Investigation of Salinity and Nutrient Characteristics of Two Groundwater Based Flow Systems on Virginia's Eastern Shore.

by

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ABSTRACT

The freshwater-saltwater transition zone was investigated in an unconfined aquifer on Virginia's Eastern Shore. The Steelman's Landing study site consisted of a well transect which began in an 800 meter wide upland agricultural field, and proceeded seaward through a 300 meter wide mesic forest, 300 meter wide saltmarsh, and 550 meters offshore into Magothy Bay. Wells in the surficial, Columbia aquifer were screened over 30 centimeters at depths of 3.05, 9.14, and 15.25 meters below the surface. Most monitoring sites consisted of clusters of multiple wells which were periodically sampled for inorganic nutrients and salinity.

In the saltmarsh portion of the study site, salinity of monitoring well samples indicated the presence of two horizontal flow systems. The deeper flow system contained freshwater flowing seaward from upland areas. The shallower system contained saline water recharged by the tides and concentrated by evaporation. Salinity measurements and positive vertical (0.019-0.046 meters/meter) and horizontal (0.001-0.005 m/m) hydraulic gradients of wells located across the marsh suggested movement of freshwater offshore which was confirmed by the direct measurement of submarine groundwater discharge (SGWD) using seepage meters. Upland wells contained high nitrate freshwater (>600μmol/l NO_3^-, <1.0‰ salinity), while shallow (3.05m) wells located from the marsh-forest interface across the saltmarsh to Magothy Bay contained

increasingly saline water and reduced nitrate levels (<1μmol/l NO_3^-, 4-21‰ salinity). Deeper (9.14m) wells across the study site from the agricultural field seaward 420 meters offshore, contained fresh water (<1.0‰). A deep (9.14m) well located 550 meters offshore contained water of nearly equal salinity to ambient water in Magothy Bay (30-32‰). This represented a point on the saline side of the transition zone. In order to more completely identify and account for movement of nutrients in groundwater across the study site from upland agricultural fields to Magothy Bay, the second portion of the study consisted of an investigation of nutrient movement through a small tidal creek located adjacent to the Steelman's Landing study site. Creek water had a higher velocity and shorter residence time in comparison to groundwater. Exercises describing nutrient movement were conducted in February and May, 1993 in Wall's Landing Creek. A seasonal component of nutrient reduction was investigated as indicated by ambient creek samples, and bulk flux of nutrients across the sediment-water interface using light and dark benthic dome chambers. Nitrate flux measurements for the February and May sampling exercises were approximately 14,500 μmol/sec (17.6kg/day as N) and 5400 μmol/sec (6.5kg/day as N), respectively. The primary mechanism of nitrate reduction on reaching the creek channel was physical dilution by seawater.

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I. General Introduction and Study Objectives

Groundwater has recently been recognized as a major source of nutrients entering the Chesapeake Bay. Nutrients enter groundwater at upland sites and flow seaward to offshore discharge points. Groundwater discharge zones are controlled by interactions between fresh groundwater and denser saline groundwater and site-specific geology. Groundwater discharge of solutes may influence the productivity of marshes and pelagic environments.

Interactions between fresh and saline groundwater form a transition zone or mixing zone of intermediate salinity. Transition zones in confined aquifers are well documented (Cooper et al. 1964). Unconfined aquifer transition zones are less well known. Groundwater flow models developed for the Eastern Shore represented the freshwater-saltwater transition zone as a sharp interface (Richardson 1992). Richardson (1992) also reported that there were no offshore data for the Eastern Shore, and, therefore, the actual position of the freshwater-saltwater interface and width of the transition zone was unknown. This flow model treated freshwater and saltwater as immiscible liquids. Thus, mixing of fresh and saline groundwater through hydrodynamic dispersion was neglected. The location of the transition zone and associated discharge region is important for controlling groundwater withdrawals. Overdrawing lowers the head of freshwater which subjects an aquifer to entry of saltwater. Management of nutrient loads in groundwater is dependent on location of the transition zone. Location of freshwater discharge may vary between sites. When considering use of marshlands for nutrient reduction, it must be known whether the nutrients will come in contact with the marsh. Flow patterns of groundwater are influenced by the location of the freshwater-saltwater transition zone.

The objective of this study was to evaluate two groundwater inputs to the marine system. At the Steelman's Landing study site groundwater entered Magothy Bay as SGWD or as baseflow from a groundwater derived creek which originated in a low lying upland area adjacent to an agricultural field. The specific points covered include:

1. Location of the freshwater-saltwater transition zone using salinity characteristics of groundwater.

2. Investigation of the relationship between groundwater flowing beneath the study site and the biologically active saltmarsh above.

3. Investigation of nutrient movement in a groundwater derived creek.

II. Study Site Description

2.1 Site Description

The Steelman's Landing study site was located in Northampton County on Virginia's Eastern Shore, approximately 0.4km (0.25 miles) north of Townsend (Figure 2.1). The site consisted of an agricultural field extending from U.S. Route 13, which generally forms the boundary of highest elevation down the spine of the Delmarva Peninsula, seaward to an adjacent mesic forest approximately 300 meters wide which abutts a tidal wetland 300 meters in width, and approximately 550 meters of intertidal zone of Magothy Bay. Magothy Bay is part of a well flushed lagoon system adjacent to the Atlantic Ocean with a mean tide range of 1.07m (3.5 feet) and spring tide range of 1.28m (4.2 feet). (National Oceanic and Atmospheric Administration 1993). Average salinity of Magothy Bay was 30-32‰.

2.2 Site Selection

The Steelman's Landing study site was chosen as the focal point for the investigation of the freshwater-saltwater transition zone because of it's proximity to the Newman's field study site where previous groundwater analyses were conducted by Reay et al. (1991), as well as the United States Geological Survey's NAWQA program. The Newman's field study site consisted of a well transect extending from the field-forest interface to a point 152.4 meters (500 feet) into the forested buffer zone. Wells screened at the water table were located at 15.24m, 30.38m, 45.72m, 60.76m, 91.44m and 152.4m into the forest. Reay (1991) suggested that nitrate in fresh groundwater in the shallow water table aquifer entering the forested buffer zone was reduced from concentrations of approximately 708μmol/l to background levels (<25μmol/l) within a horizontal distance of approximately 60 meters (Figure 2.2). This loss of nitrate from the system was attributed to uptake by vegetation, physical dilution and soil microbial respiration including denitrification. Smedley (1993) reported that groundwater nitrate levels beneath the forested region at a depth of 3.0 meters had increased to approximately 250μmol/l, suggesting the presence of a plume of high nitrate groundwater migrating horizontally and vertically beneath the forest. Smedley (1993) also identified denitrification potentials in the shallow water table of the forest as nitrate limited, but limited by carbon as depth increased.

2.3 Floristic Survey

Canopy and shrub in the forest species importance values were calculated using a modified point centered quarter method (Mueller-Dombois and Ellenberg, 1974) along transects 10 meters south of, and parallel to, monitoring well transects extending from the field-forest interface inward to a horizontal distance of 91.44m. A floristic survey (as reported by Reay, et al. 1991) identified the forest as mature mesic, coastal plain communities of either coniferous or deciduous dominance. Dominant tree species through the forested buffer zone were *Liquidamber styraciflua* L. (Sweet gum), *Nyssa sylvatica* Marshall (Black gum), *Pinus taeda* L. (Loblolly pine), and *Acer rubrum* L. (Red maple). The understory was dominated by *Ilex opaca* Aiton (Holly).

Dominant herbaceous species included *Rhus radicans* L. (Poison ivy), *Lonicera japonica* Thunberg (Japanese honey suckle), *Woodwardia areolata* (L.) Moore (Netted chain fern) *Campsis radicans* (L.) Seeman (Trumpet vine), and *Smilax rotundifolia* L. (Green briar). Herbaceous layer raw cover averaged less than forty percent. (R. Adkinson as cited by Reay et al. 1991)

Blankenship et al. (1991) reported descriptions of vegetation of marsh portion of the study area. Table 2.1 shows the wetland type, and species, subcanopy, and groundcover with distance approaching Magothy Bay from the marsh-forest interface.

2.4 Geology and Soils

The freshwater-saltwater transition zone in the Atlantic Coastal Plain, which extends from North Carolina to New Jersey, is shallowest at it's southernmost and deepens northward to Maryland and New Jersey. It deepens inland except in New Jersey & Maryland where it is deepest at the coast.

The Virginia Coastal Plain comprises the geological formation of the study area. Specifically, the sediments dealt with were of quaternary origin being the last deposited of the formations making up the coastal plain province (Meng and Harsh 1988). These formations reflected fluvial deposits and sediments left by Pleistocene sea level fluctuations.

The Columbia aquifer is defined by the predominantly sandy superficial deposits overlying the Yorktown confining unit. The Columbia aquifer is made up primarily of Holocene- (0.0-0.01 million years) and Pleistocene- (0.01-1.8 million years) age sediments that were deposited as channel fill and fluvial-marine terraces that were the result of Pleistocene marine transgressions (Meng and Harsh 1988). The aquifer is composed of interbedded gravel, sand, silt, and clay and is generally unconfined throughout the study area. However, clay lenses within it may produce local confined or semi-confined conditions. The aquifer is a major source of recharge to the underlying confined flow system and supplies water to rural and domestic users. These sediments also include sandy Pliocene (late tertiary, 1.8-5.0 million years) sediments that lie above the clay deposits of the Yorktown confining unit. The aquifer correlates with the surficial aquifers in Maryland and North Carolina (Meng and Harsh 1988). The aquifer is highly variable in thickness, but generally thickens eastward, attaining its maximum known thickness along the southeastern coast of the study area. The Pleistocene sediments consist of formations locally known as the Windsor, Charles City, Chuckatuck, Shirley, and Tabb (G.H. Johnson, College of William and Mary, oral communication, as cited by Meng and Harsh 1988). Meng and Harsh (1988) also include the upper Pliocene Chowan River Formation of the Chesapeake Group in the Columbia aquifer description. Each formation is similar in lithology and mode of deposition and generally is characterized by a fining upwards depositional sequence, much like the sediments of the Yorktown-Eastover aquifer. Each is composed of a very coarse gravelly lag deposit that grades up through sands to fine silts and clays. Generally, all land surfaces less than 30.5m above sea level are covered by sediments of the Columbia aquifer. The Columbia aquifer is used primarily for domestic or agricultural water supply, especially throughout the eastern parts of the study area.

The saturated thickness of the Columbia aquifer ranges from about 4.6m near its western extent to about 24.4m in the southeastern part of the study area (Harsh and Laczniak 1990). Spatial variation in the hydraulic properties of the aquifer are not adequately defined by available data.

Figure 2.3 shows the soil types of the Newman's Field and Steelman's Landing study areas as described by Mixon et al.

(1989). The following soil description discussion is based on their study.

The Newman's Field site, the farthest upland portion of the study area, (designated Qnb) is described as Butler's Bluff Member, described as pale-gray to light-yellowish-gray, fine to coarse, crossbedded, pebbly sand and sandy gravel comprising surficial deposits of upland. A diverse molluscan assemblage in the lower part of this unit includes *Marginells, Mulinia, Nassarius, Spisula, Pleuromeris* and *Olivella*, indicating a shallow, nearshore-shelf depositional environment. This unit was deposited as a southward-building complex of spit-platform sands and shallow shoals and may reach 18.3m in thickness. In the subsurface, the unit overlies 42.7m, or more, of pebbly to cobbly sand, clay-silt, and muddy fine-grained sand of the Stumptown Member of the Nassawadox Formation, which fills a late Pleistocene paleochannel of the Susquehanna River system.

Soils in the forest buffer zone (designated Qj) at the Steelman's Landing site are described as Joynes Neck Sand, (upper Pleistocene) comprised of yellowish-grey, fine to coarse sand coarsening downward to gravelly sand and sandy gravel. Cross-lamination in finer-grained sands is accentuated by black, heavy minerals. This unit was deposited in a nearshore-shelf depositional environment and its thickness ranges from 0.0-9.1m.

Soils in the upper marsh (designated Qwa) include the Wachapreague Formation (upper Pleistocene). The coarsening upward sequence includes a lower member of clayey and silty, fine to very fine, gray sand interbedded with clay-silt and an upper member of medium to coarse, gravelly sand. Mollusks, including *Mesodesma arctatum* and *Siliqua costata*, and ostracode assemblages dominated by *Elofsonella concinna* and *Muellerina canadensis* indicate cooling ocean temperatures during deposition of this unit. A pollen assemblage dominated by pine, spruce, birch, and alder suggests cool to cold-temperate conditions in nearby land areas. The unit is a surficial deposit of narrow, arcuate coastal lowland ranging in altitude from sea level, at the eastern border with a Holocene barrier-lagoon complex, to about 4.6m at the toe of the western boundary. Thickness varies between 0.0-12.2m. The Nassawadox Formation (upper Pleistocene) forms surficial sandy and gravelly deposits of narrow, flat upland and adjacent bay-side terrace in Northampton and southernmost Accomack Counties.

