measures were conducted.

The mean of the in-situ cylinder SOD measures, 3.1 gm/m^2/day, was 60% higher than the mean SOD in the intact lab cores, 1.9 gm/m^2/day. Similar ratios were evident between the extremes of the in-situ and laboratory measures (Table 2). Mean coefficient of variation of replicate in-situ measures, 0.20, was similar to mean coefficient of variation of replicate laboratory measures, 0.23. Mean SOD in the disturbed cores was almost 50% higher than in the undisturbed cores. SODs measured employing the nutrient domes were among the lowest of all observations. SOD measured in the stirred cylinder was within the range of SOD measured with the pump-driven cylinder.

Sediment cores collected in Fourmile Run consisted of silt and the sediment surface was perforated by worm tubes. Mean SOD measured in situ, 7 gm/m^2/day, was more than triple the mean SOD measured in the lab, 2 gm/m^2/day.

DISCUSSION

The results indicate the mean SOD measured in-situ is higher than the mean SOD measured in the lab. Statistical hypothesis testing strongly suggests the difference in means is genuine rather than an artifact of random variability in the observations ($0.01 < p < 0.025$). A primary issue to be investigated is whether the in-situ and laboratory measures are truly inconsistent. The difference in the means alone does not confirm that SOD measured by the two methodologies is different. The difference in means may be an artifact of the number of measures and stations investigated by each method or of the ambient conditions which prevailed when the measures were taken. If the in-situ and laboratory methods do yield different results, questions arise as to why the differences occur and which methodology gives results which approximate actual sediment oxygen demand in Hunting Creek.

Dissolved Oxygen, Temperature, and Spatial Variability

Dissolved oxygen concentration in the water column is a fundamental variate which affects sediment oxygen demand. As DO becomes unavailable, oxygen consumption in the sediments must decline. Temperature is another fundamental variate. As temperature increases, microbial activity in the sediments is enhanced and sediment consumption of oxygen increases. Spatial variability in SOD may be caused by differences in physical properties of the sediment, by differences in nature and activity of benthic infauna, or by differences in the supply of organic substrate to the sediments.

Dissolved oxygen and temperature were not controlled during these experiments and differed during laboratory and in-situ SOD measures conducted at the same station. If SOD is dependent on these two variables, comparison of SODs measured under different ambient conditions requires that the observations be corrected to account for the differences. Laboratory SOD measures were conducted at fewer stations than in-situ measures. If spatial variability is present in SOD, then laboratory and in-situ comparisons should be conducted on a station-by-station basis.

The in-situ cylinder measures demonstrate a linear dependence of SOD on dissolved oxygen (Figure 5). The equation which describes the dependence is

$$SOD = 0.63 + 0.54 * DO \tag{1}$$

in which SOD is sediment oxygen demand ($gm/m^2/day$) and DO is dissolved oxygen concentration (mg/L). For this relationship, $r^2 = 0.37$ and $0.001 < p < 0.002$. An interpretation of the statistics is that variations in ambient dissolved oxygen account for 37% of the total variation observed in in-situ SOD. The probability that this relation occurs by chance is less than 0.2%.

The residual variability in in-situ SOD, after the effects of DO were removed, was examined for effects of temperature and for spatial trends. No influence of temperature was evident, most likely because the range of temperature during the observation period was limited to 6 C^o. Some spatial variability was apparent, however. SOD measured at Stations 1 to A tended to be higher than predicted by Equation 1 while SOD measured at stations 4 and 5 tended to be lower than predicted. This grouping of residuals suggested that SOD at Stations 4 and 5 was fundamentally different than at the stations farther downstream. This finding was consistent with the observation that cores collected at Station 4 contained more sand than cores collected at Stations E, 3, or A.

SOD's measured at Stations 1 to A and Stations 4 and 5 were separated into groups and individual examinations of the effects of DO on SOD within the groups were conducted. The dependence of sediment oxygen demand on dissolved oxygen at Stations 1 to A was found to be

$$SOD = 0.29 + 0.73 * DO \qquad (2)$$

The r^2 for the relationship was 0.69 and $p < 0.001$. The statistics imply that variations in dissolved oxygen account for virtually 70% of the variability in SOD measured in situ at Stations 1 to A.

No significant relationship was found between DO and SOD observed in-situ at Stations 4 and 5. Absence of a discernable relationship is due, in part, to lack of SOD measures conducted at DO concentrations below 3 mg/L. The observations also indicate, however, that at DO concentrations of 5 to 7 mg/L, SOD at Stations 4 and 5 is limited to lower values than farther downstream. In the absence of any relationship to DO, SOD measured in-situ at Stations 4 and 5 is best described by the mean of all observations, 2.3 $gm/m^2/day$.

No relationship was evident between dissolved oxygen and sediment oxygen demand of intact cores removed from Hunting Creek. Absence of a relationship is likely due to the narrow range of dissolved oxygen, 4.3 to 7.3 mg/L, which prevailed at initiation of the measures. Neither were any influences of temperature or spatial variability detected in the data. Absence of these effects is attributed to the narrow range of temperatures encountered, 25 to 30 C^o, and to the limited number of stations investigated.

Temporal Variability

Sediment oxygen demand may change in the course of a season due to variations in supply of organic matter, density of benthic fauna or other factors. Temporal changes in SOD are considered to be independent of the effects of dissolved oxygen and temperature which also change as the season progresses. No distinct seasonal trend in SOD was evident in the in-situ data collected from June 30 to August 19. SOD measures performed on intact cores removed from Station 3 showed a significant decline from June 17 to August 5, however. During that period, SOD at Station 3 declined from approximately 3.9 $gm/m^2/day$ to 0.9 $gm/m^2/day$. Statistical analysis indicates less than 1% probability that the decline is an artifact of measurement error rather than a genuine trend. The decline in sediment oxygen demand corresponded to the density of benthic fauna. During June, cores collected at Station 3 were rich in worms and insects. During August, no fauna were observed while the SOD measures were conducted.

Comparison of In-Situ and Laboratory SOD

The means of all observations indicate that SOD measured in-situ is 60% higher than measured in the laboratory. Simple comparison of means neglects the influence of dissolved oxygen and the spatial and temporal variability of SOD, however. More refined comparisons can be obtained if these factors are considered.

Spatial and temporal variability can be taken into account by comparing only measures conducted at the same station at the same time. Compensation for the effects of dissolved oxygen is more problematical. The approach adopted here is to employ Equation 2 to calculate the in-situ SOD at Stations 1 to A which would have been measured if dissolved oxygen in the field equalled that in the laboratory. Since in-situ SOD at Station 4 was independent of DO, no correction is necessary. No correction is applied to data from Fourmile Run since no information on the effect of DO on SOD in this embayment is available. In cases in which replicate in-situ or lab measures are available, means of the replicates are considered. Results of this analysis (Table 3) indicate that SOD measured in-situ is 2.7 to 7 times larger than SOD measured simultaneously in the laboratory.

Effects of Sediment Disturbance on SOD

A hypothesis was formed to explain the difference in SOD measured in-situ and in the laboratory. The theory was that the sediment surface was disturbed during placement of the cylinders and that reduced substances, dissolved or particulate, were released to the overlying water. Rapid oxidation of the reduced matter consumed dissolved oxygen and created a large apparent sediment oxygen demand in the cylinders. This oxidation in the overlying water was not detected in the control cylinders because the water contained in them never contacted the sediment surface. SOD measures on intact cores were not affected by oxidation of matter released when the cores were collected. The material settled during transport to the laboratory or else was removed when water overlying the sediments was replaced with filtered water.

The first step in investigating the hypothesis was to determine the effect of sediment disturbance on oxygen demand in the sediments and overlying water. An initial comparison was obtained after accidental disturbance of a sediment core. Subsequently, several cores were intentionally disturbed. Ratios of oxygen consumption in the disturbed cores averaged almost double the oxygen consumption in the undisturbed cores (Table 4). In an extreme case, rate of oxygen consumption in a disturbed core was more than triple the rate of consumption of the undisturbed core but in another extreme, oxygen consumption declined following disturbance.

The experiments established that disturbance of the sediment surface had the potential to more than double the rate of oxygen consumption in the measurement devices. The next step was to establish that deployment of the in-situ devices resulted in sediment disturbance. Disturbance was expected to be manifest in two ways: An increase in suspended solids in the chamber relative to ambient concentration and increased oxygen consumption in the entrapped water relative to the ambient consumption. Nutrient domes were employed to detect these phenomena since water samples could be removed from the interior of the domes. The domes also allowed resuspended material to be flushed to the external environment so that TSS and IOD inside the domes was equivalent to ambient water at the initiation of the SOD measure. A pair of nutrient domes was deployed once, at Station 4. Details of the deployment have been described previously and results are presented in Table 5. Resuspension of particulate material occurred while setting one dome but not the other. Oxygen consumption of the interior water showed no difference before and after flushing. Oxygen consumption of the water inside the domes after flushing appeared higher than the ambient water but the small sample size and unknown precision of the IOD test prevent the formation of conclusions in this regard. Sediment oxygen demand measured with the domes was only 20% of sediment oxygen demand measured simultaneously in a pair of SOD cylinders. SOD measured with the domes was less than but similar to SOD of an intact core collected at Station 4 two weeks preceeding the dome deployment.

Formation of conclusions from the nutrient dome deployment is difficult due to the limited number of observations. Results indicated deployment of an in-situ device may stir up the bottom but disturbance does not always occur. The bottom at Station 4 was sandy and less subject to resuspension than fine silt, however. SOD measured in-situ with the nutrient domes more closely resembled SOD measured in an intact core rather than measured in-situ with SOD cylinders. The domes and core had in common that the water overlying the sediments was replaced before the SOD measure commenced. No difference in oxygen consumption in the domes before and after flushing was detected, however. The theory that enhanced oxygen demand in the cylinders is due to disturbance of the bottom must be regarded as reasonable, but additional investigation is needed before conclusions can be reached.

Mixing Effects

A second hypothesis which may explain the difference in SOD measured in-situ and in the lab is that mixing differs in the measurement devices. The hypothesis requires that SOD be dependent upon the mixing rate. The influence of mixing on sediment oxygen demand is controversial. Pamatmat (1977) stated oxygen uptake by sediments is independent of stirring rate provided sediment is not resuspended. That philosophy guided construction of the devices used in this study. Other investigators (James, 1974; Boynton et al., 1981) have reported, however, that SOD increases as velocity in the measurement device increases. Evidence also exists that the influence of mixing on sediment oxygen demand depends on the nature of the demand. Pamatmat (1971) reported that respiration of benthic organisms is not influenced by mixing but that sediment chemical oxygen demand is affected.

Achieving equivalence between mixing in a measurement device and in the environment is problematical. Definitive evidence does not exist as to whether velocity or turbulence should be simulated. Moreover, direct comparison of volumetric flow or rotor revolutions in a chamber to temporally and spatially varying ambient velocity or turbulence is not always possible. Estimations of the velocities inside the measurement devices employed in this study can be formed, however. Therefore, velocity is chosen as the parameter for comparison of conditions internal and external to the chamber.

Maximum tidal velocity near the surface of Hunting Creek is approximately 15 cm/sec (Cerco and Kuo, 1983). Velocity near the bottom, at a height equivalent to one-half the height of the in-situ measurement device, can be computed using the logarithmic relationship for velocity distribution near a rough boundary.

$$u = \frac{u_*}{K} \ln y/y_o \qquad (3)$$

in which u is velocity at elevation y, u_* is friction velocity, K is Von Karman's constant and y_o is the characteristic dimension of a roughness element.

A velocity scale inside the SOD cylinder and nutrient domes is obtained through dimensional analysis.

$$u = Q\ V^{-2/3} \qquad (4)$$

in which Q is volumetric flow rate and V is volume of the chamber. Studies of dye dispersion within the laboratory columns indicate the time scale for complete mixing is 40 seconds. A velocity scale can be derived by employing this time scale.

$$u = V^{1/3} T^{-1} \qquad (5)$$

In which T is the time scale for complete mixing of an instantaneous, point-source dye release.

Ambient velocity, scale velocity in each measurement device, and SOD measured with each device are presented in Table 6. Velocity in the SOD cylinders most nearly replicates ambient velocity near the bottom of Hunting Creek. Scale velocities in the laboratory columns and nutrient domes are 20 to 30% of the velocity in the cylinders and an order of magnitude lower than ambient velocity. Correspondence is evident between sediment oxygen demand and scale velocity. Sediment oxygen demand is highest in the SOD cylinders, which have the highest scale velocity, and lower in the devices which have lower scale velocities. The SOD cylinders must be regarded as superior to the laboratory cores and the nutrient domes with regard to mixing.

Current and Previous SOD Measures

Sediment oxygen demand measures for use in the Hunting Creek model were conducted during 1979 and 1980. Subsequent measures were conducted during 1981 and 1982 to verify that the values used in the model were correct. A single SOD cylinder was deployed in each measure. The cylinder was similar in construction and operation to the cylinders employed in 1986 except that mixing in the older model was provided by a battery-operated stirrer rather than a pump-driven circulation system. The older device was 10 cm in height rather than 13 cm in height. Background dissolved oxygen consumption in the water trapped in the older cylinders was considered negligible, based on BOD analylses. Time series of dissolved oxygen in the older cylinders were converted to sediment oxygen demand in the manner described for the 1986 observations. Results of the measures conducted in 1980 to 1982 are summarized in Table 7. The original data for the SOD measure conducted in 1979 has been lost.

The first step in comparison of the observations is to establish that the SOD cylinders employed in 1986 performed the same as the cylinders employed previously. In a side-by-side comparison conducted at Station 4, an older cylinder indicated higher SOD, 2.4 gm/m^2/day, than a newer cylinder, 1.3 gm/m^2/day. Similar or greater disparities were noted between identical newer cylinders deployed at Station 4 on July 1 and August 5, however, and the SOD measured with the older cylinder was centrally located in the range of SOD measured at Station 4 on several occasions in 1986. Therefore, the assumption is made here that the older and newer devices perform similarly.

