EUTROPHICATION AND NUTRIENT LOADING IN BARNEGAT BAY: IMPORTANCE OF SEDIMENT-WATER NUTRIENT INTERACTIONS
YEAR II

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SUMMARY

Barnegat Bay is a valuable commercial and recreational resource in the state of New Jersey. Eutrophication, however, due to excess nutrient inputs, poses a serious threat to Barnegat Bay. Currently, the Bay is receiving considerable inputs of nutrients which are expected to increase in the future due to continued population growth in the surrounding area. However, prediction of the effects of decreasing the current rate of nutrient inputs (e.g., from storm drains or marinas) or increased inputs from future development is not currently possible because the magnitude of the sources is not known. In addition, little is known about the relationship between nutrient inputs and eutrophication in shallow, highly productive bays such as Barnegat Bay.

The present year's study is part of a long-term program intended to obtain field data quantifying both the inputs and removal rates of nutrients in the Bay. This includes quantification of the external and internal sources of nitrogen and phosphorus, internal removal rates of nitrogen and phosphorus, and determination of the importance of these sources and sinks as factors controlling eutrophication in the Bay. We are focusing our current efforts on the sediments because sediment-water nutrient interactions are likely a major factor controlling the response of Barnegat Bay to a given rate of external nutrient loading by: (1) supplying two to ten times as much nitrogen and phosphorus for algal growth as external inputs through recycling, (2) storing pulsed inputs of nutrients to fuel summer algal blooms, (3) removing nutrient inputs by burial in the sediments or via denitrification, and (4) controlling which nutrient, nitrogen or phosphorus, is most limiting to algal production regardless of the relative amounts entering the Bay from external sources.

The first year of study (1988) was devoted primarily to the development of methods for measuring sediment-water N and P fluxes and organic matter deposition rates in Barnegat Bay. We then applied those methods at a number of locations in the highly developed northern end of the bay. While measurements were restricted to the early fall period and thus are limited in temporal coverage, the results of the first year of study have already contributed significantly to our understanding of nutrient processes in Barnegat Bay. The sediments appear to be a major sink (removal site) for both N and P in the bay, at least during the early fall. The magnitude of this sink strongly suggests that removal of N and P in the sediments is an important factor regulating the amount of N and P available in the water for algal production, and thus important in controlling eutrophication in the Bay. Based on the N:P ratio of nutrients in the northern bay area, nitrogen, not phosphorus, appears to be the nutrient most limiting to algal production in Barnegat Bay. These conclusions are, however, based on a limited set of data as measurements were made only during the

early fall and only in the northern end of the bay. Studies are now required over an annual cycle throughout the bay to provide an information base that can be reliably used to develop a more complete understanding of nutrient processes and eutrophication in Barnegat Bay. During year two we propose to apply the methods that we developed during the first year to studies of nutrient (N and P) release from the sediments) both vegetated and unvegetated), nutrient removal (both short term storage and long term burial) in the sediments, water column nutrient concentrations and primary production rates over an annual cycle. Studies will be carried out in both the highly developed northern and less developed southern bay areas.

PROBLEM STATEMENT AND NEEDS ASSESSMENT

Eutrophication poses a serious threat to Barnegat Bay and other shallow bays behind barrier islands (back bays) that line the coast of New Jersey. These shallow bays are currently receiving considerable inputs of nutrients from a variety of sources, likely including storm drains, marinas, runoff, groundwater, septic systems, leaking sewer pipes, and direct discharge. In the future, nutrient inputs are expected to increase due to continued population growth in the watershed surrounding Barnegat Bay, as well as from increased recreational use of the Bay by boaters. Barnegat Bay is already showing signs of eutrophication due to excess nutrients including summer algal blooms and localized areas of anoxia in marinas. The high coliform counts, which are indicative of nutrient inputs from sewage, result in approximately 20% of Barnegat Bay being closed to shellfishing (W. Eisele, DWR BMWCA, personal communication). Changes in the area of seagrass (Zostera), which provide important habitat for blue crabs and various finfish, may also be due to eutrophication. All of these effects of excess nutrients can ultimately lead to a decrease in both the commercial and recreational uses of Barnegat Bay and eventually to a decrease in property values. Widespread concern for the protection of this fragile ecosystem led to the passage of the Singer Bill in the New Jersey legislature (Assembly Bill No. 3659) which is aimed at providing information about how development pressures are affecting the Bay.

Gauging the effects of increased development on eutrophication in Barnegat Bay is difficult, however, because little is known about the nutrient dynamics (including the relationship between nutrient inputs and eutrophication) in any of these shallow, highly productive bays. Previous studies of eutrophication and nutrient dynamics in estuaries have focused on relatively deep estuaries such as Delaware Bay, Narragansett Bay, and Chesapeake Bay (reviews by Boynton et al. 1982; Nixon 1981) and it is not clear to what extent results from studies of deeper estuaries can be used to predict the effects of nutrient inputs to these shallow bays including Barnegat Bay.

The release of nutrients from bottom sediments may be a major source of nutrients in Barnegat Bay. Studies in deeper estuaries have demonstrated that external inputs of nutrients are not sufficient to supply the needs of phytoplankton. The sediments in deeper estuaries are a major source of nutrients providing 2 to 10 times as much nitrogen (N) and phosphorus (P) to the phytoplankton (by continual recycling) as the external inputs to the estuary (Nixon 1981; Boynton et al. 1982). In Barnegat Bay and other back bays, sediment-water exchanges of nutrients are expected to be particularly important as a source of recycled nutrients for algal growth due to the shallowness of the water column. In addition, the sediments can act as a short-term storage site for pulsed inputs of nutrients that enter the Bay from storm drains or during spring runoff. Those nutrients can be recycled back to the water column later to fuel summer algal blooms.

On the other hand, the sediments may play an important role in nutrient removal, either through burial or nitrogen removal through denitrification. Denitrification (reduction of NO_3 to N_2 gas by bacteria) is a major removal process for N in deeper estuaries; approximately 50% of the external N inputs from natural and anthropogenic sources in deeper estuaries is removed by denitrification in the sediments (Seitzinger et al. 1984; Seitzinger 1988). Denitrification in Barnegat Bay, and back bays in general, may be an even more important removal process for N because of the greater interaction between the sediments and water column. Many studies in estuaries have shown that N is more limiting to algal production than P (Durand 1984 for Great Bay, NJ; Boynton et al. 1982; D'Elia et al. 1986; and others). Thus the permanent removal of a major portion of N inputs by denitrification may be an important factor controlling the degree of eutrophication of shallow back bay estuaries like Barnegat Bay.

The sediments may also play a major role in controlling which nutrient, nitrogen or phosphorus, is most limiting to algal production. Differential removal of N or P in the sediments (by burial or denitrification) can markedly effect the N:P ratio of nutrients recycled for algal growth (Seitzinger et al. 1984) thereby influencing which nutrient, N or P, is more limiting to algal production regardless of the relative amounts of N and P coming into the Bay from external sources.

Sediment-water nutrient interactions therefore are likely a major factor controlling the response of Barnegat Bay to a given rate of nutrient loading by: greatly amplifying the magnitude of the external nutrient inputs, through recycling processes, storing pulsed inputs of nutrients to fuel summer algal blooms, permanently removing nutrient inputs by burial in the sediments or via denitrification, and controlling the ratio of N:P available for algal production. Unfortunately, there have been few previous studies of sediment-water nutrient interactions in shallow back bay

estuaries (Durand 1984; Nowicki and Nixon 1985) like Barnegat Bay. The development of cost-effective management decisions regarding control of present nutrient inputs and continued future development and use of Barnegat Bay depends on a clear understanding of the coupling between external nutrient inputs, nutrient supply or removal by the sediments, and eutrophication of the Bay.

Relation to DEP Needs

The results of our complete research program, as outlined below under "Long-Term Goals", will provide NJDEP with quantitative data on the magnitude of external (including marinas, storm drains, groundwater, etc.) and internal (sediments) sources of nutrients to the Bay, the importance of short-term storage of nutrients in the sediments which can be released later to fuel algal blooms, long-term removal of nutrients in the sediments by burial or nitrogen removal by denitrification, and factors controlling the N:P ratio of nutrients available for algal production.