Soils of the lower marsh (designated Qm) are comprised of soft mud, medium to dark-gray, and grayish-brown peat. This designation includes sediments of marshes in coastal areas and the Chesapeake Bay and varies in thickness from 0.0-3.0m.

Sediments of the offshore area (designated Qsm) are described as sandy mud and muddy fine sand, light to dark gray. Locally, they contain abundant shell material characterized by *Crassostrea virginica* and *Mercenaria mercenaria*. This designation comprises sediments of shallow bays and tidal flats in areas of coastal lagoons and varies in thickness from 0.0-9.14m.

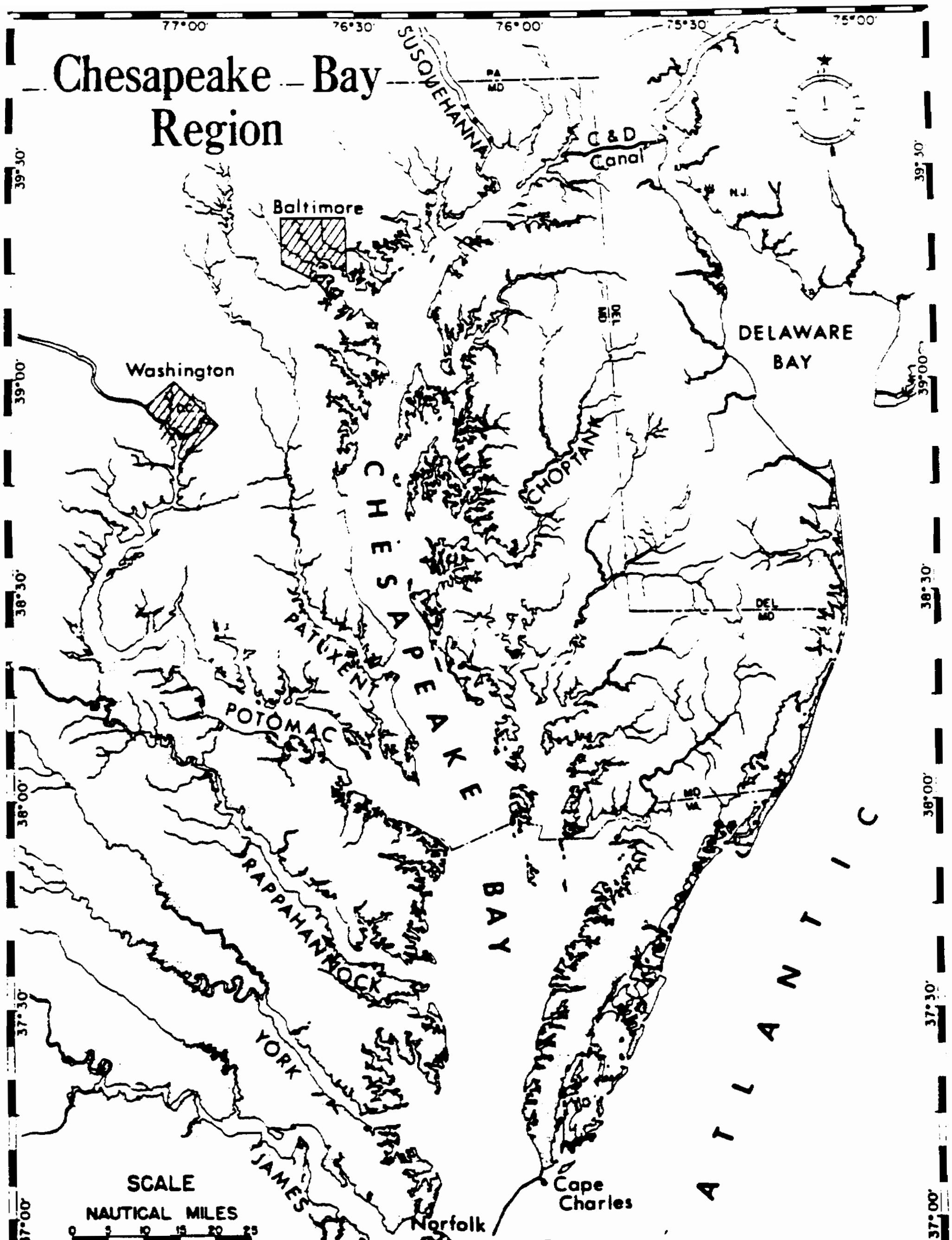

Figure 2.1. The Chesapeake Bay and it's tidal tributaries. Study site located on Virginia's Eastern Shore.

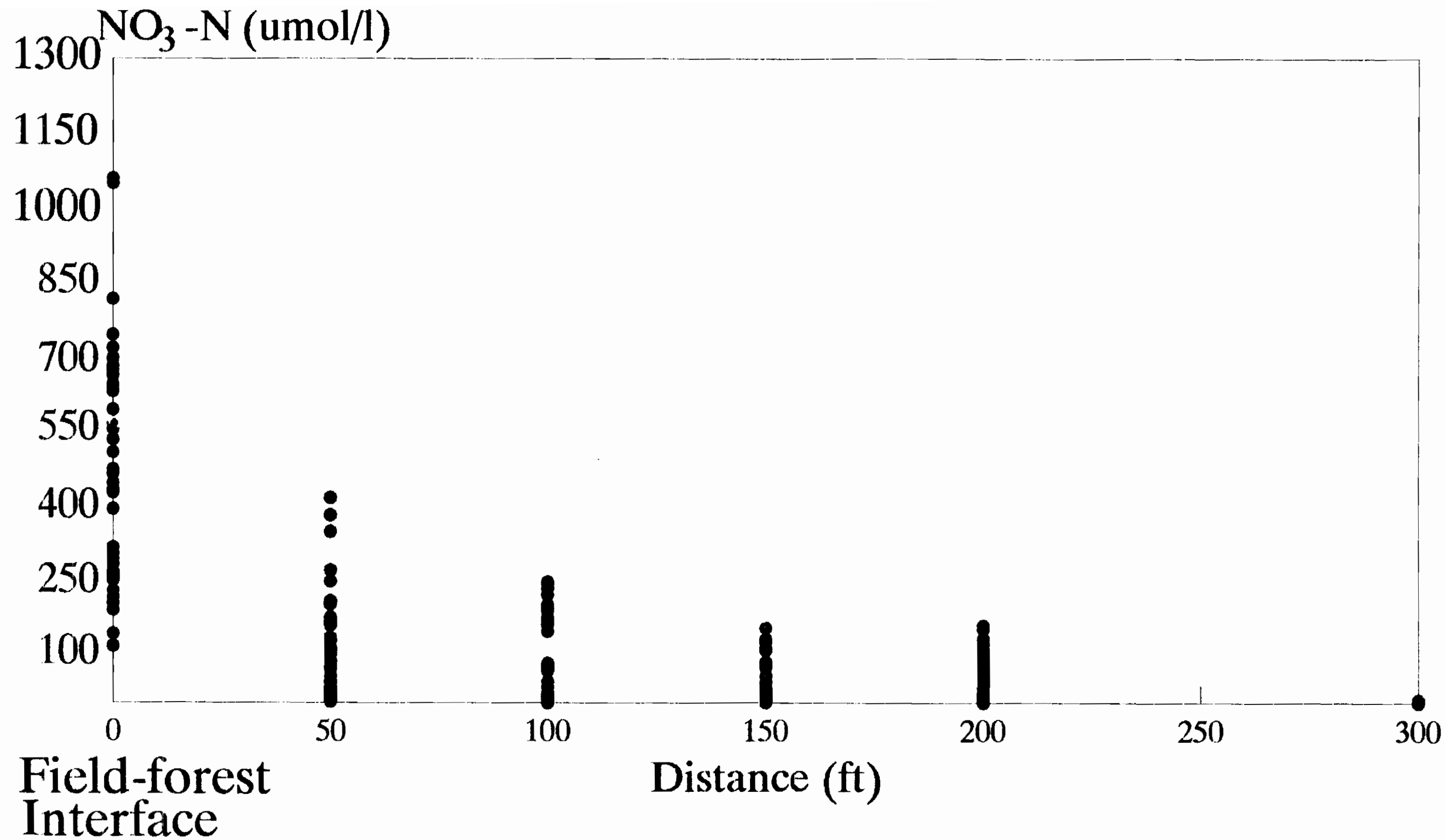

Figure 2.2. Relationship between shallow ground water nitrate concentrations in relation to distance into forest from the agricultural field-forest interface (from Reay et al. 1991).

Table 2.1. Dominant species of plants across saltmarsh at Steelman's Landing Site (from Blankenship et al. 1991).

Location on Marsh	Wetland Type	Subcanopy	Ground cover
0-30m	Scrub-shrub	Iva frutescens marshelder 80%; Baccharis halimifolia groundsel tree 15%; other 5%	Distichlis spicata30%; salt grass Spartina patens30%; salt meadow hay Juncus roemerianus black needlerush 30%; Sertaria geniculata saltmarsh foxtail 10%
30-50m	Scrub-shrub	B. halimifolia 100%	S.patens 75%; D.spicata 25%
50-90m	Emergent, non-persistent	none	S.patens 75%; D.spicata 50%
90-130m	Emergent, non-persistent	none	Salicornia virginica saltwort 100%
130-210m	Emergent persistent	none	S.virginica 50%; Spartina alterniflora saltmarsh cordgrass 50%
210-330m	Emergent persistent	none	S. alterniflora 99.5%; D. spicata 0.5%

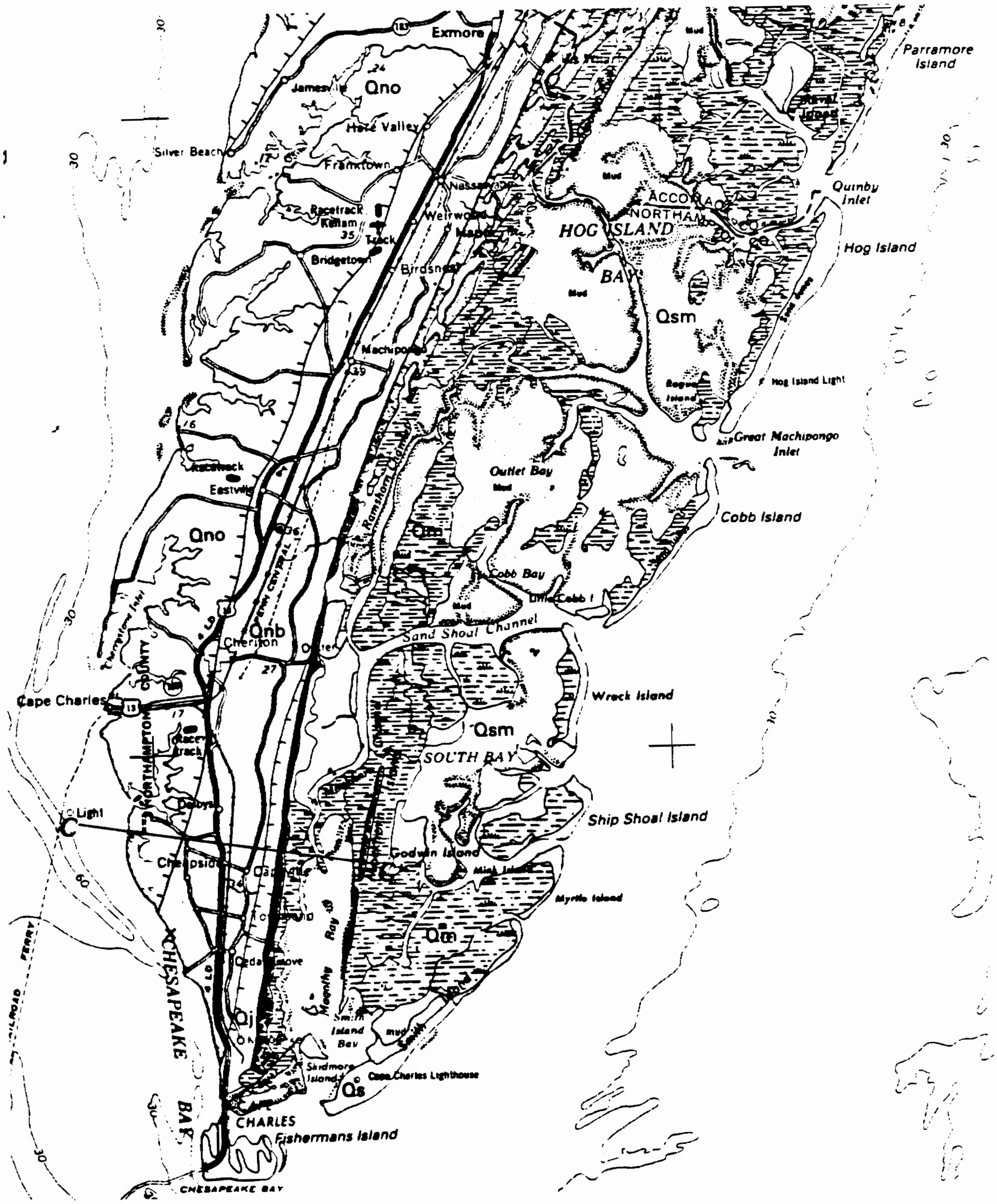

Figure 2.3. Soils map of the Eastern Shore of Virginia and southern Maryland including the Newman's Field and Steelman's Landing study sites (from Mixon et al. 1989).

