

Sedimentation and its Role in the Nutrient
Dynamics of a Tidal Freshwater Marsh

A Thesis

Presented to

The Faculty of the Virginia Institute of Marine Science
The College of William and Mary in Virginia

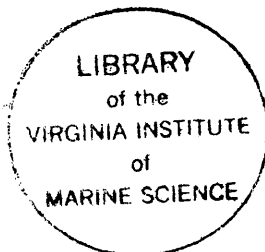
In Partial Fulfillment

Of the Requirements for the Degree of
Master of Arts

by


Jane M. Ledwin

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APPROVAL SHEET


This thesis is submitted in partial fulfillment of
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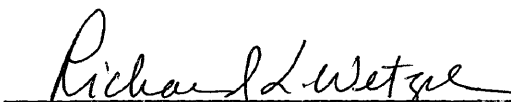

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DEDICATION

This thesis is dedicated to William M. Rizzo for his unflagging support, guidance and inspiration.

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ABSTRACT

This study describes sedimentation and its role in the introduction of nutrients to a tidal freshwater marsh. Three vegetation zones were sampled over a 14 month period to compare sedimentation and nutrient differences among both the plant zones and the seasons.

Sediment accumulation was measured using sediment traps for gross deposition, and stake observations and a marker bed technique to record net elevation changes of the marsh surface. Nutrient concentrations of trapped sediment and marsh cores were measured to quantify the amount of nitrogen, phosphorous, and organic matter associated with the incoming sediments, as well as the nutrient concentrations as they were buried.

Using sediment accumulation rates based on gross deposition and selected short-term net rates, fluxes of nitrogen, phosphorous, and organic matter to the marsh were estimated. The estimates varied greatly depending on the accumulation rate chosen. For a given rate, estimated fluxes differed 4 to 10 fold between sites and showed distinct seasonal patterns.

SEDIMENTATION AND ITS ROLE IN THE NUTRIENT
DYNAMICS OF A TIDAL FRESHWATER MARSH

Introduction

Tidal freshwater wetlands occur at the tide's uppermost limit in freshwater rivers and streams. Being in a transition zone between saline and fresh water, tidal freshwater wetlands host diverse communities of emergent vegetation, particularly broadleaf plants such as Peltandra virginica and Pontedaria chordata and often are located near the most turbid areas of estuaries.

Only recently have scientists begun to explore these wetlands and their ecology. In part, this is a result of increasing development pressures along coastal waterways. In order to understand the saline part of estuaries, it is necessary to understand the processes involved upstream, especially those in transition areas such as the fresh-saline interface.

As with saline marshes, tidal, freshwater marshes are areas of intense nutrient cycling where nutrient exchanges take place among plants, animals, water, air, and sediments. Nutrients can be introduced to the marsh through groundwater percolation, tidal inundation or non-tidal circulation, atmospheric input, detritus, and fauna living in or using the marsh system. Once on the marsh, the nutrients can be cycled many times. Nutrient losses can occur through tidal and non-tidal circulation, burial, loss to the atmosphere, or

transportation out of the system by a biovector (Odum et al., 1984; Mitsch and Gosselink, 1985).

Sedimentary processes can play a role in modifying some pathways of nutrient cycling in a marsh. Nutrients associated with incoming sediments can be introduced to the marsh on the flood tide, and can consist of dissolved organic and inorganic forms sorbed onto inorganic particles, as well as nutrients associated with particulate forms of organic matter (DeLaune et al., 1981; Pomeroy and Wiegert, 1981). Due to rising sea-level, marshes must accrete sediments to remain intertidal. Accretion through sediment trapping is accompanied by an input of nutrients to the marsh. In Louisiana's salt marshes, nutrient input through sediment accretion is "an important fertilization mechanism for marsh plants" providing as much as $21 \text{ g N m}^{-2} \text{ yr}^{-1}$ (DeLaune et al., 1981). Surface runoff via streams and creeks draining surrounding fastlands can introduce additional sediment to the marsh system. Nutrients may be retained on sediments after deposition, or they may diffuse to the surrounding pore water where they are available to plants and animals (Mitsch and Gosselink 1985). Deposited sediment is one of the largest reservoirs of phosphorous in the marsh system (Whitney et al., 1981).

Surface sediments on the marsh may go through repeated periods of deposition and resuspension which may be masked by long-term trends. Average annual net sediment and nutrient fluxes may overlook important cumulative impacts of short-term events such as storms or floods. Although these incidents are on a scale of days, they may account for a substantial fraction of the marsh's organic and nutrient budgets via

sedimentation. In order to quantify these effects gross deposition and erosion must also be recorded.

Burial of sediments as a result of further accretion, is a process through which nutrients may be lost from the system. The biologically active zone in the sediment may be no more than 25-30cm deep (Garofalo, 1980; Bowden, 1982). Consequently, continued accretion will bury sediments and their associated nutrients below the active soil zone rendering them unavailable to marsh biota. Cores taken from both fresh and salt water tidal marshes show a marked decrease in the phosphorus content of the sediment down to about 20cm (DeLaune et al., 1981; Bowden, 1984). The sediment below this depth shows no such trend. Therefore, the long-term rate of sedimentation affects not only the introduction of nutrients to the marsh, but also the loss of nutrients from the system through burial.

This study was designed to examine the role of sedimentation in the nutrient cycling of a tidal freshwater marsh. Sweet Hall Marsh was chosen for the purpose of documenting sedimentation and the accompanying nutrient input in the particulate forms of nitrogen, phosphorous, and carbon. Additionally, the study reports how, as sediments are buried, the N, P, and C depth profiles are influenced by the marsh vegetation in the biologically active strata. Because of the dynamic nature of the marsh surface, elevational changes can vary greatly over days, and may affect radically sediment and nutrient input estimates based on annual accumulation rates. The gross fluxes of sediments and associated nutrients greatly exceed average annual net fluxes of these materials, and constitute an important fraction of the system's sediment and nutrient budgets.

Specifically, the study examined sediment-nutrient input and nutrient depth profiles in an attempt to answer the following:

- (1) What is the net/gross accretion-erosion rate for the marsh and the accompanying tidal flat over the study period?
- (2) How much phosphorus, nitrogen, and organic matter is associated with incoming sediments?
- (3) What is the rate of loss of nutrients and organic matter from the system through sedimentation and burial?

The sedimentation rate of the marsh and the nutrient content associated with the incoming sediment will yield an annual nutrient input value for the marsh via sedimentation. A comparison of this value with sediment nutrient profiles will show the net changes in nutrient content of the sediments as a function of depth. With a known accretion rate, depth can be related to time, thereby giving an estimate of the annual rate of nutrient loss-gain from the sediments.

Ultimately, this information will contribute to our understanding of the role of sedimentation in the nutrient cycling of a tidal, freshwater marsh.

Literature Review

Sedimentation studies

There are a number of approaches to measuring marsh sedimentation. Ranwell (1964) deployed graduated stakes on a salt marsh in England to measure the seasonal rates and patterns of sedimentation. Although easy to use, this method actually measures only the change in the level of the marsh surface. Sediment compaction is neglected, possibly giving an inaccurate sedimentation rate. In addition, this method does not delineate between a change in the level of the marsh surface as a result of only accretion, or periods of erosion, resuspension, and accretion. Resuspension processes may play an important role in nutrient and detritus transport both within the marsh and between the marsh and the river.

Marker layers have also been widely used to gauge marsh sedimentation (Harrison and Bloom, 1977; Richard, 1978; Stumpf, 1983). Most often the marker bed is aluminum glitter or brick dust. However, the labeled horizon may sink into the mud or may be washed away by rain, eroded by ice or waves, or bioturbated beyond recognition (Richard, 1978). Furthermore, as with stakes, this method measures only the changes in the surface level of the marsh. Over the long-term, sediments may compact due to dewatering and/or decomposition of

organic matter (Kay and Barghoorn, 1964; Busch and Kellar, 1982; Stevenson et al., 1985). The only way to account for sediment compaction is to express the accretion as sediment mass (dry weight) per unit area.

Recently, the use of radioisotopes has provided a reliable method for long-term sedimentation studies (Armentano and Woodwell, 1975; Simpson et al., 1976; DeLaune et al., 1978). Sediment dating using radio-isotopes requires two basic assumptions: The isotope must have a steady-state deposition, and there must be no post-depositional mobility. One of the greatest problems in using this method in marshes is that much of the sediment is heavily bioturbated which may obscure or alter the sediment's isotope profile (Benninger et al., 1979; Robbins et al., 1979; Officer, 1982; Sharma, 1987).

The most commonly used isotopes are ^{210}Pb and ^{137}Cs . ^{210}Pb is a naturally occurring radioisotope and can be used to date sediments of the last 100 to 150 years (Armantano and Woodwell 1975). In contrast, ^{137}Cs is a fallout product from atmospheric nuclear weapons and reactors. ^{137}Cs from fallout is differentiated from ^{137}Cs from a reactor by the presence of cobalt which is also a reactor product. The appearance of ^{137}Cs in the sediment profile corresponds to the initiation of nuclear weapons testing in 1953. As a consequence of its short history, the ^{137}Cs method can be used only for sedimentation which has occurred since then.

Although some researchers have found good agreement using both ^{210}Pb and ^{137}Cs dating, others found that ^{137}Cs gave higher rates of deposition than ^{210}Pb (Sharma et al., 1987; Anderson et al., 1987; Stevenson et al., 1986). ^{137}Cs has a tendency to bind to some clay

minerals, especially in freshwater, and may be influenced by the redox potential at the sediment/water interface (Dominik et al., 1981). Davies et al. (1984) found that ^{137}Cs has an affinity for organic matter and may become mobile during decomposition. Furthermore, ^{137}Cs may be inappropriate for areas with low sedimentation rates (Dominik et al., 1981).

Sedimentation on marshes show accumulation rates of millimeters or centimeters per year. Harrison and Bloom (1977) correlated the differences between sedimentation rates of several Connecticut marshes with their respective tidal ranges, the greater the tidal range, the greater the sedimentation rate. They attributed this to a greater suspended sediment load carried in larger tidal prisms found in marshes with greater tidal ranges. While suspended sediments in tidal water contribute to marsh accretion, the daily tidal inundation may account for only a minor amount of the total deposition. Stumpf (1978) used marker layers to measure short-term accretion on a salt marsh. Thirteen weeks after laying the marker bed, during which time there was no foul weather, the glitter was still visible on the surface. In the following month, a northeaster was responsible for the deposition of 2-5mm of sediment. In addition, several layers of sand and coarse silt appeared in sediment cores of the back marsh. The size fractions of these sediments were unlike those of the particles carried in the neighboring creek. These observations led Stumpf to conclude "storms control sediment supply and movement on micro- and meso-tidal marshes."

Seasonal trends in marsh accretion and erosion may reflect influences of both the weather conditions and the vegetation of the

marsh. Richard (1978) found that mud flats and the adjacent Spartina alterniflora marsh had the greatest accretion rates March through September. This period coincides with the maximum period of Spartina production forming dense plant stands which slow water velocity and trap sediments. From September to March, Spartina production slows or ceases and sediments and detritus may be washed away by storms and ice scour (Richard 1978). He also found that accretion/erosion rates had large temporal and spatial variability and attributed much of the sedimentation differences among the sites to elevation (i.e. mudflat, low intertidal marsh, high intertidal marsh).

Sediment Nutrient Studies

The role of sediments and sedimentation in the nutrient cycling of marshes has received scant attention. Haines (1979) found the annual flux of materials to and from marsh soils is much larger than their net accumulation. She noted "...benthic deposits in shallow estuarine systems are important catalytic sites where organic materials are accumulated, consumed, and remineralized."

Haines et al. (1977) found that over 90% of the total nitrogen of all measured pools in the marshes of Sapelo Island, Georgia was soil nitrogen. The soil nitrogen pools consisted primarily of organic nitrogen and ammonium. Low marsh soils had slightly higher concentrations of nitrogen than the high marsh soils and showed little seasonal fluctuation. They also had higher and more variable levels of extractable ammonium than sediments of the high marsh. In both areas,

nitrate concentrations had the greatest seasonal fluctuation, decreasing from winter to summer. Ammonium concentrations peaked in the spring and were followed by low summer values during the periods of maximum Spartina growth. DeLaune et al., (1976) observed the same pattern of low ammonia concentrations in Louisiana's salt marshes. Low concentrations of extractable ammonium occurred during peak Spartina production in the spring and increased through summer. Maximum ammonium concentrations occurred in October and November for an inland marsh and streamside marsh sites, respectively.

The vertical soil nitrogen profiles show a variety of trends. Haines et al. (1977) found total nitrogen concentrations decreasing with depth. Soils of the high marsh had a constant C:N ratio with depth, whereas low marsh showed a C:N ratio increasing with depth. DeLaune et al. (1981) found no significant vertical trends in the concentrations of total organic nitrogen (TON) of the streamside marsh. The inland marsh site did show an increase in nitrogen with depth corresponding to a significant increase in organic carbon. The authors believed a large portion of the available inorganic nitrogen on the marsh is utilized by Spartina and remains on the marsh in organic forms.

Profiles of phosphorus seem to be fairly consistent. Both Whitney et al. (1981) and DeLaune et al. (1981) found that soil phosphorus concentrations decreased with depth. They attributed this to phosphorus uptake by Spartina. Whitney et al. (1981) also suggested dewatering during sediment compaction may force out dissolved phosphorus in the pore water. Comparing extractable phosphate concentrations in streamside and inland marshes, DeLaune et al. (1976)

found that on a volume basis, phosphate was twice as high in the streamside marsh over most of the year. However, both areas showed the same seasonal trends in phosphate. Extractable phosphate was lowest in April and May, increased through June, dropped until August, when it again increased until December. They attributed the late spring increase to chemical factors (i.e. reduction of ferric sulfate, release of occluded phosphate, displacement of phosphate from ferric to aluminum phosphate) resulting from the spring tides which mobilize more soluble forms of phosphate. The following decrease in extractable phosphate may be a consequence of plant uptake or the precipitation of insoluble phosphates in the oxidized rhizosphere of Spartina.

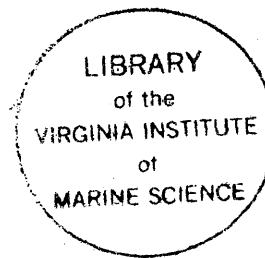
The aforementioned studies focused on nutrients in salt marshes. Studies of sediment nutrients in tidal freshwater marshes are limited to Bowden (1982, 1984). He found that free ammonium concentrations decreased with depth and were consistently greater than nitrate concentrations which varied erratically. When measured on fresh sediment samples, the depth distribution of free porewater ammonium was approximately equal to that of total extractable ammonium. The pattern of decreasing ammonium with depth agrees with the findings of Haines et al. (1977). This contrasts with the pattern of undisturbed marine sediments which show the opposite trend (Bowden, 1982). Both the ammonium and the nitrate concentrations showed little or no seasonal trends. Spatial variability was greater than temporal variability.

Total organic nitrogen (TON) did not change greatly with depth (~0.4-0.5%). However, the total organic phosphorus (TOP) decreased rapidly with depth down to 20cm. Below this depth, TOP concentrations stabilized. The atomic ratio of organic nitrogen to organic phosphorus

increased from 14:1 in the surface sediments to 32:1 in the sediments below 20cm. Bowden (1982) believes the increase in TON:TOP may imply that:

- (1) With age, more nitrogen than phosphorus is incorporated as refractory materials;
- (2) Nitrogen may be recycled more efficiently than phosphorus, and is then retained in the sediments;
- (3) Phosphorus may be more mobile in anaerobic sediments and migrate to an aerobic surface and precipitate.

Soils above 20cm show the greatest influence of plant roots and rhizomes on phosphorus and nitrogen concentrations (Garofalo, 1980). This is also where microbial mineralization of nitrogen occurs (Bowden, 1982). Below this zone, TON:TOP becomes fairly constant.



Methods

Study Site

The study area is a tidal, freshwater marsh, Sweet Hall Marsh, on the Pamunkey River, northwest of West Point, Virginia (Fig. 1). The sediments on the marsh surface are highly organic and contain both reworked marsh and riverine sediments. The vegetation is a mixed community including Peltandra virginica, Pontedaria chordata, and Spartina cynosuroides. Sweet Hall Marsh is cut by several tidal channels and one main thoroughfare. The marsh is used heavily by muskrats which are responsible for many of the smaller channels. The marsh also has a large population of fiddler crabs that further rework the sediment. The mean tidal range is 0.82m and the local subsidence rate, one of the largest in the Chesapeake Bay, is 3.2mmyr^{-1} (Holdahl and Morrison, 1974). Salinity of the river at this point ranges from 0-5ppt with a long-term average of 0.5ppt.

The sampling area was a section of the marsh fringing a fastland and was without tidal channels except for some minor muskrat runs (Fig 2). The hydrology of this area was generally dominated by sheet flow. Three sampling sites were chosen along a transect perpendicular to the river. Site one was a in the sparsely vegetated (P. virginica-P. chordata) transition zone directly landward of the mudflat in front of the marsh. Site two was in the low marsh dominated by P. virginica

Figure 1. Location of Sweet Hall Marsh.