The results of our complete research program will provide specific informational needs that the NJDEP will be able to use in addressing a number of issues including the following:

Algal Blooms: Are the sediments an important source of nutrients fueling nuisance algal blooms in Barnegat Bay? Are sediments in some areas of the Bay more important than others as a source of nutrients?

AND/OR

Are the sediments an important site for nutrient removal in Barnegat Bay, thus removing significant amounts of N and P that would otherwise be available for algal blooms? Are sediments in some areas of the Bay more important than others in removing nutrients?

Regulating Development: Are certain areas of the Bay inherently better able to assimilate increased nutrient loading from future development because of such environmental factors as their degree of vegetation (Zostera) or the composition (grain size) of their sediments (which can influence the amount of nutrients removed by or released from the sediments)?

Nutrient Control Strategy: Does the N:P ratio of nutrients in the Bay differ from the N:P ratio of nutrients entering the Bay from external sources? If so, what are the most important factors controlling the N:P ratio of nutrients in the Bay and how does this affect which nutrient (N or P) should be targeted for reduction in a nutrient control strategy for the Bay?

Marina Siting and Operations: Do marinas contribute significantly to overall nutrient loading to Barnegat Bay? Does nutrient release and oxygen consumption by marina sediments

contribute significantly to poor water quality and intermittent anoxia in the marinas?

Storm Drains: Would allocation of resources to mitigate impacts from storm drain effluent reduce nutrient loading enough to result in measurable improvement in Bay water quality?

OBJECTIVES

To address the above informational needs, our complete research program contains the six long-term goals as outlined below. During the first year of study, we adapted methodologies specifically for use in Barnegat Bay and began making measurements that address a number of these long-term goals. During year two we propose to expand those measurements both temporally and spatially, making measurements in Barnegat Bay over an annual cycle in the highly developedinstit northern and less developed southern bay areas. Such spatial and temporal coverage is required in order to more fully understand nutrient processes and eutrophication in Barnegat Bay. This information will also form a base of information that can be used to develop a sound nutrient control and development strategy for Barnegat Bay.

Long-Term Goals

(1) quantify the importance of sediment-water nutrient (N and P) exchanges as a source of nutrients for phytoplankton production throughout Barnegat Bay;

(2) quantify the magnitude of the external inputs of nutrients to the Bay throughout the year from point and non-point sources including, but not limited to, marinas, storm drains, and groundwater;

(3) quantify the importance of the sediments in Barnegat Bay as a site for long-term burial of nitrogen and phosphorus;

(4) quantify the magnitude of removal of external inputs of nitrogen to the Bay by denitrification;

(5) investigate the influence of pulsed inputs (e.g., spring runoff and storm drain inputs) on nutrient processes by examining the lags between N and P inputs to the Bay (from spring thaws and storms), short-term storage in the sediments and subsequent re-release to the water column (this relationship is likely important for understanding the sources of nutrients fueling summer algal blooms); and

(6) calibrate (verify) the direct applicability of results of a nutrient enrichment experiment using back bay estuary mesocosms at the University of Rhode Island for use in predicting nutrient

enrichment effects in New Jersey back bay estuaries, including Barnegat Bay. That study is funded by NOAA/Sea Grant.

The objectives of the second year of study are best understood in the context of the results of the first year.

Results of First Year of Study

Year 1 Accomplishments: The results of our first year of study have already contributed significantly to a number of the above NJDEP informational needs. The first year's major objectives were all accomplished despite the shortness of the field season (approx. 2 months). The major accomplishments, which were presented in the first quarterly report, are outlined below:

1. Study sites were selected in northern Barnegat Bay and at a marina location.

2. In situ benthic flux chambers for measuring sediment-water nutrient fluxes were designed and constructed.

3. Methods were developed for sediment trap collection of organic N and P deposition.

4. Measurements of sediment-water fluxes of ammonia, nitrate plus nitrite, phosphate, and oxygen were made at four locations: two locations with vegetated (Zostera and macroalgae) sandy sediments, an unvegetated fine grained silt-clay sediment, and a silty-sand location in Long Quay Marina.

5. Measurements of organic N and P deposition were made at one of the vegetated study areas in the bay.

6. Primary production measurements were made repeatedly at the same location as organic matter deposition measurements and once at each of the other three locations.

Preliminary Interpretation and Implications of Year 1 Study: We are currently completing the analysis of the data from the above measurements. However, preliminary analysis of the data available to date demonstrates that the first year of study contributed significantly to our understanding of nutrient processes in Barnegat Bay. The three major findings to date and possible implications for Barnegat Bay are listed below.

1. The N:P ratio of inorganic nutrients was very low (~2:1) in September. These low N:P ratios suggest that nitrogen, not phosphorus, is the nutrient most limiting to phytoplankton production in Barnegat Bay during that time.

2. The sediments are an important site for the decomposition of organic matter. Sandy vegetated sediments generally had higher rates of organic decomposition than silt-clay unvegetated areas. This is based on measurements during September of sediment oxygen consumption rates which ranged from approximately 2400 to 3100 umol O m^{-2} h^{-1} in the sandy vegetated sites and from 1000 to 1400 umol O m^{-2} h^{-1} in the silt-clay unvegetated areas. Rates in the summer are expected to be even higher.

3. The sediments appear to be an important site for both N and P removal and are likely important in maintaining nutrient concentrations in the water column at relatively low levels. Based on an assumed Redfield (1958) ratio of 212:16:1 for oxygen consumed to nitrogen and phosphorus released during the decomposition of organic matter, the release of N and P from the sediments can be predicted knowing the oxygen consumption rate. This method predicts a release from the sandy vegetated sediments of approximately 200 umol N m^{-2} h^{-1} and 13 umol P m^{-2} h^{-1}; approximately 90 umol N m^{-2} h^{-1} and 6 umol P m^{-2} h^{-1} should have been released from the silt-clay unvegetated areas. However, there was essentially no measurable release of either N (as ammonia or nitrate) or P (as phosphate) from the sediments at any of the four locations studied. This strongly suggests that these sediments are an important site for nutrient removal at this time of year, either through burial in the sediments or nitrogen removal by denitrification.

A rather simple but useful way to put the magnitude of this sink for N and P in perspective is to calculate the increase in concentration of N and P in the water column that would be expected if the sediments were not removing N and P at the above estimated rates, but rather returning the N and P to the water column. A release of 200 umol N m^{-2} h^{-1} from the sandy vegetated sediments would increase the nitrogen concentration in the water (assumed average depth 1.5 m) by approximately 5 uM per day or 35 uM per week; this is a large amount of nitrogen considering that ammonia plus nitrate concentrations were only about 0.5 uM during September. A release of 13 umol P m^{-2} h^{-1} would release an amount of phosphorus equivalent to an increase of 0.2 uM per day or 1.5 uM per week, which again is significant compared to the ambient water column phosphate concentration of ~0.5 uM. (The above calculations of concentration increase were made assuming no processes in the water would remove the N and P released from the sediments.)

As stated above, these conclusions are based on measurements made at only one time of year (early fall) and only in the northern end of the bay. During year two we propose to expand the temporal and spatial coverage of our sediment-water nutrient flux measurements and organic matter deposition measurements, as well as begin to estimate long term burial of N and P in the sediments.

Year 2 Study Objectives

The specific objectives of the second year of study are as follows:

(1) Measure sediment-water nutrient (NH_4, NO_3, PO_4) and oxygen fluxes over an annual cycle in the highly developed northern end of the bay and in the less developed southern end of the bay. Study sites will include both vegetated (Zostera and macroalgae) sandy sediments and unvegetated silt-clay sediments in both the northern and southern bay areas.

(2) The short-term storage of N and P in the sediments will be measured as the difference between the rate of organic N and P deposition to the sediments and the rate of release of N and P from the sediments as mineralization products (see Objective 1, above). By following the rates of these two processes over an annual cycle we can begin to understand time lags between the deposition of organic matter to the sediments, short-term storage of N and P in the sediments and release of inorganic nutrients back to the water column to fuel algal production. From frequent measurements of organic matter deposition we can also begin to clarify the importance of short-term storage in the sediments of N and P inputs from events such as storms and spring inputs. This past year we developed a method to measure deposition rates of N and P in sediments of shallow back-bay estuaries. We will make some additional modifications for use in heavy weather conditions and at deeper water sites and then will use this method to measure N and P deposition rates over an annual cycle at the same locations that benthic nutrient fluxes are measured.