The mean of the 1980 to 1982 SOD measures, 3.0 gm/m^2/day, is almost identical to the mean of the 1986 in-situ SOD cylinder measures, 3.1 gm/m^2/day. Similarity also exists in the ranges of the two series of measures. A more detailed comparison can be performed by taking into account the dates and locations of the measures and the ambient dissolved oxygen concentrations under which they were performed. Analysis of the 1986 observations indicates that SOD may decline from June to August and that SOD at Stations 4 and 5 is less than maximum SOD at stations farther downstream. Potential monthly and spatial variability in SOD can be minimized by comparing measures conducted in like months (i.e. July) and at like stations. Effects of different ambient dissolved oxygen concentrations are minimized by using Equation 2 to estimate 1986 SOD at the ambient DO concentrations which prevailed when the earlier measures were taken. Since 1986 SOD measures at Stations 4 and 5 were not dependent on DO concentration, the mean of the 1986 measures is compared to previous measures at Station 4. Results of the analysis indicate 1986 SOD at Stations 1 to 3, estimated as a function of ambient dissolved oxygen, is roughly 0.5 gm/m^2/day less than SOD observed in July 1982. The significance of this difference is dubious in view of the precision of SOD measures and the variance of the 1986 measures about the line described by Equation 2. Mean and range of SOD measured in 1986 at Station 4 are higher than SOD measured in 1981 but are comparable to SOD measured in 1982. The data suggest SOD at Station 4 has increased since 1981.

TABLE 1. SOD SAMPLE SCHEDULE

Station	1	E	2	C	3	B	A	4	5	FMR2	FMR4
Date											
June 17					2,3						
June 30					2	1	1				
July 1								1	1		
July 2	1			1							
July 3			1								
Aug 5					1,2,3		1	1,2,3			
Aug 6		1,2				1	2				
Aug 7										1,2	1
Aug 19								1,4,5			

Legend: 1 indicates in-situ SOD cylinder measure
2 indicates lab measure on intact core
3 indicates lab measure on distrubed core
4 indicates in-situ nutrient dome measure
5 indicates in-situ measure using stirred cylinders

TABLE 2. SUMMARY OF RESULTS

Hunting Creek	SOD	DO	Temp	n	
SOD Cylinders	3.1	4.6	25	25	mean
	1.3 to 7.2	1.5 to 7.3	23 to 29		range
Intact Cores	1.9	6.1	27	11	mean
	0.6 to 4.8	4.3 to 7.3	25 to 30		range
Disturbed Cores	2.8	4.5	27	4	mean
	0.4 to 5.6	3.0 to 6.1	26 to 28		range
Nutrient Domes	0.5	4.0	26	2	mean
	0.2 to 0.8				range
Stirred Cylinder	2.4	4.9	27	1	
Fourmile Run					
SOD Cylinders	7.0	5.5	26	3	mean
	6.3 to 7.4	5.1 to 5.9	25 to 26		range
Intact Cores	2.0	7.6	26	2	mean
	1.9 to 2.1	7.5 to 7.6			range

SOD in gm/m^2/day. DO in mg/L. Temp in C^o. Number of measures indicated by n. DO reported for cylinders and domes is ambient concentration at initiation of measurement. DO reported for cores is concentration in overlying water at initiation of measurement.

TABLE 3. IN-SITU VS. LABORATORY SOD

Station	Date	Lab SOD	In-Situ SOD	Corrected In Situ	Ratio of In Situ to Laboratory
E	Aug 6	1.2	1.9	4.9	4.2
3	Aug 5	0.9	2.4	3.5	3.9
A	Aug 6	0.8	4.3	5.6	7.0
4	Aug 5	1.0	2.7		2.7
FMR 2	Aug 7	2.0	6.8		3.5

SOD in gm/m^2/day. Ratio based on corrected SOD for stations E, 3, A. Ratio based on in-situ SOD for Stations 4, FMR2.

TABLE 4. SOD IN DISTURBED VS. UNDISTURBED CORES

Station	Date	Undisturbed SOD	Disturbed SOD	Ratio of Disturbed to Undisturbed
3	June 17	3.9	5.6	1.4
3	Aug 5	1.2	0.4	0.3
		0.6	1.7	2.8
4	Aug 5	1.0	3.4	3.4

TABLE 5. NUTRIENT DOME DEPLOYMENT

	Dome 1	Dome 2	Control	Ambient
TSS immediately upon setting	13	6		
TSS after flushing	6	4	6	5
TSS after 5.5 hours	0	1	0	
IOD immediately upon setting	0.026	0.052		
IOD after flushing	0.065	0.052	0.052	0.013

	Date	Device 1	Device 2
SOD in nutrient domes	Aug 19	0.8	0.2
SOD in SOD cylinders	Aug 19	2.2	2.6
SOD in intact core	Aug 5	1.0	

TSS in mg/L. IOD in mg/L/hr. SOD in gm/m^2/day

TABLE 6. EFFCT OF VELOCITY ON SOD

	Velocity	SOD
Ambient	0 to 4	
SOD Cylinders	1	1.3 to 3.5
Laboratory Columns	0.3	1.0
Nutrient Domes	0.2	0.2 to 0.8

Velocity in cm/sec. SOD from Station 4 in $gm/m^2/day$. Ambient velocity based on following parameters: $y = 7$ cm, $u_* = 0.05\ U_s$, $y_o = 1$ cm

TABLE 7. IN-SITU SOD MEASURES 1980 TO 1982

Station	Date	DO	Temp	SOD	SOD 1986
1	May 27, 1980	8.9	21	3.7	
1	July 6, 1982	5.8	25	5.1	4.5
2	May 27, 1980	5.7	20	1.6	
2	July 6, 1982	7.9	25	6.7	6.1
3	May 27, 1980	6.7	18	3.6	
3	July 6, 1982	5.9	25	5.1	4.6
4	May 27, 1980	8.8	27	1.0	
4D	July 7, 1981	5.5	28	0.5	2.3
4U	July 7, 1981	6.9	30	1.0	2.3
4	July 7, 1982	4.5	24	3.8	2.3
6	May 27, 1980	9.8	19	1.2	
Mean				3.0	

Ambient DO in mg/L. Temperature in C^o. SOD in gm/m^2/day. SOD for 1986 at Stations 1 to 3 is estimated via Equation 2. SOD for 1986 at Station 4 is mean of all observations. Station 4D is downstream of Station 4. Station 4U is upstream of Station 4.

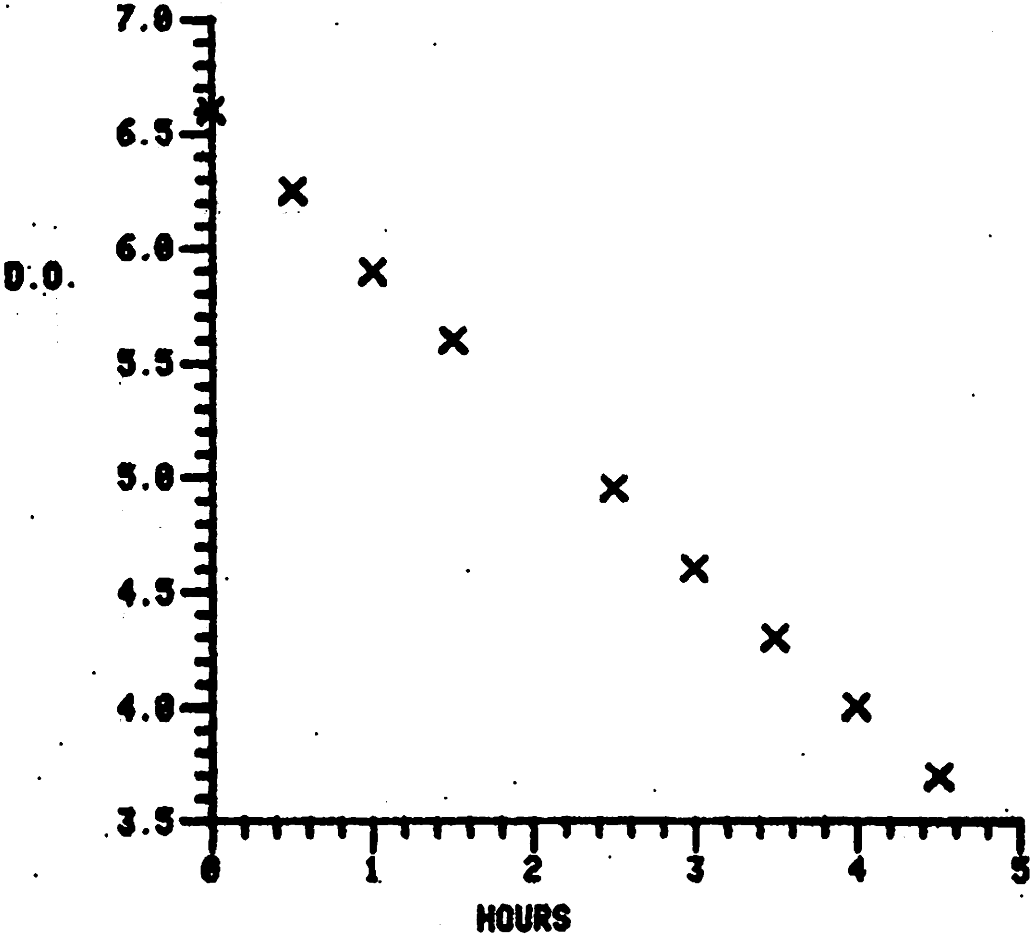

FIGURE 1. Dissolved Oxygen vs. Time in Laboratory Core. D.O. in mg/L. Analysis performed June 17 on core removed from Station 3.

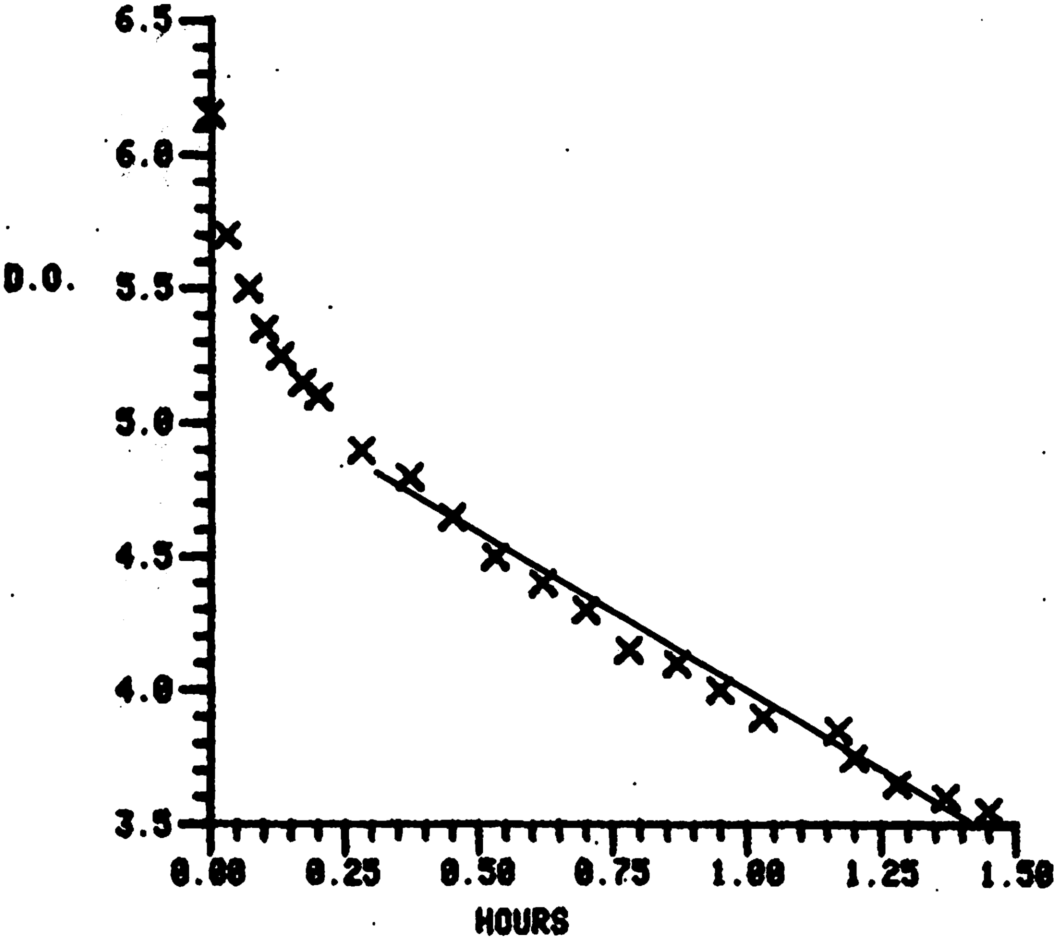

FIGURE 2. Dissolved Oxygen vs. Time in SOD Cylinder. D.O. in mg/L. Observation conducted August 5 at Station A. Solid line shows linear regression fit to data.

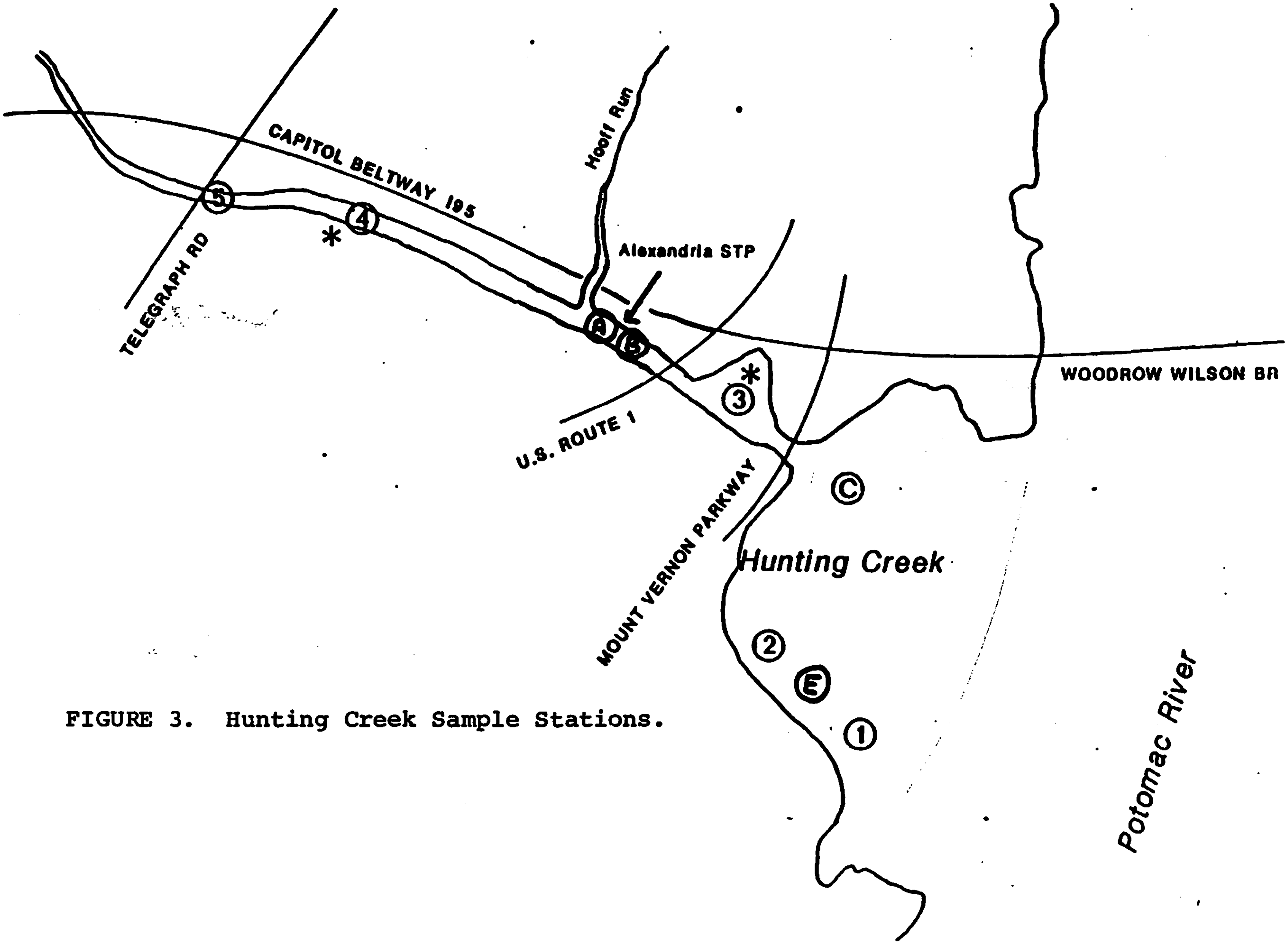

FIGURE 3. Hunting Creek Sample Stations.

