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Project Summary

Intensive Watershed Study: The Patuxent River Estuary

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This study was one of five intensive watershed studies designed by the Chesapeake Bay Program's Eutrophication Work Group to provide detailed non-point source export rates and ambient water quality data within the Chesapeake Bay drainage area.

The study was conducted within the Patuxent Estuary Watershed and consisted of estuarine slack tide surveys, intensive 24-hour water quality surveys, primary productivity measurements, sediment oxygen demand and sediment nutrient flux measurements, phytoplankton and nitrifying bacterial longitudinal surveys, non-point source monitoring at five subwatersheds, current speed and direction measurements, as well as rainfall quality and quantity measurements.

This Project Summary was developed by EPA's Chesapeake Bay Program, Annapolis, MD, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This study was one of five watershed studies funded by the U.S. Environmental Protection Agency, Chesapeake Bay Program. The study was designed to provide non-point source chemical export data for typical subwatersheds within the Chesapeake Bay Basin, as well as to provide information concerning the ambient concentrations of nutrients within the tidal river and estuary of the Patuxent River Basin. This estuarine system was chosen for study by the State of Maryland, Department of Natural Resources and the Chesapeake Bay Program because of concern for maintaining an economically important fishery and shellfish industry. Recent reports have indicated that land use activities have increased nutrient enrichment. The Patuxent Basin has experienced greater population increases and land use changes than most other watersheds within the Chesapeake Bay system. Therefore, a research monitoring study was selected for this basin in order to provide additional information for management of its water and biological resources.

The results of the study have been used by the Chesapeake Bay Program for developing baywide non-point source (NPS) data used for calibrating the Chesapeake Bay Basin Non-Point Source Model and for characterization of the nutrient enrichment of the Patuxent estuary, relative to other subestuaries within the Chesapeake Bay Basin. Data from this study are currently being used for water quality modeling purposes by other programs.

This report constitutes an initial interpretation to date of what is the most intensive study of this estuarine system. Careful documentation of the data collection efforts has been included in this report for future nutrient enrichment and habitat assessment evaluations.

Monitoring Program

Estuary and tidal river sampling stations were monitored between June 1980 and August 1981. This program included 17 slack water surveys and two 24-hour surveys. Figure 1 indicates the locations of the sample sites. The intensive water quality surveys (IWQS) were designed to provide information concerning lateral and vertical homogeneity of water column variables, as well as

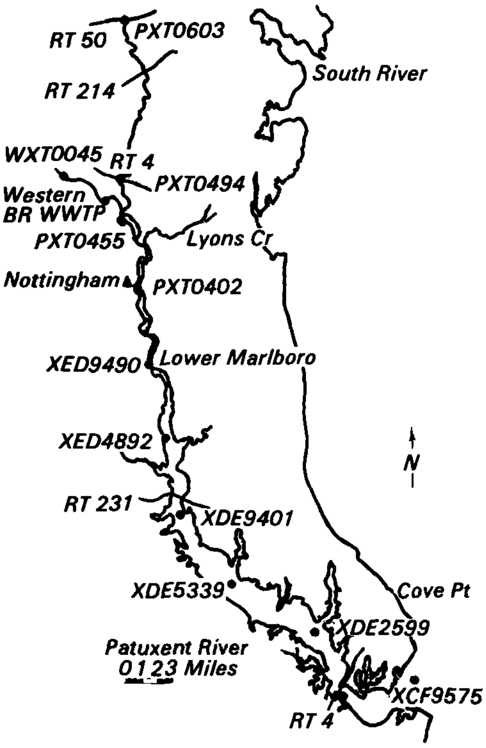

Figure 1. Mainstem of Patuxent River and Estuary showing locations of major sampling stations.

temporal changes within several tidal cycles. All data were stored in STORET. Variables measured included stage height, current velocity, wind, light penetration, pH, dissolved oxygen, temperature, relative humidity, secchi disc, chlorophyll-*a*, pheophytin, BOD_5, BOD_{20}, total organic carbon, dissolved organic carbon, chemical oxygen demand, total persulphate phosphorus, orthophosphorus,nitrate, nitrite, total suspended solids, dissolved reactive silicate, ammonia, alkalinity, and chlorides. Separate monitoring included additional measurements of sediment oxygen demand, total particulate nitrogen, total particulate carbon, and sediment nutrient fluxes. Several longitudinal surveys were conducted in order to determine the genera and to some degree, the species of algae along the estuary.