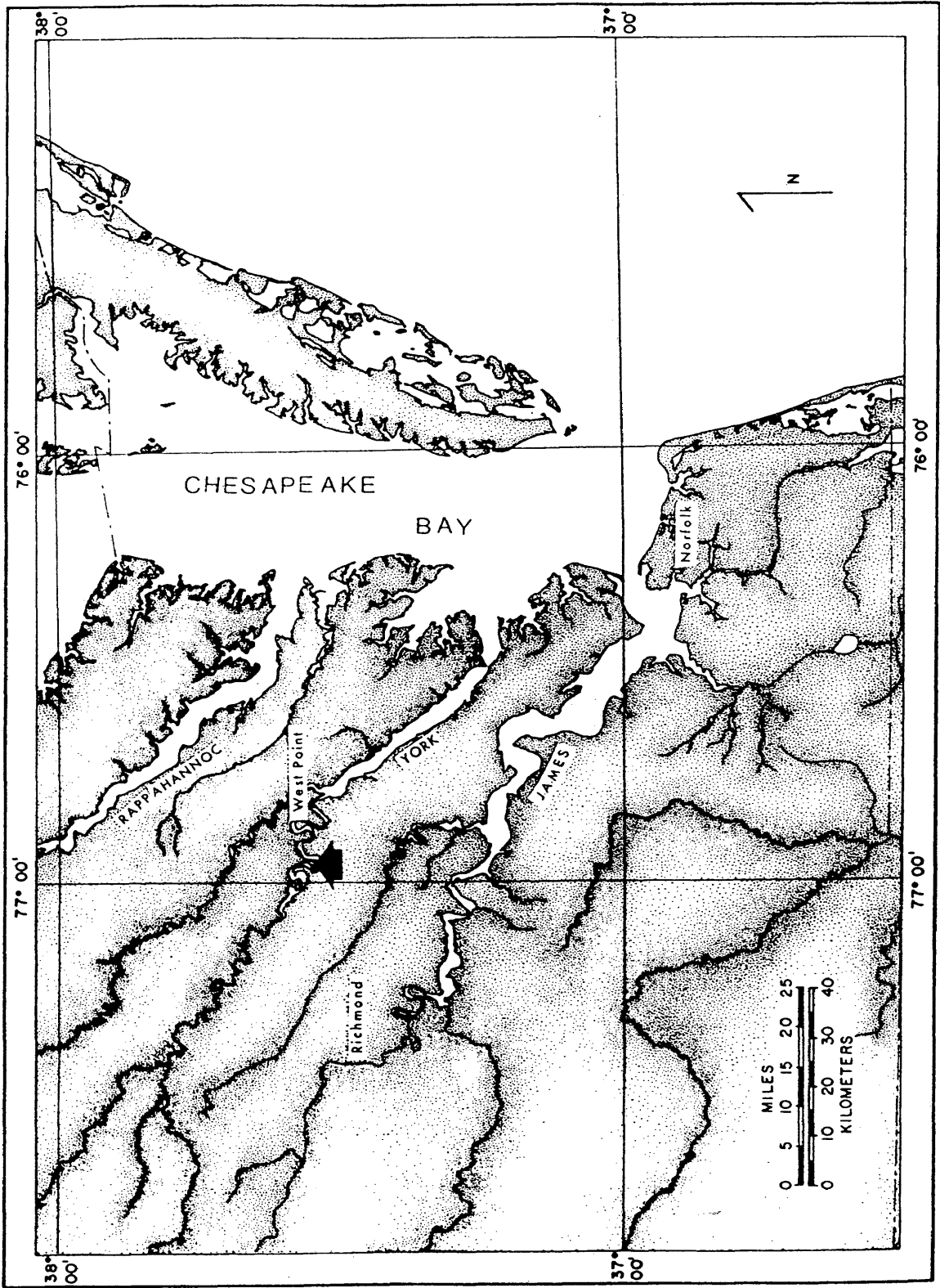
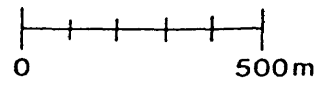
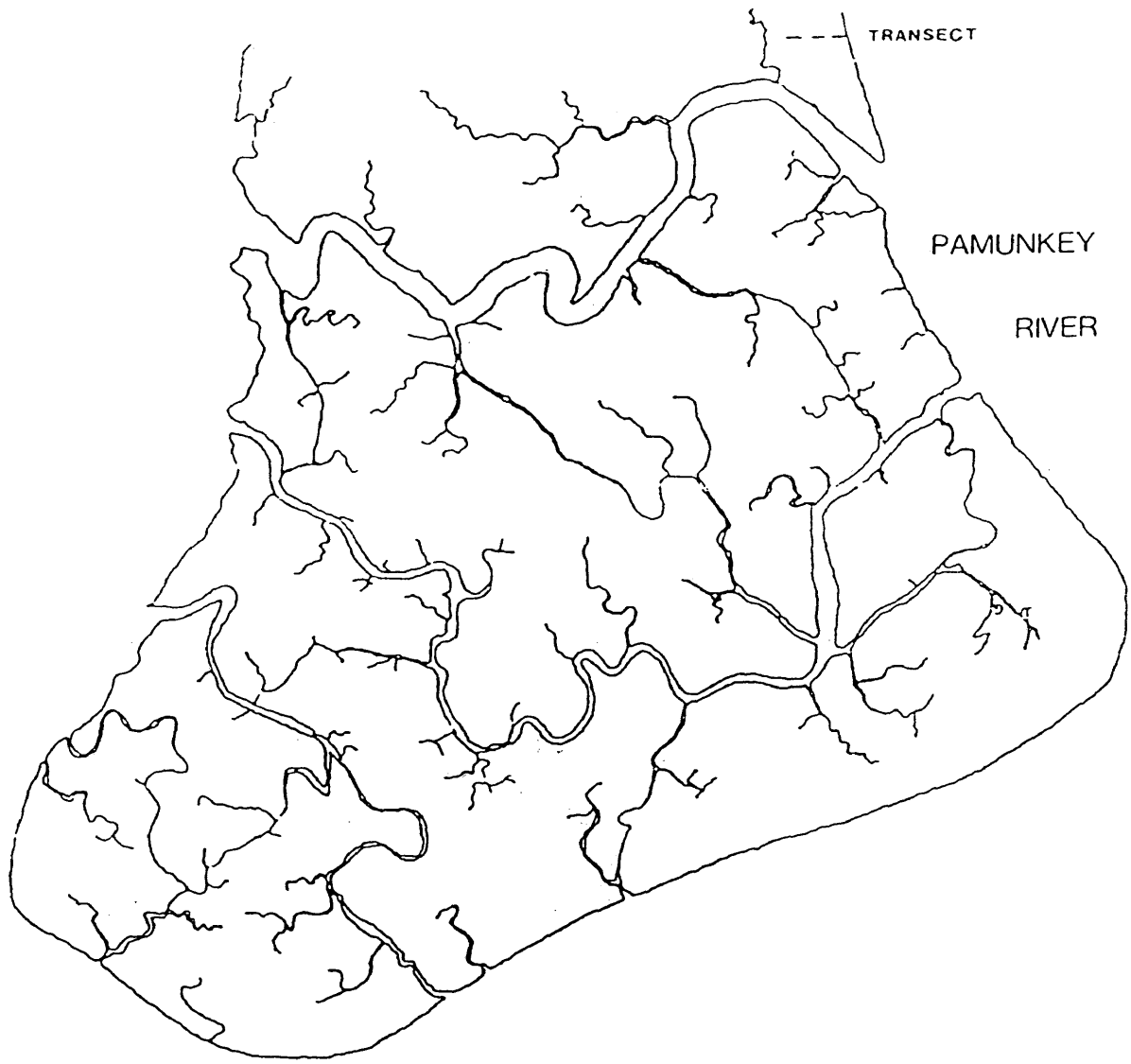


Figure 2. Location of transect.



with some Juncus effuscus. The third site was at the edge of a levee dominated by S. cynosuroides. Sites represent an elevational gradient which results in different periods of tidal inundation among the sites (Table 1). Site elevations were surveyed using an Alpha Electronics Omni Total Station. A tide gauge, installed at a boathouse adjacent to the marsh, was used to establish a tidal datum. The tide gauge at Sweet Hall Marsh provided a 45-day record and the tidal datum was compared to that of Gloucester Point to calculate the tidal components used to predict the astronomical tides at the marsh sites. The prediction generated by a colleague, Jim Perry (per. comm.), was used to arrive at the inundation time for each site. Because of the length of the initial tidal record, freshwater flow fluctuations were not incorporated into the model.

Sedimentation Measurements

Two methods were used to measure sediment input to the marsh. Annual accretion-erosion was measured using a dyed sediment core technique (R. J. Byrne, per. comm.). Fluorescent paint flakes were mixed with sediment from the respective sites and 15cm cores were then frozen and inserted into the marsh, level with the sediment surface. One was installed at each site. At the end of the study, any new (undyed) sediment overlying the sediment plug signified accretion. Replacement (with unmarked sediment) of a portion of the core indicated a period of erosion followed by accretion. This method measured not

TABLE 1. Site Descriptions

<u>Site</u>	<u>Elevation above MLW</u>	<u>Annual Inundation</u>	<u>Vegetation</u>
1	0.68m	6229hr.	<u>P. chordata-P. virginica</u>
2	0.98m	3044hr.	<u>P. chordata-P. virginia</u> <u>J. effucious</u>
3	1.03m	2205hr.	<u>S. cynosuroides</u>

only the net changes in sediment accumulation, but also reflected the greatest erosion at each site. The dyed sediment plugs were removed at the end of the study. Plastic meter sticks attached to 2x4s driven into the marsh 1 to 1.3m were placed adjacent to these cores to serve not only as reference points (to find the cores), but also to measure net changes in elevation of the marsh surface at the three sites. Stake observations were conducted every 2-3 weeks from 15 Jan. 1986 through 27 March 1987.

To determine short-term resuspension, glitter was placed on the marsh surface at each site. It was moistened to prevent it from either blowing away or floating away on the flood tide. Shallow collectors were deployed in the same area and examined every low tide for three tidal cycles. This was done on three occasions.

To measure gross deposition, three sediment traps were deployed at each site. These consisted of square polypropylene bottles pressed into the marsh surface. Bottle traps prevent little if any sediment resuspension because the mouth is smaller than the body. The traps originally had funnels attached to the mouth of the bottles for a larger sampling area (after Kraeuter and Wetzel, 1986). However, these rapidly clogged and so the funnels were eliminated. Gardner (1980) found that traps whose inlets are smaller than their bottoms tend to overestimate deposition, however the low water velocities of the incoming tide at Sweet Hall should reduce this error. The traps were collected every two to three weeks beginning 15 January 1986 and ending 21 December 1986, and analyzed for sediment weight and organic content. From each trap, four replicate 25ml sub-samples of the sediment were dried and weighed to estimate the amount of deposited sediment. These

were then combusted in a muffle furnace at 500° C for four hours, and reweighed for organic content which was measured as ash free dry weight (AFDW)/ initial dry weight. To measure the amount of N and P associated with these sediments, traps sampled concurrently with sediment nutrient cores were analyzed for total Kjeldahl nitrogen and total phosphorous.

Nutrient Analysis

To measure sediment nutrient profiles, three 30cm cores were taken quarterly at each sampling site. Sampling dates were 18 Feb. 1986, 18 May 1986, 5 Sept. 1986, and 6 Dec. 1986. Immediately after sampling, these cores were put on ice and taken to the lab, where they were cut into 5cm sections. Each section, except the bottom section which was discarded, was analyzed for both organic and inorganic nutrients, bulk density, and organic matter as follows:

Extractable Inorganic Nutrients (after Haines et al., 1977; Henriksen et al., 1981):

Fresh sediment samples were extracted three times with 1N KCl (while being shaken) to insure all inorganic nitrogen was removed from the sediments. Samples were centrifuged after each extraction and the supernatants homogenized and analyzed spectrophotometrically for:

Ammonium, Nitrate, Nitrite (after Parsons et al., 1984)

Organic Nutrients (after Bremner, 1965; Standard Methods, 1985):

A modified Kjeldahl digestion was used to determine total organic nitrogen (TON) and total phosphorous (TP). Sediment samples were digested in a solution of concentrated sulfuric acid and a copper sulfate-potassium sulfate ($\text{CuSO}_4\text{-K}_2\text{SO}_4$) mixture using an Orion Scientific Block Digester AD4020. Digestates were diluted, vortexed, and the suspended matter precipitated out. Samples were analyzed for nitrogen and phosphorous using an Orion Scientific Autoanalyzer. Nitrogen was measured as indolphenol dye at 630nm, and phosphorous was measured as a molybdate complex at 880nm.

Bulk density:

Each section was sub-sampled (1cc) using a plastic, flat-ended syringe to decrease compaction. Sediment plugs were weighed fresh and dry to yield wet and dry bulk densities, and percent water. The dried samples were combusted in a muffle furnace at 500 C for four hours. Organic content was measured as AFDW/initial dry wt.

Statistics

Preliminary statistical analyses showed heterogeneous variances of trapped sediments and nutrient analyses among sites and dates (Bartlett's Test $p < .001$). Consequently, testing among sites and dates

was done using a non-parametric analysis of variance, the Kruskal-Wallis Test (NPAR Tests, SPSS-X), and a non-parametric a posteriori multiple range test (Zar, 1974).

RESULTS

The results of sedimentation measurements showed minor erosion at each site. At the end of the study, net elevation changes were 0.0cm, -0.8cm, and -0.2cm at sites 1, 2, and 3 respectively (Fig. 3). Assuming the stakes experience the same subsidence rate as the marsh, the elevations reflect changes in addition to subsidence. Each of the dyed sediment plugs was recovered and all three showed erosion. When the amount of erosion of each sediment plug was compared to the the erosion at each site based on the stake observations, sediment plugs from sites 1, 2, and 3 showed discrepancies of -7.7cm, -5.1cm, and -2.8cm respectively. This may signify a major erosion incident followed by redeposition which took place between bi-weekly stake observations and therefore was not recorded because it was short-lived.

Sediment and nutrient input showed both large spatial and temporal variation. (Seasonal definitions for trapped sediments were made to roughly correspond to the nutrient core sampling dates for comparison, and are spring 18 Feb.- 8 June, summer 9 June-4 Sept., fall 5 Sept.-5 Dec., and winter 15 Jan.-17 Feb. (1986) and 6 Dec.- 1 Jan. (1986-1987)). Gross deposition decreased significantly ($p < .0001$) from site 1 to site 3 on an annual basis (Table 2). The organic fraction of the trapped sediment also differed significantly ($p < .0001$) among sites, with site 2 generally having the highest percentage of organics. Trapped sediment from site 3 showed the largest range in organic

content, from a high of 58.2 percent in May to a low of 3.5 percent in June (Fig. 4). When organic input is calculated (organic fraction multiplied by the dry sediment weight), almost triple the amount of organic material was deposited at site 1 than either at sites 2 or 3. The organic fraction of incoming sediment was substantially lower in the fall than during the rest of the year. For the marsh as a whole, greatest net deposition occurred in the spring, although maximum rates (up to $1.6 \text{ g cm}^{-2} \text{ d}^{-1}$) were found in the summer (Fig. 5). Only site 3 differed, where winter was the season of greatest deposition.

Nutrient results from the sediment traps also showed site and seasonal differences. Total Kjeldahl Nitrogen (TKN) concentrations from 18 Feb. were significantly ($p=.0001$) higher than those from 18 May, 5 Sept. and 6 Dec., and ranged from 0.03 to 1.04 percent dry weight over the study (Table 2). However, Total Phosphorous (TP) concentrations showed significant ($p=.0015$) differences only among sites, with site 3 having lower TP concentrations than either sites 1 or 2. Values of the trapped sediments ranged from 0.02 to 0.22 percent dry weight (Table 2).

Nutrient analysis of the sediment cores also showed large spatial and temporal variability. Average core values of organic matter differed significantly ($p=.0016$) among sites, increasing toward site 3 (Table 2). In addition, organic content showed a substantial increase at each site for 18 May (Figs. 6a-d). Percentages from this sample date were almost double the percentages of other dates. Most values were between 13 and 20 percent dry weight but 18 May values were approximately 50 percent dry weight.

Nitrogen and phosphorous profiles showed different patterns. Nitrogen had greater site variation, while phosphorous showed more temporal variation. Inorganic nitrogen (NH_4^+ -N, NO_x^- -N) values were generally quite low (Table 2). Over the study, ammonium and nitrates/nitrites showed significant ($p=.0068$, $p=.0112$) differences among sites, site 1 having the highest values of each. Average core concentrations of Total Kjeldahl Nitrogen (TKN) differed significantly ($p<.0001$) among sites for each sampling period, site 3 showing the highest concentrations (Table 3). Concentrations ranged from 0.30 to 0.64 percent dry weight (Table 2). However, Total Phosphorous showed no significant site differences (Table 4).

Seasonal differences of sediment core nutrient concentrations occurred in both the nitrogen and phosphorous. Inorganic N over sites differed significantly ($p<.0001$) between seasons with winter showing the highest concentrations (Figs. 7-9). The only significant seasonal differences in TKN values occurred at sites 1 ($p=.0315$) and 2 ($p=.0318$). TP values for sites 1 ($p<.001$) and site 2 ($p=.0025$) also showed significant seasonal differences. Generally, 6 Dec. core profiles showed the highest TP concentrations followed by 5 Sept., 18 May, 18 Feb.. Most measurements fell between 0.05 and 0.15 percent dry weight (Table 2).

Vertically, both TKN and TP concentrations over seasons decreased significantly ($p=.0051$, $p<.0001$) with depth (Figs. 10-12). However, TKN values showed a slight increase in the 15-20cm sections. Only TP concentrations showed significant ($p<.03$) decreases with depth on each sampling date.

Figure 3. Marsh surface elevations.

MARSH SURFACE ELEVATIONS

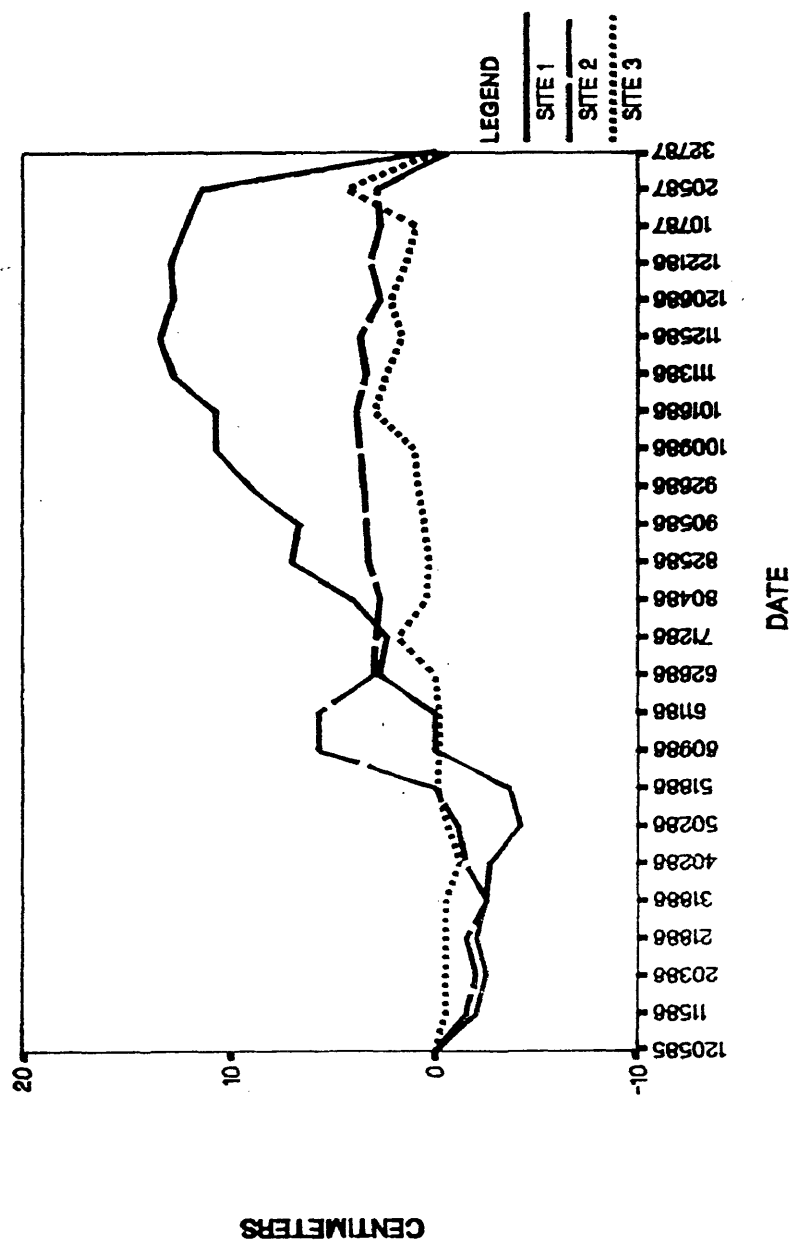


TABLE 2. Summary of sediment and nutrient analyses of traps and cores.