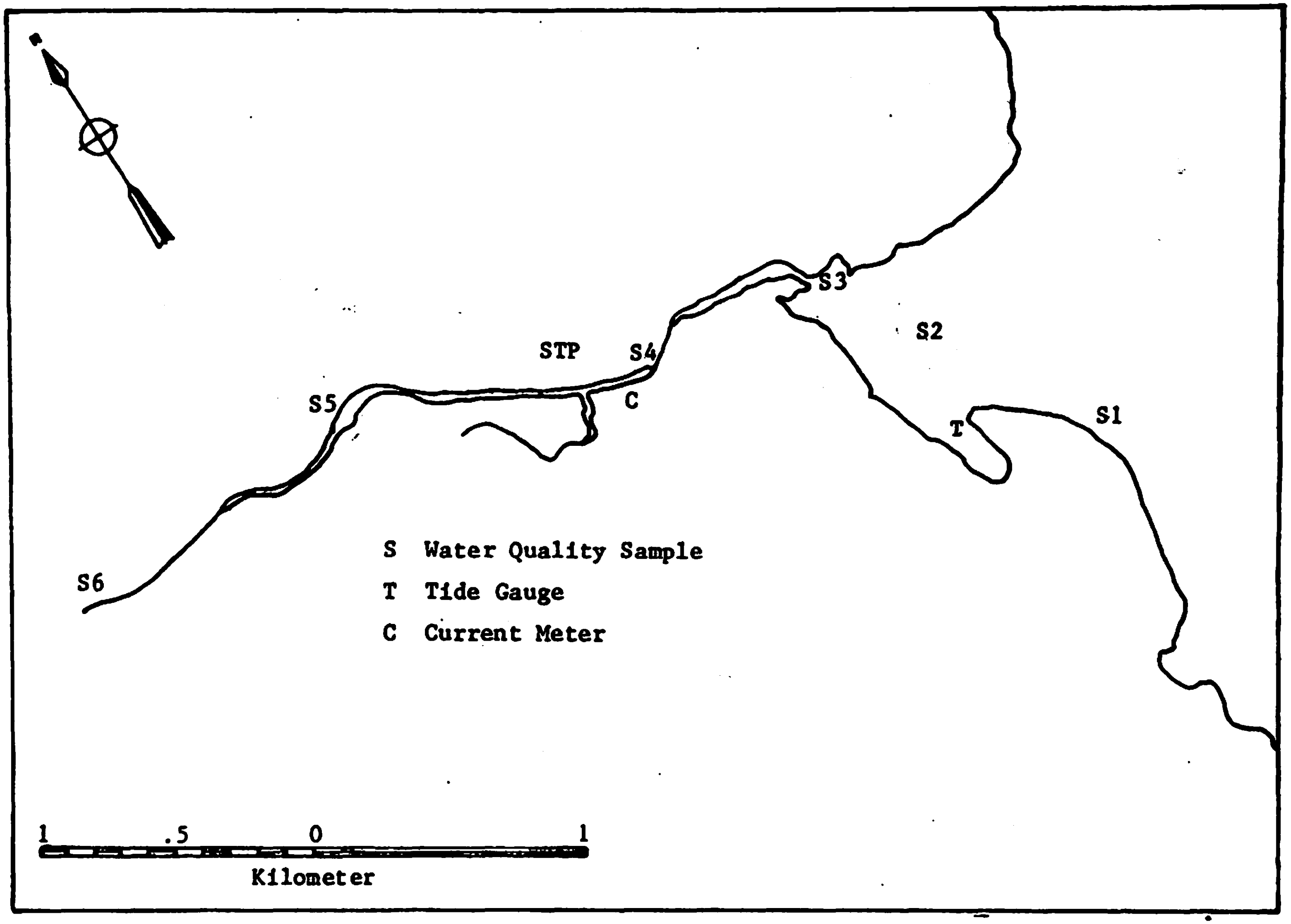

FIGURE 4. Fourmile Run Sample Stations. SOD measured in 1986 at water quality stations 2 and 4.

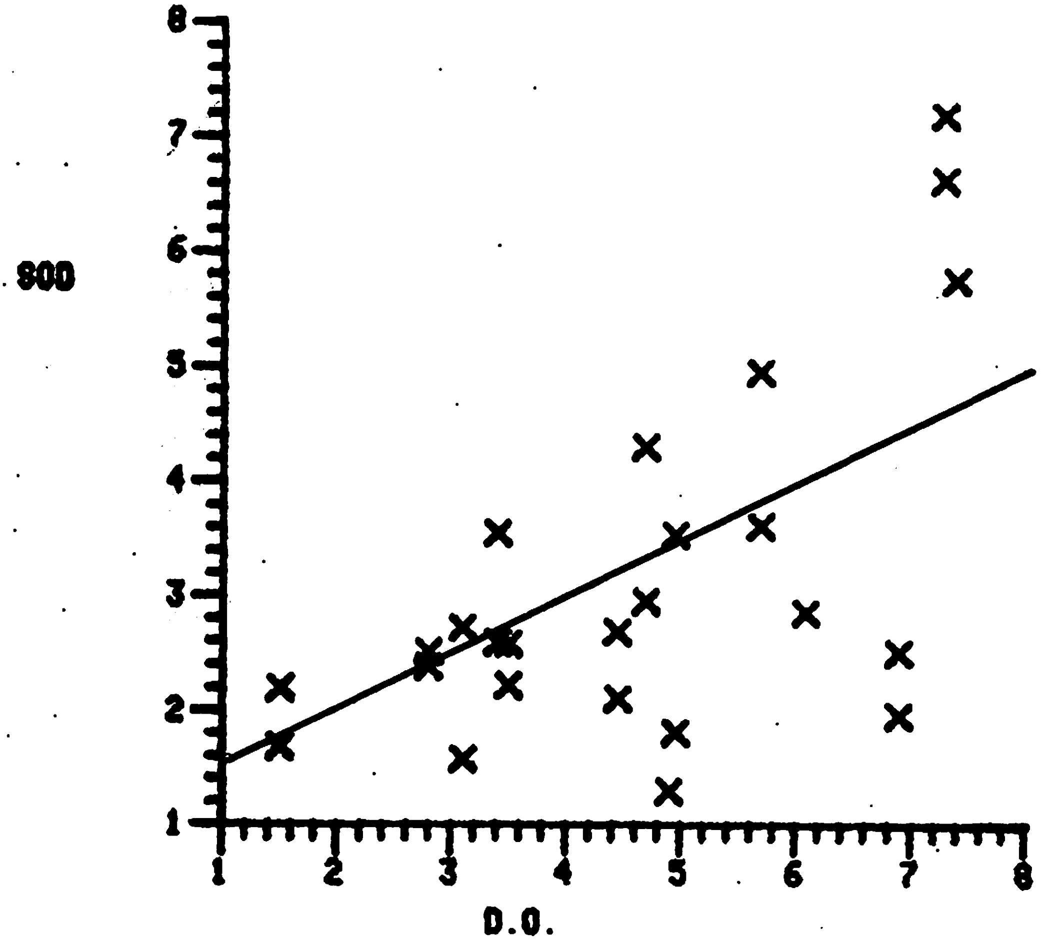

FIGURE 5. Sediment Oxygen Demand vs. Dissolved Oxygen. D.O. in mg/L. SOD in gm/sq m/day. Data from SOD cylinders at all stations. Solid line shows regression (Equation 1).

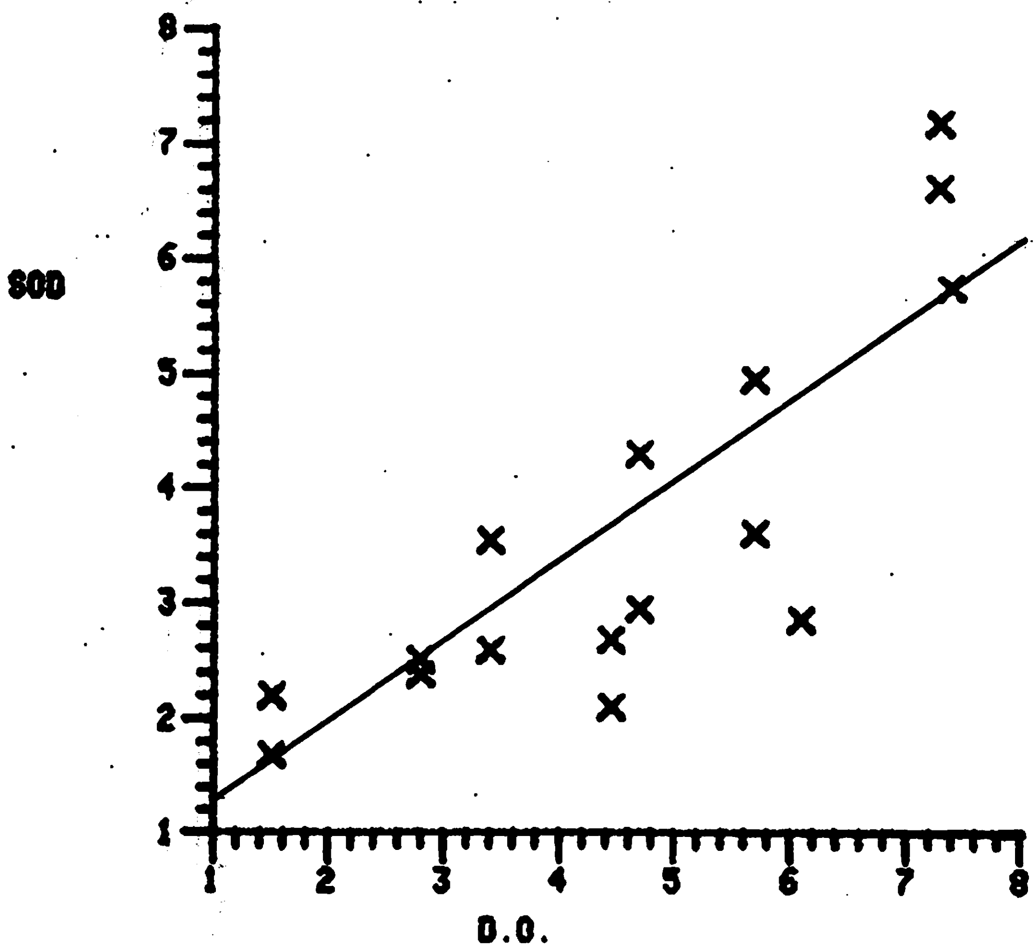

FIGURE 6. Sediment Oxygen Demand vs. Dissolved Oxygen. D.O. in mg/L. SOD in gm/sq m/day. Data from SOD cylinders at Stations 1 to A. Solid line shows regression (Equation 2).

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APPENDIX

WEATHER AND STAGE OBSERVATIONS

Date	Weather	Stage
June 30	Partly cloudy, light winds.	5
July 1	Overcast, occasional rain.	6
July 2	Overcast, occasional rain.	15
July 3	Clear and windy.	14
Aug. 5	Hot and sunny.	
Aug. 6	Hot and sunny.	11
Aug. 7	Overcast with rain.	
Aug. 19	Overcast with afternoon showers. Tropical Storm Charley passed previous day.	27

Stage is depth of water in cm flowing through notch in broad weir near I-95.

IN-SITU SEDIMENT OXYGEN DEMAND AND ASSOCIATED DATA

Station: 1 Date: 860702 Time: 1300
Depth (m): 1.6 Current:

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface	3.4	0.42	6.87	23.4
Mid-depth				
Bottom				

Sediment #1	Sediment #2	Control	Net SOD	
3.98	3.03	0.44	3.07	gm/sq m/day

Station: E Date: 860806 Time: 0800
Depth (m): 1.7 Current: Flood

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface	1.8			27.
Mid-depth	1.8	0.38	6.97	27.
Bottom	1.5			27.

Sediment #1	Sediment #2	Control	Net SOD	
2.19	1.68	0	1.94	gm/sq m/day

Station: 2 Date: 860703 Time: 1030
Depth (m): Current: Ebb

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface				
Mid-depth	4.7	0.43	6.84	23.0
Bottom				

Sediment #1	Sediment #2	Control	Net SOD	
2.95	4.30	0	3.63	gm/sq m/day

Station: C Date: 860702 Time: 1300
Depth (m): 0.8 Current: Ebb

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface				
Mid-depth	4.5	0.49	6.66	23.5
Bottom				

Sediment #1	Sediment #2	Control	Net SOD
3.33	2.75	0.65	2.39 gm/sq m/day

Station: 3 Date: 860805 Time: 0815
Depth (m): 1.1 Current: Flood

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface				
Mid-depth	2.6	0.71	6.54	25.5
Bottom	2.8			

Sediment #1	Sediment #2	Control	Net SOD
1.82	1.70	-0.68	2.44 gm/sq m/day

Station: B Date: 860630 Time: 1400
Depth (m): 0.8 Current: Ebb changing to flood

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface				
Mid-depth	7.3	0.70	6.47	26.
Bottom				

Sediment #1	Sediment #2	Control	Net SOD
6.86	7.42	0.22	6.92 gm/sq m/day

Station:	B	Date:	860806	Time:	1030
Depth (m):	1.3	Current:			

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface	6.4			26.0
Mid-depth	6.2	0.60	6.51	26.5
Bottom	6.1			26.5

Sediment #1	Sediment #2	Control	Net SOD
2.85		0	2.85 gm/sq m/day

Station:	A	Date:	860630	Time:	1345
Depth (m):	0.8	Current:	Slack changing to flood		

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface	7.4			
Mid-depth		0.52	6.81	29.
Bottom				

Sediment #1	Sediment #2	Control	Net SOD
5.76		0	5.76 gm/sq m/day

Station:	A	Date:	860805	Time:	1415
Depth (m):	0.9	Current:			

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface	6.6			29.
Mid-depth		0.53	6.67	
Bottom	5.7			27.5

Sediment #1	Sediment #2	Control	Net SOD
3.61	4.95	0	4.28 gm/sq m/day

Station:	4	Date:	860701	Time:	0915
Depth (m):	0.5	Current:	Slack		

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface				
Mid-depth	3.14	0.28	6.94	24.
Bottom				

Sediment #1	Sediment #2	Control	Net SOD
2.71	1.57	0	2.14 gm/sq m/day

Station:	4	Date:	860805	Time:	1100
Depth (m):	0.9	Current:	Slack changing to ebb		

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface	5.1			27.
Mid-depth		0.31	7.33	
Bottom	4.95			27.