Five subwatersheds in the basin were selected for measurement of chemical export representing non-point source contributions from the land surface during rainfall events. Chemical export measurements were determined for ammonia, nitrate plus nitrite, total nitrogen, total phosphorus, orthophosphorus, BOD_5, BOD_{30}, total suspended solids, total organic carbon, chemical oxygen demand and alkalinity. Four subwatersheds were predominantly agricultural and one was an undisturbed forested site. The subwatersheds ranged in size from 34 to 144 acres, with three sites in the coastal plain province and two sites in the piedmont province. Samples were collected using automated flow-compositing techniques and equipment. Flow control devices, (H-S flumes or V-notch weirs) were installed at each site. At each site, a recording tipping bucket raingauge was installed. All equipment was run by installation of alternating current electricity. Agricultural sites were dominated by corn and tobacco or field corn and pasture land uses.

Results and Summary

Data collected during this study indicate that the Patuxent estuary sediment oxygen demand measurements are among the highest values measured and reported in the literature (Figure 2)*. High sediment oxygen demand is a classical example of secondary impacts from nutrient enrichment.

Nutrient budgets were calculated from the data collected during this intensive study in order to indicate to managers and researchers the potential major sources of nutrient enrichment. The results of these budgets shown in Figures 3 thru 7 indicate the major sources of nutrient to the estuary during this study. Data indicate the major sources of total nitrogen are from fluvial sources at Rt. 50, followed by the lower estuary sediment flux and NPS loads. The data also indicate that there is a net exchange of total nitrogen out of the estuary. Figure 4 shows the dissolved $NO_2 + NO_3$ budget. This budget indicates that the largest source to the estuary is also from fluvial sources above Rt. 50, followed by the source from Chesapeake Bay.

The ammonia budget (Figure 5) indicates that the sediment flux in the upper and lower river may be the greatest source followed by the source from Chesapeake Bay. The total phosphorus budget (Figure 6) indicates that the lower estuary

*D-Elia, C.F., et al., 1981. Benthic Nutrient Studies on the Lower Patuxent River, Final Report, DNR Contract #39753.