(3) Estimates of long-term burial of N and P in the sediments will be obtained from measurements of the N and P content of sediment cores from Barnegat Bay which have been dated and archived by Lamont-Doherty Geological Observatory at Columbia University.

(4) Measurements of ammonia, nitrate plus nitrite, and phosphate concentrations will be made over an annual cycle throughout Barnegat Bay. In addition, phytoplankton production measurements will be measured at frequent intervals between April and October. These data will provide information that will be used in the interpretation of nutrient cycling processes outlined above as well as baseline information against which changes in nutrient concentrations in Barnegat Bay in future years can be compared.

(5) While there are not sufficient funds in this year's budget to make measurements of denitrification in Barnegat Bay, I currently have funding from NOAA/Sea Grant through the New Jersey Marine Sciences Consortium which includes funds to refine my current method for measuring denitrification to make it optimally reliable and sensitive for use in shallow back-bay estuaries. Preliminary measurements of denitrification in unvegetated sediments in Barnegat

Bay were made this past summer with NOAA/Sea Grant funds; the results of those measurements suggest that considerable amounts of nitrogen are being removed by denitrification in Barnegat Bay. Continued methods development is currently underway to adapt the denitrification methodology for use in vegetated sediments. The research carried out during the upcoming year with Sea Grant funding will put us in an ideal position to carry out measurements of nitrogen removal by denitrification in Barnegat Bay in subsequent years.

(6) Currently there is a Sea Grant funded experiment underway at the University of Rhode Island examining the effects of eutrophication in shallow back bay estuaries using a mesocosm facility. This is a multi-investigator, -institution and -state project examining many aspects of the relationship between nutrient loading and eutrophication in shallow back bay estuaries, including algal and seagrass production, secondary production by a variety of invertebrates and fishes, nutrient cycling and sediment-water nutrient fluxes. Our long-term goal is to use the results of our Barnegat Bay studies as well as other data available for Barnegat Bay including information stored in GIS, to provide field validation of the mesocosm studies and to determine the applicability of the results to New Jersey back bay estuaries. Our final report to NJDEP of the results of the currently proposed work in Barnegat Bay will include a preliminary analysis and interpretation of the mesocosm studies and their implications for environmental management in the Barnegat Bay area.

DETAILED DESCRIPTION OF METHODS

Sediment-Water Nutrient Fluxes

Study Areas: Sediment-water nutrient fluxes will be measured over an annual cycle (four time periods) at four locations in Barnegat Bay: one unvegetated fine grained silt-clay sediment area in the northern and one in the southern end of the bay and one vegetated (*Zostera*) sediment area in the northern and one in the southern end of the bay. Sites in both the northern and southern end of the bay will be studied to compare the highly developed (northern) and less developed (southern) portions of the bay. Both vegetated sandy sediments and unvegetated silt-clay areas will be studied as these two sediment types are estimated to comprise over 60% of the area of the bay.

Nutrient Flux Measurements: Measurements of the net flux of ammonia, nitrate plus nitrite, phosphate and oxygen between sediments and overlying water will be made at the locations described above. We are currently planning to make these measurements using field collected cores incubated under ambient field conditions in the laboratory; however, *in situ* and lab methods

will be compared as discussed below. The reason for using laboratory incubations are also outlined below.

Sediment cores (six from each location) for benthic nutrient and oxygen flux measurements will be collected by SCUBA-equipped divers using plastic coring tubes. Care will be taken during coring to avoid disturbance of the sediment surface, of any vegetation or the loss of flocculent material. At the time of sediment collection, water will be collected from each location in acid-washed carboys. The cores will be maintained at ambient bay water temperature during transport to the laboratory. The water over the cores will be kept aerated during transport with the use of portable aerators. Once in the laboratory the sediment cores and overlying water will be maintained at ambient bay water temperature in a temperature and light controlled environmental room. The water over the cores will be continuously aerated and mixed by a gentle stream of air.

The sediment-water exchanges of ammonia, nitrite plus nitrate, phosphate and oxygen will be measured according to procedures used previously by Seitzinger (1987a, 1987b) in other estuaries. Approximately 24 hours after the sediment cores are collected, the water over each core will be changed with water collected from the site of sediment collection. Approximately 1 h after the water is changed, an initial water sample will be collected from each core; time series samples will then be collected from each core over the following 6 to 24 h. The exact incubation times will depend on the rate of sediment-water exchange of nutrients. Oxygen levels will be carefully monitored and controlled to prevent oxygen levels in the overlying water from dropping below 4 mg O_2 per liter. Sediment-water nutrient and oxygen fluxes will be measured on six cores from each site, including two maintained at ambient light levels (at the sediment surface at mid-day in the field), two at 45% ambient mid-day light levels, and two in the dark.

In addition to chamber incubations, a series of light and dark bottles will be filled with bay water from the site of sediment collection and used as controls for assessing changes in nutrient concentrations in the water over the sediments due to water column processes.

Time series samples for nutrient analysis will be taken from the chambers and control bottles with large plastic syringes fitted with 4-mm diameter tygon tubing. Table 1 presents a summary of the analytical techniques which will be used to determine concentrations of ammonia, nitrate plus nitrite, and phosphate in the water samples. Ammonia samples will be analyzed immediately after collection. All other samples will be filtered immediately after collection and frozen for later analysis.

The rate of release of nutrients from the sediments to the water column will be calculated based on the time rate of change in

concentration in the water over the sediments (after correcting for any changes noted in the control bottles due to water column processes), the volume of water in the chambers, and the area of sediment. The "benthic flux" method assumes a linear change in concentration over time. Traditionally, samples are taken only at the beginning and end of an incubation. We will check for linearity directly by taking time series samples at intermediate time periods during an incubation.

Rates of sediment-water nutrient fluxes will be reported as umol m^{-2} h^{-1}, as a function of light intensity, as well as an average rate calculated for a 24-h period based on the results of the measurements at various light levels and on the variation in light levels in the field over 24 h.

Rational for Using Laboratory Incubations: There is no standard method for measuring sediment-water nutrient fluxes; a variety of field and laboratory techniques are currently in use. While the objective in all studies of sediment-water nutrient fluxes is to assess the true field rates, both field and laboratory measurements involve some manipulation of the environment. We have used both field and laboratory techniques to measure sediment-water nutrient fluxes in estuaries. We have chosen to make the measurements under controlled laboratory conditions, as opposed to making in situ measurements, for the reasons outlined below.

(1) Measurement of oxygen concentration is more precise in the laboratory. Oxygen probes are more precise under controlled laboratory conditions; the ability to take samples for Winkler titration is also greatly improved. Since measurement of oxygen consumption (or production) depends on precise measurements of oxygen concentration in the water over the sediments, the added precision of measurement in the laboratory is important.

(2) In the field, incubation times are limited by oxygen consumption rates. In the lab, we can prolong the incubation times by aerating the water over the sediments. Longer incubation times permit more accurate detection of low rates of nutrient release from the sediments.

(3) The controlled conditions in the lab are preferable because there is less possibility of nutrient sample contamination. In addition, samples can be filtered and analyzed (or frozen) immediately instead of waiting a number of hours after collection to transport the samples to a laboratory for processing.

(4) The low visibility in the water in Barnegat Bay makes collection of undisturbed samples from the in situ incubation chambers difficult.

(5) More samples can be analyzed in less time, and thus at lower cost in the lab.

(6) Laboratory measurements of sediment-water nutrient and oxygen fluxes generally compare favorably with field measurements (Hargrave 1973; Davies 1975; Boynton EPA Chesapeake Bay study unpubl. data).

(6) The basic methods proposed here for measuring sediment water nutrient fluxes have also been used in Narragansett Bay, Delaware Bay, the Potomac River and Ochlockonee Bay by Dr. Seitzinger (e.g. Seitzinger et al. 1984; Seitzinger 1987a, 1987b). Numerous other investigators have used essentially the same technique as proposed for the laboratory measurements (Hargrave 1973; Davies 1975; Kelly and Nixon 1984; Garber 1982; and others).