Sediment #1	Sediment #2	Control	Net SOD
3.53	1.81	0	2.67 gm/sq m/day

Station:	4	Date:	860819	Time:	0930
Depth (m):	0.7	Current:	Beginning of ebb		

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface	3.55			26.
Mid-depth		0.84	6.83	
Bottom	3.50			26.

Sediment #1	Sediment #2	Control	Net SOD
2.21	2.58	0	2.39 gm/sq m/day

Station:	4	Date:	860819	Time:	1430
Depth (m):		Current:	Ebb		

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface	4.9			26.5
Mid-depth				
Bottom	4.9			26.5

Stirrer	Pump	
2.38	1.29	gm/sq m/day

NOTE: This measure is a comparison of SOD cylinders with stirrers and circulating pumps.

Station:	4	Date:	860819	Time:	1200
Depth (m):	1.0	Current:	Ebb		

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface				
Mid-depth	4.04			26.4
Bottom				

Sediment #1	Sediment #2	Control	Net SOD	
1.97	2.61	1.81	0.48	gm/sq m/day

NOTE: This measure employs nutrient domes which are flushed before beginning the SOD measure.

Station:	5	Date:	860701	Time:	1030
Depth (m):	0.8	Current:	Slack changing to ebb		

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface				
Mid-depth	6.9	0.27	7.46	22.5
Bottom				

Sediment #1	Sediment #2	Control	Net SOD	
2.50	1.96	0	2.23	gm/sq m/day

Station:	FMR 2	Date:	860807	Time:	0900
Depth (m):	3.7	Current:	Flood		

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface	5.8			27.
Mid-depth	5.8	0.33	7.43	26.5
Bottom	5.05			26.

Sediment #1	Sediment #2	Control	Net SOD
6.33	7.24	0	6.79 gm/sq m/day

Station:	FMR 4	Date:	860807	Time:	1200
Depth (m):	1.6	Current:			

In situ	DO mg/L	Cond. mmho/cm	pH	Temp. C
Surface	6.90			28.0
Mid-depth	6.80	0.44	7.63	26.5
Bottom	5.85			25.0

Sediment #1	Sediment #2	Control	Net SOD
7.41		0	7.41 gm/sq m/day

LABORATORY SEDIMENT OXYGEN DEMAND AND ASSOCIATED DATA

Station: E **Date:** 860806 **Time:** 1700

Description: Sandy. Surface is mottled dark and light. Dark brown or black sediments immediately under surface.

Laboratory	DO mg/L	Temp. C
Sediment 1	6.30	26.0
Sediment 2	6.30	26.0
Control	6.65	26.0

Sediment #1	Sediment #2	Control	Net SOD
1.68	1.39	0.38	1.16 gm/sq m/day

Station: 3 **Date:** 860617 **Time:** 1030

Description: Cores collected circa 1200 June 16. Measures conducted in VIMS lab the next day. Threadlike worms are present.

Laboratory	DO mg/L	Temp. C
Sediment 1	6.35	28.
Sediment 2	6.60	28.
Control	7.15	28.

Sediment #1	Sediment #2	Control	Net SOD
3.02	4.81	0	3.92 gm/sq m/day

Station: 3 **Date:** 860630 **Time:** 1500

Description: Cores are gray sand with 0.5 cm greenish sediment on top. Small white insects and threadlike worms are present.

Laboratory	DO mg/L	Temp. C
Sediment 1	5.6	25.
Sediment 2	5.8	25.
Control	6.8	24.

Sediment #1	Sediment #2	Control	Net SOD
2.62	2.47	-0.48	3.03 gm/sq m/day

Station: 3 **Date:** 860805 **Time:** 1300

Description: Sandy. Light brown surface sediments 0 to 1 cm thick. Next layer is gray 2 to 3 cm thick. Black sediments lie below the upper two layers.

Laboratory	DO mg/L	Temp. C
Sediment 1	4.5	30.
Sediment 2	4.25	29.
Control	4.80	26.5

Sediment #1	Sediment #2	Control	Net SOD
1.19	0.59	0	0.89 gm/sq m/day

Station: A **Date:** 860806 **Time:** 1330

Description: Sandy with 1 cm light-brown silt on top. Below silt is 25 cm gray sand and then black sediments.

Laboratory	DO mg/L	Temp. C
Sediment 1	7.30	27.
Sediment 2	7.20	27.
Control	7.40	26.5

Sediment #1	Sediment #2	Control	Net SOD
1.70	1.42	0.72	0.84 gm/sq m/day

Station: 4 **Date:** 860805 **Time:** 1745

Description: Sandy sediments. Green on surface, uniform black beneath.

Laboratory	DO mg/L	Temp. C
Sediment 1	6.60	27.0
Sediment 2		
Control	6.40	26.0

Sediment #1	Sediment #2	Control	Net SOD
1.00		0	1.00 gm/sq m/day

Station: FMR 2 **Date:** 860807 **Time:** 1230

Description: Fine brown silt shading to gray approximately 3 cm down. Gas bubbles appear roughly 3 cm down. Numerous threadlike worms and some white insects are present.

Laboratory	DO mg/L	Temp. C
Sediment 1	7.50	26.
Sediment 2	7.60	26.
Control	8.00	26.

Sediment #1	Sediment #2	Control	Net SOD
2.34	2.14	0.24	2.00 gm/sq m/day

Station: 3 **Date:** 860617 **Time:** 1030

Description: Disturbed core.

Laboratory	DO mg/L	Temp. C
Sediment 1	6.10	28.
Sediment 2		
Control		

Sediment #1	Sediment #2	Control	Net SOD
5.63 gm/sq m/day			

Station: 3 **Date:** 860805 **Time:** 2030

Description: Disturbed cores.

Laboratory	DO mg/L	Temp. C
Sediment 1	3.20	26.
Sediment 2	3.00	26.
Control		

Sediment #1	Sediment #2	Control	Net SOD
0.36	1.66 gm/sq m/day		

Station:	4	Date:	860805	Time:	2030

Description: Disturbed core.

Laboratory	DO mg/L	Temp. C
Sediment 1	5.85	26.5
Sediment 2		
Control		

Sediment #1	Sediment #2	Control	Net SOD
3.38 gm/sq m/day			

EFFECT OF MIXING AND DISSOLVED OXYGEN CONCENTRATION ON SEDIMENT OXYGEN DEMAND

January 12, 1987

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FIELD PROGRAM

Cores were collected near the mouth of Hunting Creek in the vicinity of Station 2. Collection took place at low tide the morning of November 14, 1986. Carboys of water, measures of dissolved oxygen (DO) and temperature, and samples for analysis of total suspended solids (TSS) were also collected. Ambient conditions are summarized in Table 1.

Sediment cores exhibited a light-brown, fluffy surficial layer. Approximately 1 cm into the sediments a transition to darker brown sediments occurred. A second transition to black sediments occurred at a depth of 8 to 10 cm.

Worm tubes were present on the sediment surface and worms were noted during the experiment. The water had a strong smell of chlorine.

LABORATORY PROGRAM

Program of Experiment

The program was intended to examine the effects of stirring and of DO on measures of sediment oxygen demand (SOD) and sediment-water flux of ammonium and nitrate. Measures were conducted at five DO concentrations and four mixing rates. Additional measures were conducted employing the BOD stirrers used to measure Potomac River and Hunting Creek SOD last summer. DO concentrations were 0.0, 1.5, 3.0, 5.0 and 7.0 mg/L. Stirring rates employed are presented in Table 2. A code number and scale velocity are associated with each rate.

Measures were conducted on replicate cores. A single core was kept at constant DO concentration and mixing rate in order to examine temporal change in SOD. Two columns filled with water only were employed to examine DO uptake and nutrient transformations in the water overlying the sediments. The experimental program is summarized in Table 3.

Apparatus

Columns 1 to 6 were placed in an apparatus which provided variable mixing rate and maintained DO concentration. Each column was fitted with a cap which incorporated a propeller and a YSI Model 5739 DO probe.

The propeller was driven by a variable-speed motor with a range of 100 to 1600 rpm. The probe was monitored by a microprocessor. When DO fell below a preset level, a relay-operated valve was opened and oxygen gas bubbled through the water until the desired DO concentration was attained. The valve opened when DO was 0.25 mg/L below the nominal value for the experiment and oxygen was supplied until DO was 0.25 mg/L above the nominal value.

Columns 7 to 9 were fitted with a cap which incorporated a YSI Model 5720A BOD probe. The probe provided stirring and indicated DO. This apparatus was used in the laboratory measurement of SOD in Hunting Creek and the Potomac River during the summer of 1986 and was described in "Sediment Oxygen Demand in Hunting Creek". DO concentration in these columns was maintained manually and control was less precise than the automated mode. DO varied as much as 1 mg/L above or below the nominal value.

Procedure

At the beginning of each day, water in all columns was siphoned off and replaced with fresh carboy water. A portion of the refill water was reserved and analyzed for ammonium and nitrate. This sample indicated the initial nitrogen concentrations in the columns. DO concentration was brought to the desired level using gaseous nitrogen or oxygen and the measure commenced. Measures in columns 1 to 4 were conducted four hours. At the end of the period, nutrient and TSS samples were collected from each column, Mixing was switched to the second speed for the day and another four-hour measure was conducted. A single daily measure, of four to six hours duration, was conducted in columns 5 to 9. At the end of each day, DO concentration in columns 1 to 6 was brought to the concentration planned for use the next day, mixing was set to 1200 rpm, and the columns were left overnight. Columns 7 to 9 were stagnant when not in use.

DO probes were air calibrated at the beginning of each day. Water temperature ranged from 23 to 27.5 °C.

Determination of SOD and Nutrient Flux

Volumetric rate of oxygen consumption was determined through division of the total oxygen consumed by the measurement duration. Time elapsed during reaeration intervals was not considered. Multiplication of the volumetric rate by the depth of water yielded SOD on an areal basis. Apparent SOD in the columns containing only water was used to correct SOD in the sediment columns for oxygen consumption in the overlying water. SOD was also corrected for any probe drift which occurred.

Volumetric nutrient transformation rates were determined through division of the difference in the final and initial nutrient concentrations by the measurement duration. Volumetric rates were converted to areal flux rates through multiplication by the water depth. Flux rates were corrected for transformations in the overlying water. Changes in ammonium concentration were obscured by lack of analytical precision at the high concentrations observed. Ammonium flux is therefore not considered in the balance of this report.

Determination of Scale Velocity

Mixing in each column was determined by the rpm of the stirring device and the water volume. A scale velocity was associated with each mixing rate through determination of a mixing time scale. Dye was injected into the water in a manner approximating an instantaneous point source. The time scale was interpreted as the time necessary for dye in the column to attain 90% of the completely-mixed concentration. Once the time scale was known, scale velocity was computed

$$u = \frac{V^{1/3}}{T} \qquad (1)$$

in which u is velocity, V is water volume, and T is time scale.

This method was satisfactory for velocity up to approximately 0.6 cm/sec. Above this velocity, mixing time was not much greater than the time needed to completed the injection and collect a sample. Reproducible results were difficult to obtain. Velocity in the columns with the BOD probes was especially difficult to evaluate. The velocity obtained in conjunction with this experiment is more than twice the velocity determined last summer.

RESULTS

Presentation of Results

Observed SOD and sediment nitrate uptake rates are presented in Tables 4 and 5. Measures in which SOD did not attain steady state are omitted. Discrimination of unsteady from steady nitrate uptake rate is not possible. As presented, the SOD data are not suitable for analysis for the following reasons:

1) Initial SOD in the columns, measured at identical mixing rates and DO concentrations, differed.

2) SOD increased throughout the experiment in a column maintained at constant mixing and DO (Figure 1).

Effects of variations among the columns and temporal variations are reduced through a process which normalizes SOD by the mean SOD in all columns on the first day of the experiment. The normalization relationship is:

$$\mathrm{SOD(normalized)} = \mathrm{SOD(observed)} * \frac{\mathrm{SODM}}{\mathrm{SOD1}} * \frac{\mathrm{SOD51}}{\mathrm{SOD5D}} \qquad (2)$$

in which SODM is mean SOD in all columns on day 1, SOD1 is SOD on day 1 in the column to be normalized, SOD51 is SOD in column 5 on day 1 and SOD5D is SOD in column 5 on the day to be normalized. Revised SOD data are presented in Table 6. Nitrate data are not normalized.

Effect of DO Concentration on SOD

SOD is plotted as a function of DO in Figure 2. SOD declines as DO falls below 3 mg/L and is virtually independent of DO at concentrations above 3 mg/L. Some observations indicate a decline in SOD at 7 mg/L but this phenomenon is likely an artifact of the normalization process.

The influence of DO on SOD can be described by an equation

$$\mathrm{SOD} = \mathrm{SODMAX} * (1 - e^{a * \mathrm{DO}}) \qquad (3)$$

in which SODMAX is maximum SOD and a is an empirical constant. Application of non-linear regression to the data in Table 6 yields:

$\mathrm{SODMAX} = 2.67 \pm 0.12$

$a = -0.62 \pm 0.11$

$R^2 = 0.47$

Effect of Mixing on SOD

SOD is plotted as a function of mixing in Figure 3. SOD is maximum at a moderate mixing rate, corresponding to a scale velocity of 0.27 cm/sec, and declines at higher and lower mixing rates. The phenomenon is paradoxical but is present at all four DO concentrations. Regression analysis is used to evaluate SODMAX for each mixing speed. The value of the constant 'a' which expresses the effect of DO on SOD is altered by the analysis. Results are

Mixing	SODMAX
1	2.13 ± 0.15
2	3.10 ± 0.12
3	2.57 ± 0.17

4	2.59 ± 0.15
5	2.34 ± 0.15

$a = -0.72 \pm 0.10$

$R^2 = 0.75$

Analysis of Nitrate Uptake

The primary factors affecting nitrate uptake are the DO and nitrate concentrations. Sediment nitrate uptake is enhanced by low DO and by high nitrate concentrations (Figure 4). No influence of mixing is apparent in the columns stirred by the propellers. The columns which were stirred by BOD probes exhibited lower nitrate uptake than the propeller-stirred columns but the phenomenon may be an artifact of the few observations in the columns with BOD stirrers.