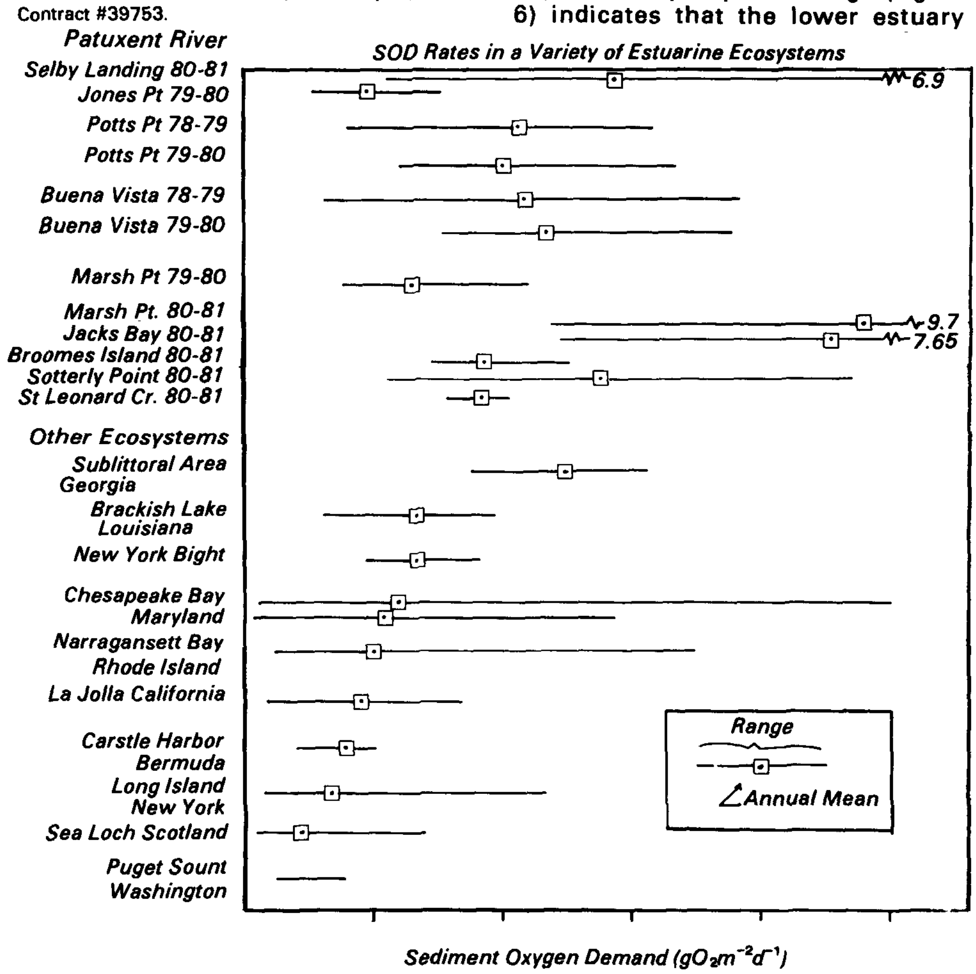

Figure 2. Sediment oxygen demand rates in estuarine systems compiled by D'Elia, et al. for this study.

sediment flux and non-point sources in the lower estuary may be the same order of magnitude and represents the largest sources. The dissolved orthophosphorus budget indicates that the lower estuary sediment flux and fluvial sources above Rt. 50 are the major sources followed by the potential source from Chesapeake Bay.

Theoretical conservative mixing diagrams also indicate potential sources of nutrients in the estuary. These diagrams indicated high variability from month to month but on a seasonal and annual basis trends were apparent. A mid to lower estuary peak was observed from station averages for orthophosphorus, total phosphorus, and silica conservative mixing diagrams. These diagrams support the view, as well as the phosphorus budgets that a source of phosphorus to the estuary water column exists in the area of the turbidity maximum.

The estimated flushing time of the tidal river and estuary is around 315 days. This information, in conjunction with the dissolved nitrogen conservative mixing diagram, indicates that the estuary serves as a sink for most of the fluvial nitrogen. Conservative mixing diagrams for nitrate, nitrite, and dissolved nitrogen also indicated a sink of nitrogen in the mid to upper estuary and a source near the mouth of the estuary. If this is the case, one would expect high sediment-nutrient fluxes of inorganic nitrogen, especially ammonia, due to remineralization of organic matter, and associated high sediment oxygen demand due to settling out and resulting decay of organic material. The budget for ammonia (Figure 5) indicates a major source of ammonia in the estuary is from the sediments.

Data also indicate that ammonia behaves as a conservative substance in the water column, except in the lower estuary where a source is indicated (due to higher bottom concentrations). Thus, the fate of nitrogen introduced into the estuary appears to be that it remains in the system for a relatively long period and is probably remineralized by sedimentation and biological processes, yielding high ammonia concentrations in bottom waters.