As a check on the comparability of the field and laboratory measurements, sediment-water fluxes of ammonia, nitrate plus nitrite, phosphate and oxygen will be measured using both in situ and laboratory methods at one location in Barnegat Bay (vegetated northern bay location) under dark conditions. If the results differ significantly, we will discuss the possible causes with NJDEP OSR personnel and together make a decision as to whether to proceed with field or lab measurements for the remainder of the study.

Organic Matter Deposition Measurements

Sediment Trap Collections: The quantity of organic N and P deposited in the sediments will be measured using sediment traps. Sediment traps have been used extensively to measure the vertical flux of particulate matter. A number of studies have evaluated the efficiency of various designs (Hargrave and Burns 1979; Bloesch and Burns 1980; Gardner 1980). The major problem with the use of sediment traps in estuaries is that they collect not only newly deposited material but also resuspended material. Resuspension often greatly exceeds the newly deposited material (Hargrave and Taguchi 1978; Oviatt and Nixon 1975).

In order to overcome the resuspension problem, we will isolate columns of water from resuspension for short periods of time. The sedimenting material will be collected in a series of sediment traps over a period of approximately 3 days. The basic design is shown in Figure 1. Once enclosed, the material collected by the traps is initially a combination of previously resuspended material plus newly deposited material. The rate of deposition of resuspended material decreases exponentially as it is depleted from the enclosed water column. The deposition of new organic matter should be constant against the decreasing input of resuspended material. The sequential collection of the sedimenting material will allow separation of the two components.

The objective of the enclosures is to isolate a column of water from further resuspension of bottom sediments long enough to measure new deposition of organic P and N, and briefly enough to avoid

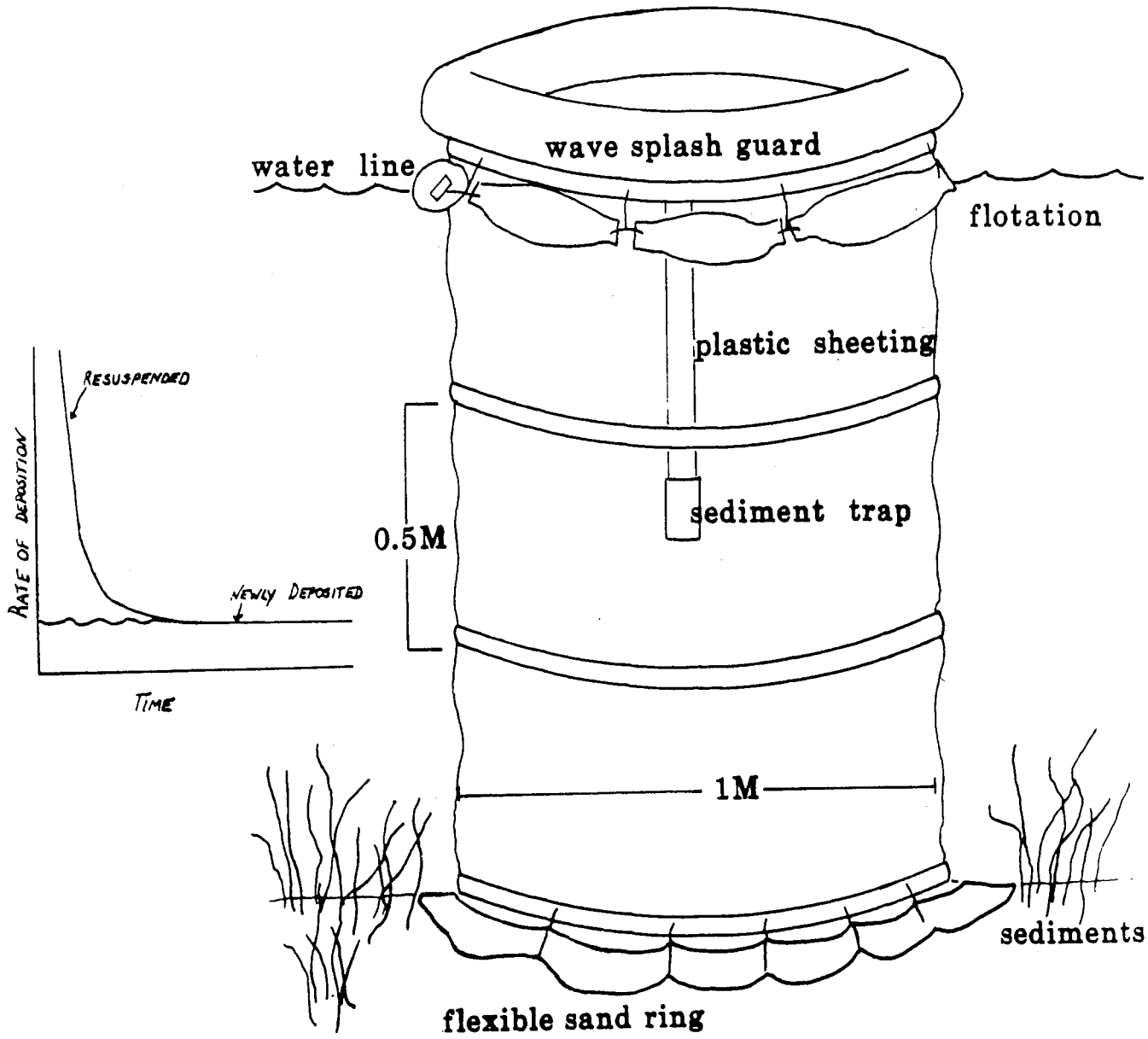


Figure 1. Schematic of water column enclosure with sediment trap used for measuring organic matter deposition in Barnegat Bay.

measurably altering the natural rate of organic sedimentation. The assumption is that the rate of sedimentation of newly deposited (not resuspended) organic matter inside the enclosures is the same as that outside the enclosures, if the primary production rate and phytoplankton species and abundances are similar in both. These sediment traps and enclosures underwent preliminary testing in Barnegat Bay during 1988 with very good results as discussed below.

Experiments with various construction materials, procedures for filling the enclosures with a column of water, methods for anchoring the enclosure, methods of deploying and retrieving the sediment traps, measurements of the turbulence regime, and measurements of primary production rates inside and outside the enclosures were carried out during 1988. The enclosures are cylindrical (1.0-m diameter) and made of clear, 6-mil plastic sheeting with hoop supports at 0.5-m intervals. The tubes are anchored at the bottom with a flexible sand ring, open to the air at the top, and float at the surface. A collar extends 15 cm above the surface of the water to prevent outside water from entering. The enclosures are filled by vertically collapsing the enclosure at the surface and then slowly lowering the sand ring to the sediment surface. The entire water column is thus enclosed. Cylindrical traps with a height-to-diameter ratio of 3 are used to minimize resuspension in the traps (Bloesch and Burns 1980; Hargrave and Burns 1979). The traps are located away from the walls of the enclosure.

Initial experiments were carried out to examine the time necessary to deplete most of the resuspended material in the enclosure. The top 0.5 cm of sediment cores was stained with Fuschin basic dye, which stains essentially all organic matter, live or dead. That material was then added to an enclosure and time series water samples were collected, filtered, and the suspended matter examined microscopically for stained organic matter. Those experiments showed that 24-36 h is sufficient to settle out essentially all of the resuspended matter.

Repeated measurements of the primary production rates (light-dark bottle O_2 measurements), algal densities and plankton composition were made during the summer of 1986 in Great Bay and demonstrated that these parameters were similar inside and outside the enclosures. This past summer repeated measurements of primary production rates (light-dark bottle O2 measurements) were made inside and outside the enclosures with the recent enclosure modifications and again found to be similar inside and outside. Primary production rates inside and outside the enclosures have been tested for enclosure deployment periods of up to five days. Repeated studies of the rate of dye dispersion inside and outside the enclosures this past year indicate that the turbulence inside and outside the enclosures is similar. By keeping the amount of weight at the bottom of the enclosure just sufficient to hold the bottom down, the plastic sheet stays flexible and the movement of

the plastic maintains turbulence inside the enclosure. [According to Stokes' Law, turbulence will have no effect on small organic particles (<500 um) settling in water because their particle Reynolds numbers are usually less than 0.5 (Bloesch and Burns 1980). Thus the flow around these particles, when moving through a fluid, is laminar and the drag force on a particle is proportional to its velocity of movement through the fluid. However, turbulence does affect the distribution of particles in the water column and thus may effect the net rate of settling.]