The effects of DO and nitrate concentration on nitrate uptake can be expressed

$$\text{Uptake} = b * \text{NO3} * e^{a*\text{DO}} \qquad (4)$$

in which NO3 is nitrate concentration (mg/L) and a and b are empirical constants. Non-linear regression indicates

$b = 817 \pm 56$

$a = -0.20 \pm 0.02$

$R^2 = 0.78$

Analysis of Total Suspended Solids

An empirical approach to the problem of mixing and SOD measures is to set the mixing rate such that TSS in the sediment column are equivalent to ambient TSS. TSS at mixing rates 3 and 4 occasionally were in the ambient range of 12 to 20 mg/L but TSS in the experiment generally were less than ambient concentrations (Figure 5).

Table 1. Ambient Conditions

Dissolved Oxygen	7.6 mg/L
Temperature	6 °C
Ammonium	12 to 15 mg/L
Nitrate + Nitrite	0.3 to 0.8 mg/L
Total Suspended Solids	12 to 20 mg/L

Table 2. Stirring Rates

Rate	Code	Water Depth	Water Volume	Scale Velocity
100	1	30	2400	0.03
1200	2	30	2400	0.27
1600	3	30	2400	0.58
1600	4	25	2000	0.66
BOD Stirrer	5	20	1600	0.78

Rate in rpm. Depth in cm. Volume in cm^3. Velocity in cm/sec.

Table 3. Experimental Program

Date	Column 1,2	Column 3,4	Column 5	Column 6	Column 7,8	Column 9	
Nov. 16	7.	7.	7.	7.	7.	7.	DO
	2	2	2	2	5	5	Mixing
Nov. 17	3.	3.	7.	3.	3.	3.	DO
	1,2	3,4	2	2	5	5	Mixing
Nov. 18	5.	5.	7.	5.	1.5	1.5	DO
	1,2	3,4	2	2	5	5	Mixing
Nov. 19	1.5	1.5	7.	1.5			DO
	1,2	3,4	2	2			Mixing
Nov. 20	0.	0.	7.	7.	5.	5.	DO
	1,2	3,4	2	2	5	5	Mixing
Nov. 26	7.	7.	7.	7.			DO
	3,4	1,2	2	2			Mixing

Column 5 examined temporal change in SOD. Columns 6 and 9 examined DO uptake and nutrient transformations in water only.

Table 4. Observed Sediment Oxygen Demand

Mixing	1	2	3	4	5
DO					
1.5	1.70	us	us	1.40	1.81
	1.35	2.38	2.11	1.92	1.83
3.0	2.24	3.67	us	2.82	1.62
	2.31	3.72	us	3.32	2.64
5.0	2.68	3.00	2.79	2.92	2.21
	2.77	3.92	3.66	3.41	2.61
7.0	2.57	4.07	3.78	3.26	2.52
	3.00	4.54	3.47	3.62	3.02
		2.80			
		3.20			
		2.73			
		3.33			
		2.61			
		2.91			
		3.12			
		3.27			
		3.19			
		3.97			

SOD in $gm/m^2/day$. us indicates steady state not attained.

Table 5. Sediment Nitrate Uptake

Mixing	1	2	3	4	5
DO					
0.0	36	72	90	60	nm
	54	72	144	60	nm
1.5	288	270	324	210	284
	306	270	288	210	316
3.0	324	234	342	195	nm
	342	252	306	195	nm
5.0	216	180	180	180	nm
	234	198	144	165	nm
7.0	nm	nm	nm	nm	34
	nm	nm	nm	nm	33
		36			
		108			
		72			
		54			
		54			
		72			
		90			
		52			
		61			
		nm			

Nitrate uptake in $mg/m^2/day$. nm indicates no measure.

Table 6. Normalized Sediment Oxygen Demand

Mixing	1	2	3	4	5
DO					
1.5	1.47			1.24	1.67
	1.02	1.79	1.54	1.40	1.41
3.0	2.18	3.57		2.82	1.60
	1.95	3.15		2.72	2.19
5.0	2.43	2.72	2.60	2.72	1.99
	2.19	3.10	2.80	2.61	1.97
7.0	1.88	2.98	2.69	2.32	2.77
	1.80	2.73	2.15	2.25	2.78

SOD in gm/m^2/day.

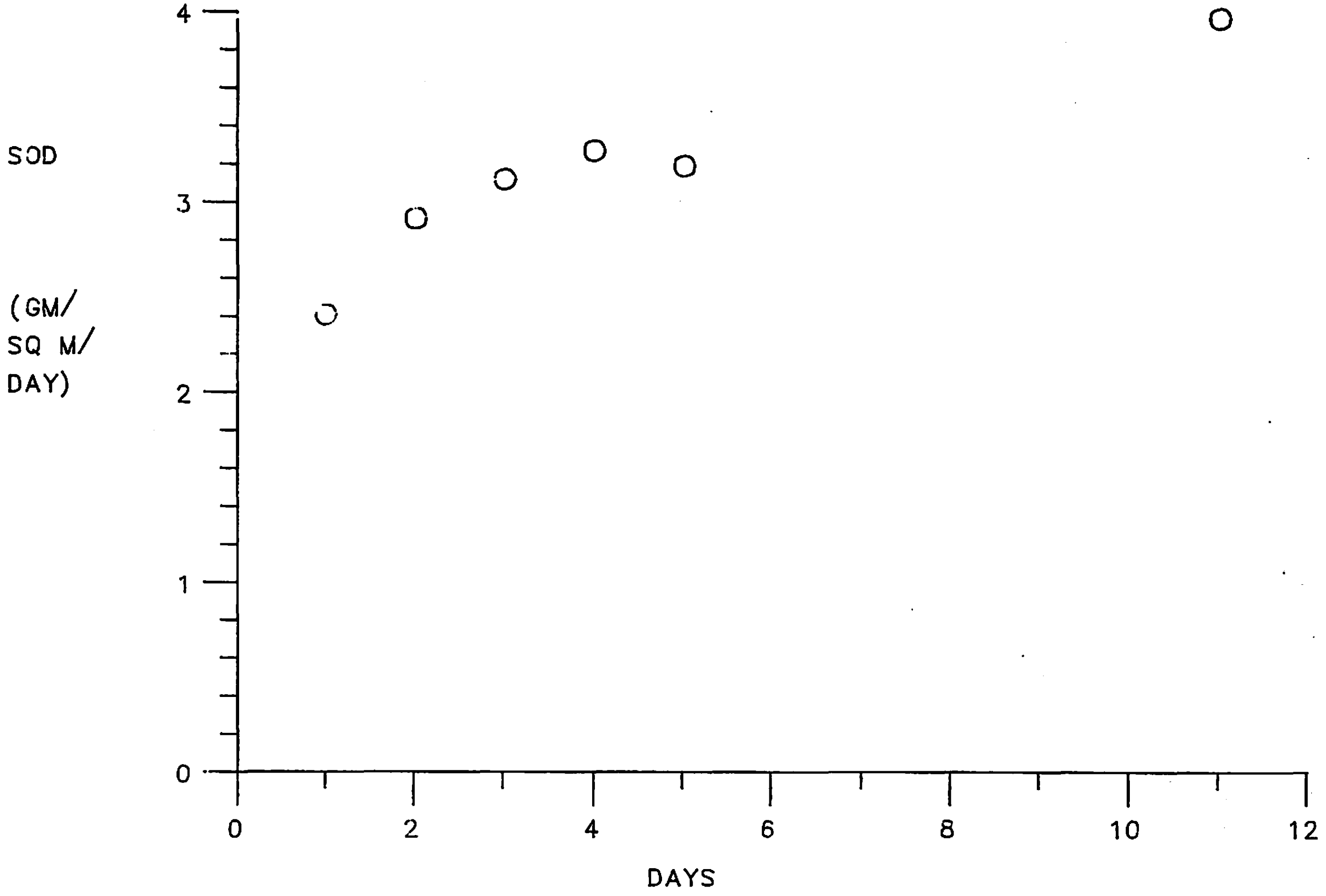


Figure 1. SOD vs. time in Column 5.

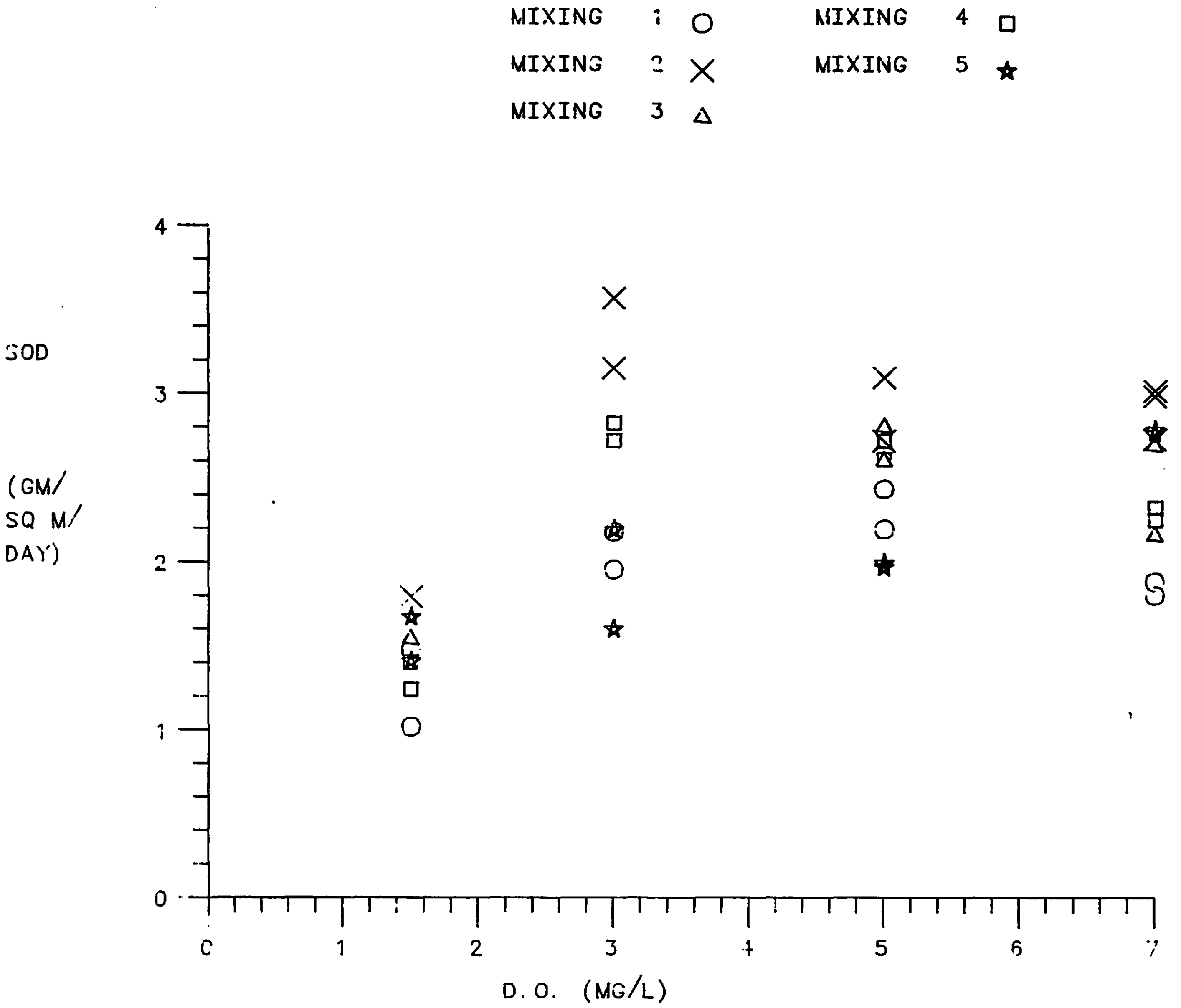


Figure 2. SOD vs. DO concentration.

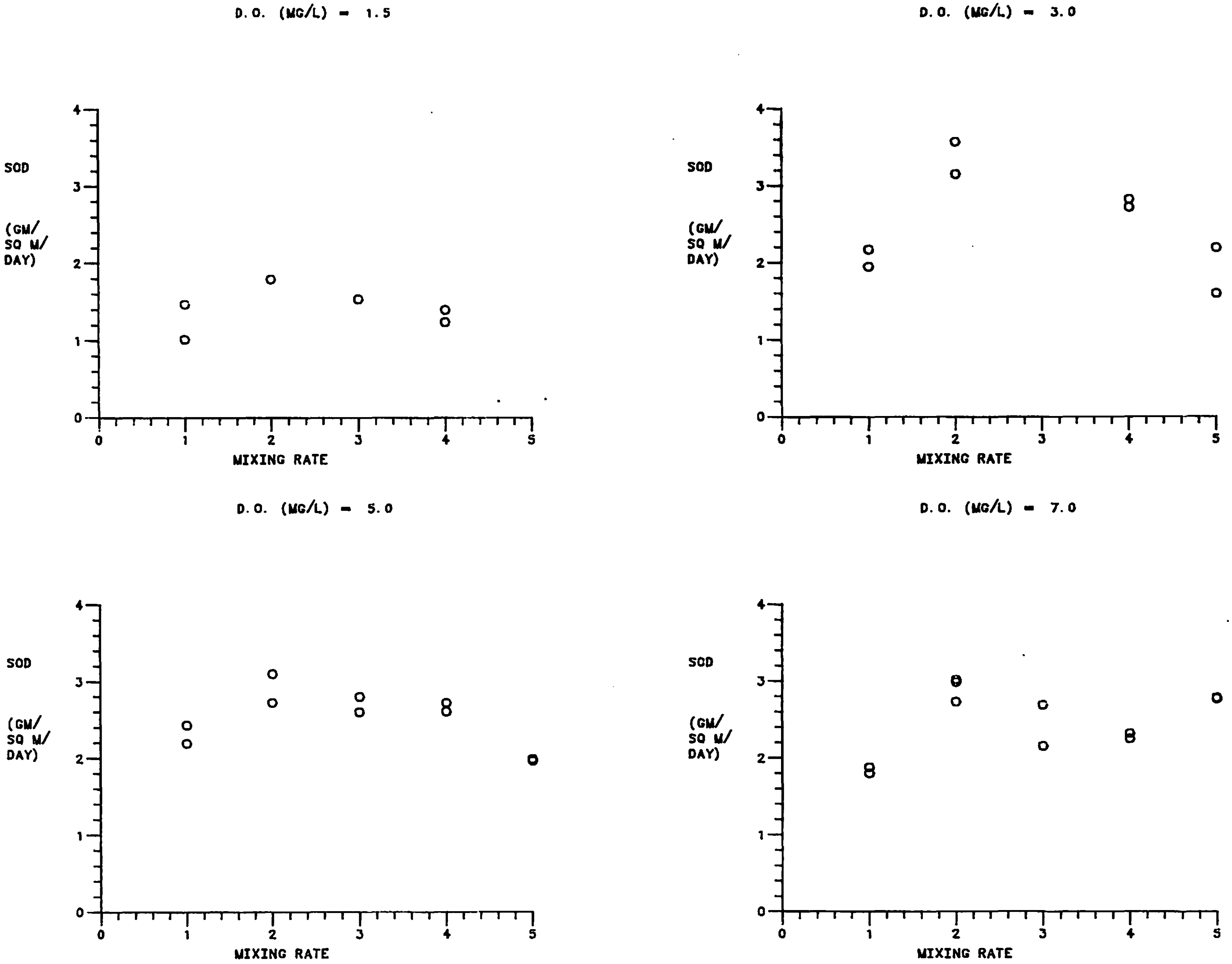


Figure 3. SOD vs. mixing rate.