III. Geohydrologic Framework

3.1 Introduction

3.1.1 Freshwater-Saltwater Transition Zone The specific weight of pure freshwater is 1000kg/m^3 compared to that of saltwater which measures 1025kg/m^3. The density of water in natural aquifer systems ranges from 0.9982 kg/l at 20° C for pure freshwater, to greater than 1.345 kg/l in the Saldo Brine of New Mexico (Reilly and Goodman 1985). The density of average surface seawater ranges from 1.022 to 1.028 kg/l (Chow 1964 cited by Reilly and Goodman 1985). Average seawater contains approximately 34.48‰ total dissolved solids.

Viscosity and density differences exist in areas where freshwater and saline water come in contact. These areas include a landward sloping interface in which the saline water adopts the shape of a wedge in the aquifer floor (Newport 1977). The overlying freshwater decreases in thickness moving seaward while thickness of saltwater in the aquifer decreases landward. Instead of a sharp interface boundary, which infers a rigid line between the two miscible liquids, the interface forms a mixing zone (Figure 3.1). The terms "zone of dispersion" or "transition zone" are more appropriate in describing the continually changing conditions found in coastal areas. These terms indicate that both physical mixing and chemical diffusion contribute to dispersion of the strict boundary. The transition zone can be represented by a sharp interface, but more likely forms a thicker zone, representing a significant portion of the aquifer thickness (Meisler 1989).

Depth of the transition zone is controlled by the natural flow pattern of fresh groundwater. Areas where the saltwater transition zone is relatively shallow coincide with areas of freshwater discharge such as Delaware Bay, lower Chesapeake Bay, Albemarle Sound, and the Cape Fear River. Studies have shown similar relationships between the occurrence of saltwater and the fresh ground-water flow system. Back (1966 as cited by Meisler 1989) stated that the position of deep saltwater is regulated by hydraulic head of freshwater compared to that of underriding saltwater. Upson (1966 as cited by Meisler 1989) concluded that "the circulation pattern of fresh groundwater in general and the location of discharge zones in particular control the locations of saltwater boundaries in coastal regions. Theoretically, equilibrium between freshwater and seawater in a coastal region requires that the hydraulic head of the freshwater be at least high enough to balance the head of saltwater in the vicinity, considering the differences in density." Higher heads maintain the saltwater at deeper depths in recharge areas as compared to lower heads in discharge areas where saltwater appears at lesser depths. The broad freshwater-saltwater transition zone is attributed to mixing of freshwater and saltwater caused by large scale sea level fluctuations, probably during late Tertiary and Quaternary.

In unconsolidated coastal sediments, Cooper (1984, cited by Reilly and Goodman 1985) found denser seawater retaining its integrity from lighter, overlying freshwater. A mixing zone formed between the two as a result of movement of tides, movement of freshwater driven by upland hydraulic heads, diffusion, and convection currents of circulating seawater. At ebb tide, the weight of seawater overtop of the transition zone is less and seaward freshwater movement increases. At high tide, the weight of seawater overcomes that of freshwater and forces the transition zone back toward it's previous position. At this contact zone, some of the saltwater mixes with freshwater and begins to move seaward with the freshwater, causing additional saltwater to enter the mixing zone in a convection pattern of circulation. The brackish water resulting from the mixing is replaced by freshwater flowing from upland areas. Heterogenous, porous sediments can result in various mixing zones caused by circulation differences in the layers of varying permeability.

The Badon Ghyben-Herzberg equation was an early attempt to relate elevation of water table in an unconfined aquifer to the elevation of the interface between the fresh groundwater and saline groundwater. This theory, developed through field measurements, was the first quantitative theory that attempted to explain the interface. It stated that on either side of the sharp interface, water pressure must be equal and the pressure is given by water depth multiplied by the specific weight. The Badon Ghyben-Herzberg equation is as follows: (Freeze and Cherry 1979)

$$z_s = \frac{\rho_f}{\rho_s - \rho_f} \times z_w$$

Where:

z_s = Depth to saltwater

z_w = Water table elevation at that point

ρ_f = Density freshwater (kg/l)

ρ_s = Density saltwater (kg/l)

for ρ_f=1.0 (kg/l) and ρ_s=1.025 (kg/l),

The equation simplifies to:

$$z_s = 40\ z_w$$

This formula represented a gross oversimplification of actual conditions because it assumed that the groundwater head at the water table is equal to that of the freshwater at the interface, implying no vertical head gradient. This suggested that the thickness of the freshwater zone was zero at the shore where the water table elevation is zero. Also, for every 30 centimeters (1') of water table elevation, there exists a 12.2 meter (40') pillow of freshwater above the saltwedge (Figure 3.2).

Bear and Todd (1960 as cited by Meisler et al 1984) reported strong tidal influences on the freshwater-saltwater interface. They concluded that the boundary was not static as predicted by the Ghyben-Herzberg relationship. When no freshwater was removed from the coastal areas, the interface was static and dependent on tide magnitudes (Kohout et al 1964). Kohout et al. (1964) suggested a brackish mixing zone at the base of the sea floor that moved landward and seaward at high and low tide, respectively.

Freshwater flowing seaward from upland areas travels through sediments from higher head toward lower head. This groundwater will continue to flow underground until contacting a barrier or boundary condition, such as that formed by the wedge of saltwater.

The dominant factors influencing movement of the saltwater interface may be groundwater pumping, and tidal oscillation of sea level, hydraulic conductivity of the aquifer, or eustatic sea level changes (Inouchi et al. 1990). This occurs as tide moves in and out, as the force exerted by the saltwater increases as tide rises and decreases as tide falls. The rate of movement of the interface can be influenced by the balance between freshwater and saltwater. These two opposing forces push the zone one way or the other when the force applied by one becomes greater than the other. Recharge of upland freshwater affects the freshwater head and exerts force on the saltwater. Saltwater intrusion occurs when the freshwater head is lowered and the saltwater can overcome the pressure of the freshwater and enter zones previously occupied by freshwater.

In the freshwater lenses of the Pacific Island Tarawa Atolls, Volker et al. (1985) observed that similar circumstances govern the thickness of the transition zone. On ocean atolls and small islands, the land mass rises from the sea and a pillow or lens of freshwater in the porous sediments lies (perched aquifer) on top of the underlying saltwater. These islands are usually lacking in ponds or streams for storage of water so groundwater supplies are important for suiting needs of the inhabitants. This perched freshwater lens seeps freshwater to the ocean, and when withdrawals are made or insufficient recharge occurs, seepage slows. Excessive pumpage lowers the amount of water in the lens, allowing the underlying saltwater to intrude and permanently diminish the capacity of the lens. Between these phases, lies an interface including a mixing zone. Balancing the influence of saltwater while retaining adequate freshwater supplies is necessary to control loss of the freshwater lens to invading saltwater.

3.1.2 Location of Transition Zone in Relation to Sea Level

The present position of the transition zone is not in equilibrium with present sea levels. It represents that of a sea level 15.2-30.5m (50-100′) below present sea level (Meisler et al. 1984). The most recent rise in sea level, over the last 20,000 years, is probably causing the transition zone to move upward and landward toward equilibrium. The non-equilibrated location of the transition zone is representative of a time when the interface was at equilibrium and the freshwater may have discharged at sea level. As the sea level rose, the transition zone, located in the sediment where flow is restricted, was not capable of free exchange, and lagged behind in the movement to the new equilibrium position consistent with the present sea level.

The sea level during the middle Miocene and part of Pliocene was higher than present. During late Tertiary and Quaternary, the sea level was lower than present. Using oxygen isotope data, Shakleton and Opdyke (1973; cited by Meisler et al. 1984) formulated a eustatic sea level curve for the past 130,000 years and correlated the volume of glacial ice with oxygen isotope data from a deep sea core from the Pacific Ocean. Zellmer (1979; as cited by Meisler et al. 1984) recalibrated Shakleton and Opdyke's model and determined the average sea level for the last 900,000 years, approximately 45.7m (150 feet) below present. Prell (1980 as cited by Meisler et al. 1984) estimated the average sea level over early Quaternary (older than 690,000 yrs.) was about 35.1m (115 feet) higher than that of later Quaternary. Figure 3.3, (Zellmer 1979 as cited by Meisler 1984), shows sea level fluctuations for the last 900,000 years.

<u>3.1.3 Saltwater Interface</u> The 250mg/l isochlor, or contour of equal salinity, approximately 0.5‰ (EPA potable water standard) is considered the acceptable limit and in most planning studies defined as the upper level for potable water. The 10,000mg/l isochlor, approximately 18.5‰ is the generally accepted level defining the freshwater-saltwater transition zone. Seawater typically contains 19,000mg/l chloride so a small amount of entering saltwater can render freshwater supplies unsuitable (Meisler 1989).

<u>3.1.4 Nitrate in the Columbia Aquifer</u> The water of the Columbia aquifer is easily contaminated because it is unconfined and the sediments are highly permeable. Nitrate is one of the most common contaminants in this aquifer, but is not naturally occurring in high concentrations (Bachman 1984). Nitrogen is not naturally occurring amoung the minerals in the Columbia aquifer. Nitrogen in the soil must be brought in by

biogenic additions such as fixation by plants and bacteria, decay of organic matter, rainfall and/or land applications by humans and livestock. Nitrogen in the form of nitrate is used by plants, but returns to the soil upon decay. There is often a natural balance of nitrogen species between soil and plants. When excess is applied to the soil, it will eventually leach into the groundwater. The potential for nitrate infiltration at any site is governed by the specific lithology of the area, and the land use over the site in question.

Nitrogen applications include three main types: inorganic fertilizers, livestock wastes, and human wastes. Fertilizers are applied frequently because of the tendency to leach from the highly porous, sandy soils of the Columbia (Ragone et al. 1980 as cited by Bachman 1984). Livestock wastes become runoff or are used as fertilizer. Chicken farms are the most common forms of livestock wastes on the Delmarva Peninsula. Human wastes enter the system from sewage disposal at rural and suburban residences. Values of nitrates found in the Columbia Aquifer can be classified as follows (Ragone et al. 1980 as cited by Bachman 1984).

<0.2mg/l (14.2μmol/l) as N - Unaffected by human activity.

0.2-3.0mg/l (14.2-214μmol/l) - may or may not be affected by human activity.

3.0-10.0mg/l (214-714μmol/l) - clearly affected by human activity, but still below EPA standards of 10 mg/l.

>10.0mg/l (714μmol/l) - exceeds the EPA water quality standard.

Naturally occurring dissolved nitrogen species are low in groundwater. Measurements from the shallow glacial aquifer of Long Island, similar to the Columbia, indicated natural concentrations approximately 0.2 mg/l (14.2μmol/l) as N. (Perlmutter and Koch, 1972; and Ragone et al, 1980 as cited by Bachman 1984). Higher values were common due to nitrogen application to the land as fertilizer.

Commercial inorganic fertilizer is spread over a large area, thus affecting the area by raising concentrations over the entire expanse. Livestock manure used as fertilizer is more concentrated and spread over smaller areas tending to have greater effect on local wells by higher concentrations.

3.2 Methods

3.2.1 Well Installation A series of well clusters were installed across the study area into Magothy Bay. Clusters consisted of wells screened at depths of 3.05m (10') and 9.14m (30'). An additional well screened at a depth of 15.25m (50') was located at the field-forest interface. Figure 3.4 shows the spatial layout of the Steelman's Landing study site including location of all wells and cores. Table 3.1 shows the cluster designation, location, individual well depths.

Casings consisted of 5.08cm (2") schedule 40 PVC pipe with 10.16 cm (4") deep bell end couplings to prevent leakage at the joints. Well screens consisted of 30cm (1') of 0.0254cm (0.01") slotted PVC well screening.