Sediment traps:

<u>Site</u>	<u>Dry Sediment Weight</u>	<u>% Organic</u>	<u>TKN*</u>	<u>TP*</u>
1	0.72 ± 0.36 g cm ⁻² d ⁻¹	15.8 ± 4.1	0.34 ± 0.17	0.12 ± 0.04
2	0.17 ± 0.15 g cm ⁻² d ⁻¹	20.0 ± 6.8	0.29 ± 0.26	0.12 ± 0.11
3	0.13 ± 0.24 g cm ⁻² d ⁻¹	22.0 ± 15.8	0.28 ± 0.46	0.03 ± 0.03

Sediment cores:

<u>Site</u>	<u>TKN*</u>	<u>TP*</u>	<u>NH₄[#]</u>	<u>NO_x[#]</u>
1	0.35 ± 0.09	0.10 ± 0.05	3.81 ± 2.13	0.46 ± 0.31
2	0.43 ± 0.07	0.09 ± 0.04	3.03 ± 2.47	0.34 ± 0.20
3	0.53 ± 0.10	0.09 ± 0.04	3.08 ± 3.00	0.38 ± 0.21

<u>Site</u>	<u>% Organic</u>	<u>Dry Bulk Density</u>
1	23.6 ± 17.8	0.37 ± 0.07 g cm ⁻²
2	24.9 ± 18.4	0.33 ± 0.07 g cm ⁻²
3	27.8 ± 13.4	0.22 ± 0.06 g cm ⁻²

* percent dry weight

ug g⁻¹ sediment

Figure 4. Sediment trap percent organic matter.

SEDIMENT TRAP PERCENT ORGANIC MATTER

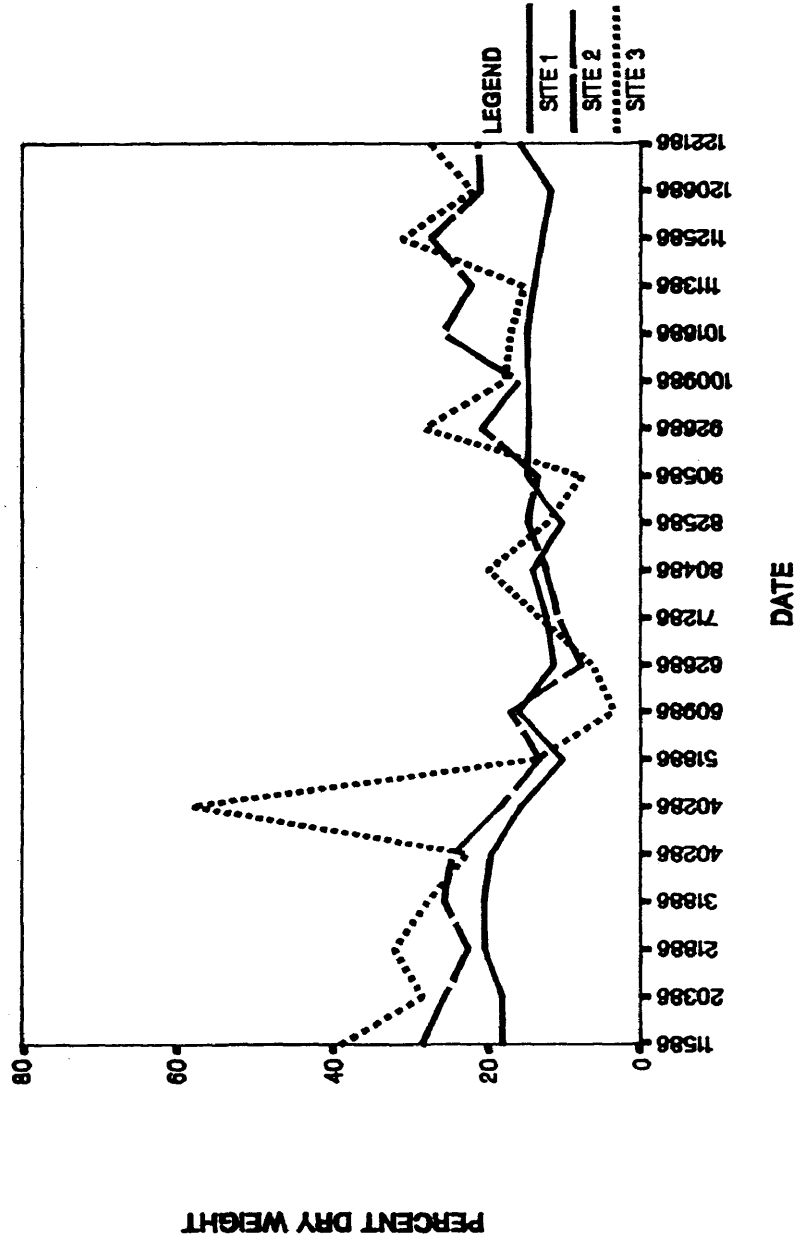


Figure 5. Sediment trap gross deposition.

DRY SEDIMENT WEIGHT

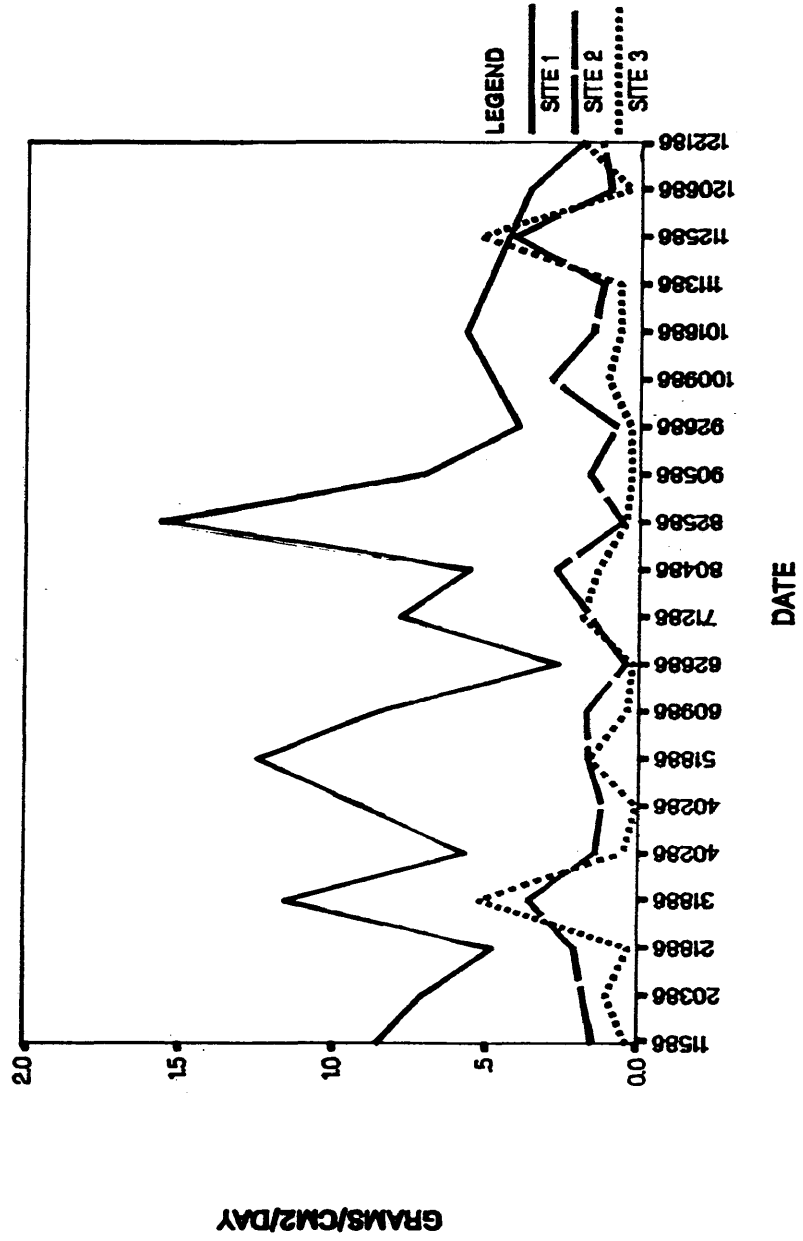
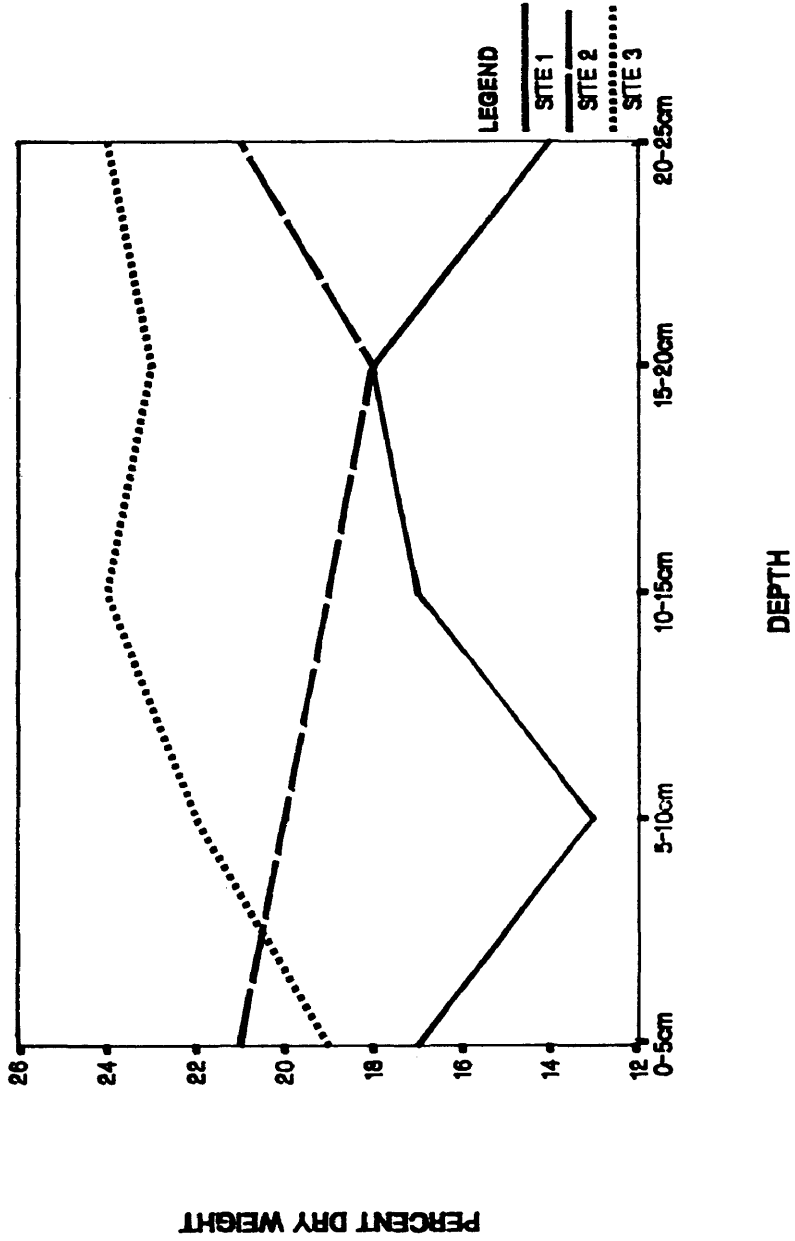


Figure 6. Sediment core percent organic matter.
a.) 18 Feb.
b.) 18 May
c.) 5 Sept.
d.) 6 Dec.