Thus, the role that sediments play in regulating water column concentrations in the Patuxent estuary appears to be important, as reported by other studies. As part of this study, D'Elia et al. calculated that the sediments may supply approximately 30% of the daily phytoplankton demand for water column ammonium. This fact also indicates that

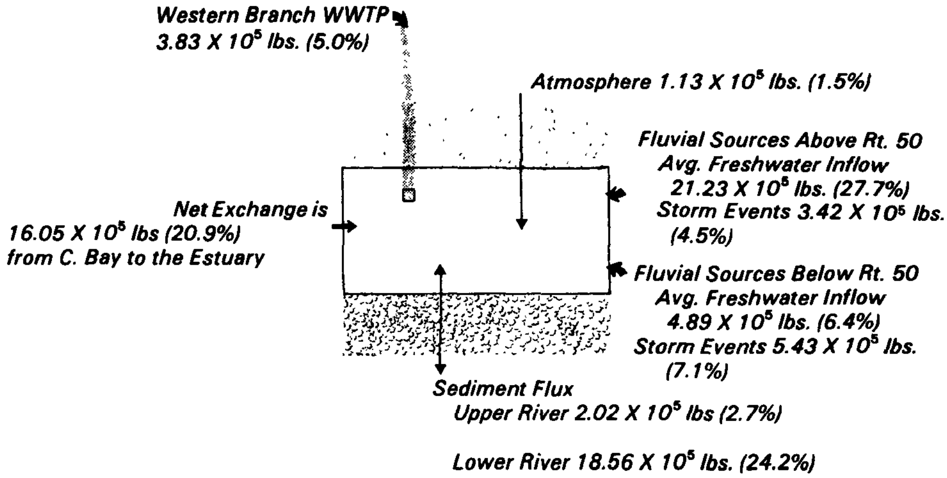

Figure 3. *Patuxent Estuary estimated total nitrogen budget for April thru October.*

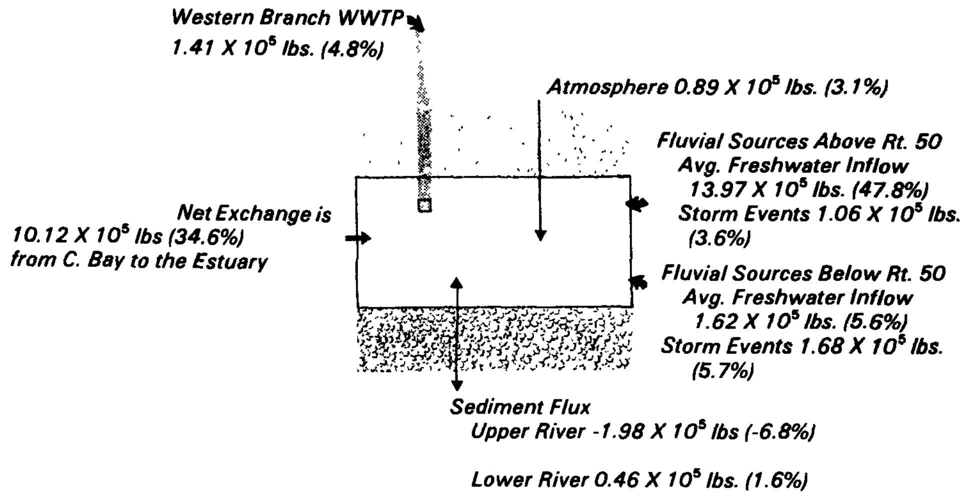

Figure 4. *Patuxent Estuary dissolved $NO_2^- + NO_3^-$ budget for April thru October.*