Wells were installed using a portable modification of the normal rotary method. Drilling apparatus consisted of a gasoline powered Honda water pump which circulated Baroid drilling fluid (Baroid Drilling Fluids, Wyoming) through hollow 3.05m (10 foot) steel pipes attached to a 1.52m (5 foot) bit. The pointed hollow bit, turned manually with a pipewrench, scraped and loosened the sediment. Drilling fluid increased viscosity of water circulating through the system, increasing its capacity to carry sediment from the borehole. Sediment flowed from the borehole into the first of two settling basins. In the first settling basin, velocity of the fluid slowed, allowing sediment to settle out. Drilling fluid was withdrawn from the second basin and recirculated down the bore hole.

Upon reaching the desired depth for location of the well screen, drilling fluid was circulated for several minutes to allow complete removal of sediment from the borehole. After this time, the bit was removed and the well casing was inserted into the borehole. Upon locating the well screen at the desired depth, the well was developed by surging clean water down the well casing to clear the well screen of sediment. The well screen was packed in coarse sand and gravel. The first two meters of borehole above the screened portion were packed with 0.64cm (1/4") bentonite pellets or chips (Baroid Drilling Fluids, Wyoming). The remainder of the well casing was then packed with coarse 0.95cm (3/8") bentonite chips.

Wells were then pumped of approximately 950 liters (250 gallons) of water using a Honda water pump. Wells were then capped with 5.08 cm (2") PVC well caps and locked to prevent tampering or contamination through the top of the open well casing. Wells were allowed to equilibrate for a one month period prior to the first sampling for nutrients and salinity.

A series of ten wells screened at one meter below the surface of the saltmarsh were installed in order to obtain salinity values from the saltmarsh surface, approximate the salinity of the root zones of saltmarsh plants, and identify salinity changes as a function of distance from the bay. Wells consisting of 15cm of slotted well screen and one meter of 5.08cm (2") PVC monitoring well casing were installed using a hand auger. Screens were packed in coarse sand and the remainder of the annular space cased with 1.91cm (3/4") bentonite chips. Location of one meter salinity wells and salinity values from these wells are located in Table 3.2.

Proper installation of well casings is important to prevent contamination between aquifers. Once a hole is established through a confining bed, exchange of water can occur between the two aquifers. This also can occur in different flow patterns in the same aquifer. The primarily horizontal flow lines established naturally can be interrupted as leaking or improperly sealed well casings act as conduits for flow and mixing. Also, steps must be taken to avert surface water from following the improperly sealed borehole into the aquifer thus allowing contamination from the surface (Everett 1980).

3.2.2 Core Logging Continuous cores were taken using a modification of the Drive Point/ Piston Sampler apparatus (Starr and Ingleton, 1992). Core tubes consisting of 5.08cm (2") PVC pipes with brass core catchers were driven straight into the ground using a 27.2kg (60lb.) Cobra, gasoline powered, jackhammer with a fence post driving attachment. A 3.05m (10 foot) scaffold was located overhead with a 9000kg (10 ton) boat winch attached to a 10.2x10.2cm (4"x4") wooden beam. Upon driving the pipe to the desired depth, the core was retrieved by sliding an iron cuff around the pipe at ground level. The cuff was hooked to the overhead boat winch by a steel cable. The pipe was then pulled out of the ground, capped at both ends with PVC caps, labeled, and transported to the lab for analysis. In sandy soil, it was possible to drive

3.05m (10 foot) sections of pipe at once. In clayey or rocky soil, it was necessary to pull up shorter sections of core, then remove caved in material from above the current sampling depth, and proceed as before until downward movement of the core tube ceased.

Analysis of cores consisted of cutting core tubes in half lengthwise on a band saw with a tungsten-carbide blade. One half of the core was wrapped in cellophane for later visual analysis and photography. The other half was marked off in 10 centimeter sections, sliced at these lines, and these ten centimeter sections were retained for sediment analysis. Sections of ten centimeters were homogenized and then analyzed for ash-free dry weight and relative percent grain size. Soil organic matter was determined by combusting oven dried samples at 500° C for five hours followed by reweighing. Organic matter is expressed as a percentage weight loss from combustion of the dried sample. Analysis of grain size was done by wet sieve and pipet analysis (Fischler 1986 adapted from Folk 1980).

<u>3.2.3 Well Sampling Procedures</u> Sampling consisted of purging the well casing of three to four volumes of water with a Geotech peristaltic pump (Geotech Environmental Equipment, Denver, CO) with Tygon tubing, prior to obtaining the sample volume. Most sampling techniques assume that the volume of

water held in a well bore does not represent the aquifer pore water because it is stagnant. Thus, it was required to purge several well volumes in order to get a representative sample (Blegen et al., 1988 as cited by Kaplan et al., 1991). Samples were collected in acid washed polyethylene sample bottles and stored on ice until returning to the lab. Samples were filtered using rinsed Gelman Supor-450 membrane filters (0.45 μM), and analysis of inorganic nutrients, except nitrate, was begun within eight hours of collection. Nitrate samples were frozen and returned to VPI&SU and analyzed within two to five days of collection.

Samples were analyzed for salinity and nutrients including ammonia, nitrite, nitrate, dissolved inorganic phosphate. All analyses were performed according to E.P.A. standards. Ammonia was analyzed by reaction to alkaline phenol, hypochlorite, and sodium nitroprusside to form indophenol blue, read spectrophotometrically at 630nm (Strickland and Parsons, 1972). Nitrite was analyzed by diazotization with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride to form an azo dye which was measured spectrophotometrically at 543nm (APHA, 1989). Nitrate was analyzed by cadmium reduction to nitrite and subsequent measurement of nitrite (APHA, 1989). Standard curves were prepared for each individual reducing column. Soluble reactive phosphate was measured using colorimetric, ascorbic acid, single reagent method and read spectrophotometrically at 880nm (APHA, 1989). Dissolved oxygen was determined using the azide modification of the standard iodometric method (APHA, 1989). Salinity was measured using a Beckman Industrial Induction Salinometer (Rosemount Analytical Inc. Cedar Grove, NJ).

3.2.4 Quality Control Quality assurance guidelines were provided by procedures outlined by Standard Operating Procedure for the Coastal Ground Water Research Program (SOP) (Miles et al. 1992). This QA/QC document outlined the collection and handling of samples, as well as duplicate analyses, and control chart analyses for use in preparation of standard curves. In addition, shelf lives of reagents and storage time of samples prior to analysis were addressed. Spectrophotometric absorbances of each standard curve prepared for nutrient analysis were compared to acceptable limits outlined in the SOP (Miles et al. 1992).

Table 3.3 shows the number of replicates of each nutrient concentration during standard curve preparation and the percent of replicates performed during sample nutrient analysis. Table 3.4 shows the range of detection capability for each individual nutrient by each analytical method (from Parsons et al. 1984).

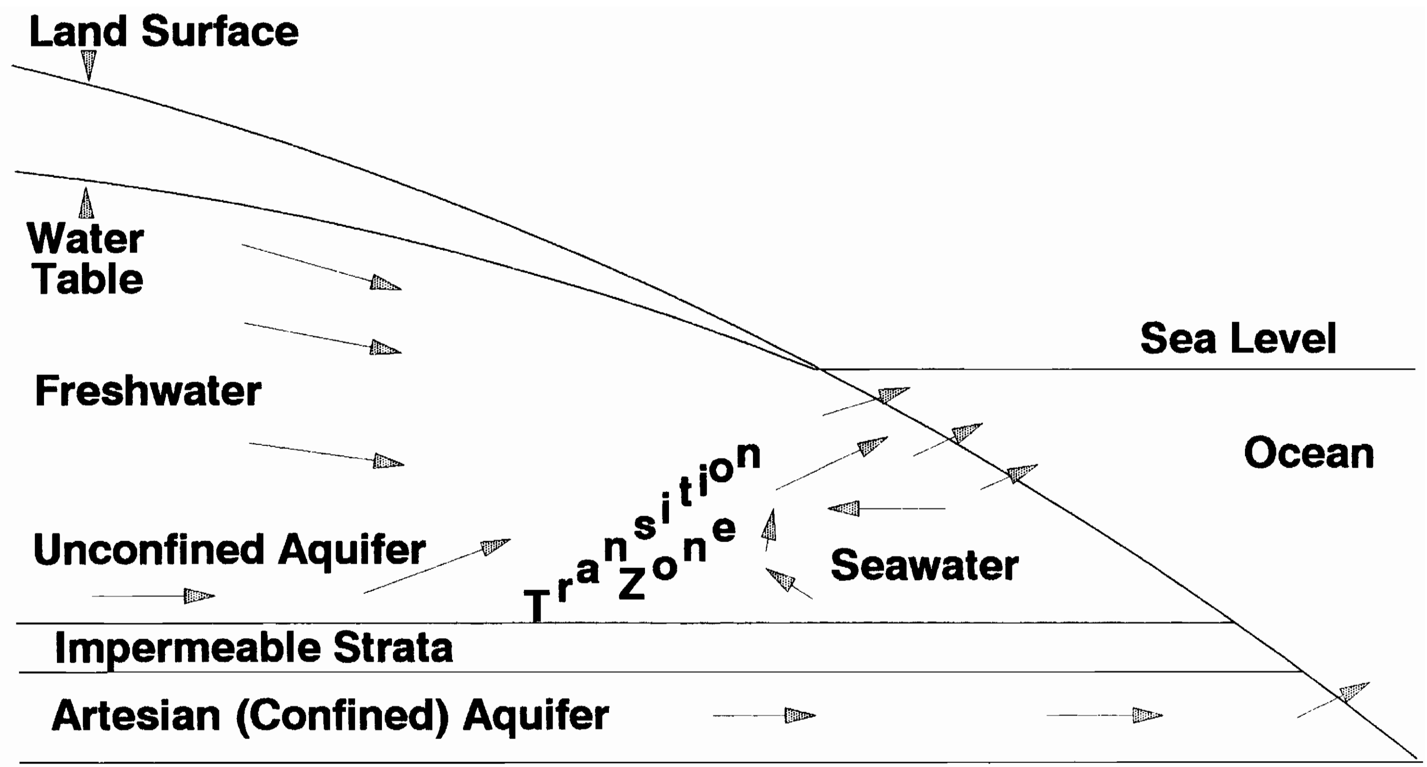

Figure 3.1. Schematic diagram of the transition zone between fresh and saline goundwater systems in a coastal environment (from Johannes 1980).

Badon Ghyben-Herzberg Equation :

$Zs = 40\ Zf$

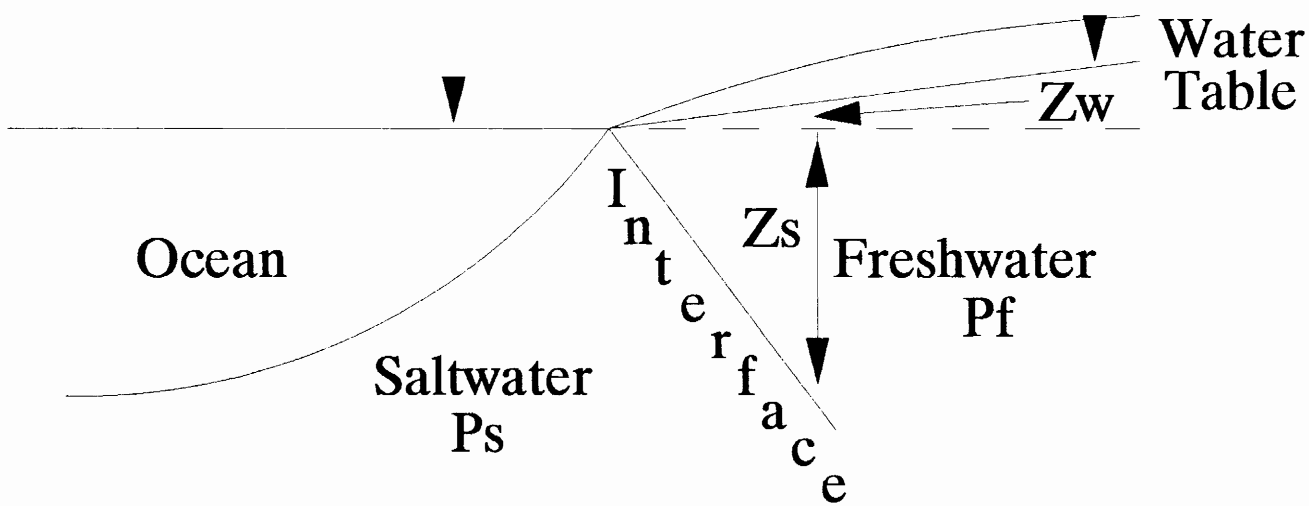

Figure 3.2. Schematic diagram of the freshwater-saltwater transition zone as described by the Badon Ghyben-Herzberg equation (from Freeze and Cherry 1979).