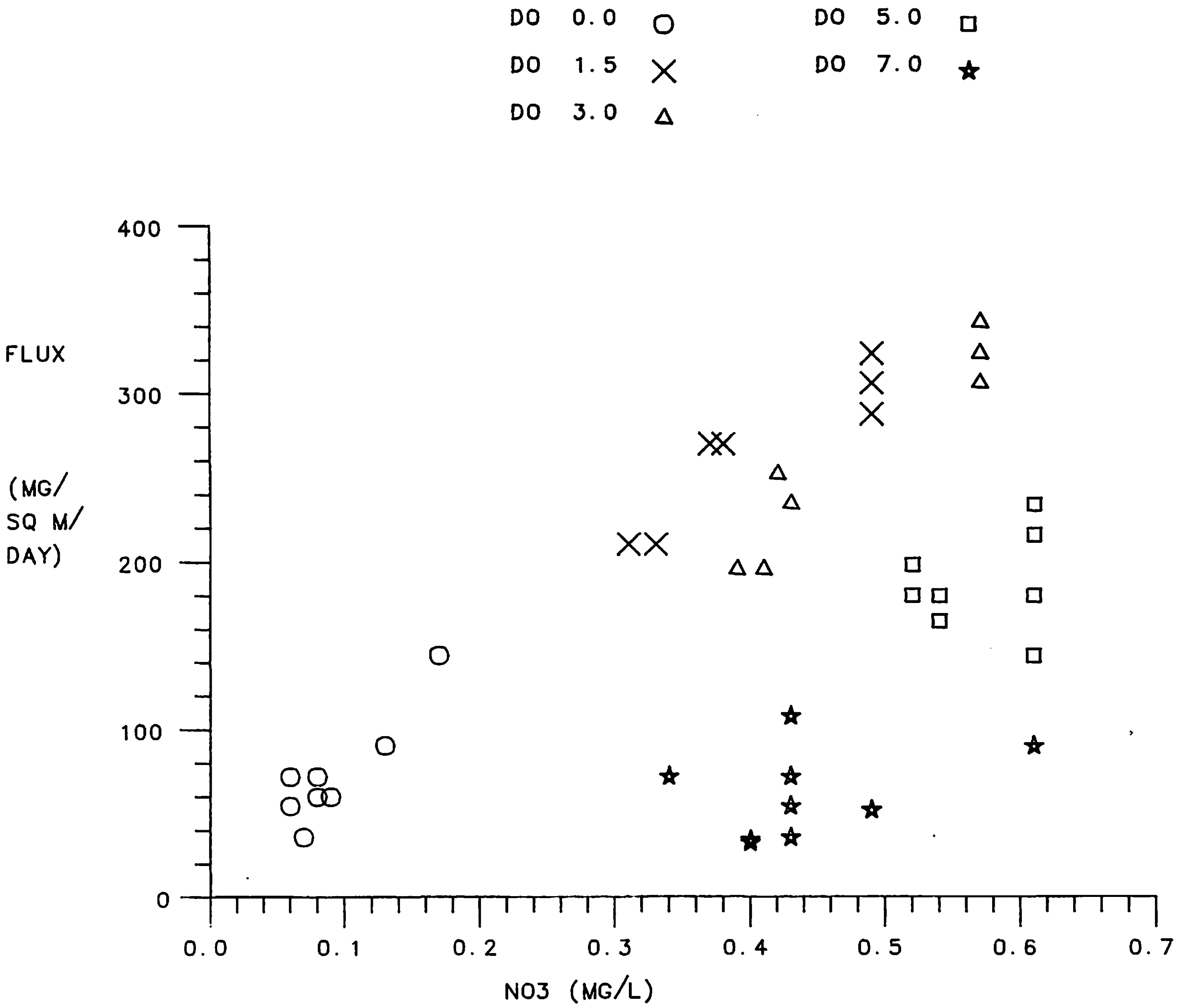


Figure 4. Nitrate uptake rate vs. concentration.

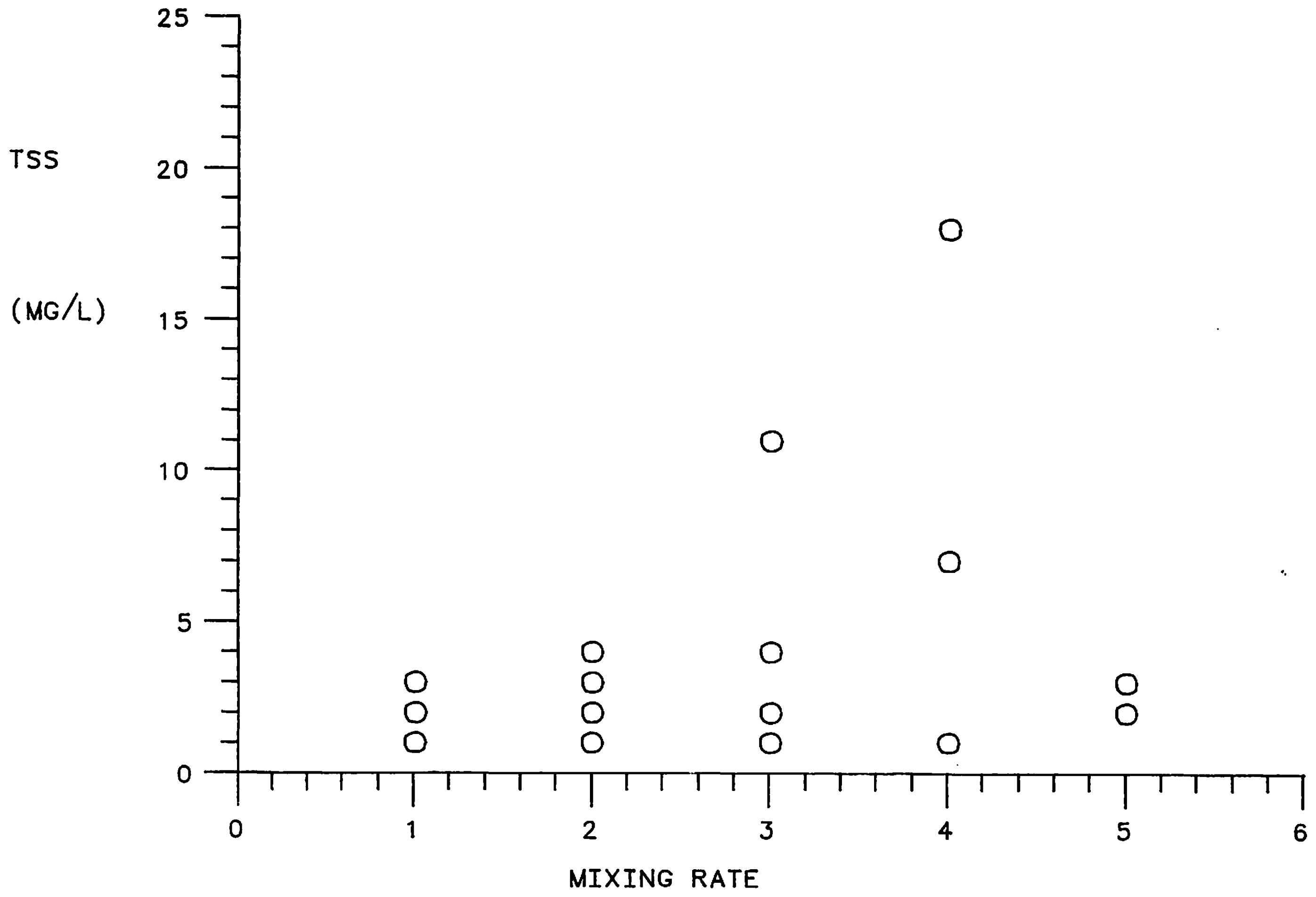


Figure 5. Total suspended solids vs. mixing rate.

POTOMAC RIVER OBSERVATIONS

and

COMPUTED SEDIMENT-WATER FLUXES

Methodology

Laboratory measures of sediment oxygen demand (SOD), sediment-water nutrient flux, and sediment gas generation were conducted on intact sediment cores. A diver collected cores and overlying water in transparent acrylic tubes 40 cm long and 10 cm in diameter. Sediment occupied roughly half the length of the tube. Following collection of the cores, ambient bottom water was pumped into a carboy and the samples were transported to a lab at the Alexandria Sanitation Authority. At the lab, a description of each core was noted and depth of water overlying each core was measured. Carboy water was pumped through a series of one-micron string filters to remove the majority of particulate matter. Water overlying the cores was siphoned off and replaced with filtered water. A portion of the refill water was reserved for subsequent analysis of initial ammonium (NH4), nitrate+nitrite (NO3), and phosphate (PO4) concentrations. Initial pH and temperature were measured at the time the columns were refilled. A control column, identical to the sediment columns except it contained only water, was set up. Each column was fitted with an air-tight cap into which was inserted a YSI Model 5720A Self-Stirring BOD Bottle Probe. The probe continuously stirred the water and measured DO concentration. A baffle was placed around the stirrer so that water overlying the sediments was in motion but no resuspension of particulates occurred. The probes were air calibrated before and after each use.

Stirring continued for two to four hours during which DO and temperature were recorded. Next, the stirrers were removed and replaced with a tube leading to an inverted, water-filled bottle intended to trap gases generated by the sediments. The columns were left stagnant for a period which was typically twelve hours. At the end of the period, the water was stirred briefly, DO, pH, and temperature measured, and a sample for analysis of nutrients collected. The volume of water, if any, displaced by gas generation was noted and the gas bottle was refilled with water.

Following the first measure of sediment-water nutrient flux and gas generation, a second measure was usually conducted. The intention of the measures was to collect oxic and anoxic measures of nutrient flux and gas generation. Columns were intended to become anoxic through internal consumption of oxygen. Due to the low rate of oxygen consumption in the stagnant columns, however, DO was sometimes forced down by bubbling gaseous nitrogen through the water. Duration of the second measure was typically twelve hours. At the end of the measure, the water was stirred briefly, DO, pH, and temperature measured, and a sample for analysis of nutrients collected. The volume of water, if any, displaced by gas generation was noted.

Flux Computation

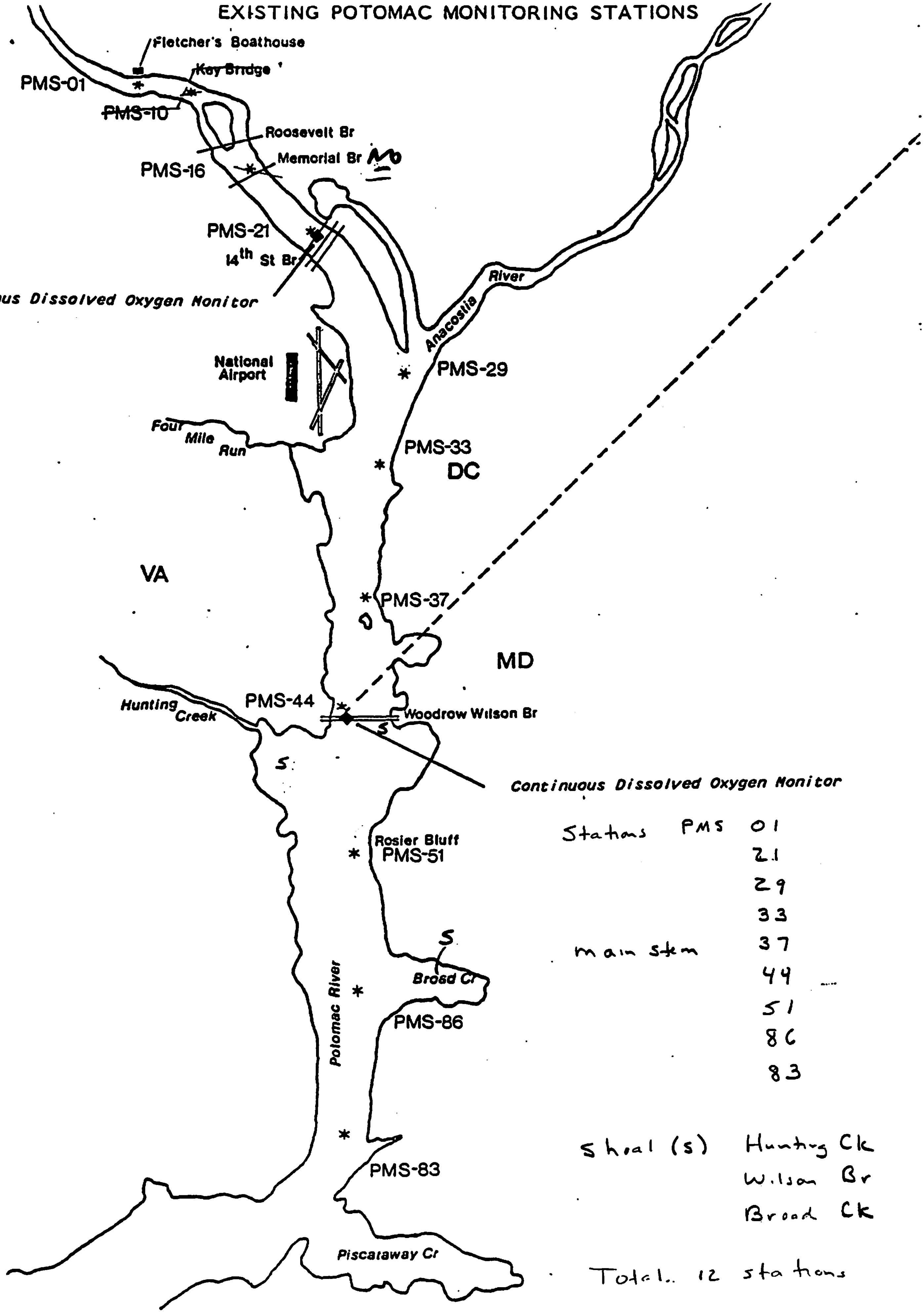
Sediment-water fluxes of oxygen and nutrients were computed by the relationship

$$\text{Flux} = \frac{Cf - Ci}{T} * H$$

in which Cf is concentration at the end of a measure, Ci is concentration at the beginning of a measure, T is duration of the measure, and H is depth of water in the column.