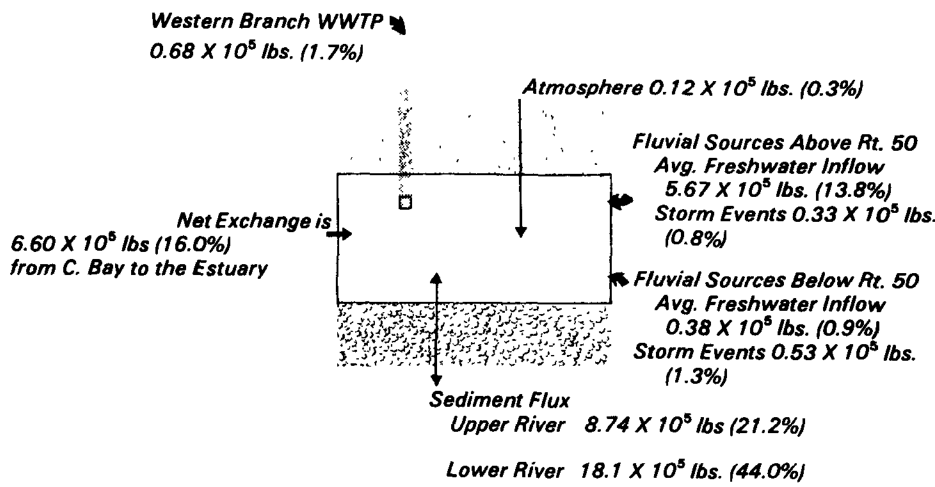

Figure 5. *Patuxent Estuary dissolved NH_3 budget for April thru October.*

the sediments may be responsible for controlling water column concentrations occasionally.

A typical concern in estuarine management is determination of the limiting factors to plant or algal production. Although temperature is one of the most dominant controlling factors, knowledge of the controlling nutrient has been used to help focus management scenarios for point and non-point source nutrient controls.

Unfortunately, the limiting nutrient affecting plant production is not consistent spatially and temporally which makes management strategies difficult to develop as well as to determine their effectiveness. An evaluation of the redfield ratio (N/P ratio) was conducted using data collected during this study. This analysis showed that the apparent limiting nutrient varies longitudinally as well as monthly. A multiple regression analysis indicated that approximately 75% of the variability of the redfield ratio could be explained by location (i.e. nautical mile), salinity, timing of the survey to the previous storm event and characteristics which describe the size of the previous storm event, i.e. peak daily CFS, average daily CFS during storm event, and sum of daily CFS from beginning to the end of the storm. From this analysis, as well as examination of the data, it can be inferred that storm events and their associated export of nutrients cause pulses of nutrients to enter the estuary, which in turn determine the limiting nutrient. From a management perspective, this clearly shows the need for considering the effect of storm events and associated chemical export from land use activities on the management of the estuarine resources. It also supports the fact that nutrient limitation would be poorly estimated from steady state eutrophication models.

One measure of the suitability of an aquatic habitat for fisheries and shellfish production is the level of dissolved oxygen needed for growth and reproduction. The effects of nutrient enrichment can be expressed in the dissolved oxygen found in the water column. One effect of increasing nutrient enrichment should be observed through low dissolved oxygen in bottom waters. Historical dissolved oxygen measurements (approximately 5,000) were collected from historical reports and studies conducted in the mainstem Patuxent River. Statistical analyses were performed in order to determine trends. A mean dissolved oxygen deficit occurred throughout the mainstem estuary. Monthly average