Measurements of sediment deposition rates will be made over an annual cycle at the four locations used for sediment-water nutrient flux studied using the sediment traps described above. Some additional modifications to the design will be made before those measurements begin, including using plastic sheeting with increased strength so that they can withstand heavy wind conditions. Tests will be carried out to ensure that conditions inside the enclosures are similar to those outside the enclosures including primary production rates, phytoplankton composition and nutrient concentrations. Measurements of the rate of fallout of resuspended sediment will also be repeated. Tests will be carried out to determine the variability between replicate enclosures. The variability between replicate traps is expected to be low (less than 10%) based on a number of previous studies in other aquatic systems (Eadie et al. 1984; Rowe and Gardner 1979; Hargrave and Taguchi 1978; Knauer and Martin 1981; Hargrave and Burns 1979; Hamilton-Taylor et al. 1984).

Analysis of Collected Material: The contents of each sediment trap will be analyzed for organic C, N and P. Subsamples will be treated with dilute HCl to remove carbonates and analyzed for C and N using a Carlo Erba Model 1106 Elemental Analyzer. Subsamples will be analyzed for phosphorus by digestion according to Martin and Knauer (1973) and colorimetric analysis using the method of Murphy and Riley (1962).

Water Column Nutrient Concentrations and Primary Production Rates:

Water column concentrations of ammonia (Solorzano 1969), nitrate plus nitrite (modified from Technicon 1977), and phosphate (modified from Technicon 1977) will be measured at a series of locations (at least four) extending from the less developed southern to the highly developed northern end of the bay over an annual cycle. Measurements will be made at least once during the winter, spring, summer and fall. Primary production rates (light/dark bottle O2 measurements) will be measured during spring, summer and fall at the same locations. More frequent measurements will be made at selected locations from April through October. Both NJDEP and Academy scientists will be involved in those measurements. The areas of responsibility are outlined below.

Particulate N and P Concentrations in Sediment Cores:

Estimates of N and P long-term burial rates will be made based on net sediment accumulation rates provided by Lamont-Doherty and analysis of the organic N (total Kjeldahl N analysis) and total P (Froelich et al. 1988) with depth in those cores. The NJDEP Leeds Point laboratory will be responsible for the organic N analysis. Total P analysis will be carried out at the Academy of Natural Sciences.

DELIVERABLES

Interim data reports will be submitted at 3-mo intervals, beginning 3 mo after funding begins. An interpretive report will be submitted at the end of the project. It will describe all methods, present data and interpret the results in terms of the goals of the study. Graphical presentations will be used where appropriate.

ANTICIPATED SCHEDULE

	1989								1990				
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Organic matter deposition measurements		A		A		A						A	
Benthic nutrient and oxygen fluxes		A		A		A						A	
Water column:													
nutrient concentrations		D	D	D	D	D		A				D	
primary production		D	D	D	D	D						D	
Long-term N & P burial						A	----------		A				
Quarterly reports				A			A			A			
Final Report													A

A = Academy of Natural Sciences
D = Department of Environmental Protection

RESOURCES

The Academy of Natural Sciences has all of the major pieces of equipment necessary to carry out the proposed studies including spectrophotometer, Elemental Analyzer, light meters, etc.

The New Jersey DEP has agreed to provide and maintain a 16 to 20 foot boat for use daily throughout the May to October field season and a boat (and operator) or similar size to their Mako for the April sampling. The NJDEP Office of Science and Research will be responsible for the water column nutrient concentrations and primary production measurements throughout the bay during the April through October sampling periods. Academy of Natural Sciences personnel will be responsible for winter measurements including providing a boat.

In addition, the New Jersey DEP (W. Eisele, R. Connell) has agreed to provide analytical services required for nitrate and phosphate measurements in this study. We expect to require approximately 200 nitrate plus nitrite determinations and 200 soluble reactive phosphate measurements during each benthic nutrient flux measurement series (i.e. 4 times per year for a total of approx. 800 samples/year for each nutrient). The Academy of Natural Sciences will be responsible for the ammonia analysis for both benthic flux and water column concentration measurements. Additional nitrate and phosphate samples from water column concentration surveys (collected by NJDEP OSR) will be analyzed by the Leeds Point lab. The Leeds Point lab will also be responsible for the total Kjeldahl N analysis of sediment core samples. The Academy of Natural Sciences will be responsible for the particulate P analysis of samples from the sediment cores. (The lower limit of detection

and sensitivity required for the nitrate, phosphate and ammonia analysis are listed in Table 1.)

QUALITY ASSURANCE/QUALITY CONTROL

Data Usage: Data resulting from this study will be used to develop a scientifically sound understanding of nutrient processes in Barnegat Bay, therefore high data integrity is essential. The same level of QA/QC will be used in this study for methods development and preliminary measurements as will be required for future phases.

Sampling Plan: The present study involves significant components of methods refinement, so the specifics of the sampling plan will be developed during the study in response to on-going results. The details, as closely as known, are outlined above in the Methods section.

Parameters and Analytical Protocols: The parameters to be analyzed and related information are presented in Table 1.

For chemical analyses, 10% of samples analyzed will be field or laboratory spikes. All samples will be analyzed in duplicate. Standards (at least a three point curve with duplicate determinations) covering the range of sample concentrations will be run with every sample batch. Complete records of sampling times and locations and analysis dates will be maintained. All data sheets will be signed and dated.

Analyses of nitrate and phosphate will be conducted by the New Jersey DEP. Ammonia analyses and particulate nitrogen and phosphorus analyses from the sediment trap samples will be conducted by the Academy. QA/QC procedures used by both groups will be reviewed before the start of the sampling program, and will be documented in the final report.

Data Validation and Storage: The end usage of the data is for inclusion in the final report in addressing the goals of the study. Data records will be stored in laboratory notebooks. All data input to computer files will be proofed against original data sheets; data presented in the report will be proofed against computer printouts.

Further QA/QC Elements: The level of QA/QC outlined above is similar to that used on all research programs and ensures high data quality while minimizing costs. However, if desired by NJDEP, we are prepared to provide further QA/QC elements including a Quality Assurance Officer, field and lab audits, chain of custody records, and Standard Operating Procedures (SOP) for the major analyses. The costs to provide these additional elements are presented in the

Table 1. Analytical methods used for nutrient analyses including lower limit of detection and precision required for analyses. All units are uM.

Nutrient	Lower Limit of Detection	Precision	Method
Ammonia	0.25	+/- 0.25 @ 1 uM level	Solorzano 1969; indophenol
Nitrite plus nitrate	0.25	+/- 0.05	Technicon 1977; Cd reduction with azo dye
Soluble reactive phosphate	0.05	+/- 0.1 @ 1 uM level	Murphy and Riley 1962; Mb blue

budget as "Increased QA/QC Elements." A copy of the Academy's QA/QC program is attached to this proposal.