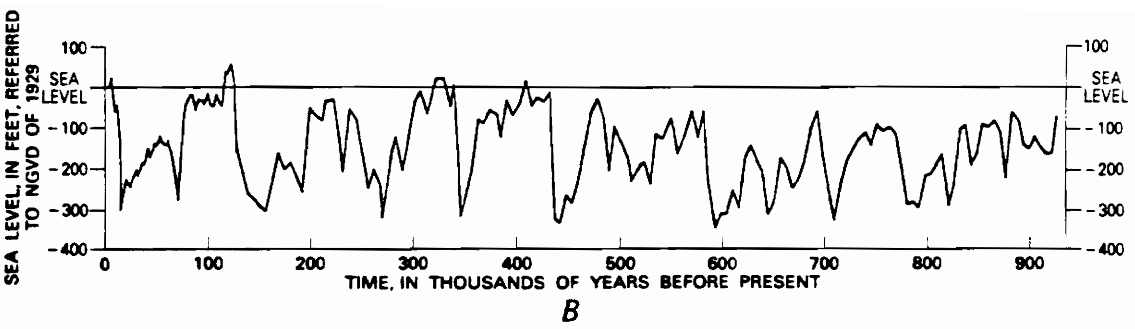

Figure 3.3. Sea level fluctuations for the last 900,000 years before present (from Zellmer 1979 as cited by Meisler et al. 1984).

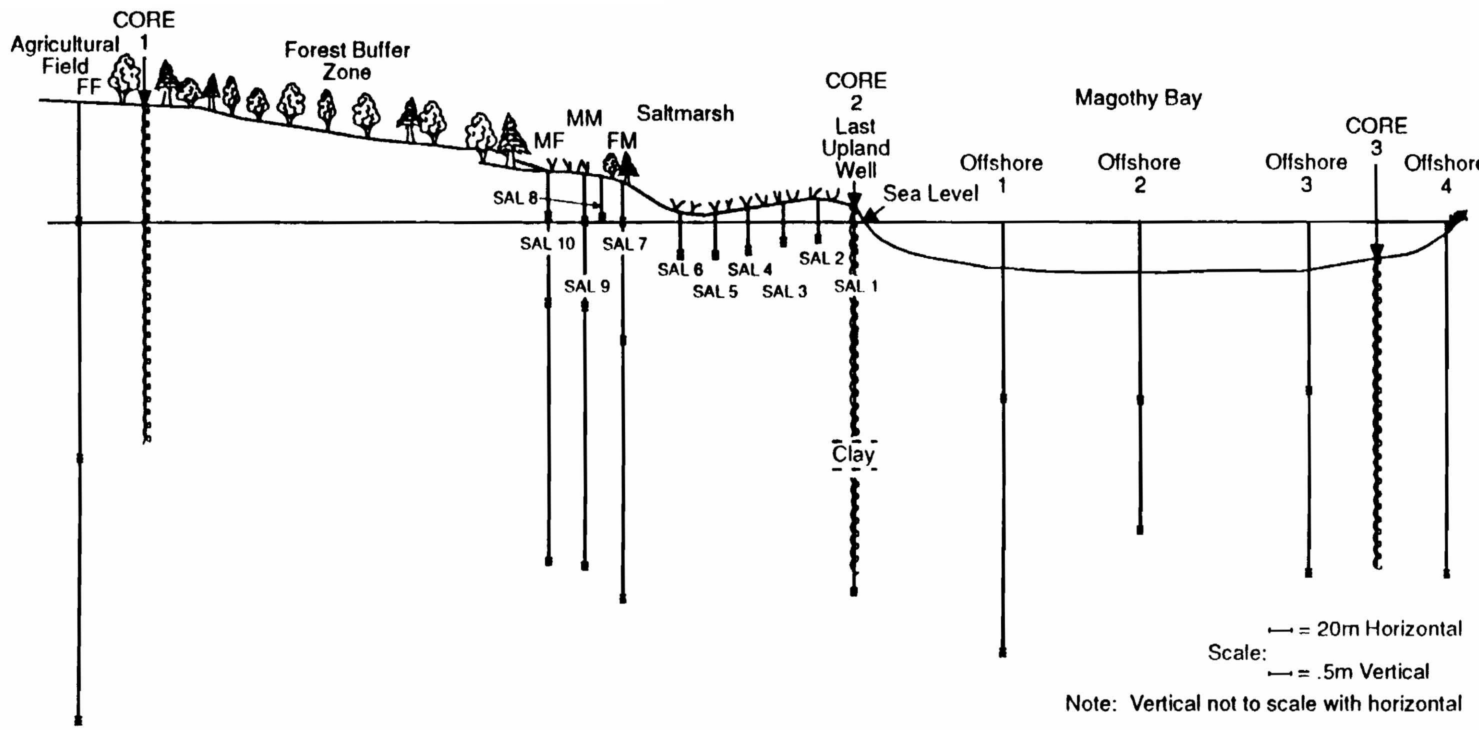

Figure 3.4. Spatial layout of Steelman's Landing study site including relative well locations and depths as well as locations of continuous sediment cores.

Table 3.1. Well cluster designation, location, and individual well depths.

Cluster Designation	Cluster Location	Individual Well Name	Depth (m)
FF	Field-Forest Interface	FF1 FF2 FF3	3.05 8.84 14.33
MF	Marsh-Forest Interface	MF1 MF2	3.05 8.53
MM	30.48m seaward from Marsh-Forest Interface	MM1 MM2	3.05 9.14
FM	100m seaward from Marsh-Forest Interface	FM1 FM2	3.05 9.14
LO	Shoreline of Magothy Bay	LO1 LO2	3.05 9.14
OS1	140m offshore	OS1-1 OS1-2	3.05 9.14
OS2	265m offshore	OS2-1 OS2-2	3.05 6.10
OS3	420m offshore	OS3-1 OS3-2	3.05 9.14
OS4	650m offshore	OS4	8.23

Table 3.2. Location of one meter salinity wells across marsh.

Well	Salinity (‰)	Location
Sal 10	15.10	MF Cluster (300.0m from shoreline)
Sal 9	29.25	MM Cluster (266.2m from shoreline)
Sal 8	30.05	234.2m from shoreline
Sal 7	34.60	FM Cluster (204m from shoreline)
Sal 6	33.22	164.2m from shoreline
Sal 5	33.22	129.2m from shoreline
Sal 4	32.90	97.8m from shoreline
Sal 3	26.47	66.4m from shoreline
Sal 2	29.98	35.0m from shoreline
Sal 1	32.93	Last Onshore (@ Shoreline)

Table 3.3. Number of replicates of each standard concentration and percent of sample nutrient replicates.

Nutrient	# reps each standard	% field replicates
Ammonia	6	20
Nitrite	3	20
Nitrate	3 (1 per column)	20
Phosphate	6	20

Table 3.4. Concentration ranges for detection of nutrients (from Parsons et al. 1984).

Nutrient	Range (uM/l)
Ammonia	0.1-10
Nitrite	0.01-2.5
Nitrate	0.05-45
Phosphate	0.03-5

3.3 Results

3.3.1 Location of Transition Zone

A freshwater discharge zone previously detected by seepage meters (Simmons 1988) in Magothy Bay off Steelman's Landing was investigated for underlying sediment and salinity characteristics. Simmons (1988) found that when seepage meters were installed in the intertidal zone of Magothy Bay and incubated for 24-48 hour periods, water collected showed a net decrease in salinity in relation to ambient salinity (Figure 3.5). As incubation time increased, the deviation in salinity from ambient also increased. This served as an indication that submarine groundwater discharge (SGWD) was occurring in this area.

This zone of fresh SGWD was found to extend from the shoreline to approximately 400 meters offshore. Seepage meter exercises conducted beyond this point showed discharge of water across the sediment-water interface, but this water was of equal salinity to that of ambient seawater. Seepage meters were installed in the deep offshore area, in the vicinity of the offshore 3 well location (approximately 420m offshore) in July 1992 and the mid-depth area, approximately 100m offshore in December 1992. Results from July indicated an average discharge of $1.4 l/m^2/hr$ and an average decrease in salinity of 0.165‰. Results from December indicated an average discharge of $0.396 l/m^2/hr$, and an average decrease in salinity of 1.22‰.

These differences in salinity of SGWD correlated with data of Simmons (1988) who reported freshwater discharge at different rates and salinities at three offshore locations investigated. Table 3.5 shows Simmons' (1988) seepage meter data collected from three points in the offshore area. Seepage meters installed in the shallow nearshore area and deep offshore area showed smaller decreases in salinity than the mid-depth offshore area. The majority of freshwater discharged in the mid-depth area of Magothy Bay.

Freshwater flowing from upland discharged between the shoreline and deep offshore areas. The large decrease in salinity in the mid-depth offshore area suggested this was the primary region of fresh SGWD, resulting from interaction of upland derived freshwater with the salinity wedge located below. The small decrease in salinity of discharging water in the deep offshore area suggests that although there was SGWD, it consisted primarily of seawater moving in convection currents through the sediments. The deep offshore discharge zone was located atop a point on the saline side of the transition zone.

Salinity values of monitoring wells screened across the saltmarsh and into Magothy Bay showed saline water in shallow (3.05m) wells. Salinity of shallow wells increased from 1.6‰ at the marsh forest (MF1) interface across the saltmarsh to the shoreline (LO-1), where salinity of well water was nearly equal to that of ambient seawater. Deeper wells (9.14m) contained fresh water across the saltmarsh and Magothy Bay to a distance of 420m offshore. A deep well located approximately 550m offshore contained water of approximately 27‰.

Freshwater discharged in the nearshore area was forced to the surface by the presence of the "salinity wedge." Discharging saltwater from farther offshore resulted from recirculating seawater moving in a convection current through the sediments.

<u>3.3.2 Salinity Contour of Marsh Cross-Section</u> Figure 3.6 represents a salinity contour of a cross-sectional diagram of the Steelman's Landing study site. Using vertical and horizontal map coordinates to locate monitoring well screens, salinity values of monitoring wells at these locations, and geologic site characteristics as indicated by continuous sediment cores, a diagram of the geohydrologic framework of the Steelman's Landing study site was constructed. This figure was slightly modified by adjusting contour lines to correspond with coordinates designated by known well salinities. The Systat (Systat Inc., Evanston, IL) generated contour plot included several well screen locations with known salinity values in isopleths of differing salinity. Figure 3.6 indicates that a large band of freshwater originating in

the uplands flowed beneath the forest and saltmarsh into the offshore area. The more dense distribution of contour lines beneath Magothy Bay represented a zone of mixing of fresh groundwater with saline interstitial water in the sediments. The presence of deeper lying saltwater in the vicinity of the offshore 4 well formed the wedge shaped density barrier which forced freshwater towards the surface. High salinity values on the marsh surface indicated the presence of a perched, hypersaline aquifer.

3.3.3 Head vs. Tide Height Study A study evaluating tide height vs. vertical hydraulic gradient in two wells located directly adjacent to the shore was conducted over a 10 hour period beginning at the final rise of the tide, through the ebb tide, and the rise again. The last onshore well cluster with depths of the wells 3.05m, and 9.14m was used. Figure 3.7 shows the results of head measurements and tide height in relation to sea level. Three points in time were chosen, 7:00AM, 12:00PM, and 4:45PM and the vertical hydraulic gradients were calculated. Respective results were as follows: 0.034 meters/meter (m/m), 0.041m/m, and 0.035m/m. These large hydraulic gradients indicated that freshwater from below exerted a large vertical force toward the surface. The deeper, last onshore 2 well overflowed the top of the well casing in artesian fashion throughout much of the tidal cycle.

At ebb tide, weight of the overlying saltwater was removed and the density barrier was lessened, increasing potential for freshwater discharge.

3.3.4 Hydraulic Gradients of Wells Across Study Site Tables 3.6 and 3.7 show the horizontal hydraulic gradients expressed in m/m of shallow and deep wells, respectively, across the study site. Horizontal hydraulic gradients generally decreased from the uplands toward the offshore area. Horizontal hydraulic gradients between upland wells and offshore wells were very low. Due to the large horizontal distance between wells, and the accuracy of the surveying method, the values were not significant. Values that were calculated were on the order of <0.0010 m/m, suggesting that there was a very small, if any, horizontal flow component remaining in the offshore area.