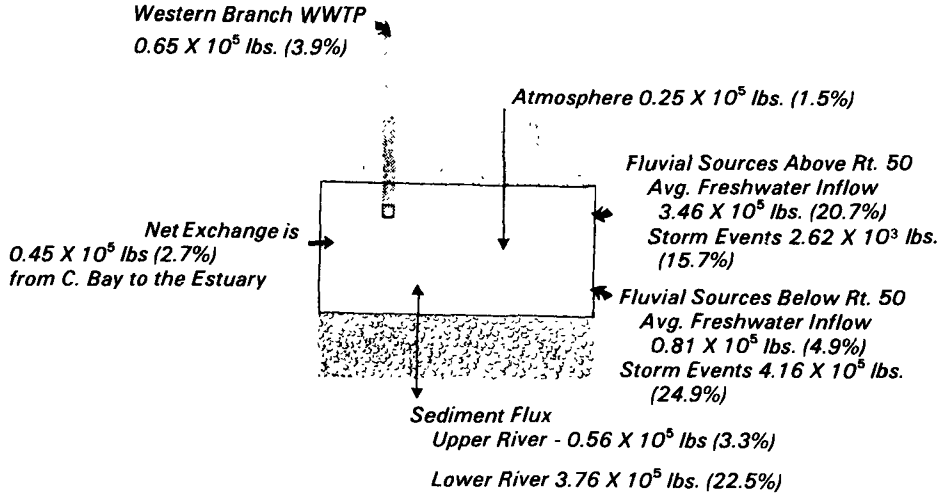

Figure 6. *Patuxent Estuary total phosphorus budget for April thru October.*

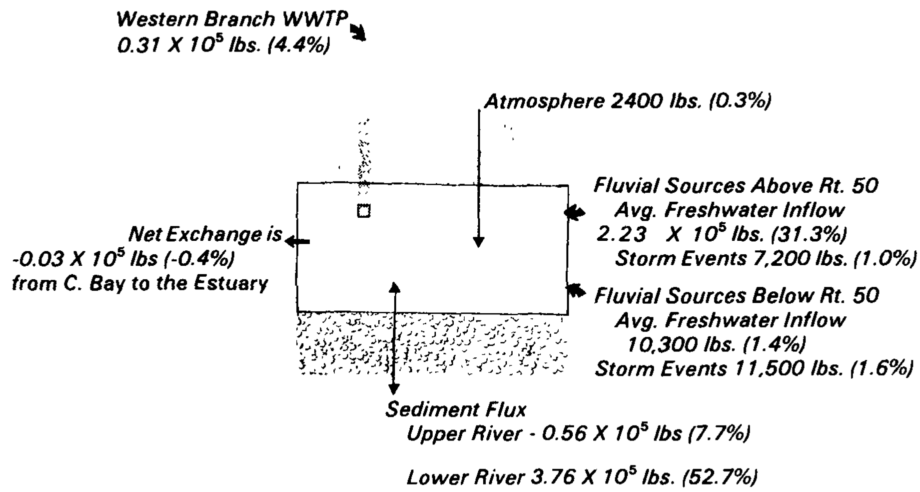

Figure 7. *Patuxent Estuary dissolved orthophosphorus budget for April thru October.*

summer deficits are around 2 mg/l with a maximum average deficit around 2.3 mg/l in September. The mean dissolved oxygen deficit is around 3 mg/l in the lower river (10-24 ppt salinity) at depths greater than 30 feet. Yearly mean dissolved oxygen plots show no apparent trends for the entire river. However, a strong trend towards lower dissolved oxygen is observed for a river segment above the Western Branch tributary based upon seasonal mean dissolved oxygen. A low dissolved oxygen trend is observed when historical dissolved oxygen deficits are regressed for the upper estuary. A similar trend is indicated in the lower estuary when all values are regressed versus time, although it is not as apparent as in the upper estuary. A detailed analysis of dissolved oxygen deficits categorized by months, depths and time of day clearly showed the lack of consistent monitoring in the estuary, especially in deeper waters in the lower estuary where dissolved oxygen reaches anoxia level. Lack of consistent historical measurements indicates ambiguous results when more detailed statistical analyses of dissolved oxygen deficits are performed.

The relative importance of freshwater flow effects on nutrient concentrations was examined by conducting regression analysis between station nutrient concentrations, surface to bottom salinity differences, and transformations of average freshwater inflow before the estuarine water quality surveys. This analysis was performed to indicate the effect of advective processes on water column stratification. The results of this analysis indicated that stratification at each station may be uniquely controlled. In addition, water column stratification (indicated by surface to bottom salinity differences) and freshwater inflow explained approximately 50% of the variability of nutrient concentrations. Further analyses should be performed to more fully explain dominant physical processes at different longitudinal stations.