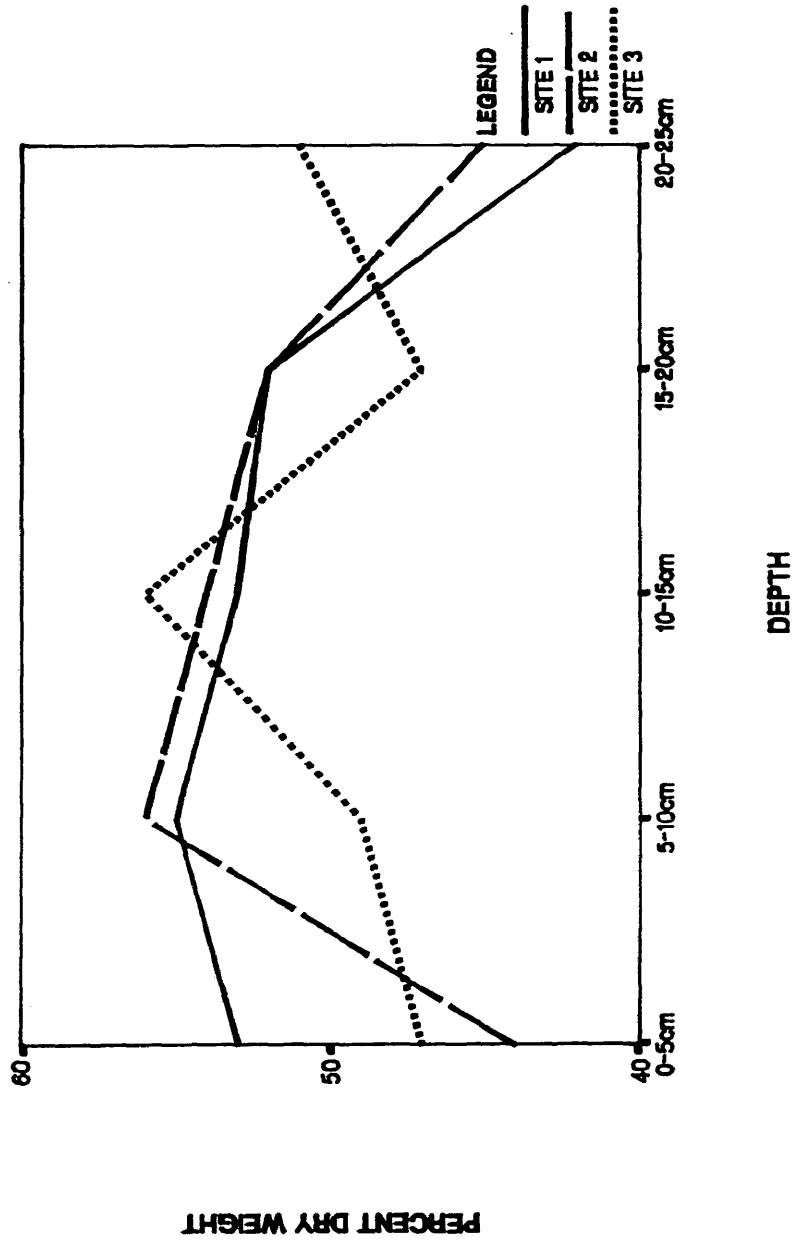
SEDIMENT CORE ORGANICS

2-18-86



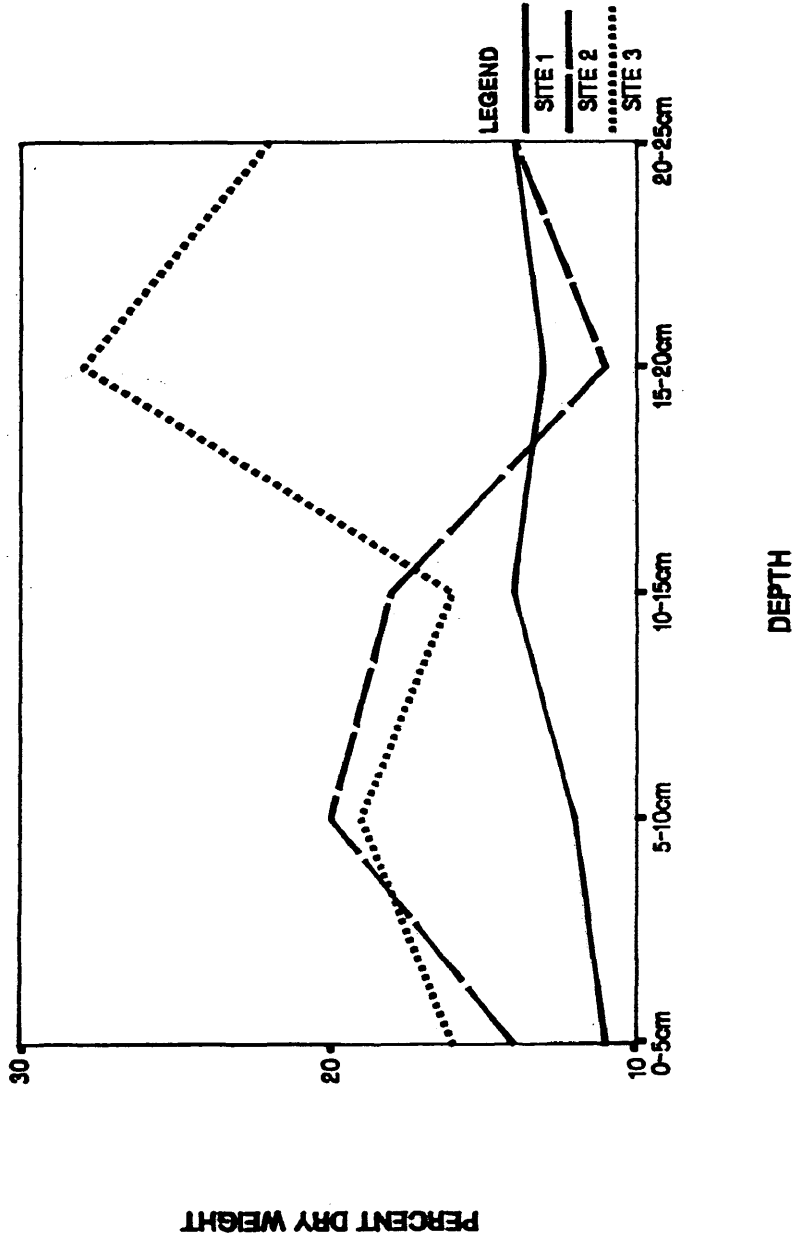
SEDIMENT CORE ORGANICS

5-18-86



SEDIMENT CORE ORGANICS

9-5-86



SEDIMENT CORE ORGANICS

12-6-86

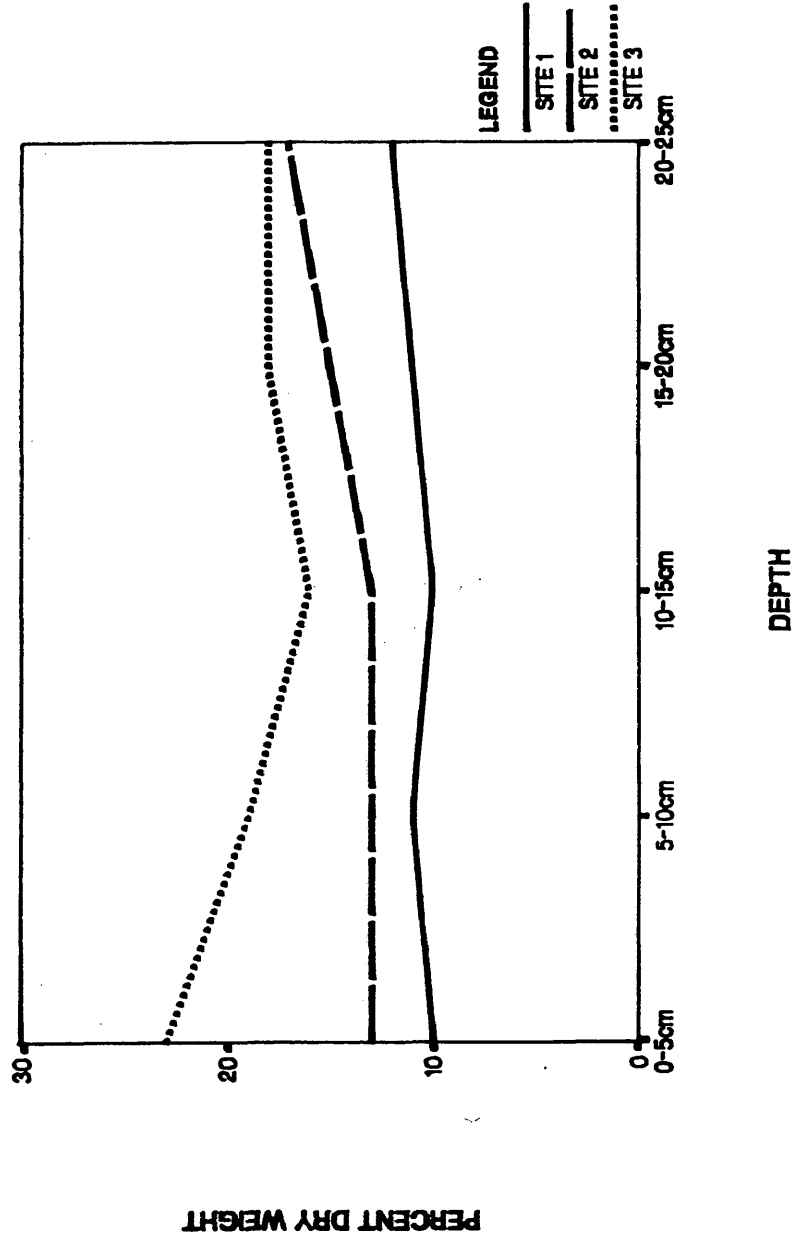


Table 3. TKN Sediment Analysis

differences due to:	<u>Date</u> (K-W)	<u>Site</u> (K-W) (MR)	<u>Section</u> (K-W) (MR)
annual	N.S.	.0000 3>2>1	.0051 1,2,4>3,5

<u>Date</u>	<u>differences among sites</u>	<u>differences among sections</u>
1	.0000 3>2>1	N.S.
2	.0001 3,2>1	N.S.
3	.0079 3>2>1	.0030 1,2,4,>3,5
4	.0000 3>2>1	N.S.

<u>Site</u>	<u>differences among dates</u>	<u>differences among sections</u>
1	.0315 N.D.	.0002 1,2>3,4>5
2	.0318 1,2,3>4	.0170 N.D.
3	N.S.	N.S.

N.S. - not significant

N.D. - not discernable

K-W - Kruskal-Wallis non-parametric anova

MR - Multiple Range test

Table 4. TP Sediment Analysis

differences due to:	<u>Date</u>		<u>Site</u>	<u>Section</u>	
	(K-W)	(MR)	(K-W)	(K-W)	(MR)
annual	.0000	4,3>2,1	N.S.	.0000	1>2>3,4>5

<u>Date</u>	<u>differences among sites</u>	<u>differences among sections</u>
1	N.S.	.0142 N.D.
2	N.S.	.0000 1,2>3,4,5
3	N.S.	.0000 1,2>3,4>5
4	.0001 1>2,3	.0268 N.D.

<u>Site</u>	<u>differences among dates</u>	<u>differences among sections</u>
1	.0000 4>3>2,1	.0124 N.D.
2	.0025 4>3>2,1	.0000 1>2,3,4,5
3	N.S.	.0000 1,2>3,4,5

N.S. - not significant

N.D. - not discernable

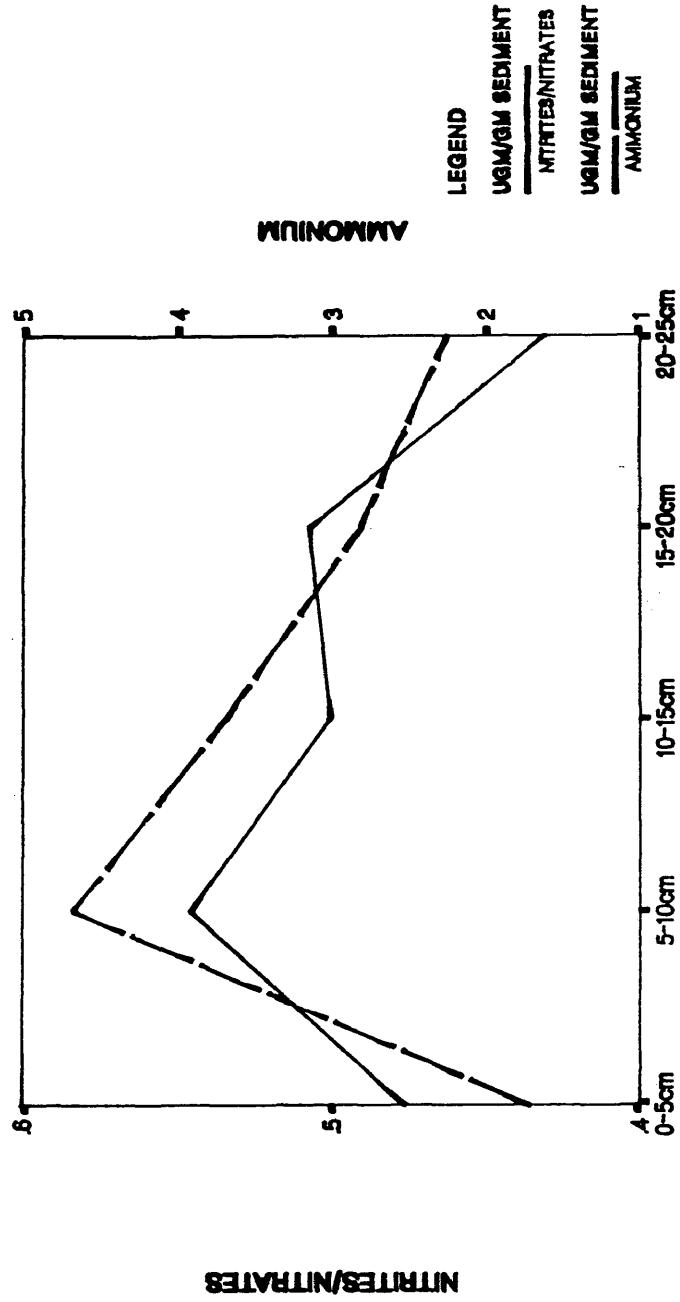
K-W - Kruskal-Wallis non-parametric anova

MR - Mutliple Range test

Figure 7. Sediment core inorganic nitrogen, site 1.
a.) 18 Feb.
b.) 18 May
c.) 5 Sept.
d.) 6 Dec.

SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

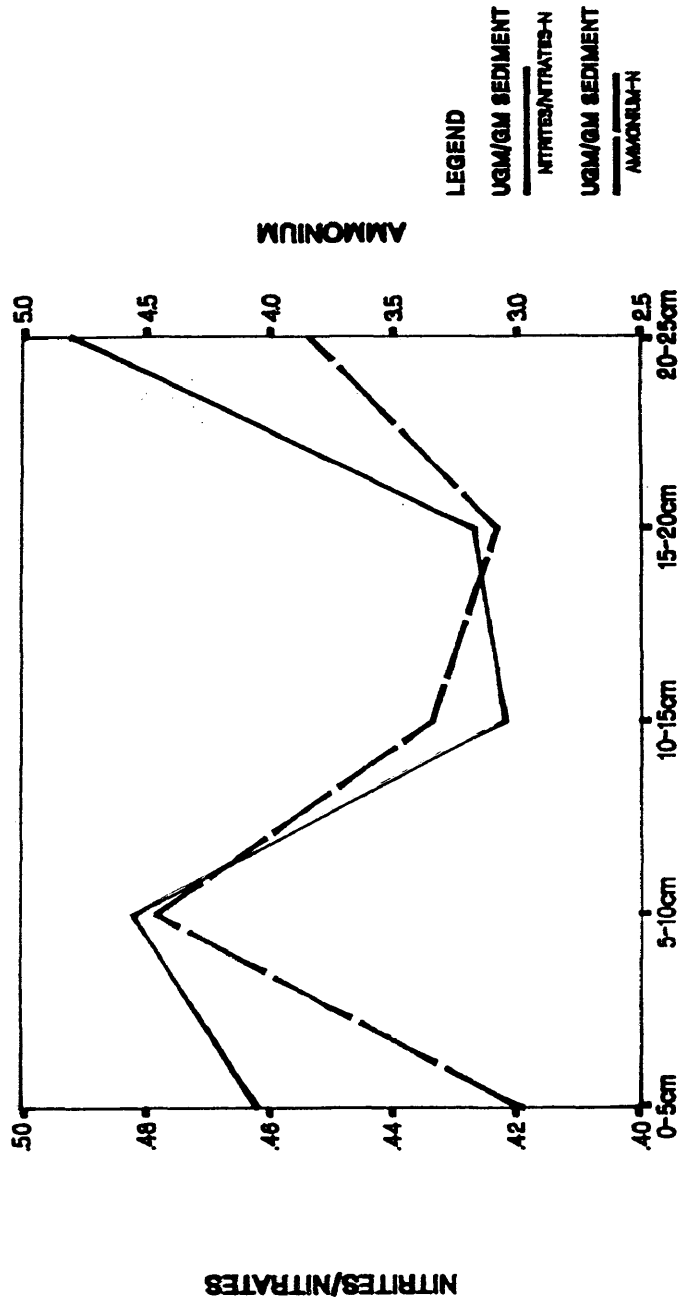
SITE 1



DEPTH
2-18-86

SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

SITE 1

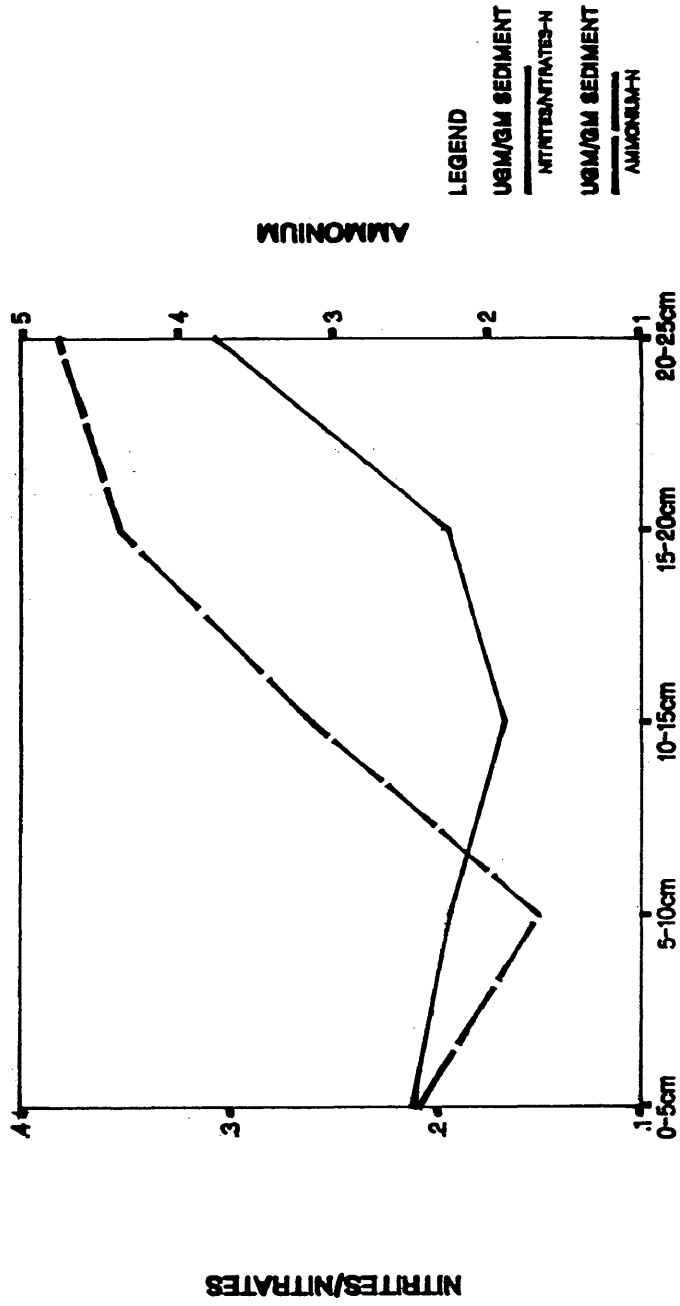


DEPTH

5-10-00

SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

SITE 1

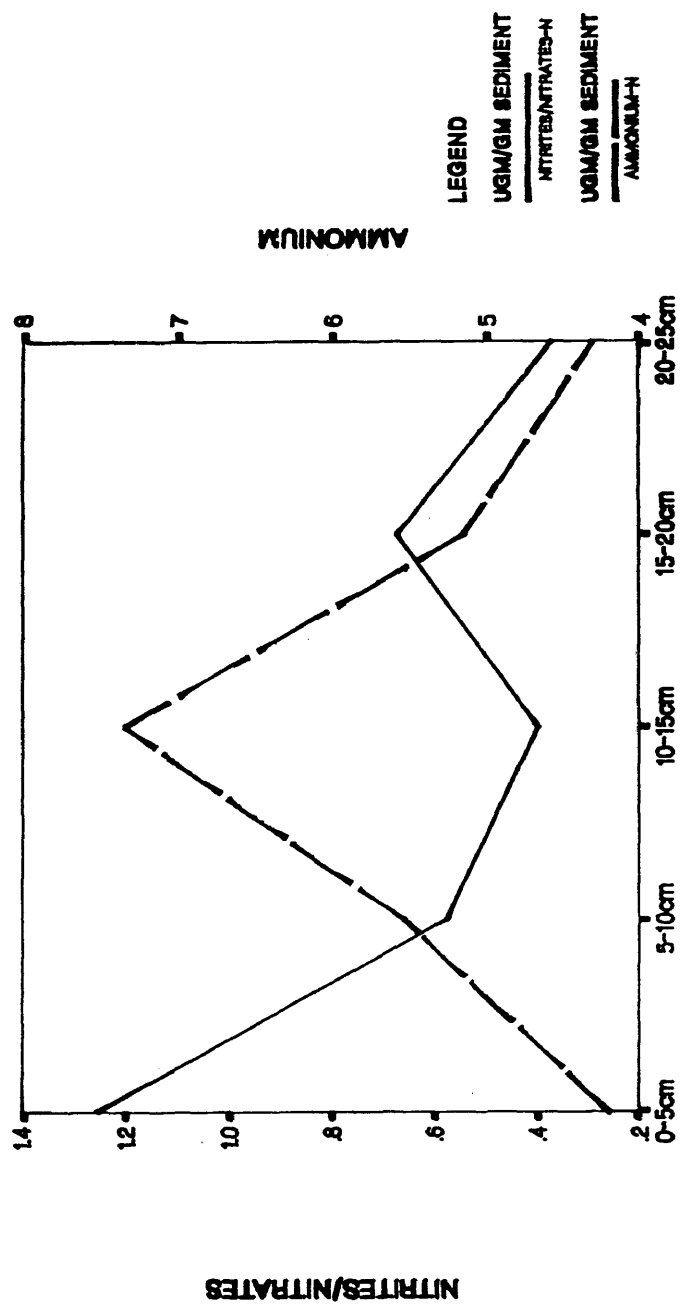


DEPTH

9-5-86

SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

SITE 1

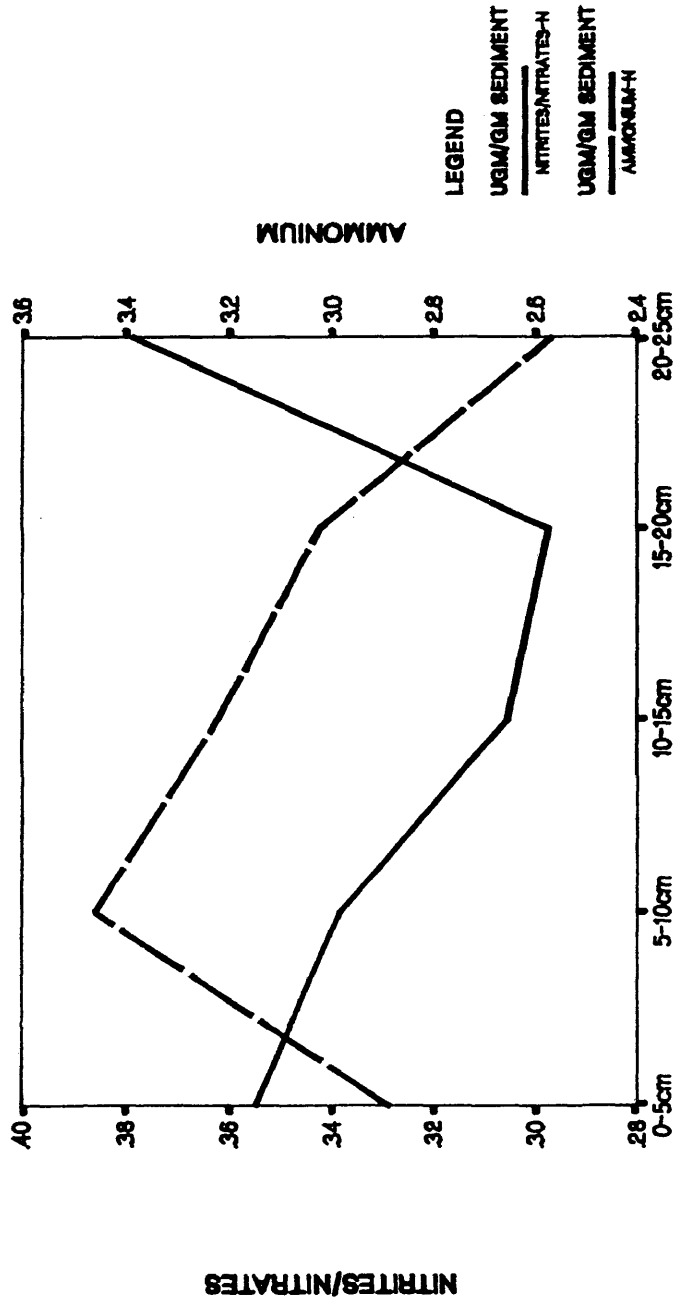


DEPTH
12-6-66

Figure 8. Sediment core inorganic nitrogen, site 2.
a.) 18 Feb.
b.) 18 May.
c.) 5 Sept.
d.) 6 Dec.

SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

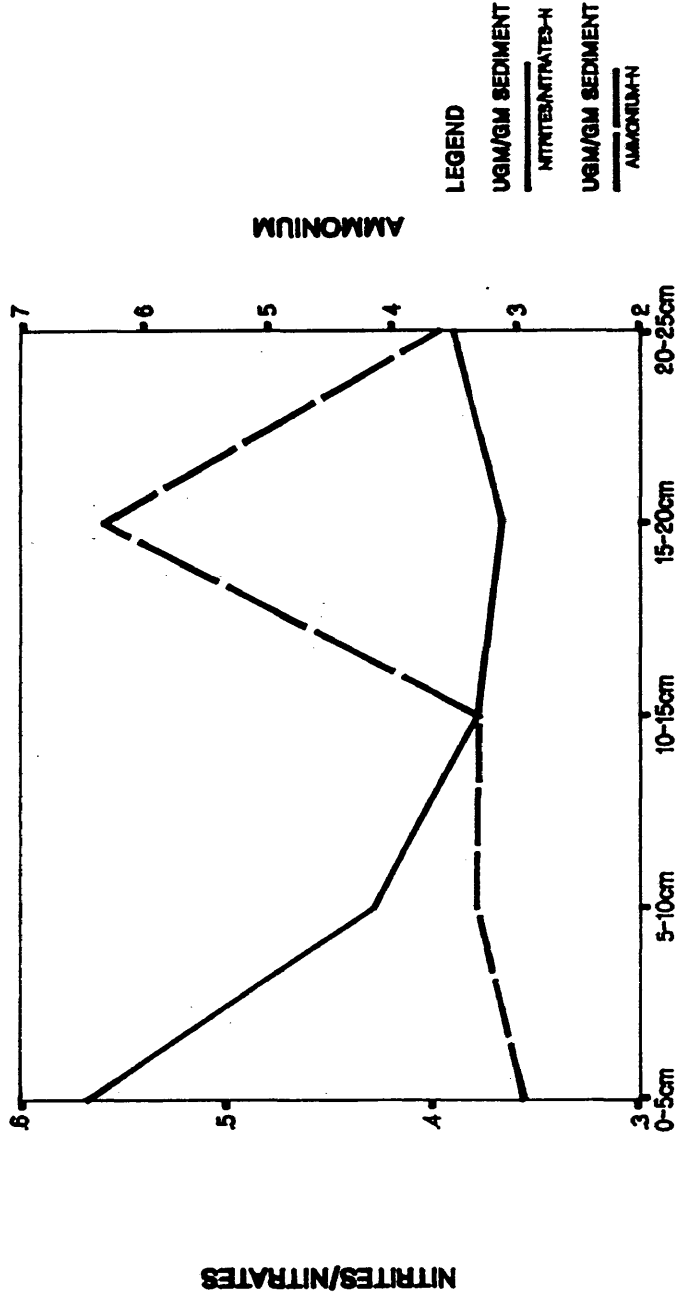
SITE 2



DEPTH
2-18-06

SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

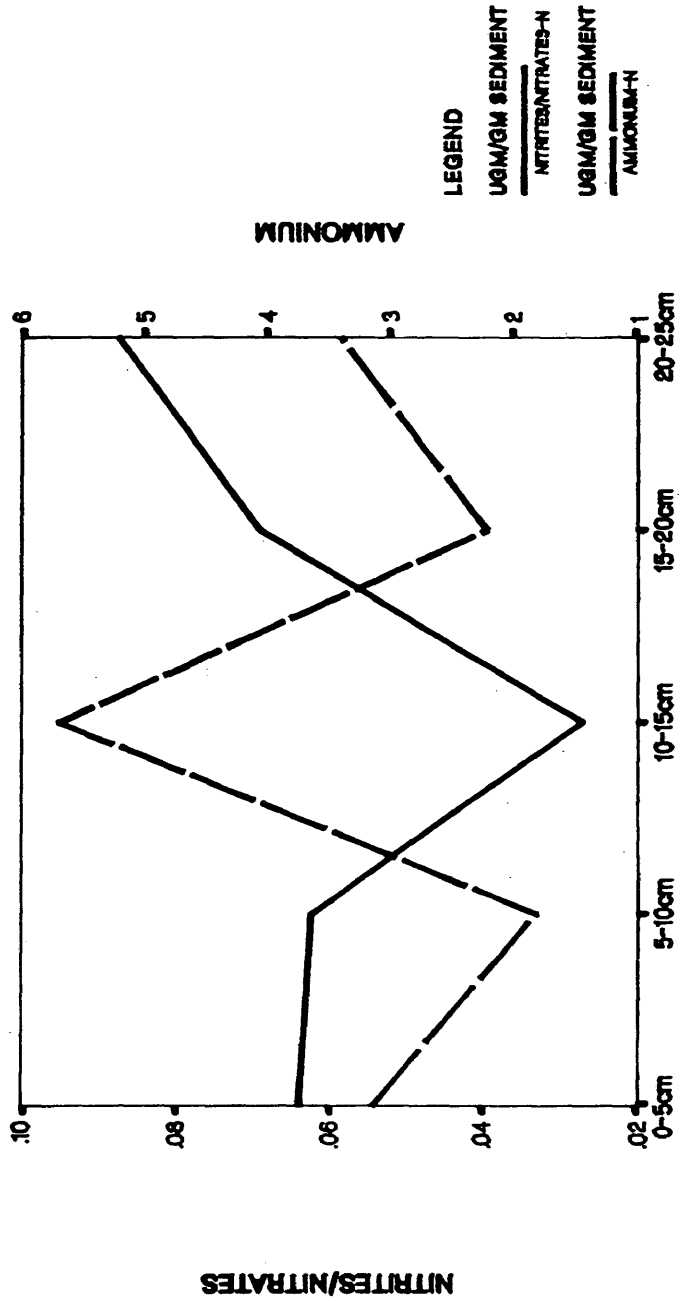
SITE 2



DEPTH
5-18-88

SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

SITE 2

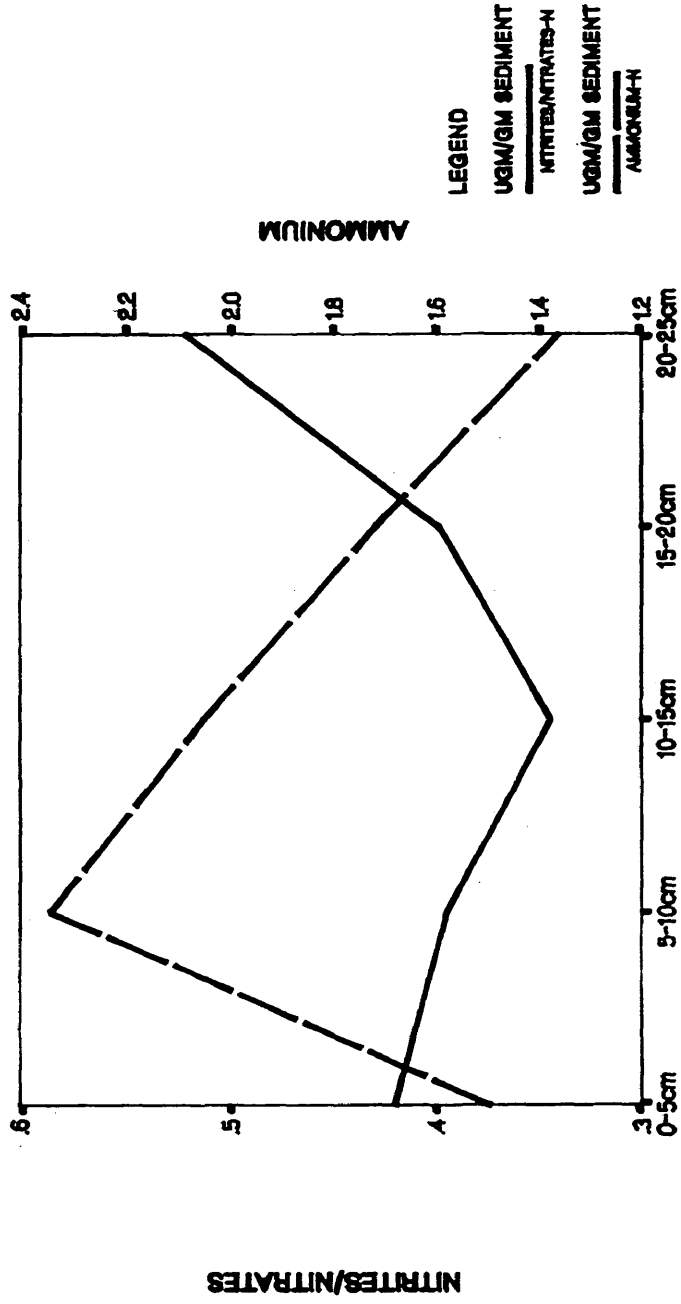


DEPTH

9-5-86

SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

SITE 2

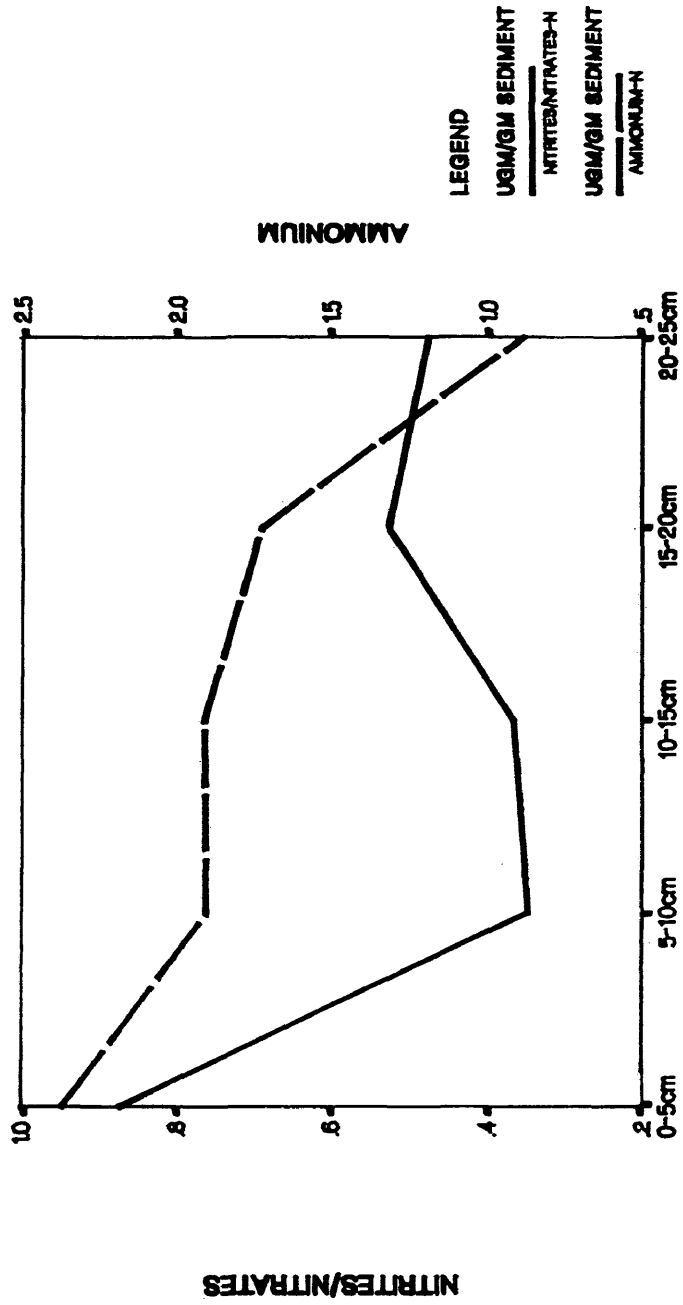


DEPTH
12-6-86

Figure 9. Sediment core inorganic nitrogen, site 3.
a.) 18 Feb.
b.) 18 May
c.) 5 Sept.
d.) 6 Dec.

SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

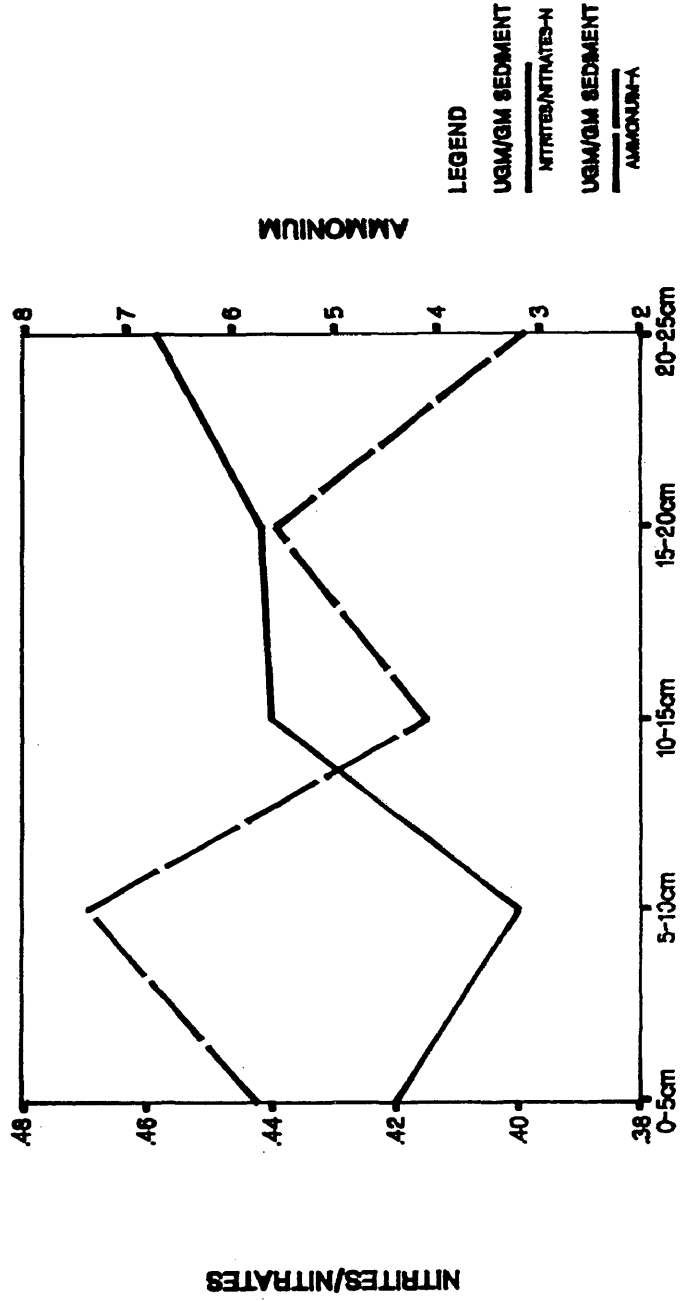
SITE 3



DEPTH
2-10-86

SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

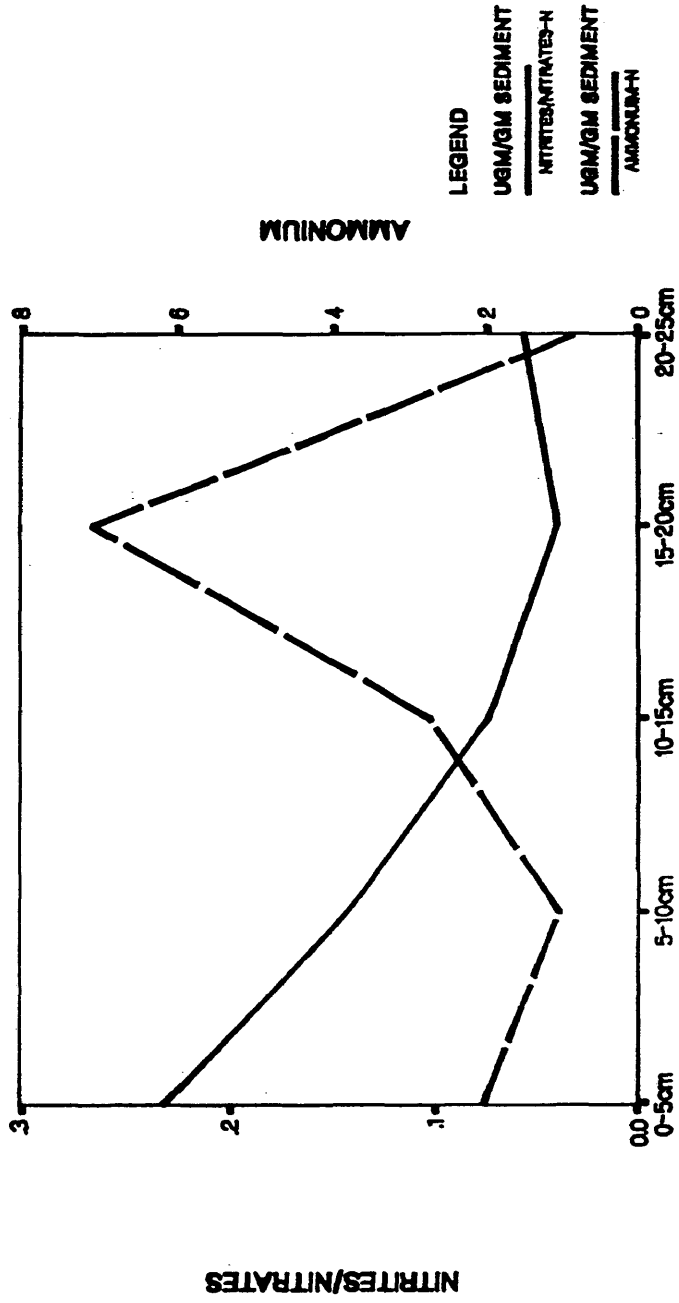
SITE 3



DEPTH
5-16-66

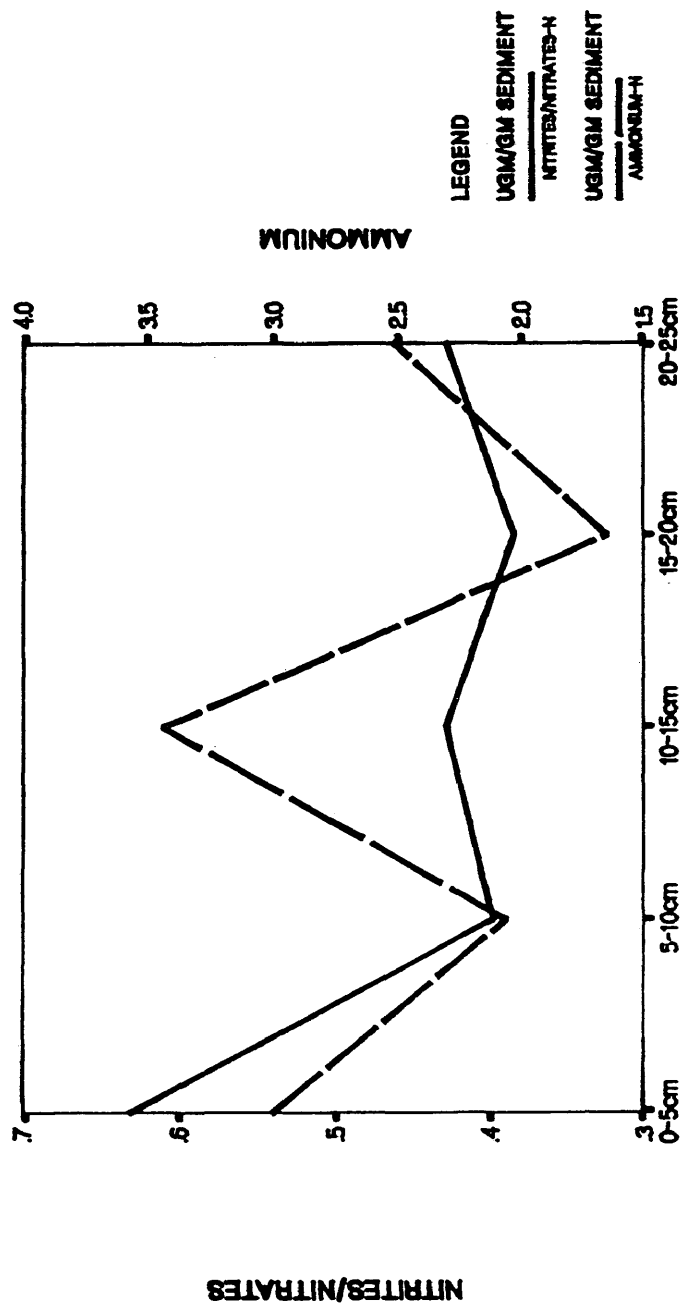
SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

SITE 3



SEDIMENT NUTRIENT DEPTH PROFILE INORGANIC NITROGEN

SITE 3

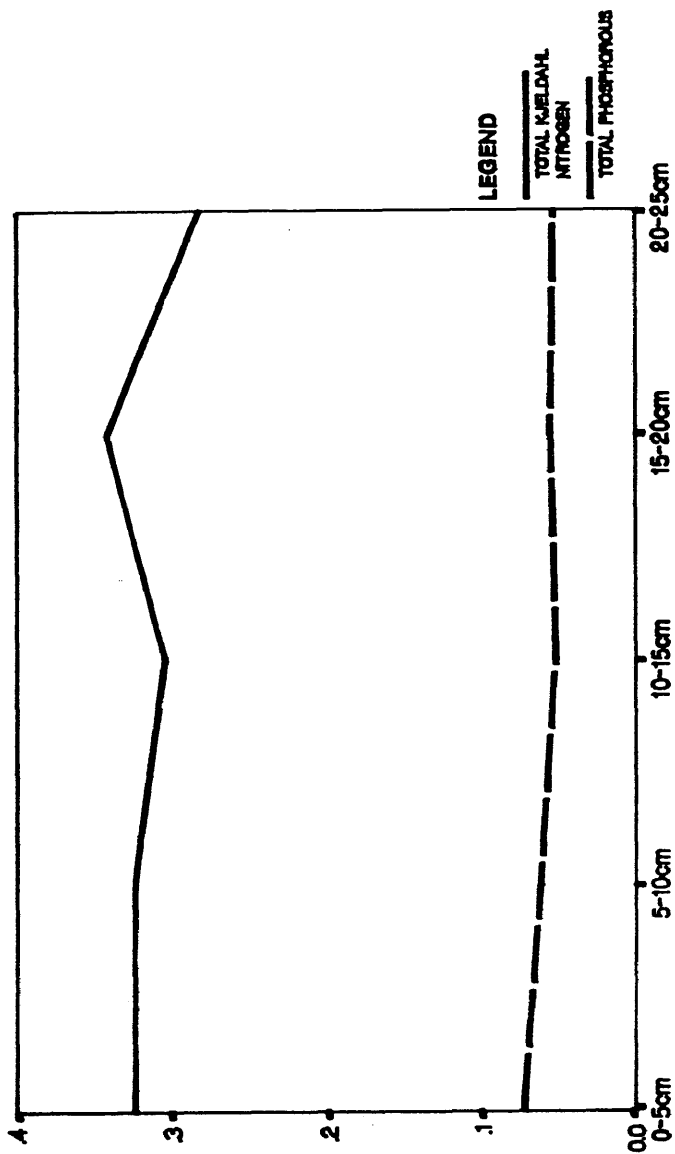


DEPTH
12-6-86

Figure 10. Sediment core TKN and TP, site 1.
a.) 18 Feb.
b.) 18 May
c.) 5 Sept.
d.) 6 Dec.

SEDIMENT NUTRIENT DEPTH PROFILE

SITE 1



LEGEND

TOTAL KJELDAHL
NITROGEN

TOTAL PHOSPHOROUS

DEPTH

2-18-86

PERCENT DRY WEIGHT

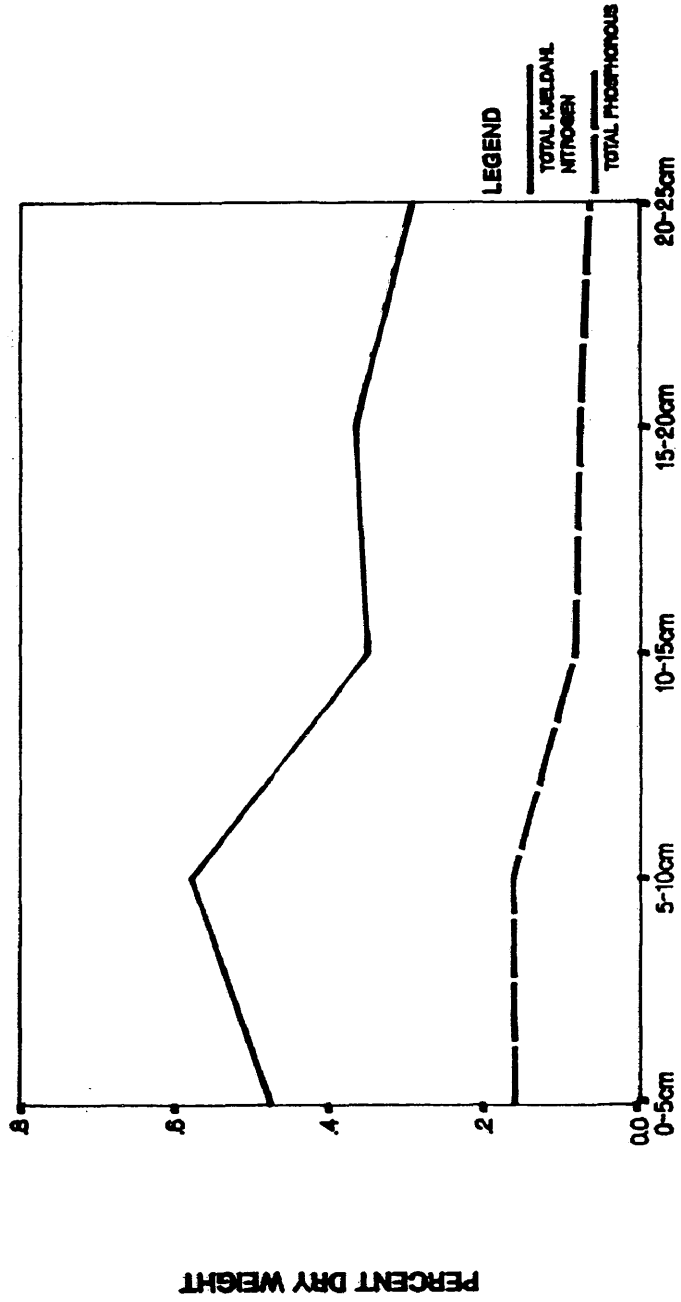
SEDIMENT NUTRIENT DEPTH PROFILE

SITE 1



SEDIMENT NUTRIENT DEPTH PROFILE

SITE 1

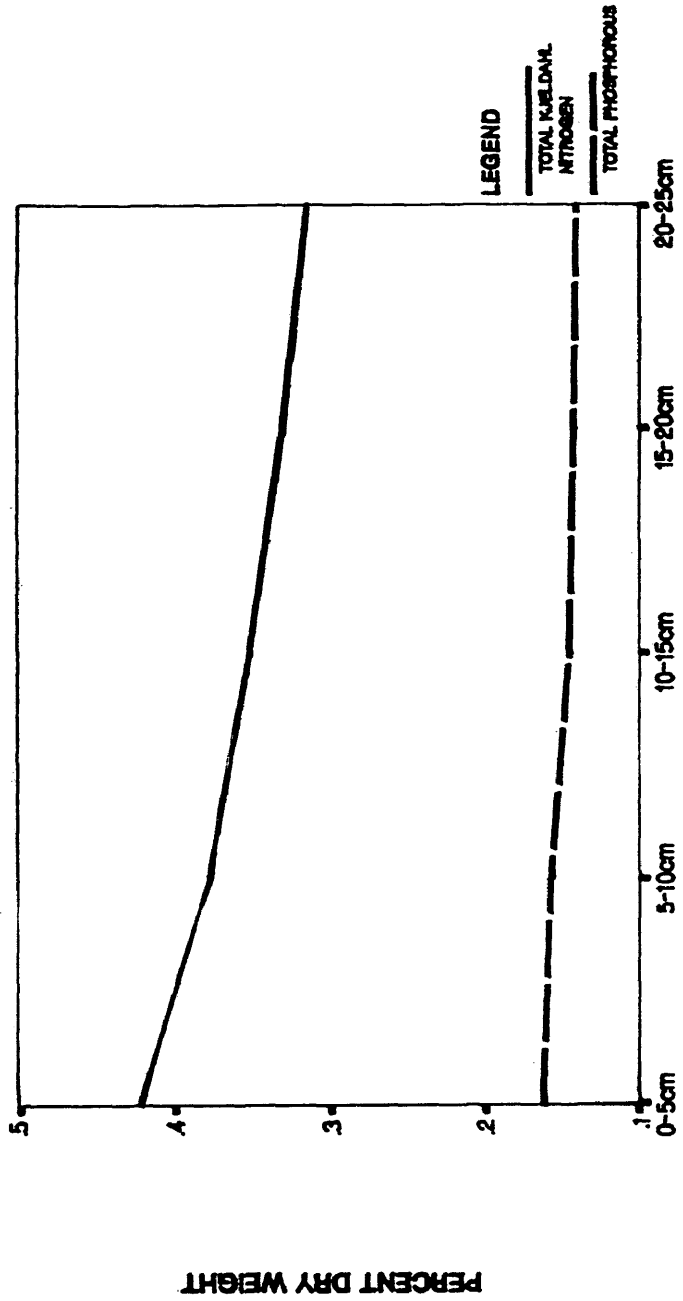


DEPTH

9-5-86

SEDIMENT NUTRIENT DEPTH PROFILE

SITE 1



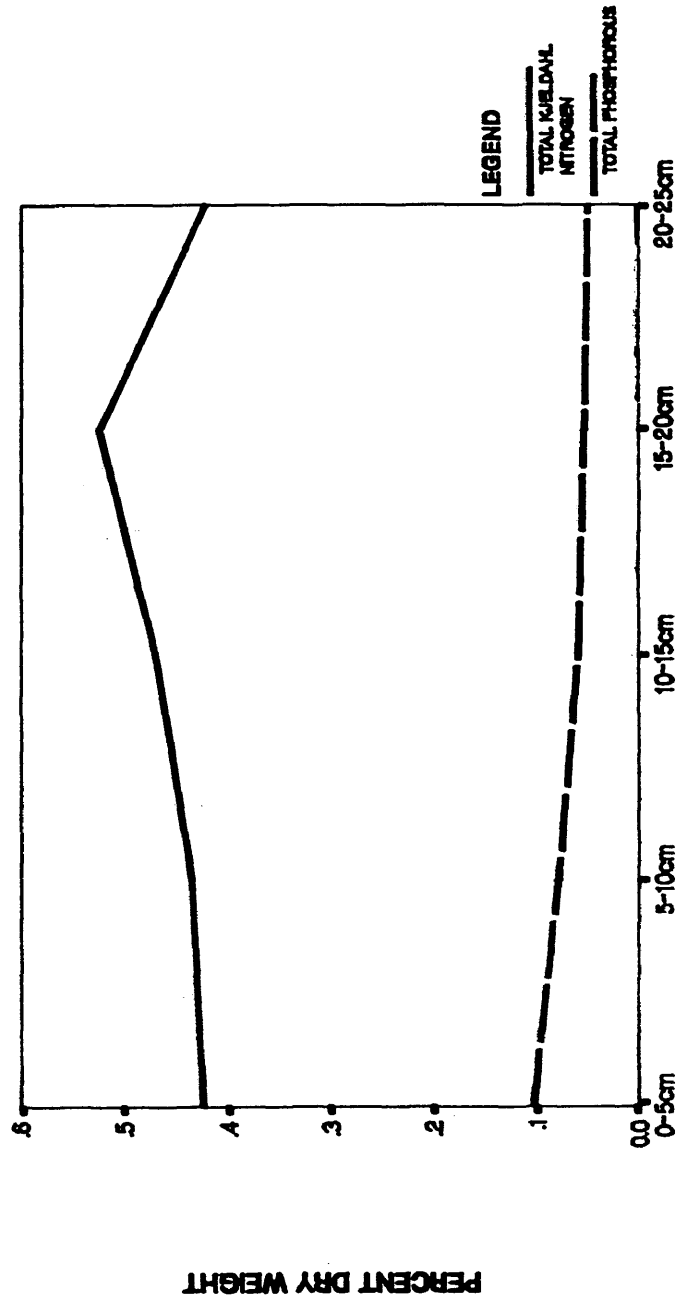
DEPTH

12-0-00

Figure 11. Sediment core TKN and TP, site 2.
a.) 18 Feb.
b.) 18 May
c.) 5 Sept.
d.) 6 Dec.