Figure 3.8 represents a flow net constructed using hydraulic head measurements referenced against sea level from wells across the saltmarsh and offshore areas. Arrows represent flow patterns of groundwater from the upland areas to the discharge zone in Magothy Bay. Hydraulic heads of upland wells were used. Across the saltmarsh surface, shallow wells in saturated low marsh areas showed hydraulic heads at the surface of the saltmarsh. Therefore, head measurements were equal to the surface elevations at those points. In the offshore area hydraulic heads of shallow (3.05m) wells varied with change in tide height. Hydraulic heads of these wells were equal to the tide height. Referencing these heads to mean sea level, a hydraulic head of zero was used in flow net construction. Average hydraulic gradients of offshore wells were used to calibrate hydraulic heads of deeper wells in the offshore area. Arrows representing groundwater flow were then drawn perpendicular to contour lines of equal hydraulic head from high to low gradients.

Table 3.8 shows the vertical hydraulic gradients expressed in m/m between shallow and deep wells of each individual cluster. Vertical hydraulic gradients increased from upland at the marsh-forest cluster toward the last onshore cluster. No hydraulic gradient calculations were made for the offshore 1 and offshore 2 well clusters due to the inability to measure the hydraulic head of these wells. Deeper wells (offshore 1-2 and offshore 2-2) continuously flowed in artesian fashion. The head measurements could not be obtained due to their constantly overflowing the top of the casing. Addition of adequate casing to avoid overflowing would not have allowed the measurement of the hydraulic head due inability to reach the well top. Between the period of December 1992 and May 1993, both the offshore 1 and offshore 2 clusters were vandalized and lost. At the offshore 3 cluster, the vertical hydraulic gradient was greatly reduced, suggesting that the upward vertical force of freshwater had lessened. The offshore 3 cluster was located 65% (420m/650m) of the distance across the offshore discharge zone.

<u>3.3.5 Site Geology:Cores</u> Core 1 was obtained approximately 53.5m into the forest from the agricultural field. This core displayed a reddish-rust color below one meter in depth suggesting iron compounds under well aerated conditions. Core 2 was obtained from the last onshore well site, located at the shoreline of Magothy Bay, at the approximate mean high tide level. This core, represents the lithology of 9.75m of sediment from the last onshore well cluster. Core 3 was obtained adjacent to the offshore 3 well location, approximately 420m into Magothy Bay. Figure 3.4 shows the location of sediment cores in relation to monitoring wells and the spatial layout of the study site.

Figures 3.9, 3.10, and 3.11 represent relative grain size percentages from cores 1,2, and 3, respectively. Core 1 (Figure 3.9), showed a relatively homogeneous soil profile in the forest dominated by sand and gravel to a depth of 8.3m. There was a slight increase in silt and clay size particles in the first 0.5m, most probably due to the breakdown of organic matter. Figure 3.12 shows percent organic matter vs. depth from cores 1,2, and 3. Organic matter in the first 0.5m of core 1 ranged from near 2-12% in the forest and generally

decreased with increasing depth. Core 2 (Figure 3.10), represents the sediment profile of the last onshore well location. This figure describes a sand dominated the system to a depth of approximately 6.3 meters where a 60 centimeter thick horizontal layer of increased silt and clay divided the system into two flow systems. There was no corresponding increase in organic matter at this depth suggesting that the layer was an inorganic silt and clay barrier. Core 3 (Figure 3.11), taken from the offshore 3 well location, was dominated by sand, but exhibited layers of reduced permeability due to increases in silt and clay size particles at depths of approximately 1.0 and 6.2 meters. Percent organic matter in core 3 was approximately 2-3% through the first 1.2 meters from the surface, and then near zero to a depth of two meters.

Figure 3.13 represents a schematic diagram of alluvial deposits in a coastal area. Clay and silt veins appear periodically in the sedimentation process as remnants of ancient creek channels. Through meandering of these creek channels, these veins of low permeability material are patchy in their extent and not necessarily portions of continuous lenses (Miller 1974).

3.3.6 Water Chemistry: Nutrients and Salinity Wells located at the field-forest interface showed nitrate concentrations at approximately 600-800μmol/l at 3.05m and 9.14m, and approximately 2.0μmol/l at 15.25m. Average nitrate concentrations in all wells across the saltmarsh and offshore area were less than 2μmol/l. Ammonia concentrations were generally higher in shallow (3.05m) wells than in deeper (9.14m) wells across the saltmarsh and offshore area. Nitrite concentrations were below 1.5μmol/l in all wells. Dissolved inorganic phosphate (DIP) concentrations were generally higher in deeper wells across the saltmarsh and offshore area. Overall, however, DIP concentrations in groundwater were low. Table 3.9 contains mean, standard deviation, and number of samples taken for nutrients and salinity from each well throughout the sampling period.

Oxidized nitrogen species concentrations (NO_2^- and NO_3^-) were low in the saltmarsh and offshore wells in both shallow and deep wells (<1.5 μmol/l NO_2^-, <1.4μmol/l NO_3^-). Elevated ammonia concentrations (6.50-25.75μmol/l) were found in the shallower 3.05m wells.

Wells located at the field-forest interface at depths of 3.05m, 9.14m, and 15.25m (FF1, FF2, FF3, respectively) contained freshwater less than one part per thousand at all depths. Wells located across the marsh show higher salinity values at 3.05m depths than in the corresponding deeper 9.14m wells at the same cluster. However, comparing wells of similar heights across the marsh, the salinity of both shallow and deep wells increased seaward because tide heights caused the lower marsh to be more frequently covered by seawater. The shallow wells increased in salinity much more quickly moving seaward until the salinity in the last onshore 1 well, screened at 3.05m was nearly equal to the ambient seawater.

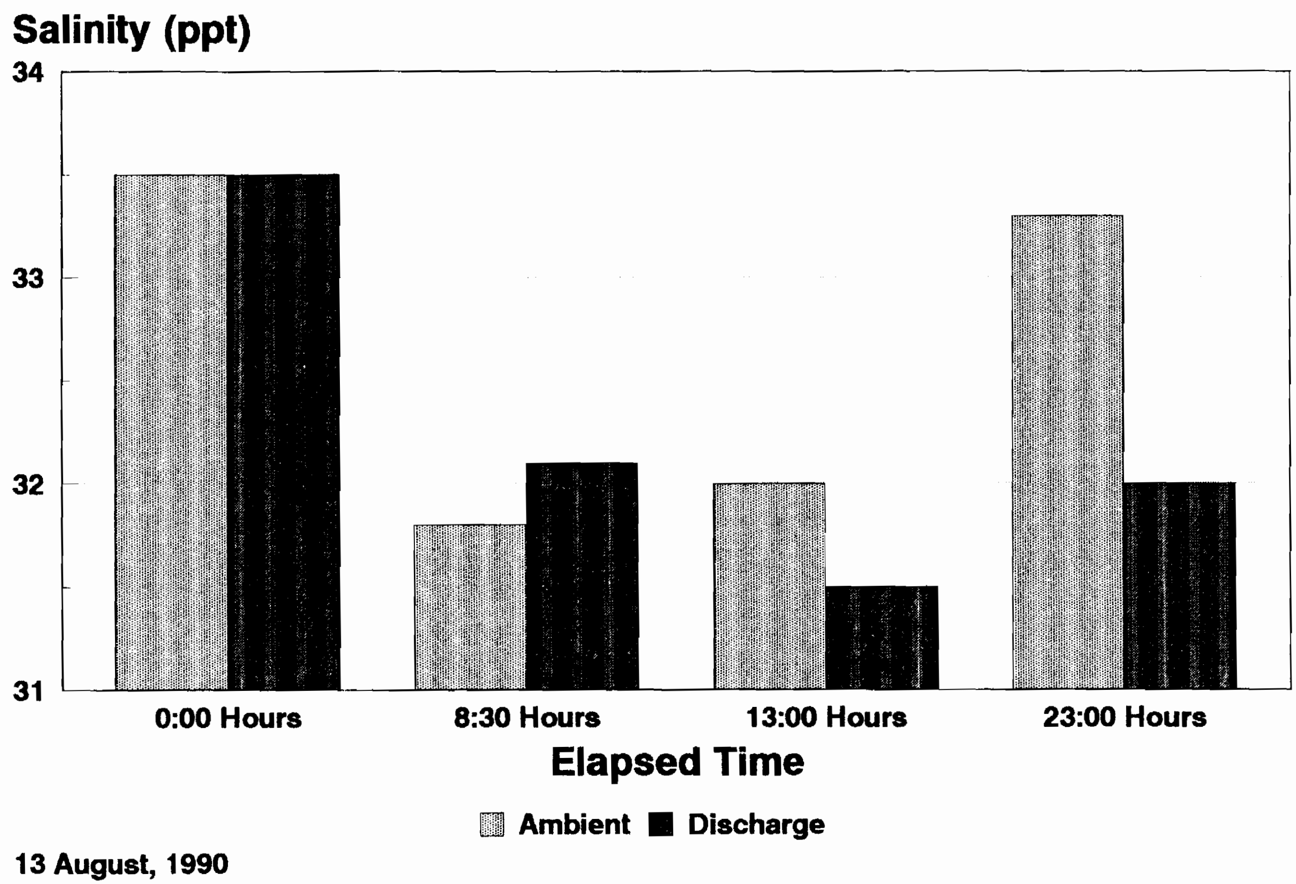

Figure 3.5. Change in salinity of seepage meter sample with time in relation to ambient salinity in Magothy Bay (from Simmons 1988).

Table 3.5. Salinity and discharge measurements from seepage meters at shallow, mid, and deep areas in Magothy Bay (Simmons 1988).

	Magothy Bay	Shallow	Mid	Deep
Mean (ppt)	31.5	30.8	25.5	31.0
Range	30.4-32.8	29.8-32.4	24.7-27.5	29.8-33.5
n	7	8	6	9
Q $l/m^2/hr$	NA	2.58	3.56	5.14

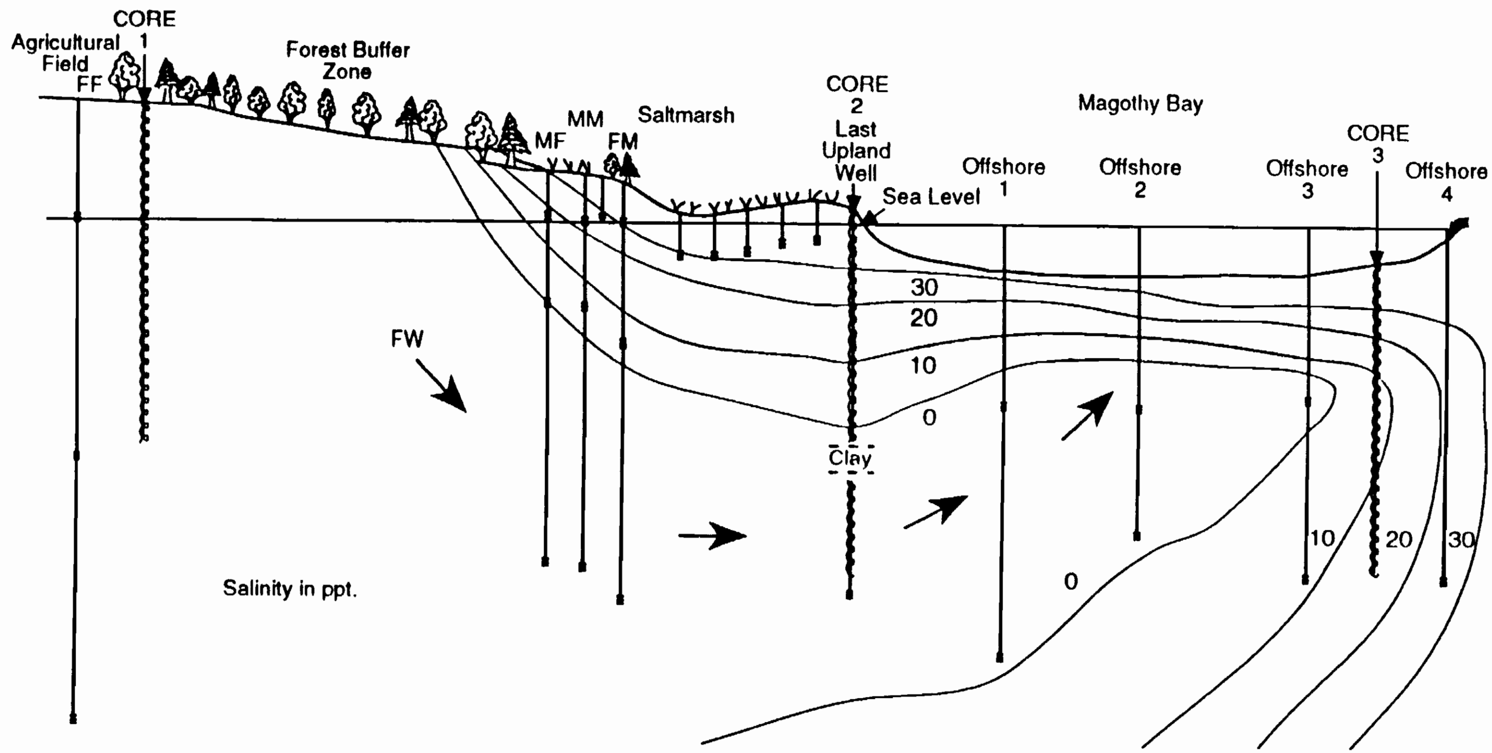

Figure 3.6. Salinity contour of Steelman's Landing study site cross-section indicating freshwater movement offshore and transition zone beneath Magothy Bay.