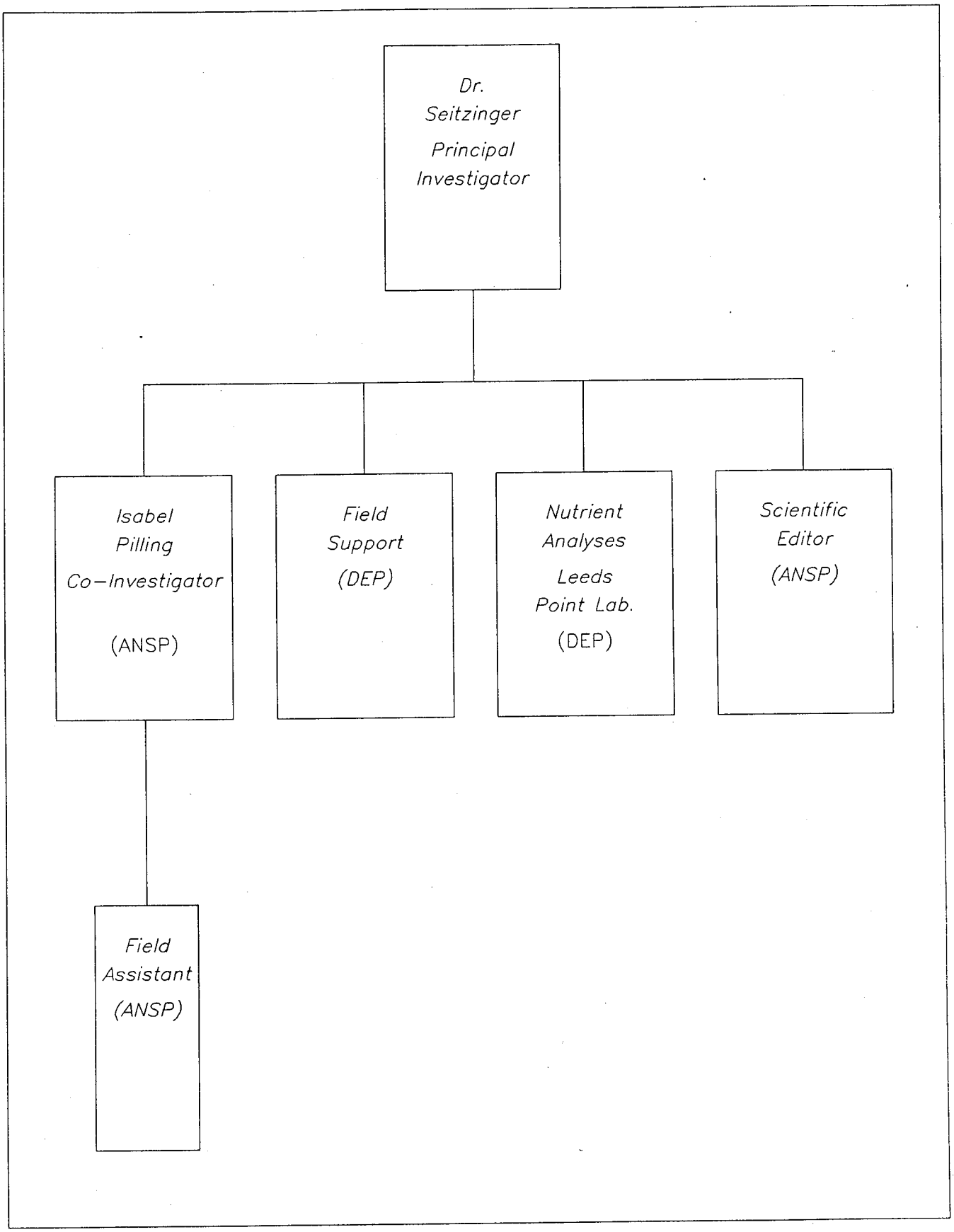
PERSONNEL

Dr. Sybil Seitzinger will be the Principal Investigator, responsible for overall study design, and all aspects of field and laboratory work (except as specified below), as well as data analysis and interpretation. Dr. Seitzinger has carried out numerous previous studies of nutrient processes, including sediment-water nutrient exchanges in estuaries including Narragansett Bay, Delaware Bay, the Potomac Estuary, Ochlockonee Bay, FL, and the Tejo Estuary, Portugal. Ms. Isabel E. Pilling will be responsible for the day to day field and laboratory operations, coordination of field and lab personnel, and will assist with study design, methods development, data analysis, interpretation, and report preparation. The Academy's Scientific Editor, Ms. Robin Davis, will be responsible for internal consistency and clarity of the final report.

Personnel from the New Jersey DEP will be responsible for providing and maintaining a boat (as specified above) for all field sampling during April through October, for analysis of nitrate, phosphate, and total Kjeldahl N samples and for the water column nutrient concentrations and primary production measurements as outlined above. They will also be responsible for delivering the samples from the water column measurements for analysis to either the Philadelphia lab (ammonia) or the Leeds Point lab (phosphate and nitrite plus nitrate).

The organization of the project team is shown on the accompanying chart (Fig. 2).

Figure 2 Organizational overview of the project team for the proposed study.



BUDGET

The first budget presents the costs for the project including our standard level of QA/QC for research projects; the second budget presents the additional costs required to implement an expanded QA program, which would include a QA Officer and internal audits.

Personnel	
S. Seitzinger (3 months)	9,251
I.E. Pilling (10 months field & lab)	13,634
Hourly field help (boat operator and general)	4,358
SCUBA divers (16 days)	1,142
Editorial (4 days)	412
QA Personnel	154
Total Salaries	28,951
Salary Benefits (16.5%)	4,777
Total Direct Labor	33,728
Fringe Benefits (19.5%)	6,577
Total Labor & Fringe	40,305
Nonlabor	
Laboratory Supplies	3,000
Sediment Traps	600
Vehicles & Travel (60 d * $50/day)	3,000
Food & Lodging at field site	4,000
Boat and vehicle for winter sampling	470
Misc. (incl. graphics, computing, phone)	1,050
Total Nonlabor	12,120
Total Direct Costs	52,425
Indirect Costs (45% of labor)	15,178
Total Direct and Indirect	67,603
Research Fee (8% of total direct + indirect)	5,408
TOTAL PROJECT COSTS	73,011

BUDGET for Expanded Quality Assurance Element

Personnel Costs	
Labor and Fringe	3,731
Nonlabor	
Misc. (incl. phone, Xerox)	100
Total Direct Costs	3,831
Indirect Costs (45% of labor)	1,405
Total Direct and Indirect	5,236
Research Fee (8% of total direct + indirect)	419
TOTAL COST FOR EXPANDED QA/QC	5,655

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Curriculum Vitae

Sybil Putnam Seitzinger

Position: Assistant Curator, Patrick Center for Environmental Research. Division of Environmental Research, Academy of Natural Sciences of Philadelphia.

Birth Date: 13 January 1952

Education

1982	Ph.D., Biological Oceanography; Univ. of Rhode Island, Kingston, R.I.
1974	B.S., Biology; Boston Univ., Boston, MA.

Professional Experience

1986 to present	Assistant Curator, Academy of Natural Sciences of Philadelphia.
1984-1986	Senior Scientist, Academy of Natural Sciences of Philadelphia.
1981	Research Associate, Marine Ecosystem Research Laboratory, Graduate School of Oceanography, Univ. of Rhode Island. Estuarine nutrient dynamics using intermediate-sized microcosms.
1980	Instructor in Marine Sciences, International Sea Grant Program, Univ. of Pertanian, Malaysia.
1976	Graduate Research Assistant, Graduate School of Oceanography, Univ. of Rhode Island. Nitrogen dynamics in coastal ecosystems.
1973	Research Assistant, Boston Univ., Marine Biological Laboratory, Woods Hole, MA. Salt marsh ecosystem research.

Professional Interests

Comparisons of nutrient dynamics in marine, freshwater and terrestrial ecosystems.

Ecology of coastal marine ecosystems. Benthic-pelagic coupling of nutrient cycles and production.

Effects of eutrophication on patterns of nutrient cycling and production.
Application of ecological research results to ecosystem management.

Affiliations

American Association for the Advancement of Science
American Geophysical Union
American Society of Limnology and Oceanography
Malaysian Society of Marine Sciences

Publications

In prep. Seitzinger, S.P. Denitrification in a high nitrate estuary, Delaware Bay.

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PATRICK CENTER FOR ENVIRONMENTAL RESEARCH

9 February 1989

Mr. Robert Scro
New Jersey Department of Environmental
Protection
Division of Science and Research
CN 409
Trenton, NJ 08625

Dear Bob:

Enclosed is additional information for our second Quarterly Report for the study of "Eutrophication and nutrient loading in Barnegat Bay: importance of sediment-water nutrient interactions." This data printout contains the nutrient concentrations measured in the benthic chambers during the September benthic flux studies.

If you require additional information, please let me know.