The relative importance of NPS loads to the basin is indicated by the nutrient budgets. The NPS chemical export data indicated that the predominant NPS loads of total phosphorus and total nitrogen may come from agricultural lands (Table 1). These data are consistent with other estimates. Table 2 shows the ratio of agricultural to forested chemical export during storm events. Data from this study indicate that total phosphorus is six to seven times higher in agricultural runoff than from forested land runoff. Total suspended solids (representative of suspended sediment) was five times higher in agricultural runoff than in the forested site monitored in this study.

Fluvial sources above Rt. 50 are the major source of $NO_2^- + NO_3^-$ with Chesapeake Bay being the major source. Nonpoint source export of ammonia on a basin-wide basis appears insignificant. Total phosphorus NPS export is indicated as the major source to the estuary as shown in Figure 6. NPS chemical export of orthophosphorus is insignificant compared to the sediment flux in the estuary.

Table 1. *Estimated Average Potential Watershed Chemical Export for Total Phosphorus During Storm Events to the Patuxent River Basin*

Land Use Activity	*Estimated Acres In Basin**	*Potential Load lb/yr.*	*Loading Rate lb/acre/yr*	*Source*
Agricultural	*205,743*	*532,813*	*2.5897*	*this study*
Forested	*272,738*	*104,131*	*.3818*	*this study*
Other (i.e. residential, commercial, industrial, and idle)	*58,843*	*37,574*	*1.180*	*
All Activities	*537,324*	*674,518*	—	—

**Provided by Maryland Department of State Planning.*

Table 2. *Relative Comparison of Estimated Average Agricultural to Forested Wastershed Chemical Export*

Variable	*Ratio of average Agricultural to Average Forested Export (lb/acre/inch of rain)*
BOD_5	2.7
BOD_{30}	2.3
TSS	5.2
NO_2	0.3*
NO_3	1.6
NO_2NO_3	4.2
NH_3	3.2
TKN	3.0
TKND	1.8
TPHOS	6.8
TPHOSD	2.4
DPO_4	2.5
TOC	2.5
COD	2.8
ALKLIN	3.6

**Suspect data due to holding time and analytical procedure used.*

The duncan multiple range test was applied to the data for characterizing zones of chemical similarity. This test clearly shows river segments which have relatively unique concentrations. In many cases, this analysis identified the surface water concentrations as a unique class in the turbidity maximum region of the estuary. Unique zones were identified in the turbidity maximum region for silica, salinity, BOD_5, total suspended solids, and total organic carbon. Unique zones were identified in the lower estuary for surface water pH; bottom water alkalinity and chlorophyll-*a* near the mouth of the estuary; and silica in bottom water and surface water at the mouth of the estuary. It is interesting to note a unique zone in the lower estuary was identified for dissolved oxygen and dissolved nitrate. This zone showed the lowest average concentrations for both dissolved oxygen and dissolved nitrite. This zone or region of the estuary occurs downstream of the mid-estuary sill. This zone is also the region where lower estuary dissolved oxygen values have historically been close to zero. Observations from the slack water survey data indicate that this may also be a region of upwelling of anoxic bottom water due to a combination of advective and tidal mixing. The existence midriver of the sill (near nautical mile 25) as well as the fact that the rate of change of water depth increases in this area, makes the region susceptible to upwelling phenomena. Plots of temperature and salinity profiles in this region of the estuary indicated inversions, i.e. higher salinity and lower temperature in surface waters. High chlorophyll-*a* values in this region of the lower estuary may also be due to upwelling of nutrient rich bottom waters. Dinoflagellates (cells/ml) increase in this region where upwelling may predominate under certain mixing conditions. The predominance of marine dinoflagellates in the region just below the apex of the midriver sill and upstream of the bottom water D.O. minimum, as well as vertical instability of the water column, is one of the most interesting findings of the study. Figure 8 (a and b) shows that low dissolved oxygen has historically occurred downstream of the region where upwelling processes are indicated.