During the first nutrient flux measure, the column was stirred part of the time and stagnant the remainder. During subsequent measures, the column was stagnant virtually all the time. SOD was computed over two time periods: the interval during which stirring took place, and total measurement duration. Stirred SOD is reported in a September 30 memo attached. Reported values are the average of SOD in two columns and are corrected for oxygen consumption in the control column. Partly-stirred and unstirred SOD are reported along with the nutrient flux and gas generation results.

EXISTING POTOMAC MONITORING STATIONS



Stations PMS 01
21
29
33
main stem 37
44
51
86
83

Shoal (s) Hunting Ck
Wilson Br
Broad Ck

Total.. 12 stations

THE COLLEGE OF WILLIAM AND MARY
School of Marine Science / Virginia Institute of Marine Science
Departmental Communication

September 30, 1986

To: Stuart Freudberg
From: Carl Cerco

I am listing below the best current measures of Potomac River SOD (in gm/sq m/day). These are based on laboratory measures over two to four hours and were stirred continuously.

Station	SOD	Temperature
1	2.19	26.
21	1.66	25.3
29	1.27	26.4
37	1.88	25.4
Wilson Bridge Shoals	2.20	27.5
44	1.15	27.3
83	1.40	28.1
86	1.17	26.8

POTOMAC MAIN STEM STATION 1

Station location and depth: Below Fletcher's Boat House on right side of channel looking upstream. Approximately 25 m offshore opposite an Arrowhead marsh. Depth is 2.7 m.

Cores collected: 0800 July 9, 1986.

Weather: Hazy and calm.

Description of cores: Light brown floculent layer roughly 1 cm thick overlying an irregular dark layer. The dark layer is 1 to 3 cm thick in column A and 9 to 10 cm thick in column B. The balance of each core is composed of a claylike substance. No biota are present but some pores, possibly worm borrows, are in mud.

In situ	DO	Cond	pH	Temp
Surface	5.3	0.31	7.94	30.3
Mid-depth	5.2	0.32	7.88	30.3
Bottom	5.15	0.32	8.11	30.3

Sediment and Water column A

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 9	1145	0.00	6.95	27.0	7.92	0.087	0.065	0.011
	1200	0.25	6.80					
	1330	1.75	5.90					
	1520	3.58	4.90	25.0				
	1545	4.00			7.50	0.169	0.059	0.051*
	1700	5.25						
	1745	6.00	0.80	24.5				
Jul 10	0930	21.75	0.05	21.5	7.81	0.384	0.021	0.019

Sediment and Water Column B

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 9	1145	0.00	6.95	27.0	7.92	0.087	0.065	0.011
	1200	0.25	6.80					
	1330	1.75	5.95					
	1520	3.58	5.25	25.0				
	1545	4.00			7.64	0.283	0.058	0.022
	1700	5.25						
	1745	6.00	0.60	24.0				
Jul 10	0930	21.75	0.00	21.5	7.79	0.486	0.023	0.021

Water Column C

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 9	1145	0.00	7.35	27.0	7.92	0.087	0.065	0.011
	1200	0.25	7.40					
	1330	1.75	7.35					
	1520	3.58	7.30	24.5				
	1545	4.00			7.75	0.055	0.072	0.022
	1700	5.25						
	1745	6.00	0.60	24.0				
Jul 10	0930	21.75	0.10	22.0	8.28	0.028	0.070	0.009

Surface measures taken 30 cm below surface. Bottom measures taken 30 cm above bottom. DO, NH4, NO3, PO4 in mg/L. Conductivity in mmho/cm. Temperature in degrees Celsius. Questionable analysis indicated by *.

STATION 1 POTOMAC MAIN STEM

Column	DO	NH4	NO3	PO4	Gas	
Sed A	5.9	0.13	0.06			Conc.
	-2310	83	-6		0	Flux
Sed A	0.4	0.27	0.04			Conc.
	-190	55	-6		45	Flux
Sed B	6.1	0.19	0.06	0.017		Conc.
	-2250	232	-8	13	0	Flux
Sed B	0.3	0.36	0.04	0.021		Conc.
	-180	67	-7	0.3	0	Flux
Cntl.	7.3	0.07	0.07	0.017		Conc.
	-70	-38	8	13		Flux
Cntl.	0.4	0.04	0.07	0.015		Conc.
	-150	-23	12	-13		Flux

Conc. is average of initial and final concentrations in mg/L. Flux is in mg/sq m/day for DO and nutrients, in mL/sq m/day for gas. Positive flux is out of the sediments, negative flux is into the sediments.

POTOMAC MAIN STEM STATION 21

Station location and depth: Below railroad bridge on right side of river looking upstream. Depth is 2.7 m.

Cores collected: 0800 July 10, 1986.

Weather: Scattered clouds, breezy.

Description of cores: Upper cm is medium brown and composed of coarse sand. Balance of core is gray claylike substance. Some dead plant material present. Gas pockets 4 to 5 cm beneath sediment surface. Numerous white insects roughly the size of sand grains present. Several dead worms present on surface of column A after it became anoxic.

In situ	DO	Cond	pH	Temp
Surface	4.3		7.75	27.7
Mid-depth	4.2	0.31	7.73	27.7
Bottom	4.15	0.32	7.72	27.7

Sediment and water column A

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 10	1145	0.00	7.20	26.5	7.96	0.140	0.085	0.027
	1340	1.92	6.05					
	1355	2.17	5.95					
	1415	2.50	5.80					
	1430	2.75	5.70					
	1620	4.58	5.20	24.0		0.191	0.090	0.012
	1745	6.00	1.85					
Jul 11	0920	21.58	0.05	21.5		0.272	0.050	0.009

Sediment and Water Column B

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 10	1145	0.00	7.10	26.5	7.96	0.140	0.085	0.027
	1340	1.92	6.20					
	1355	2.17	6.10					
	1415	2.50	5.95					
	1430	2.75	5.85					
	1620	4.58	5.30	24.0		0.179	0.075	0.012
	1745	6.00	3.15					
Jul 11	0920	21.58	0.30	21.5		0.330	0.039	0.011

Water Column C

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 10	1145	0.00	7.40	26.5	7.96	0.140	0.085	0.027
	1340	1.92	7.30					
	1355	2.17	7.25					
	1415	2.50	7.25					
	1430	2.75	7.25					
	1620	4.58	7.20	24.0		0.116	0.075	0.009
	1745	6.00	2.20					
Jul 11	0920	21.58	1.80	21.5		0.092	0.075	0.007

Surface measures taken 30 cm below surface. Bottom measures taken 30 cm above bottom. DO, NH4, NO3, PO4 in mg/L. Conductivity in mmho/cm. Temperature in degrees Celsius.

STATION 21 POTOMAC MAIN STEM

Column	DO	NH4	NO3	PO4	Gas	
Sed A	6.2	0.17	0.09	0.020		Conc.
	-1990	51	5	-15	0	Flux
Sed A	1.0	0.21	0.06	0.010		Conc.
	-530	32	-6	-0.5	0	Flux
Sed B	6.2	0.16	0.08	0.020		Conc.
	-1730	37	-10	-14	0	Flux
Sed B	1.7	0.24	0.05	0.011		Conc.
	-800	48	-5	0.3	0	Flux
Cntl.	7.3	0.13	0.08	0.018		Conc.
	-210	-25	-10	-19		Flux
Cntl.	2.0	0.10	0.07	0.008		Conc.
	-120	-1	2	-0.6		Flux

Conc. is average of initial and final concentrations in mg/L. Flux is in mg/sq m/day for DO and nutrients, in mL/sq m/day for gas. Positive flux is out of the sediments, negative flux is into the sediments.

POTOMAC MAIN STEM STATION 29

Station location and depth: Between Bouy C11 and QKFLG. Approximately 100 m from shore in 10 m deep water.

Cores collected: 0800 July 7, 1986.

Weather: Hazy and windy.

Description of cores: Upper layer composed of 1 to 2 cm of light brown silt. Remainder of core is light gray silt. Gas pockets 10 to 15 cm below sediment surface. A few white, threadlike worms present at initiation. During incubation, numerous white insects the size of a sand grain appeared.

In situ	DO	Cond	pH	Temp
Surface	7.0	0.31		32.0
Mid-depth	7.1	0.30		32.0
Bottom	7.2	0.33		32.0

Sediment and water column A

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 7	1140	0.00	7.90	27.5	8.14	0.260	1.47	0.014
	1155	0.25	7.80					
	1210	0.50	7.70					
	1225	0.75	7.60					
	1300	1.33	7.40					
	1310	1.50	7.35					
	1345	2.08	7.20					
	2300	11.33	4.55	25.0	7.72	0.505	1.16	0.017
Jul 8	0900	21.33	2.40	24.0				
	1600	28.33	1.10	25.5	7.33	0.836	0.63	0.034
Jul 9	1600	52.33	0.65	24.5	7.26	0.948	0.34	0.054

Sediment and Water Column B

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 7	1140	0.00	7.90	27.5	8.14	0.260	1.47	0.014
	1345	2.08	7.35					
	2300	11.33	5.70	25.5	7.70	0.498	1.32	0.019
Jul 8	0900	21.33	4.10	24.0				
	1330	25.83	3.45	24.5	7.50	0.778	0.99	0.017

Water Column C

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 7	1140	0.00	8.15	27.5	8.14	0.260	1.47	0.014
	1155	0.25	8.15					
	1210	0.50	8.15					
	1225	0.75	8.05					
	1300	1.33	8.05					
	1310	1.50	8.05					
	1345	2.08	8.00					
	2300	11.33	7.25	25.0	7.82	0.204	1.47	0.007
Jul 8	0900	21.33	6.60	24.0				
	1000	22.33			7.97	0.169	0.49*	0.006

Surface measures taken 30 cm below surface. Bottom measures taken 30 cm above bottom. DO, NH4, NO3, PO4 in mg/L. Conductivity in mmho/cm. Temperature in degrees Celsius. Questionable analysis indicated by *.

STATION 29 POTOMAC MAIN STEM

Column	DO	NH4	NO3	PO4	Gas	
Sed A	6.2	0.38	1.32	0.016		Conc.
	-1510	111	-140	1.4	0	Flux
Sed A	3.5	0.60	0.72	0.024		Conc.
	-1040	145	-54	6.0	119	Flux
Sed A	0.9	0.83	0.44	0.042		Conc.
	-100	51	-43	5.1	0	Flux
Sed B	6.8	0.38	1.40	0.017		Conc.
	-1120	121	-76	2.5	0	Flux
Sed B	4.6	0.60	1.06	0.017		Conc.
	-540	85	-31	0	0	Flux
Cntl.	7.7	0.23	1.47	0.011		Conc.
	-380	-24	0	-3.0		Flux
Cntl.	6.9	0.17		0.007		Conc.
	-310	0		-0.4		Flux

Conc. is average of initial and final concentrations in mg/L. Flux is in mg/sq m/day for DO and nutrients, in mL/sq m/day for gas. Positive flux is out of the sediments, negative flux is into the sediments.

POTOMAC MAIN STEM STATION 37

Station location and depth: Approximately 100 m upstream of red bouy on right side of channel looking upstream. Depth is 9 m.

Cores collected: 1000 July 9, 1986.

Weather: Light breeze.

Description of cores: Fine brown silt throughout with no distinct color transition. Gas pockets plentiful 2 cm below surface. No biota evident at initiation. Numerous white insects in column B at completion of incubation.

In situ	DO	Cond	pH	Temp
Surface	5.95	0.30	7.65	28.7
Mid-depth	5.90	0.30	7.71	28.7
Bottom	5.85	0.31	7.79	28.8

Sediment and water column A

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 9	1715	0.00	7.10	26.0	7.60	0.325	1.54	0.024
	1745	0.50	6.85					
	1800	0.75	6.70					
	2035	3.33	5.20	24.5				
Jul 10	0945	16.50	1.30	21.5	7.24	0.865	1.23	0.017
Jul 11	0915	40.00	0.10	22.0		1.21	0.82	0.024

Sediment and Water Column B

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 9	1715	0.00	7.20	26.0	7.60	0.325	1.54	0.024
	1745	0.50	7.00					
	1800	0.75	6.90					
	2035	3.33	6.05	25.0				
Jul 10	0945	16.50	3.40	22.0	7.48	0.797	1.29	0.012
Jul 11	0915	40.00	0.30	22.0		1.19	0.82	0.024

Water Column C

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 9	1715	0.00	7.45	26.0	7.60	0.325	1.54	0.024
	1745	0.50	7.40					
	1800	0.75	7.40					
	2035	3.33	7.30	25.0				
Jul 10	0945	16.50	6.70	22.5	7.71	0.286	1.63	0.007

Surface measures taken 30 cm below surface. Bottom measures taken 30 cm above bottom. DO, NH4, NO3, PO4 in mg/L. Conductivity in mmho/cm. Temperature in degrees Celsius.

STATION 37 POTOMAC MAIN STEM

Column	DO	NH4	NO3	PO4	Gas	
Sed A	4.2	0.60	1.39	0.021		Conc.
	-1580	147	-84	-1.9	0	Flux
Sed A	0.7	0.99	0.95	0.020		Conc.
	-230	82	-50	1.5	0	Flux
Sed B	5.3	0.56	1.42	0.018		Conc.
	-1080	134	-71	-3.4	0	Flux
Sed B	1.9	0.94	0.97	0.018		Conc.
	-620	98	-62	2.6	0	Flux
Cntl.	7.1	0.31	1.59	0.017		Conc.
	-220	-11	26	-4.9		Flux

Conc. is average of initial and final concentrations in mg/L. Flux is in mg/sq m/day for DO and nutrients, in mL/sq m/day for gas. Positive flux is out of the sediments, negative flux is into the sediments.