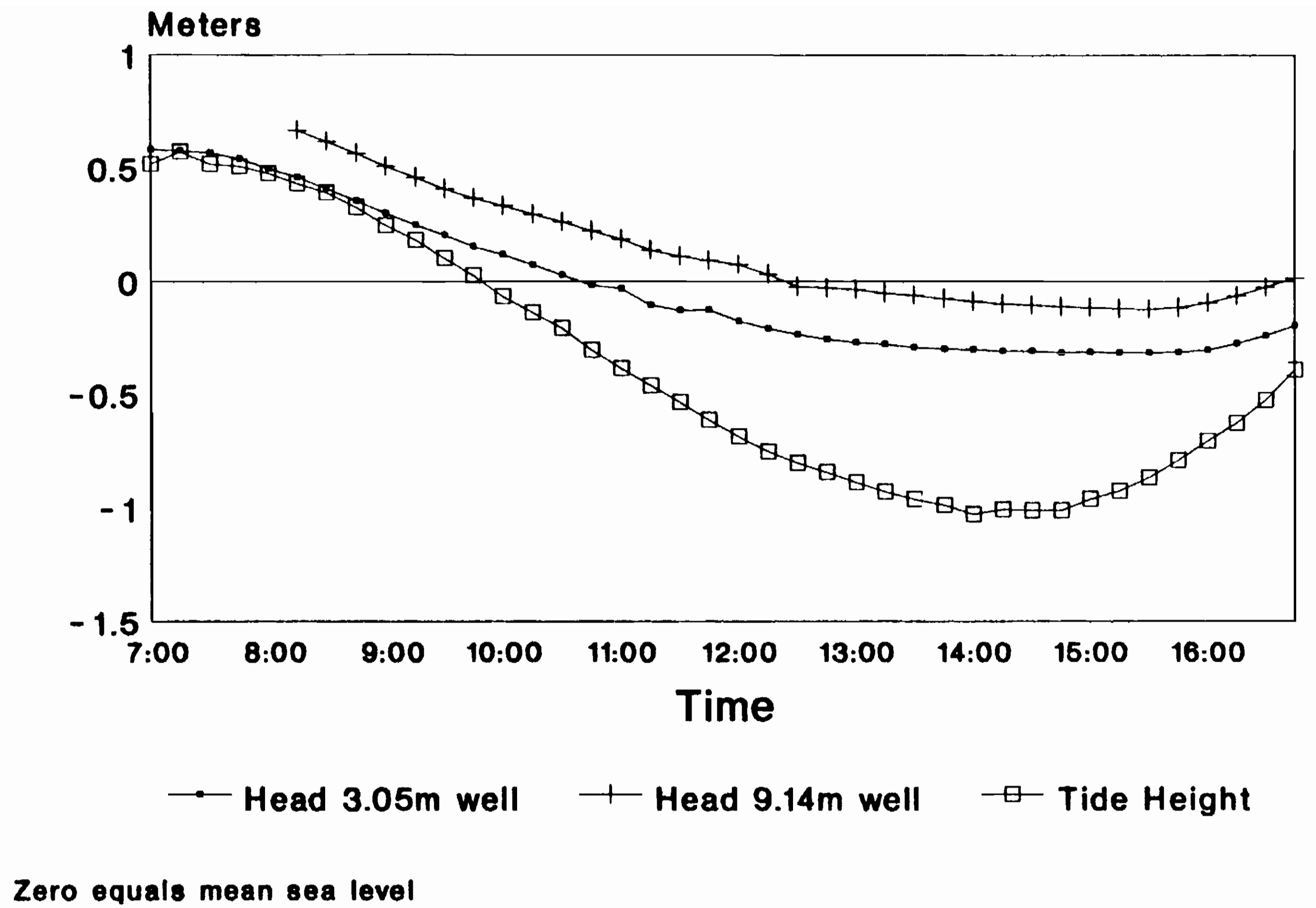

Figure 3.7. Tide height in relation to hydraulic head of last onshore 1 (3.05m) and last onshore 2 (9.14m) wells.

Table 3.6. Horizontal hydraulic gradients ($\Delta h/\Delta l$) (m/m) for shallow (3.05m) wells across study site.

	MF	**MM**	**FM**	**LO**	**OS3**
MF	~	0.0036	0.0025	0.0014	0.0008
MM	0.0036	~	0.0025	0.0013	0.0007
FM	0.0025	0.0025	~	0.0010	0.0005
LO	0.0014	0.0013	0.0010	~	0.0002
OS3	0.0008	0.0007	0.0005	0.0002	~

Table 3.7. Horizontal hydraulic gradients ($\Delta h/\Delta l$) (m/m) for deep (9.14m) wells across study site.

	MF	MM	FM	LO	OS3	OS4
MF	~	0.0051	0.0030	0.0010	0.0010	0.0010
MM	0.0051	~	0.0019	0.0009	0.0010	0.0009
FM	0.0030	0.0019	~	0.0015	0.0005	0.0005
LO	0.0010	0.0009	0.0015	~	0.0009	0.0010
OS3	0.0010	0.0010	0.0005	0.0009	~	-0.0001
OS4	0.0010	0.0009	0.0005	0.0010	-0.0001	~

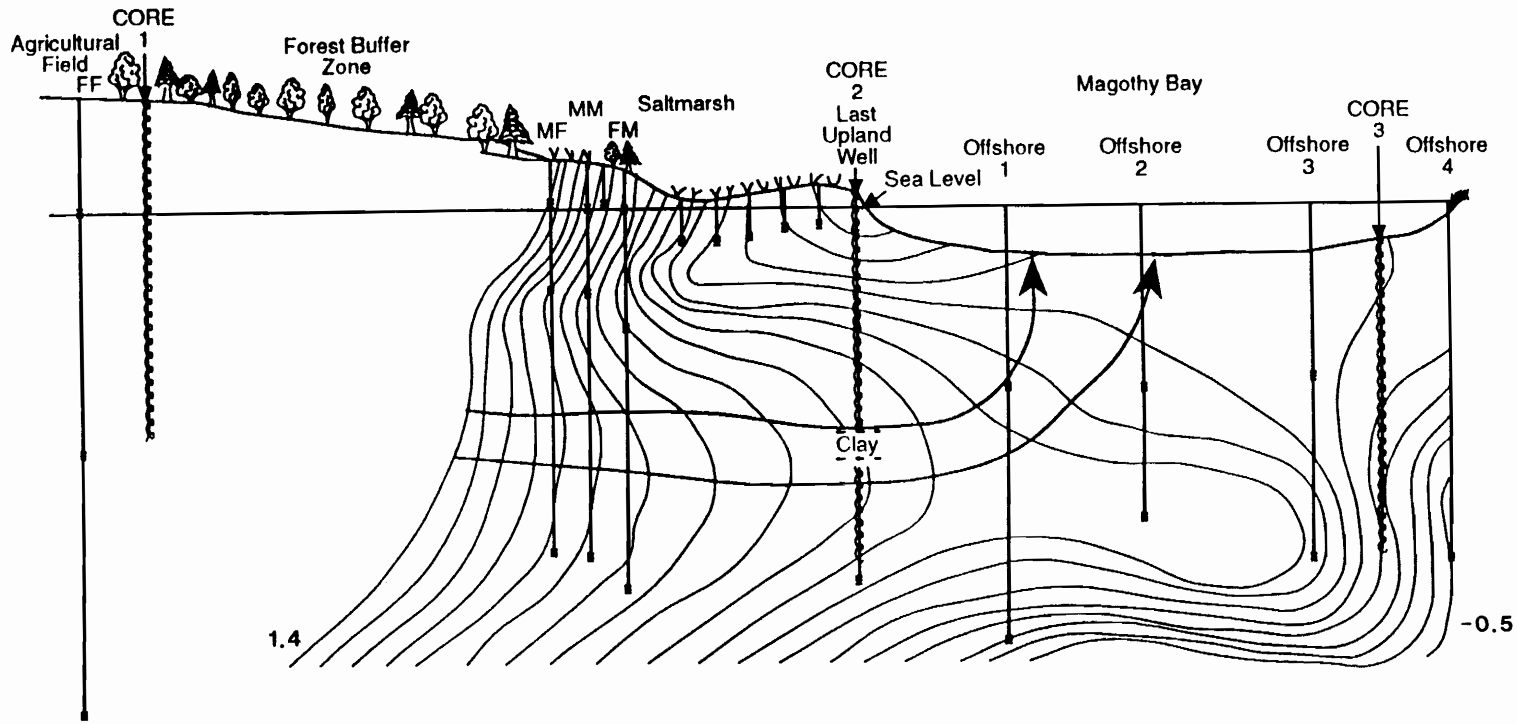

Figure 3.8. Flow net for Steelman's Landing study site cross-section. Contours represent equal hydraulic head. Arrows indicate direction of groundwater flow. Hydraulic head expressed in meters/meter.

Table 3.8. Vertical hydraulic gradients ($\Delta h/\Delta l$) (m/m) of individual well clusters across study site.

Well Cluster	**Hydraulic Gradient ($\Delta h/\Delta l$)(m/m)**
MF1-MF2	0.0188
MM1-MM2	0.0161
FM1-FM2	0.0270
LO1-LO2	0.0457
OS3 1-OS3 2	0.0215

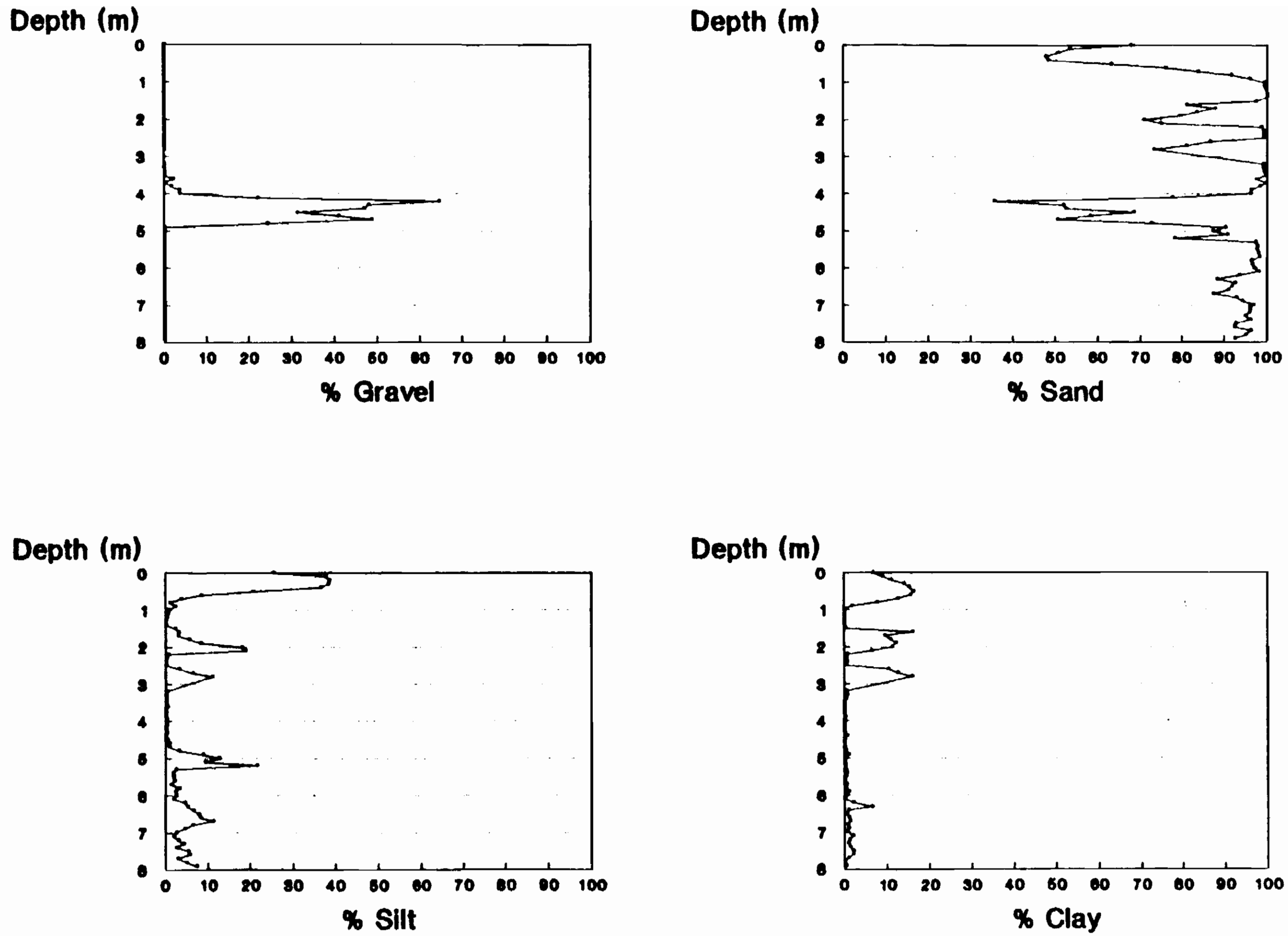

Figure 3.9. Relative grain size percentages vs. depth (m) of core 1: forest.