Conclusions

Data collected and initially analyzed under this grant indicate that a trend exists for lower dissolved oxygen above Western Branch, based on a seasonal analysis. Fluvial inputs (including point source loads) represent the greatest sources of $NO_2 + NO_3$, orthophosphorus, total nitrogen, and total phosphorus. Simple nutrient budgets indicate Chesapeake Bay may be a major source for $NO_2 + NO_3$ (34.6%), NH_3 (16%) and total nitrogen (20.9%). A significant source of total phosphorus from NPS chemical export (40% of the total) to the estuary is indicated. The data suggest that upwelling of lower estuary water, rich in nutrients from sediment-nutrient fluxes may be

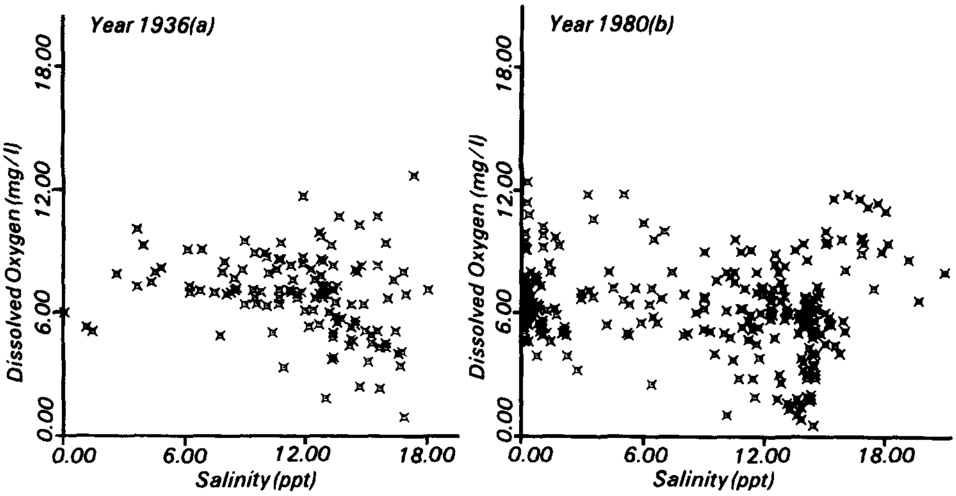

Figure 8. *Historical dissolved oxygen versus salinity for years 1936(a) and 1980(b) in the Patuxent Estuary.*

responsible for episodes of high chlorophyll-*a* in the lower estuary.

Recommendations

- Investigations should continue to determine the future trends of lower dissolved oxygen in the upper estuary.
- A statistically based monitoring program should be established around Sheridan point and above, in order to determine if historically low dissolved oxygen is increasing in extent and frequency of occurrence.
- The above monitoring should be coupled with dynamic monitoring in order to determine to what extent lower estuary high chlorophyll-*a* may reflect periods and processes related to upwelling of bottom, and nutrient rich waters, characteristic of phytoplankton derived from Chesapeake Bay.
- Continued monitoring of sediments and sedimentation is necessary for developing a baseline of SOD and Sediment Nutrient Fluxes.
- Once completed, the variability over time with respect to SOD and Sediment Nutrient Fluxes should be monitored to determine the dominant processes involved, as well as the effectiveness of point and non-point source controls.
- Monitoring of dissolved oxygen in oyster bed areas will be needed to determine if these living resources are being impacted by point or non-point source land use activities and low dissolved oxygen.
- Data collected during this study should be used to calibrate and validate a real-time model of water quality and hydrodynamics.
- Real-time hydrological simulation modeling will be needed in order to prioritize subwatersheds in the basin for applying best management practices. Data from this study should be used for this purpose.

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***James Smullen** is the EPA Project Officer (see below).*
The complete report, entitled "Intensive Watershed Study: The Patuxent River Estuary," (Order No. PB 83-251 470; Cost: $64.00, subject to change) will be available only from:
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