SEDIMENT NUTRIENT DEPTH PROFILE

SITE 2

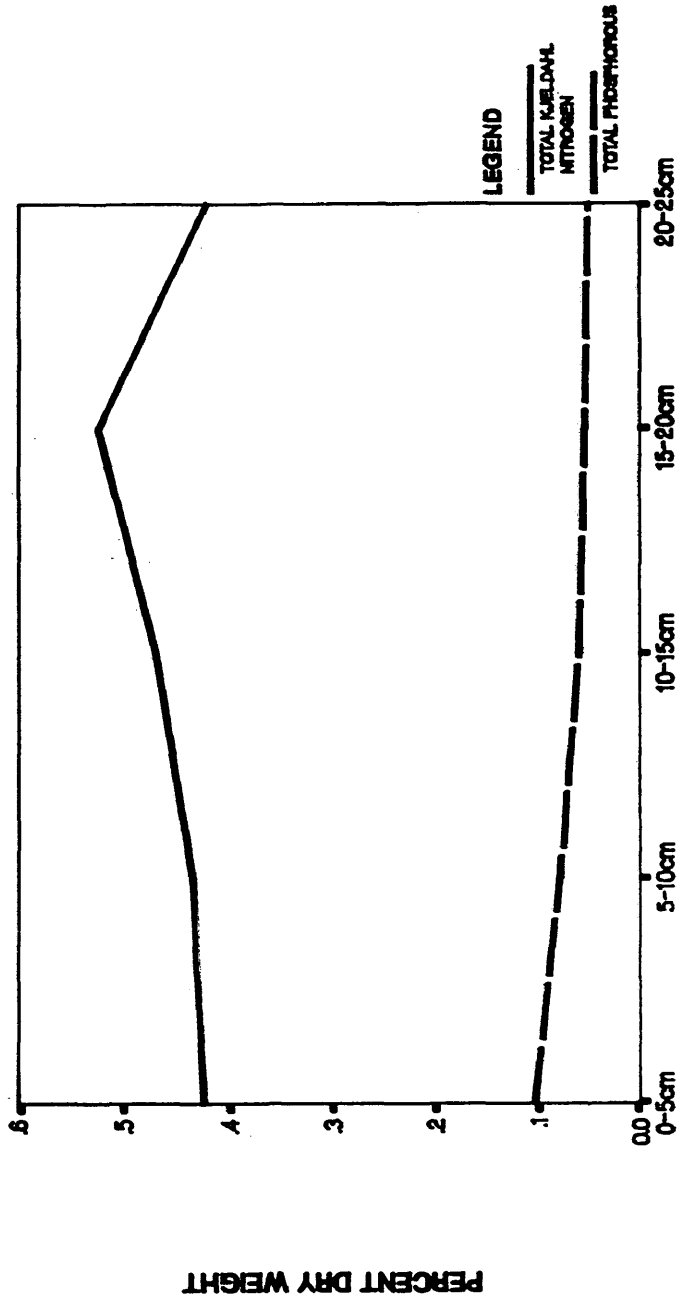


DEPTH

2-18-86

SEDIMENT NUTRIENT DEPTH PROFILE

SITE 2

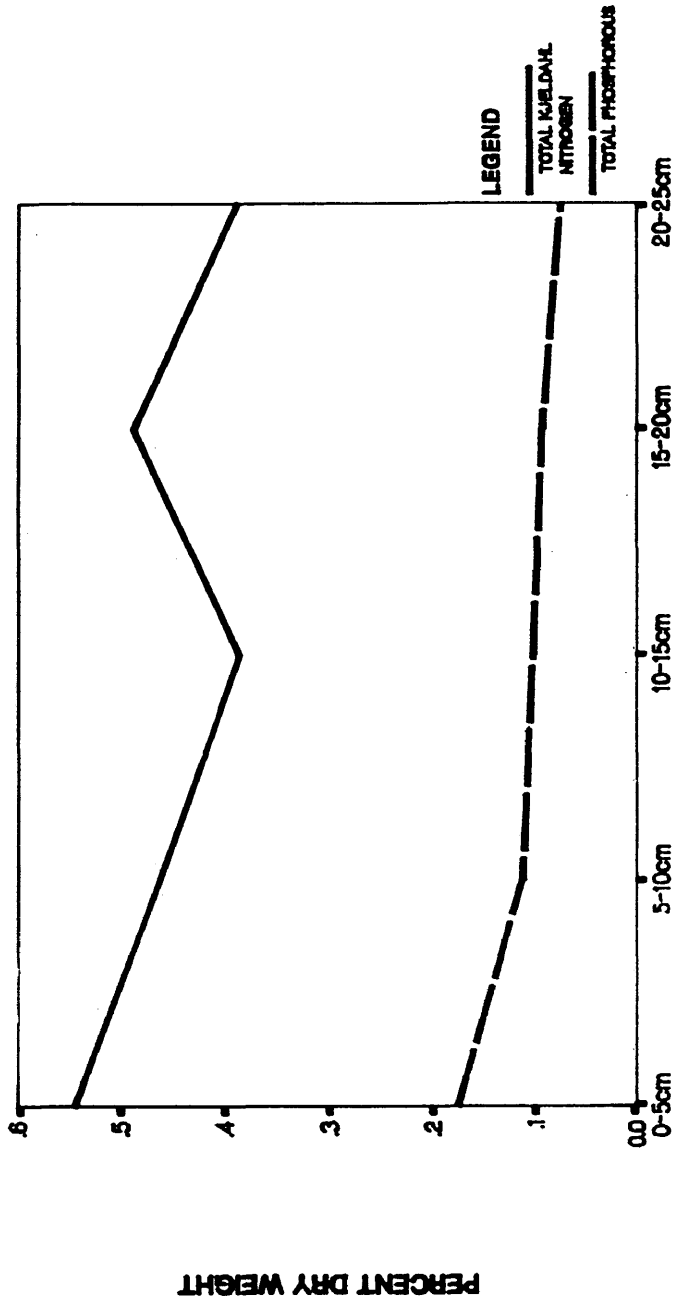


DEPTH

5-18-88

SEDIMENT NUTRIENT DEPTH PROFILE

SITE 2

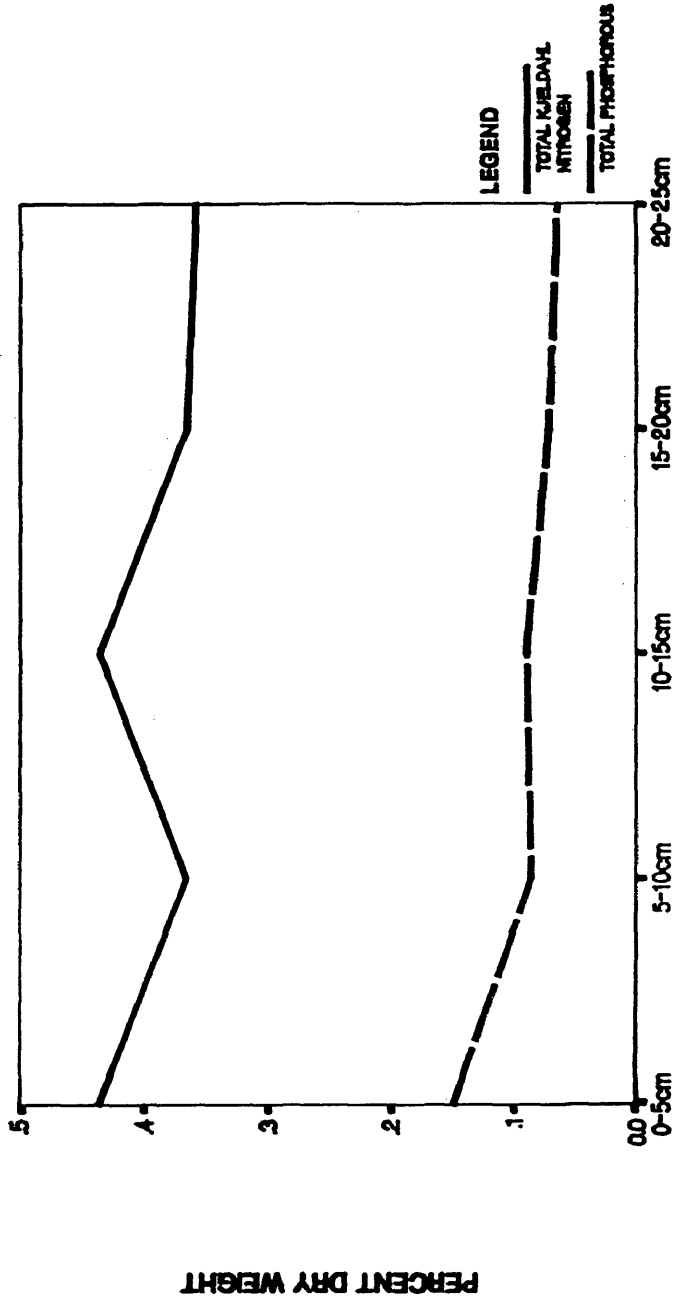


DEPTH

9-5-88

SEDIMENT NUTRIENT DEPTH PROFILE

SITE 2



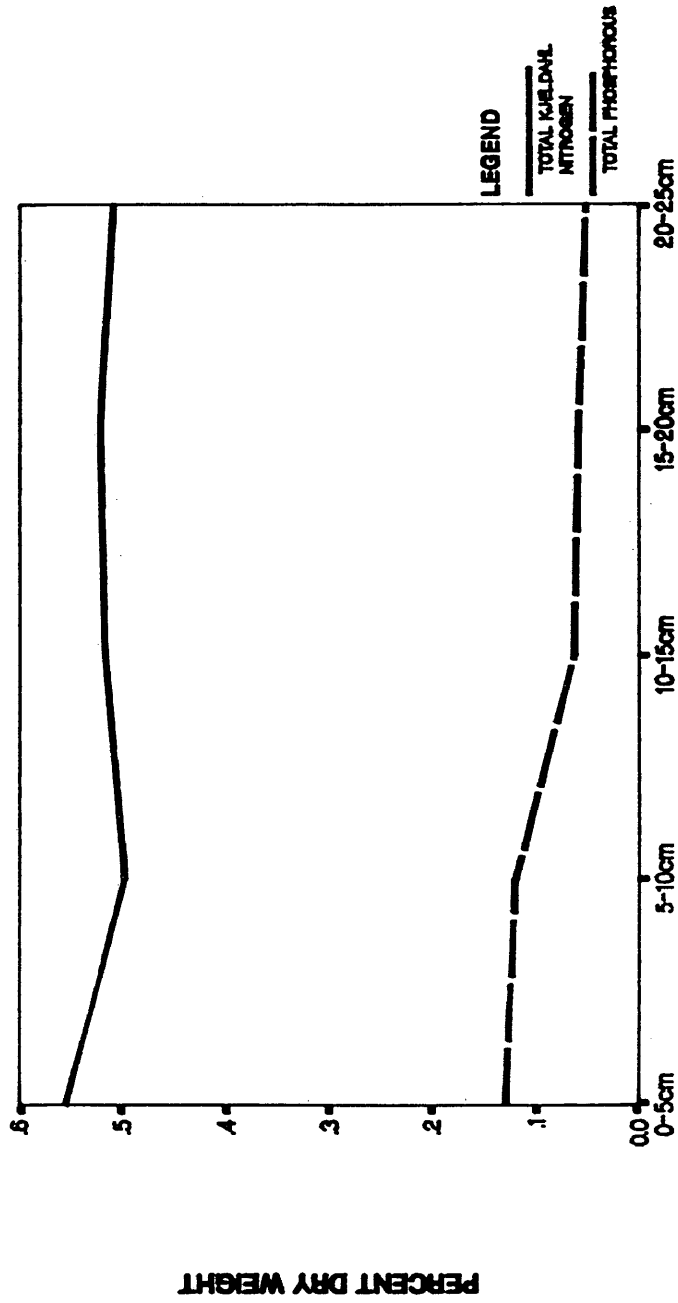
DEPTH

12-6-66

Figure 12. Sediment core TKN and TP, site 3.
a.) 18 Feb.
b.) 18 May
c.) 5 Sept.
d.) 6 Dec.