Sincerely,

Sybil Seitzinger

Sybil P. Seitzinger

enclosure

Printout for Quarterly Rpt. #11 2/9/89

Note: Concentrations have not been checked for lower limit of detection corrections. S. Seitzinger

FILENAME: nutflux 1988 Barnegat Bay flux with cont
proofed and corrected jan6,89 iep
NUTRIENT FLUXES - NH4, NO3, PO4

CORE I.D.	INITIAL CORE SAMPLES			FINAL CORE SAMPLES		
sandyveg	SAMP DAY	HOURS	MINUTES	SAMP DAY	HOURS	MINUTES

FILENAME: nutflux 1988 Barnegat Bay flux with cont
proofed and corrected jan6,89 iep
NUTRIENT FLUXES - NH4, NO3, PO4

CORE I.D.	INITIAL CORE SAMPLES			FINAL CORE SAMPLES		
sandyveg	SAMP DAY	HOURS	MINUTES	SAMP DAY	HOURS	MINUTES
11t1t2	sept20	12	40	sept20	14	45
11t2t3	sept20	14	45	sept20	17	30
	sept20			sept20		
	sept20			sept20		
12t1t2	sept20	12	50	sept20	14	35
12t2t3	sept20	14	35	sept20	17	45
	sept20			sept20		
	sept20			sept20		
m1t1t2	sept20	12	50	sept20	14	40
m1t2t3	sept20	14	40	sept20	17	25
	sept20			sept20		
	sept20			sept20		
m2t1t2	sept20	12	45	sept20	14	40
m2t2t3	sept20	14	40	sept20	17	35
	sept20			sept20		
	sept20			sept20		
d1t1t2	sept20	12	35	sept20	14	25
d1t2t3	sept20	14	25	sept20	17	15
	sept20			sept20		
	sept20			sept20		
d2t1t2	sept20	12	45	sept20	14	35
d2t2t3	sept20	14	35	sept20	17	20
deepmud						
11t1t2	sept22	11	30	sept22	13	45
11t2t3	sept22	13	45	sept22	16	50
	sept22			sept22		
	sept22			sept22		
12t1t2	sept22	11	20	sept22	13	50
12t2t3	sept22	13	50	sept22	17	5
	sept22			sept22		
	sept22			sept22		
m1t1t2	sept22	11	30	sept22	13	45
m1t2t3	sept22	13	45	sept22	16	45
	sept22			sept22		
	sept22			sept22		
m2t1t2	sept22	11	25	sept22	13	55
m2t2t3	sept22	13	55	sept22	16	40
	sept22			sept22		
	sept22			sept22		
d1t1t2	sept22	11	15	sept22	13	40
d1t2t3	sept22	13	40	sept22	16	50
	sept22			sept22		
	sept22			sept22		

FILENAME: nutflux 1988 Barnegat Bay flux with cont
proofed and corrected jan6,89 iep
NUTRIENT FLUXES - NH4, NO3, PO4

CORE I.D.	INITIAL CORE SAMPLES			FINAL CORE SAMPLES		
sandyveg	SAMP DAY	HOURS	MINUTES	SAMP DAY	HOURS	MINUTES
d2t1t2	sept22	11	10	sept22	13	35
d2t2t3	sept22	13	35	sept22	17	0
longquay						
l1t1t2	sept26	11	30	sept26	13	30
l1t2t3	sept26	13	30	sept26	17	0
	sept26			sept26		
	sept26			sept26		
l2t1t2	sept26	11	45	sept26	14	10
l2t2t3	sept26	14	10	sept26	17	40
	sept26			sept26		
	sept26			sept26		
m1t1t2	sept26	11	35	sept26	13	40
m1t2t3	sept26	13	40	sept26	17	10
	sept26			sept26		
	sept26			sept26		
m2t1t2	sept26	11	30	sept26	13	50
m2t2t3	sept26	13	50	sept26	17	25
	sept26			sept26		
	sept26			sept26		
d1t1t2	sept26	11	40	sept26	14	0
d1t2t3	sept26	14	0	sept26	17	30
	sept26			sept26		
	sept26			sept26		
d2t1t2	sept26	11	30	sept26	13	55
d2t2t3	sept26	13	55	sept26	17	20
W-NWpoint						
l1t1t2	sept29	11	20	sept29	14	15
l1t2t3	sept29	14	15	sept29	17	40
	sept29			sept29		
	sept29			sept29		
l2t1t2	sept29	11	30	sept29	14	20
l2t2t3	sept29	14	20	sept29	17	45
	sept29			sept29		
	sept29			sept29		
m1t1t2	sept29	11	25	sept29	14	20
m1t2t3	sept29	14	20	sept29	17	40
	sept29			sept29		
	sept29			sept29		
m2t1t2	sept29	11	15	sept29	14	10
m2t2t3	sept29	14	10	sept29	17	35
	sept29			sept29		
	sept29			sept29		
d1t1t2	sept29	11	5	sept29	14	5
d1t2t3	sept29	14	5	sept29	17	30
	sept29			sept29		
	sept29			sept29		
d2t1t2	sept29	11	10	sept29	14	5
d2t2t3	sept29	14	5	sept29	17	30

rol data

INITIAL CONTROL SAMPLES			FINAL CONTROL SAMPLES			L WATER	cm2 AREA OF
SAMP DAY	HOURS	MINUTES	SAMP DAY	HOURS	MINUTES	VOLUME	SEDIMENT

rol data

INITIAL CONTROL SAMPLES			FINAL CONTROL SAMPLES			L WATER	cm2 AREA OF
SAMP DAY	HOURS	MINUTES	SAMP DAY	HOURS	MINUTES	VOLUME	SEDIMENT
sept20	12	45	sept20	14	55	2.265	226.9
sept20	14	55	sept20	17	15	2.205	226.9
sept20			sept20				226.9
sept20			sept20				226.9
sept20	12	45	sept20	14	55	2.379	226.9
sept20	14	55	sept20	17	15	2.319	226.9
sept20			sept20				226.9
sept20			sept20				226.9
sept20	12	50	sept20	14	55	2.435	226.9
sept20	14	55	sept20	17	15	2.375	226.9
sept20			sept20				226.9
sept20			sept20				226.9
sept20	12	50	sept20	14	55	2.209	226.9
sept20	14	55	sept20	17	15	2.149	226.9
sept20			sept20				226.9
sept20			sept20				226.9
sept20	12	50	sept20	14	55	2.435	226.9
sept20	14	55	sept20	17	15	2.375	226.9
sept20			sept20				226.9
sept20			sept20				226.9
sept20	12	50	sept20	14	55	2.549	226.9
sept20	14	55	sept20	17	15	2.489	226.9
							226.9
							226.9
sept22	11	0	sept22	14	0	2.379	226.9
sept22	14	0	sept22	17	10	2.319	226.9
sept22			sept22				226.9
sept22			sept22				226.9
sept22	11	0	sept22	14	0	2.322	226.9
sept22	14	0	sept22	17	10	2.262	226.9
sept22			sept22				226.9
sept22			sept22				226.9
sept22	11	0	sept22	14	0	2.492	226.9
sept22	14	0	sept22	17	10	2.432	226.9
sept22			sept22				226.9
sept22			sept22				226.9
sept22	11	0	sept22	14	0	2.515	226.9
sept22	14	0	sept22	17	10	2.455	226.9
sept22			sept22				226.9
sept22			sept22				226.9
sept22	11	0	sept22	14	0	2.515	226.9
sept22	14	0	sept22	17	10	2.455	226.9
sept22			sept22				226.9
sept22			sept22				226.9