POTOMAC MAIN STEM STATION 44

Station location and depth: Approximately 75 m downstream of bridge in mid-channel. Depth is 14 m.

Cores collected: 1200 July 10, 1986.

Weather: Partly cloudy with 5 to 10 knot winds.

Description of cores: Fine brown silt throughout. No distinct color transition. Gas pockets 3 to 5 cm below surface. No biota evident at initiation. White insects plentiful in column A at end of incubation.

In situ	DO	Cond	pH	Temp
Surface	5.6	0.31	7.68	28.9
Mid-depth	4.9	0.30	7.60	28.2
Bottom	4.85	0.30	7.62	28.1

Sediment and water column A

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 10	1500	0.00	7.30	27.5	7.91	0.255	1.79	0.026
	1515	0.25	7.25					
	1600	1.00	6.90					
	1645	1.75	6.60					
	1700	2.00	6.55	27.0				
	2100	6.00	5.70	25.0				
	2130	6.50	1.50					
Jul 11	0920	18.33	0.25	21.5		0.486	1.43	0.014

Sediment and Water Column B

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 10	1500	0.00	7.25	27.5	7.91	0.255	1.79	0.026
	1515	0.25	7.15					
	1600	1.00	6.85					
	1645	1.75	6.60					
	1700	2.00	6.50	27.0				
	2100	6.00	5.60	25.0				
	2130	6.50	1.95					
Jul 11	0920	18.33	0.50	21.5		0.543	1.36	0.016

Water Column C

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 10	1500	0.00	7.60	27.0	7.91	0.255	1.79	0.007
	1515	0.25	7.55					
	1600	1.00	7.50					
	1645	1.75	7.40					
	1700	2.00	7.40	25.5				
	2100	6.00	7.30					
	2130	6.50	2.75					
Jul 11	0920	18.33	2.30	22.0		0.252	1.75	0.012

Surface measures taken 30 cm below surface. Bottom measures taken 30 cm above bottom. DO, NH4, NO3, PO4 in mg/L. Conductivity in mmho/cm. Temperature in degrees Celsius.

STATION 44 POTOMAC MAIN STEM

Column	DO	NH4	NO3	PO4	Gas	
Sed A	6.5					Conc.
	-1180				0	Flux
Sed A	0.9					Conc.
	-470				0	Flux
Sed B	6.4					Conc.
	-1110				0	Flux
Sed B	0.7					Conc.
	-490				0	Flux
Cntl.	7.5					Conc.
	-240					Flux
Cntl.	2.5					Conc.
	-183					Flux

Conc. is average of initial and final concentrations in mg/L. Flux is in mg/sq m/day for DO and nutrients, in mL/sq m/day for gas. Positive flux is out of the sediments, negative flux is into the sediments.

WOODROW WILSON BRIDGE SHOALS

Station location and depth: Approximately 200 m downstream of bridge in shoals with Hydrilla present. Depth is 1.7 m.

Cores collected: 1100 July 7, 1986.

Weather: Windy.

Description of cores: Cores are light brown silt to a depth of 15 cm with light gray silt below. Many gas pockets are present. No biological activity is apparent.

In situ	DO	Cond	pH	Temp
Surface	8.8	0.31	8.02	27.8
Mid-depth				
Bottom	8.6	0.30	8.01	27.7

Sediment and water column A

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 7	1425	0.00	7.70	28.0	8.21	0.174	1.58	0.012
	1440	0.25	7.65					
	1600	1.58	7.35					
	1617	1.87	7.30					
	1630	2.08	7.25	27.0				
	2300	8.58	6.10	26.0	7.73	0.218	1.50	0.009
Jul 8	0900	18.58	5.05	24.0				
	1330	23.08	4.70	24.5	7.47	0.354	1.09	0.006

Sediment and Water Column B

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 7	1425	0.00	7.50	28.0	8.21	0.174	1.58	0.012
	1440	0.25	7.45					
	1600	1.58	6.95					
	1617	1.87	6.65					
	1630	2.08	6.55	27.0				
	2300	8.58	4.35	26.0	7.59	0.364	1.33	0.017
Jul 8	0900	18.58	2.30	24.0				
	1600	25.58	1.20	25.5	7.47	0.593	0.96	0.017
Jul 9	0800	49.58	0.0	24.5	7.35	0.826	0.42	0.014

Water Column C

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 7	1425	0.00	7.85	28.0	8.21	0.174	1.58	0.012
	1440	0.25	7.85					
	1600	1.58	8.05					
	1617	1.87	8.05					
	1630	2.08	8.10	26.5				
	2300	8.58	7.10	25.0	7.97	0.111	1.59	0.007
Jul 8	0900	18.58	6.50	24.0				
	1330	23.08	6.30	24.5	7.71	0.087	1.44	0.007

Surface measures taken 30 cm below surface. Bottom measures taken 30 cm above bottom. DO, NH4, NO3, PO4 in mg/L. Conductivity in mmho/cm. Temperature in degrees Celsius.

WOODROW WILSON BRIDGE SHOALS

Column	DO	NH4	NO3	PO4	Gas	
Sed A	6.9	0.20	1.54	0.011		Conc.
	-960	26	-48	-1.8	0	Flux
Sed A	5.4	0.27	1.16	0.008		Conc.
	-500	62	-53	-1.1	0	Flux
Sed B	5.9	0.27	1.46	0.015		Conc.
	-1750	105	-138	2.8	0	Flux
Sed B	2.8	0.46	1.07	0.017		Conc.
	-880	75	-61	0.3	0	Flux
Sed B	0.6	0.68	0.64	0.015		Conc.
	-240	59	-87	-0.4	20	Flux
Cntl.	7.5	0.14	1.59	0.010		Conc.
	-420	-35	0	-2.8		Flux
Cntl.	6.7	0.09	1.42	0.007		Conc.
	-270	-3	17	0		Flux

Conc. is average of initial and final concentrations in mg/L. Flux is in mg/sq m/day for DO and nutrients, in mL/sq m/day for gas. Positive flux is out of the sediments, negative flux is into the sediments.

HUNTING CREEK STATION 3

Station location and depth: In wide embayment upstream of Parkway crossing. Depth is 1 m.

Cores collected: 1100 June 30, 1986.

Weather: Partly cloudy, light winds.

Description of cores: Cores are gray sand with 0.5 cm of greenish sediment on top. White insects about the size of a sand grain and white, threadlike worms are abundant. The sediments are penetrated by worm tubes.

In situ	DO	Cond	pH	Temp
Surface				
Mid-depth	4.4	0.62	6.68	25.9
Bottom				

Sediment and Water column C

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jun 30	1504	0.00	5.80	25.0				
	1554	0.83	5.45					
	1619	1.25	5.20					
	1631	1.45	5.10					
	1700	1.93	4.95					
	1704	2.00	4.90	25.5				
	1900	3.93	>20	25.0	7.09	14.0	0.050	0.012
Jul 1	0900	17.93	13.0	25.5	6.75	13.0	0.036	0.011

Sediment and Water Column B

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jun 30	1504	0.00	5.60	25.0				
	1554	0.83	5.15					
	1619	1.25	4.95					
	1631	1.45	4.85					
	1700	1.93	4.70					
	1704	2.00	4.60	24.0				
	1900	3.93	>20	25.0	7.01	14.0	0.050	0.009
Jul 1	0900	17.93	6.90	25.5	6.66	14.0	0.029	0.012

Water Column C1

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jun 30	1504	0.00	6.80	24.0				
	1554	0.83	6.80					
	1619	1.25	6.85					
	1631	1.45	6.90					
	1700	1.93	6.95					
	1704	2.00	7.00	23.5				
	1900	3.93	>20	24.0	7.10	14.0	0.070	0.022
Jul 1	0900	17.93			7.11	12.0	0.065	0.012

Surface measures taken 30 cm below surface. Bottom measures taken 30 cm above bottom. DO, NH4, NO3, PO4 in mg/L. Conductivity in mmho/cm. Temperature in degrees Celsius.

HUNTING CREEK STATION 3

Column	DO	NH4	NO3	PO4	Gas	
Sed A	>16	14	0.04	0.012		Conc.
			-6	-0.4		Flux
Sed B	>13	14	0.04	0.011		Conc.
			-8	1.1		Flux
Cntl.	>10	14	0.07	0.017		Conc.
			-2	-3.4		Flux

Conc. is average of initial and final concentrations in mg/L. Flux is in mg/sq m/day for DO and nutrients, in mL/sq m/day for gas. Positive flux is out of the sediments, negative flux is into the sediments.

POTOMAC MAIN STEM STATION 83

Station location and depth: Mid-channel of Potomac between red and green markers leading into creek on right side. Depth is 18 m.

Cores collected: 1030 July 8, 1986.

Weather: Sunny with 10 to 15 knot winds.

Description of cores: Very fine brown silt throughout core. No distinct color transition. Live bivalves and snails present as well as shell fragments. Gas pockets in upper 10 cm of sediments.

In situ	DO	Cond	pH	Temp
Surface	7.5	0.32	7.93	27.8
Mid-depth	7.3	0.32	7.81	27.7
Bottom	7.2	0.30	7.96	27.7

Sediment and water column A

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 8	1510	0.00	7.80	28.5	8.11	0.116	2.02	0.024
	1540	0.50	7.45					
	1625	1.25	7.15					
	1645	1.58	6.95					
	1710	2.00	6.75					
	1725	2.25	6.65					
	1740	2.50	6.55	28.0				
Jul 9	0930	18.33	2.20	24.0	7.17	0.657	1.45	0.021
Jul 10	0900	41.83	0.70	22.0	7.20	1.29	0.78	0.024

Sediment and Water Column B

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 8	1510	0.00	7.40	28.0	8.11	0.116	2.02	0.024
	1540	0.50	7.15					
	1625	1.25	6.75					
	1645	1.58	6.55					
	1710	2.00	6.35					
	1725	2.25	6.25					
	1740	2.50	6.10	28.0				
Jul 9	0930	18.33	1.40	23.5	7.23	0.936	1.45	0.021
Jul 10	0900	41.83	0.20	22.0	7.12	1.38	0.82	0.022

Water Column C

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 8	1510	0.00	8.00	28.0	8.11	0.116	2.02	0.024
	1540	0.50	8.00					
	1625	1.25	7.90					
	1645	1.58	7.90					
	1710	2.00	7.85					
	1725	2.25	7.85					
	1740	2.50	7.80	27.0				
Jul 9	0930	18.33	6.30	24.5	7.70	0.072	1.97	0.012

Surface measures taken 30 cm below surface. Bottom measures taken 30 cm above bottom. DO, NH4, NO3, PO4 in mg/L. Conductivity in mmho/cm. Temperature in degrees Celsius.

STATION 83 POTOMAC MAIN STEM

Column	DO	NH4	NO3	PO4	Gas	
Sed A	5.0	0.39	1.74	0.023		Conc.
	-1170	113	-119	-0.6	47	Flux
Sed A	1.5	0.91	0.97	0.021		Conc.
	-250	128	-63	0.5	*	Flux
Sed B	4.4	0.53	1.74	0.023		Conc.
	-1050	144	-100	-0.5	0	Flux
Sed B	0.8	1.08	1.02	0.020		Conc.
	-170	83	-56	0.6	*	Flux
Cntl.	7.2	0.09	2.00	0.018		Conc.
	-380	-12	-13	-3.1		Flux

Conc. is average of initial and final concentrations in mg/L. Flux is in mg/sq m/day for DO and nutrients, in mL/sq m/day for gas. Positive flux is out of the sediments, negative flux is into the sediments. (*) Gas release occurred but evolution was too erratic to quantify.

POTOMAC MAIN STEM STATION 86

Station location and depth: Between Bouys 86 and 84. Depth is 10 m.

Cores collected: 0800 July 8, 1986.

Weather: Sunny.

Description of cores: Column A is brown silt with no distinct color transition. Column B is fine sand with shiny particles resembling mica. The upper cm of sand is slighly darker than the rest of the core. Gas pockets are present in both cores 10 to 15 cm below surface. Shrimplike creatures roughly 0.5 cm long and white insects the size of sand grains are present.

In situ	DO	Cond	pH	Temp
Surface	7.1	0.33	7.85	27.9
Mid-depth	7.15	0.31	7.72	27.8
Bottom	7.3	0.31	7.89	27.8

Sediment and Water column A

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 8	1125	0.00	7.80	27.5	7.83	0.171	0.743*	0.024
	1240	1.25	7.45					
	1310	1.75	7.40					
	1355	2.50	7.25	26.0				
Jul 9	0930	22.08	3.10	24.0	7.34	0.450	1.66	0.009
Jul 10	0915	45.83	0.20	22.0	7.24	0.907	1.23	0.029

Sediment and Water Column B

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 8	1125	0.00	7.90	27.5	7.83	0.171	0.743*	0.024
	1240	1.25	7.40					
	1310	1.75	7.20					
	1355	2.50	7.00	26.0				
Jul 9	0930	22.08	3.70	24.5	7.31	0.466	1.58	0.015
Jul 10	0915	45.83	1.95	22.0	7.22	0.649	1.13	0.019

Water Column C

Date	Time	Hour	DO	Temp	pH	NH4	NO3	PO4
Jul 8	1125	0.00	8.30	27.5	7.83	0.171	0.743*	0.024
	1240	1.25	8.20					
	1310	1.75	8.20					
	1355	2.50	8.15	25.5				
Jul 9	0930	22.08	6.30	24.5	7.70	0.089	2.01	0.012

Surface measures taken 30 cm below surface. Bottom measures taken 30 cm above bottom. DO, NH4, NO3, PO4 in mg/L. Conductivity in mmho/cm. Temperature in degrees Celsius. Questionable analysis indicated by *.

STATION 86 POTOMAC MAIN STEM

Column	DO	NH4	NO3	PO4	Gas	
Sed A	5.5	0.31		0.017		Conc.
	-1060	63		-3.4	47	Flux
Sed A	1.7	0.65	1.33	0.019		Conc.
	-610	109	-42	4.4	0	Flux
Sed B	5.8	0.32		0.020		Conc.
	-940	66		-2.0	0	Flux
Sed B	2.8	0.52	1.22	0.017		Conc.
	-360	55	-37	1.0	0	Flux
Cntl.	7.3	0.13		0.018		Conc.
	-440	-18		-2.6		Flux

Conc. is average of initial and final concentrations in mg/L. Flux is in mg/sq m/day for DO and nutrients, in mL/sq m/day for gas. Positive flux is out of the sediments, negative flux is into the sediments.