SEDIMENT NUTRIENT DEPTH PROFILE

SITE 3

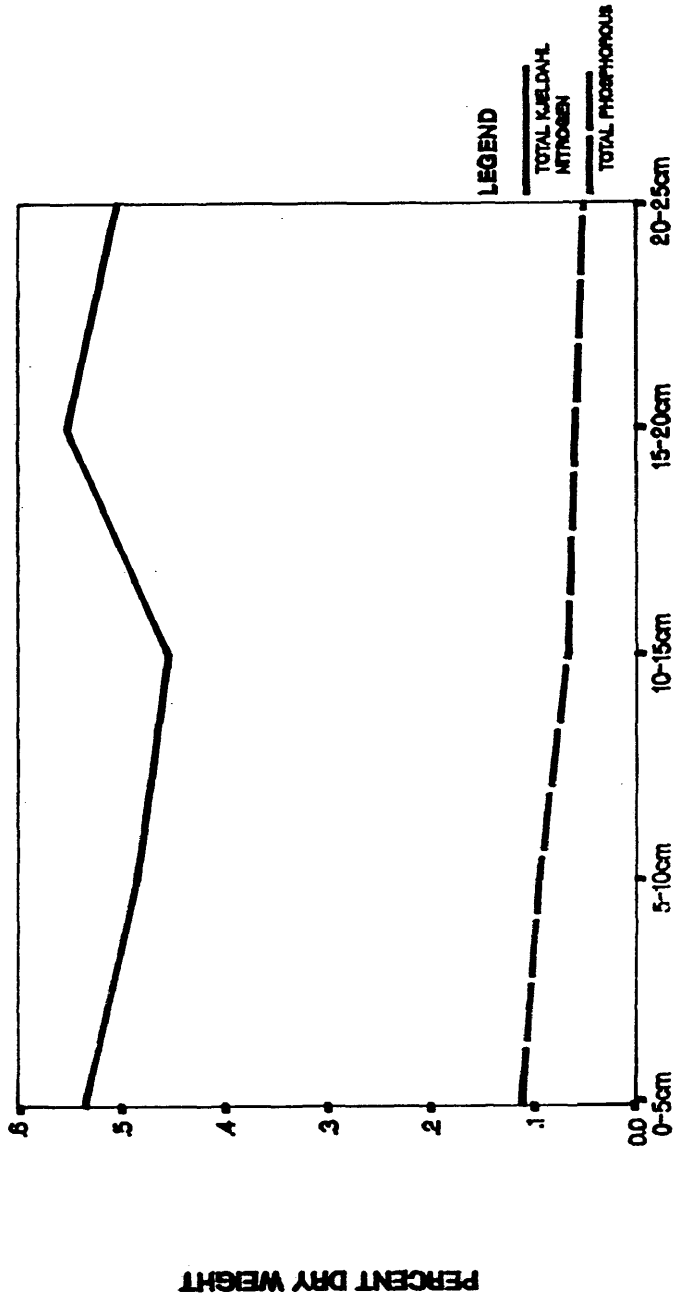


DEPTH

2-18-86

SEDIMENT NUTRIENT DEPTH PROFILE

SITE 3

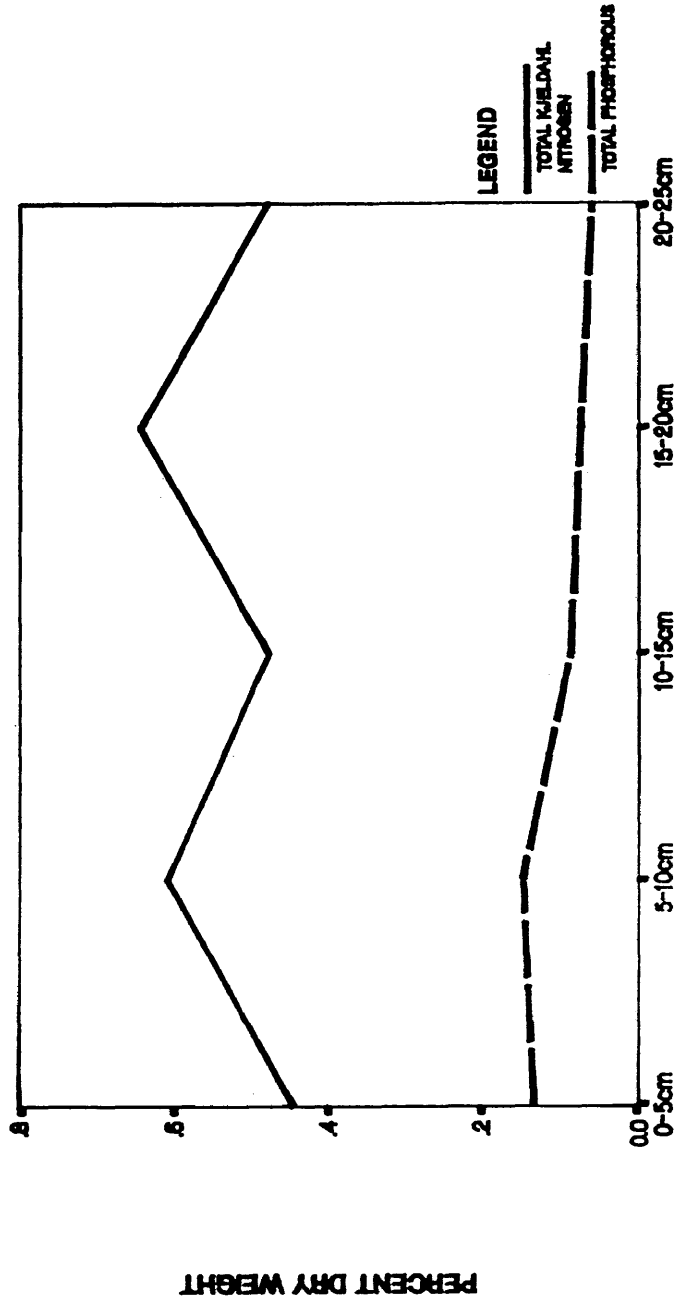


DEPTH

5-10-66

SEDIMENT NUTRIENT DEPTH PROFILE

SITE 3

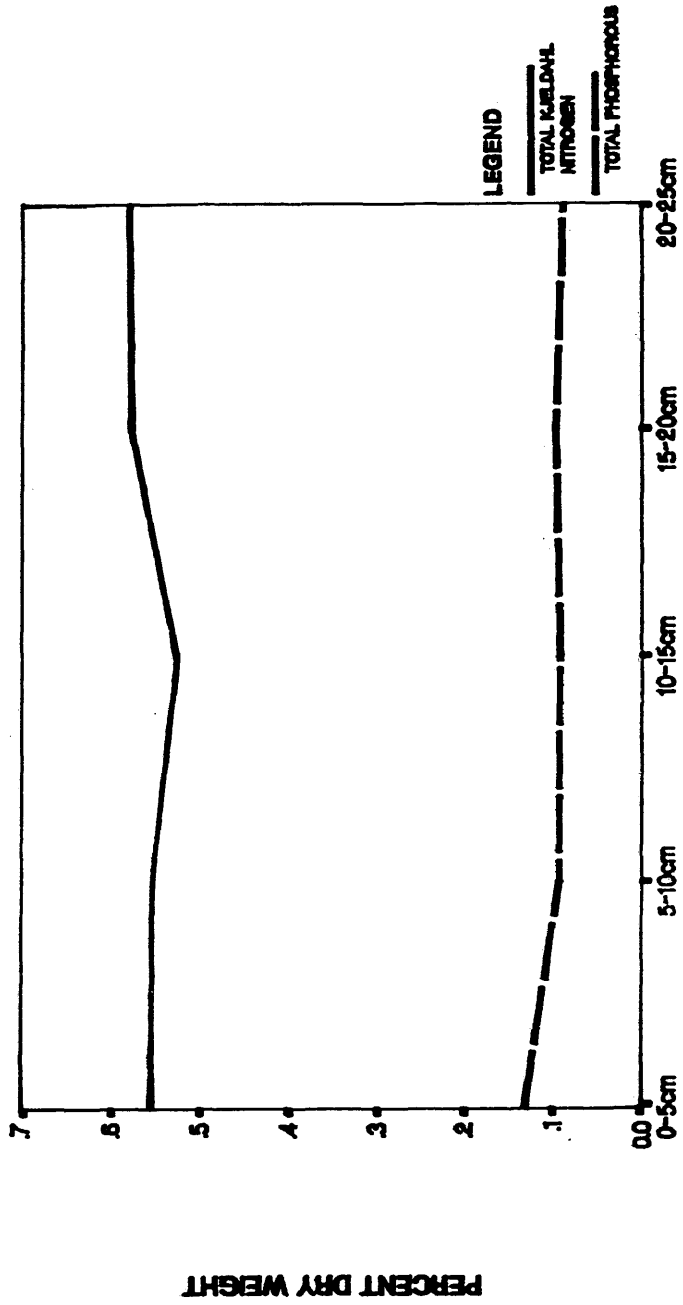


DEPTH

9-5-88

SEDIMENT NUTRIENT DEPTH PROFILE

SITE 3



DEPTH

12-6-66

Discussion

Determination of an accretion/erosion rate from stake observations is influenced greatly by the timing of the measurements. Although the study's final surface elevations showed minor erosion across the transect, a reading after exactly a year would show as much as 12cm accumulation at site 1. The large accretion may be a seasonal phenomenon. Most deposition occurred in the summer as a result of plants trapping the sediment and slowing the water velocity which allowed suspended particles to settle out. Richard (1978) found a similar pattern in the salt marshes in Flax Pond, Long Island. During the growing season, mudflats and areas of pioneer Spartina growth showed marked accretion followed by winter erosion. Established Spartina areas showed few elevational changes, much like the S. cynosuroides (site 3) area in Sweet Hall. Richard (1978) and Harrison and Bloom (1977) attributed accretional differences in salt marshes to the amount of sediment supplied by their respective tidal prisms. This would seem to be the case in Sweet Hall Marsh, site 1 having significantly greater deposition than either sites 2 or 3, corresponding to a greater tidal prism and inundation time.

Richard (1978) also found short-term accretion rates exceeding long-term rates at Flax Pond. Although autocompaction of the sediments might account for some of this difference, Richard felt the discrepancy between rates was a function of winter erosion in an individual year.

Sweet Hall Marsh also shows differing long and short-term rates. Based on historical data (aerial photographs; Doumlele, 1981), the distribution of plant populations at Sweet Hall Marsh has remained fairly constant over the last forty years. A sinking or subsiding marsh would be expected to experience greater inundation, both in frequency and duration, which would alter the composition of the vegetative community due to each species particular hydrologic constraints. As a subsiding marsh is increasingly flooded, dominant vegetation would change from high marsh to low marsh species. In addition, increased flooding would be accompanied by higher salinities as the salt wedge migrates upstream and would be reflected in marsh vegetation by a change from freshwater species to more salt tolerant species. If, however, sea level were to rise too quickly, the marsh would be flooded completely. Because of the relative stability of the plant populations in Sweet Hall Marsh (C. Hershner and J. Perry, unpubl. data), the marsh appears to be accreting at approximately the same rate as sea level rise (at least 3.6mm^{-1}). However, this study showed no net accretion at any site and suggests that the marsh is eroding.

Holdahl and Morrison (1974) examined subsidence rates on the East Coast during the period from roughly 1950-1973. In the area of Sweet Hall, much of the subsidence is a result of local groundwater withdrawal that has increased over the last decade and may have accelerated the subsidence rate. This may lead to a build up of stress on the marsh vegetation which we see responding now through changes in plant population distributions. Stevenson et al. (1986) reported on the recent inability of marshes of the Chesapeake Bay region to accrete

sediment at the same rate as increasingly rapid sea level rise. Because this study lasted 14 months, it is impossible to determine if the marsh erosion is a new trend or merely small scale "noise" in a long-term trend of accretion.

The results from the dyed sediment plugs reflected not only net changes in elevational, but also showed what was probably the greatest extent of erosion at each site. When recovered, the plugs were clearly delineated in the extruded cores. The upper horizons of the dyed sections showed no signs of bioturbation or leaching, and therefore the discrepancies between the observed surface readings and the remains of the dyed plugs may indicate a short-lived period of substantial erosion followed by redeposition. This suggests that a great deal of material is being moved through the system. Although unrelated to the net accretion/erosion rate, erosion and resuspension underscore the dynamic nature of the marsh and are important when examining sediment and nutrient fluxes to and from the marsh.

Throughout the study, the pattern of gross deposition in the traps bore little relationship to the observed elevational changes of the marsh surface. The temporal differences between periods of high gross deposition and periods of accretion, particularly in May and August, indicate a great deal of the sediments may be resuspended. Resuspension plays an important role in sedimentation. As sediments accrete and are submerged, they may become anoxic and eventually they are buried beneath the biologically active zone. Resuspension keeps the sediments in contact with the oxygenated water and the marsh biota, preventing them from being "lost" to the system through burial. Further evidence for resuspension was provided by short-term glitter

studies. They showed redeposited glitter present in the area of placement, both in collectors and on the marsh surface, even after three tidal cycles. Kraeuter and Wetzel (1986) working on mudflats in Gates Bay on the Eastern Shore estimated suspended sediment deposition on the order of $20-25 \text{ kg m}^{-2} \text{ y}^{-1}$, most of which they believe to be locally resuspended sediments. Winter observations may be conservative due to ice formation on the sediment traps and the marsh surface. Because ice formed around the base of the plants and was well anchored, it was not displaced by the flood tide. It is unclear what effect ice cover has on sediment resuspension or marsh sedimentation. An ice sheet may form a barrier between the marsh surface and the flood tide protecting the marsh from erosion, but also preventing any deposition. No deposition was found on ice sheets during this study.

The pattern of nutrient input through sedimentation also indicated that the marsh was a source for part of the deposited material. The organic content of the trapped sediments generally was higher in winter and spring. Much of the organic matter probably was dead plant material from the previous growing season, similar to the pattern found by Kraeuter and Wetzel (1986). The low winter values of organic matter at site 1 were most likely a result of ice caused erosion of recently deposited macro-detritus. Ice scour has been found to account for winter erosion particularly in mudflats (Anderson, 1983; Richard, 1978). Richard (1978) observed established Spartina stands underlain by peat were scarcely affected by ice scour; this would be consistent with the higher organic values observed at site 3.

During most of the study, the organic fraction of the trapped sediment was highest at site 3 and lowest at site 1. However, the

pattern was reversed on 2 sampling dates, 26 June and 5 Sept., corresponding to periods of low gross deposition at sites 1 and 3. Kraueter and Wetzel (1986) found a similar pattern of deposition inversely correlated with organic matter. The 26 June incident may be a result of the peak P. virginica community standing crop (Doumlele, 1981) at site 1 filtering macro-detritus from the flood tide before it can reach site 3. Wohlgemuth (per. comm.) found that the P. virginica community turns over quite rapidly at this time, which also may account for high organic values at sites 1 and 2. By August, however, much of this community has died off (Doumlele, 1981) and dead plant material from this die-off might account for the high organic values seen in September.

The TKN values of trapped sediment were generally lower than those found by DeLaune et al. (1981). TKN concentrations did show a seasonal pattern, 18 Feb. samples having significantly higher values than 18 May, 5 Sept., and 6 Dec. corresponding to high organic deposition. Although one would expect to find high TKN values corresponding to high organics, trapped sediments at site 1 generally showed the highest TKN concentrations in spite of low organic content. Odum et al. (1984) note that broadleaved annuals (eg. sites 1 and 2) have higher nitrogen concentrations in their tissues than those of perennial grasses (e.g. site 3). The pattern of TKN concentrations from the sediment traps may reflect detrital differences produced by the plant communities at each site. If this is the case, it suggests that the trapped organic matter, particularly at higher elevations, originates largely within the marsh.

The TP content of the trapped sediments was greater than that found by DeLaune et al. (1981), but generally was similar to TP content of the sediment cores. The significantly ($p=.0015$) lower TP concentrations at site 3 (vs. sites 1 or 2) may result from enhanced phosphorous binding to sediments which have lower organic content and richer P-binding clay minerals usually found in traps at the latter sites.

Using the accretion rate and trap data from this study, one can estimate nutrient input to the marsh via sedimentation by multiplying the percent TKN, TP, and C of the deposited sediments by the sediment mass, and then multiplying by an accretion rate. To compare estimates based on short-term and long-term rate, four accumulation rates were chosen. One was based on gross deposition, one on a yearly scale, another on the final marsh surface elevations, and the last using the long-term sea level rise rates (Table 5). Depending on the accretion rate chosen, inputs can vary by orders of magnitude. DeLaune et al. (1981) found nitrogen and phosphorous were introduced to a Louisiana streamside salt marsh at rates of $23\text{g m}^{-2}\text{y}^{-1}$ and $2.3\text{g m}^{-2}\text{y}^{-1}$ respectively, and are closest to the estimates for site 2 and 3 based on accretion rates of 7 Jan. 1987. Pomeroy and Wiegert (1981) also found similar phosphorous accumulation rates of $3.2\text{g m}^{-2}\text{y}^{-1}$ on Sapelo Island, Georgia. Using sediment traps similar to those used in this study, Krauter and Wetzel (1986) measured organic input to a tidal flat on the Eastern Shore at approximately $1.4\text{g m}^{-2}\text{y}^{-1}$. This again falls between the estimates of sites 2 and 3 based on 1 Jan. 1987 accretion rates. It appears the annual accretion rates of sites 2 and

Table 5. Input through sedimentation.

	Site	Gross deposition	Accretion rate 3/27/87	Accretion rate 1/7/87	Historical rate (3.6mm/y)
Organic Matter	1	420.48	0.00	5.62	0.17
	2	124.10	-0.46	1.57	0.21
	3	104.39	-0.10	0.47	0.19
TKN	1	8.94	0.00	0.12	$3.53 * 10^{-3}$
	2	1.80	$-6.69 * 10^{-3}$	0.02	$3.01 * 10^{-3}$
	3	1.33	$-1.33 * 10^{-3}$	$6.00 * 10^{-3}$	$2.39 * 10^{-3}$
TP	1	3.15	0.00	0.04	$1.26 * 10^{-3}$
	2	0.19	$-6.92 * 10^{-4}$	$2.34 * 10^{-3}$	$3.11 * 10^{-4}$
	3	0.14	$-1.46 * 10^{-4}$	$6.39 * 10^{-4}$	$2.56 * 10^{-4}$

NOTE: all measurements are in $kg\ m^{-2}\ y^{-1}$.

3 are most like those reported in other salt marsh studies. Unfortunately, there are no comparable data available for other tidal, freshwater marshes.

The variation between nutrient input based on different accretion rates underscores the problem in obtaining a reliable sediment-nutrient flux estimate. Gross deposition obviously overestimates input because it fails to account for resuspension. The historical accretion rate is influenced by sediment compaction below the marsh surface and may yield erroneous deposition rates. Although accumulation rates of 7 Jan. 1987 seem to agree most closely with other studies, net erosion based on 17 March rates would indicate export of nitrogen, phosphorous, and carbon from the marsh and may be more representative of eroding marshes of the Chesapeake Bay, as mentioned by Stevenson et al. (1986).

The sediment nutrient profiles did not decrease consistently with depth as expected. The organic content at each site was homogeneous over the length of the cores, unlike the findings of DeLaune et al. (1981) in Louisiana. The uniform organic content may be due to biological reworking of the soil by benthic and marsh fauna. The organic fraction of the sediment cores increased from site 1 to site 3, and may reflect increased belowground biomass of their respective communities. Although broadleaved annuals have lower root:shoot ratios than perennial grasses (Garofalo, 1980), their productivity is so much higher that they would show larger belowground biomass values than annuals. 18 May values of sediment organics showed a marked increase at each site. This might be a result of peak root/rhizome growth. However, the organic content returned to

approximately 15-20 percent by the next sampling date, and it is hard to conceive of such a large portion of organics being so rapidly decomposed. No other studies report such findings, and therefore the organic values of 18 May remain unexplained.

The TKN values of the sediment cores were comparable, but a bit lower than similar studies. There were no significant seasonal differences in TKN values, much the same as the findings of other studies (Haines et al., 1977; Bowden, 1984). However, unlike Haines et al. (1977), low marsh TKN values were significantly lower than high marsh values, and may be the result of tidal flushing at site 1. Similar to the findings of Haines et al. (1977) TKN decreased over depth with the exception of an increase of TKN in the 15-20cm section. This increase may be due to a root horizon. This pattern contrasts with the findings of DeLaune et al. (1981) who reported a positive correlation between the organic fraction of the sediments and their TKN concentrations.

Total phosphorous core values consistently show decreasing vertical profiles which is in keeping with other studies (DeLaune et al., 1981; Whitney et al., 1981; Bowden, 1982). A number of mechanisms may account for these types of profiles. Whitney et al. (1981) have suggested this may be a result of dissolved phosphorous in the pore water being pushed out of the soil during compaction and may be true, in part, at Sweet Hall where percent water decreased significantly ($p < .0001$) with depth. DeLaune et al. (1981) believe the phosphorous decrease is due to the uptake of phosphorous by roots and rhizomes. Evidence for this can be found in this study in the seasonal pattern of TP values which were significantly lower on 18 May and 5 Sept. during

the growing season, and which dropped radically in the root zone. Comparing phosphorous and nitrogen profiles, there is no increase in nitrogen/phosphorous ratios with depth, as was seen by Bowden (1982) and DeLaune et al. (1981). Rather the TKN/TP ratios seemed to be influenced more by site differences than depth, and may be a consequence of their respective plant communities.

Nutrient loss from the marsh through burial was estimated using sediment nutrient concentrations from the 20-25cm core sections and the historical accretion rate to account for compaction (Table 6). When this is compared to sediment nutrient input (also using historical accretion), sedimentation makes up for a large share of the nutrient loss through burial of N, P, and C.

Table 6. Estimates of nutrient loss through burial*

<u>Site</u>	<u>TKN</u>	<u>TP</u>	<u>Organic matter</u>
1	$4.63 * 10^{-3}$	$1.32 * 10^{-3}$	0.33
2	$5.26 * 10^{-3}$	$8.64 * 10^{-4}$	0.35
3	$4.31 * 10^{-3}$	$4.97 * 10^{-4}$	0.24

Note: all measurements in $\text{kg m}^{-2} \text{y}^{-1}$

* using historical accretion rate of 3.6mm y^{-1}

Conclusion

This study found sedimentation to be important in the introduction of nutrients and organic matter to the marsh. Sedimentation processes also played a large role in the redistribution of sediments within the marsh. Although gross deposition in Sweet Hall Marsh was large, the net elevation change at Sweet Hall showed minor erosion of the marsh. Average gross deposition for the sites ranged from 0.13-0.72 g cm⁻²d⁻¹. Great daily variability of marsh surface elevations makes determination of an 'annual' accretion rate difficult. At the end of the study, the three sampling sites showed erosion of 0.0cm, 0.8cm, and 0.2cm. Based on this, the marsh exports nitrogen, phosphorous, and carbon to the river as opposed to acting as a nutrient "sink." A long-term (3-7 years) study could help clarify this flux.

Nutrient and organic matter input via sedimentation varied greatly among sites and seasons. Much of this input appeared to be locally redeposited sediments. Average TKN and TP concentrations associated with the incoming sediments were higher at the low marsh site and ranged from 0.28-0.34% dry weight and 0.09-0.10% dry weight respectively. On a seasonal scale, sediment deposition in the spring and summer delivers large quantities of nutrients and organic matter to the marsh when the plants are rapidly growing. Export of

the sediments/nutrients the following winter by ice scour and storm erosion generally is restricted to the less vegetated sections of the marsh. This lag time allows nutrients associated with the sediments to be incorporated into the marsh through microbial mineralization and plant uptake. Accretion rates based on an annual, average accretion rate, (Armentano and Woodwell, 1977; Stumpf, 1981; DeLaune et al., 1981) can underestimate the importance of sedimentary inputs of nutrients because of its seasonal nature. This seasonality of nutrient input should be considered in the nutrient flux studies and the ecology of this type of marsh.

The magnitude of the loss of nutrients and organic matter from the marsh through burial ranged from $0.24-0.33 \text{ kg m}^{-2} \text{ y}^{-1}$ (organic matter), $4.31 \cdot 10^{-3}-5.26 \cdot 10^{-3} \text{ kg m}^{-2} \text{ y}^{-1}$ (TKN), and $4.97 \cdot 10^{-4}-1.32 \cdot 10^{-3} \text{ kg m}^{-2} \text{ y}^{-1}$ (TP) and was nearly equivalent to the nutrient input from sedimentation based on long-term accretion rates.

As the sediment is buried, organic nitrogen and phosphorous concentrations decrease with depth as the nutrients are taken up by the biota. Sweet Hall Marsh nutrient concentrations showed no preferential uptake of nitrogen over phosphorous. The largest effects were seen among the sites and this may be due to plant zonation. When nutrient loss from the marsh through sedimentation and burial based on long-term accretion rates is compared to sediment and nutrient input estimates using historical accretion, the magnitude of nutrient input through sedimentation is almost equal to that of the loss the nutrients through burial. The additional nutrients provided by the seasonal deposition "pulse" can be utilized by the vegetation during the growing season. Much of this deposited material may be recycled sediments originating

within the marsh, a pattern also observed in salt marshes by Haines et al. (1977) and DeLaune et al. (1981).

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