rol data

INITIAL CONTROL SAMPLES SAMP DAY	HOURS	MINUTES	FINAL CONTROL SAMPLES SAMP DAY	HOURS	MINUTES	L WATER VOLUME	cm2 AREA OF SEDIMENT
sept22	11	0	sept22	14	0	2.265	226.9
sept22	14	0	sept22	17	10	2.205	226.9
							226.9
							226.9
sept26	10	45	sept26	14	25	2.277	226.9
sept26	14	25	sept26	17	50	2.217	226.9
sept26			sept26				226.9
sept26			sept26				226.9
sept26	10	45	sept26	14	25	1.982	226.9
sept26	14	25	sept26	17	50	1.922	226.9
sept26			sept26				226.9
sept26			sept26				226.9
sept26	10	45	sept26	14	25	2.549	226.9
sept26	14	25	sept26	17	50	2.489	226.9
sept26			sept26				226.9
sept26			sept26				226.9
sept26	10	45	sept26	14	25	2.379	226.9
sept26	14	25	sept26	17	50	2.319	226.9
sept26			sept26				226.9
sept26			sept26				226.9
sept26	10	45	sept26	14	25	2.379	226.9
sept26	14	25	sept26	17	50	2.319	226.9
sept26			sept26				226.9
sept26			sept26				226.9
sept26	10	45	sept26	14	25	2.379	226.9
sept26	14	25	sept26	17	50	2.319	226.9
							226.9
							226.9
sept29	11	0	sept29	14	25	2.662	226.9
sept29	14	25	sept29	17	50	2.602	226.9
sept29			sept29				226.9
sept29			sept29				226.9
sept29	11	0	sept29	14	25	2.458	226.9
sept29	14	25	sept29	17	50	2.398	226.9
sept29			sept29				226.9
sept29			sept29				226.9
sept29	11	0	sept29	14	25	2.549	226.9
sept29	14	25	sept29	17	50	2.489	226.9
sept29			sept29				226.9
sept29			sept29				226.9
sept29	11	0	sept29	14	25	2.606	226.9
sept29	14	25	sept29	17	50	2.546	226.9
sept29			sept29				226.9
sept29			sept29				226.9
sept29	11	0	sept29	14	25	2.577	226.9
sept29	14	25	sept29	17	50	2.517	226.9
sept29			sept29				226.9
sept29			sept29				226.9
sept29	11	0	sept29	14	25	2.662	226.9
sept29	14	25	sept29	17	50	2.602	226.9

detection=0.3 for NH4 correctedNo3 sept26 b2

uM NH4 CONCENTRATIONS				uM NO3 CONCENTRATIONS			
CORE INITIAL	CORE FINAL	CONTROL INITIAL	CONTROL FINAL	CORE INITIAL	CORE FINAL	CONTROL INITIAL	CONTROL FINAL
0.33	0.00	0.00	0.00	0.11	0.11	0.88	0.37
0.00	0.83	0.00	0.40	0.11	0.11	0.37	0.12
0.00	0.37	0.00	0.00	0.11	0.11	0.88	0.28
0.37	0.00	0.00	0.40	0.11	0.19	0.28	0.12
0.00	0.00	0.52	0.00	0.30	0.11	1.11	0.31
0.00	0.00	0.00	0.00	0.11	0.11	0.31	0.60
0.00	0.32	0.52	0.00	0.12	0.11	1.11	0.31
0.32	0.00	0.00	0.00	0.11	0.09	0.31	0.60
1.24	0.00	0.00	0.00	0.12	0.10	1.02	0.27
0.00	0.47	0.00	0.40	0.10	0.12	0.29	0.30
0.46	0.39	0.00	0.00	0.11	0.12	1.04	0.27
0.39	0.00	0.00	0.40	0.12	0.12	0.29	0.30
0.00	0.00	0.00	0.00	0.12	0.11	0.44	0.30
0.00	0.00	0.00	0.00	0.11	0.09	0.30	0.14
0.00	0.00	0.00	0.00	0.09	0.09	0.44	0.30
0.00	0.52	0.00	0.00	0.09	0.09	0.30	0.14
0.00	0.34	0.39	0.00	0.23	0.15	0.43	0.24
0.34	0.00	0.00	0.00	0.15	0.11	0.24	0.14
0.00	0.00	0.39	0.00	0.13	0.10	0.43	0.24
0.00	0.00	0.00	0.00	0.10	0.06	0.24	0.14
0.88	1.63	0.00	0.00	0.13	0.14	0.39	0.36
1.63	0.00	0.00	0.00	0.14	0.13	0.34	0.32

correctedNo3 sept26 b2

detection=0.3 for NH4

uM NH4 CONCENTRATIONS				uM NO3 CONCENTRATIONS			
CORE INITIAL	CORE FINAL	CONTROL INITIAL	CONTROL FINAL	CORE INITIAL	CORE FINAL	CONTROL INITIAL	CONTROL FINAL
0.00	0.00	0.00	0.00	0.14	0.37	0.39	0.36
0.00	0.00	0.00	0.00	0.37	0.12	0.36	0.32
0.00	0.33	0.00	1.16	0.16	0.24	0.16	0.16
0.33	0.00	1.16	0.00	0.24	0.24	0.16	0.06
0.00	0.38	0.00	1.16	0.16	0.21	0.16	0.16
0.38	0.00	1.16	0.00	0.21	0.19	0.16	0.06
0.00	0.60	1.06	0.89	0.22	0.21	0.13	0.29
0.60	0.79	0.89	0.00	0.21	0.24	0.29	0.42
0.54	0.00	1.06	0.89	0.18	0.12	0.13	0.29
0.00	0.00	0.89	0.00	0.12	0.24	0.29	0.42
0.00	0.64	0.00	0.00	0.16	0.24	0.36	0.89
0.64	0.00	0.00	0.00	0.24	0.11	0.89	0.93
0.00	0.00	0.00	0.00	0.36	0.26	0.36	0.89
0.00	1.53	0.00	0.00	0.26	0.18	0.89	0.93
0.00	0.38	0.00	0.00	0.13	0.16	0.80	0.14
0.38	0.43	0.00	0.43	0.16	0.11	0.14	0.16
0.00	0.00	0.00	0.00	0.14	0.44	0.80	0.14
0.00	0.37	0.00	0.43	0.44	0.13	0.14	0.16
0.00	0.00	0.00	0.00	0.15	0.20	0.88	1.08
0.00	0.00	0.00	0.63	0.20	0.22	1.08	0.25
0.00	0.00	0.00	0.00	0.13	0.16	0.88	1.08
0.00	0.00	0.00	0.63	0.16	0.16	1.08	0.25
0.00	0.00	0.00	0.00	0.15	0.10	0.37	0.37
0.00	0.00	0.00	0.43	0.10	0.20	0.37	0.44
0.00	0.00	0.00	0.00	0.14	0.16	0.37	0.37
0.00	0.30	0.00	0.43	0.16	0.23	0.37	0.44

flux

uM
PO4 CONCENTRATIONS

CORE INITIAL	CORE FINAL	CONTROL INITIAL	CONTROL FINAL

flux

uM
PO4 CONCENTRATIONS

CORE INITIAL	CORE FINAL	CONTROL INITIAL	CONTROL FINAL
0.49	0.55	0.51	0.51
0.55	0.53	0.51	0.51
0.50	0.53	0.49	0.51
0.53	0.56	0.51	0.51
0.53	0.53	0.55	0.49
0.53	0.51	0.49	0.48
0.56	0.49	0.55	0.49
0.49	0.49	0.49	0.48
0.53	0.51	0.53	0.51
0.51	0.53	0.51	0.48
0.51	0.65	0.51	0.51
0.65	0.55	0.51	0.48
0.56	0.52	0.57	0.52
0.52	0.57	0.52	0.55
0.54	0.53	0.57	0.52
0.53	0.55	0.52	0.55
0.54	0.55	0.52	0.53
0.55	0.52	0.53	0.53
0.55	0.53	0.52	0.53
0.53	0.53	0.53	0.53
0.52	0.55	0.50	0.55
0.55	0.59	0.55	0.51

flux

uM PO4 CONCENTRATIONS

CORE INITIAL	CORE FINAL	CONTROL INITIAL	CONTROL FINAL
0.52	0.46	0.52	0.55
0.46	0.52	0.55	0.51
0.89	0.83	0.90	0.69
0.83	0.72	0.69	0.71
1.21	1.07	0.90	0.69
1.07	0.89	0.69	0.71
0.94	0.96	0.90	0.69
0.96	0.91	0.69	0.65
0.80	0.94	0.90	0.69
0.94	0.88	0.69	0.65
1.00	0.87	1.12	0.67
0.87	1.09	0.67	0.62
0.83	0.90	1.12	0.67
0.90	0.81	0.67	0.62
0.29	0.38	0.22	0.21
0.38	0.49	0.21	0.20
0.28	0.36	0.22	0.21
0.36	0.33	0.21	0.20
0.24	0.26	0.52	0.33
0.26	0.34	0.33	0.45
0.29	0.23	0.52	0.33
0.23	0.37	0.33	0.45
0.41	0.32	0.17	0.17
0.32	0.19	0.17	0.11
0.42	0.20	0.17	0.17
0.20	0.28	0.17	0.11