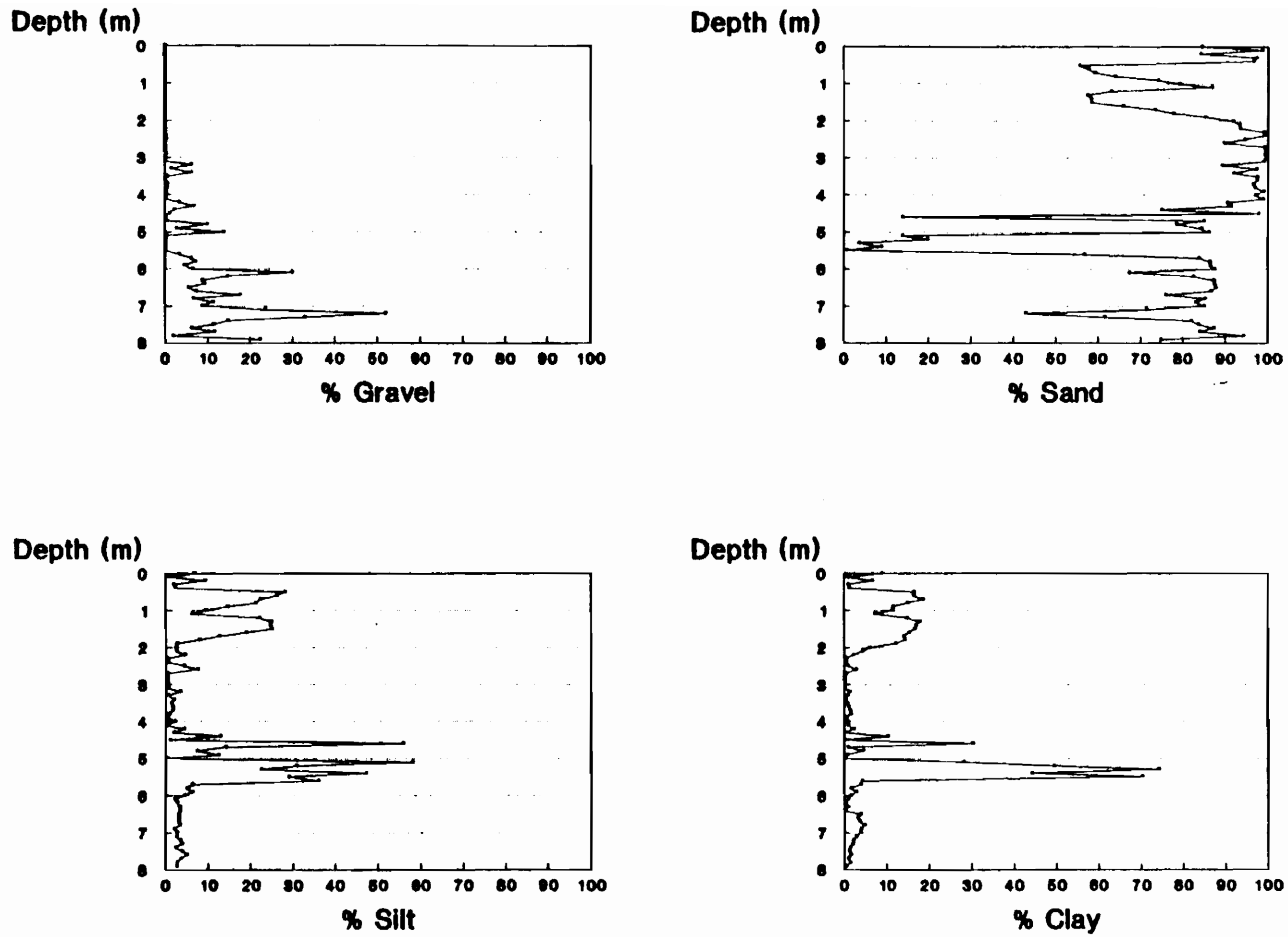

Figure 3.10. Relative grain size percentages vs. depth (m) of core 2: last onshore well location.

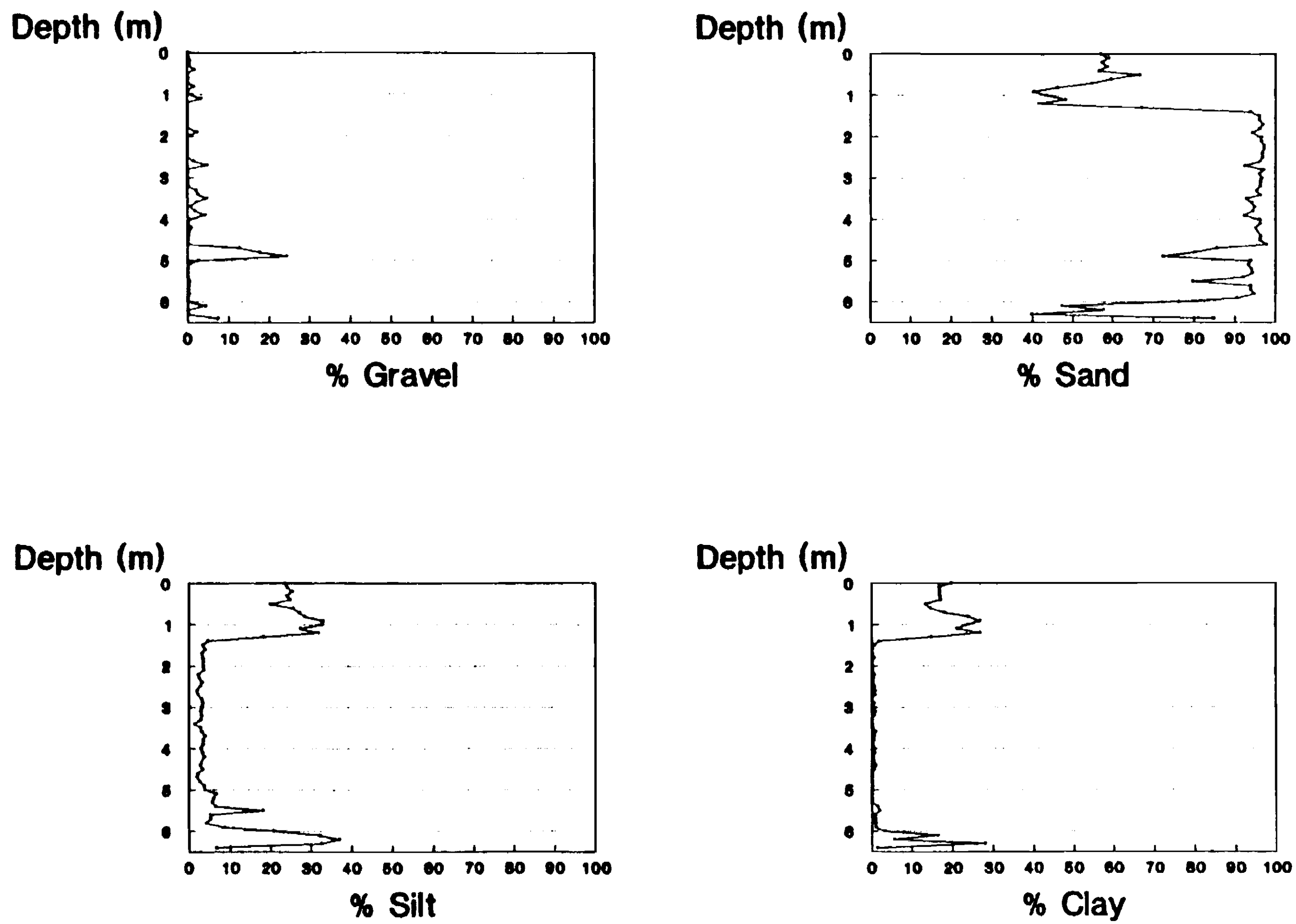

Figure 3.11. Relative grain size percentages vs. depth (m) of core 3: offshore.

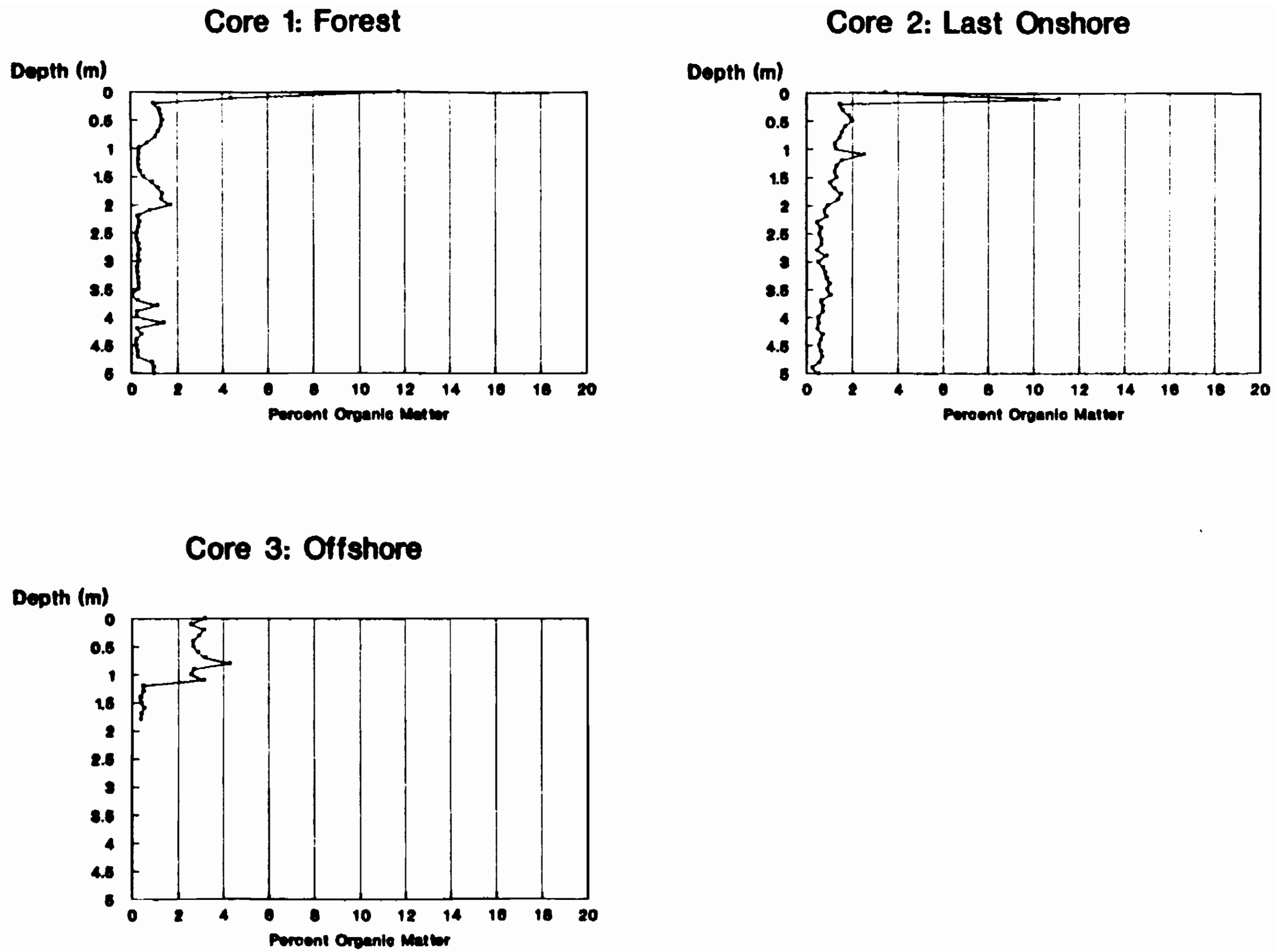

Figure 3.12. Ash free dry weight vs. depth (m) from cores 1,2, and 3, respectively, expressed as % organic matter.

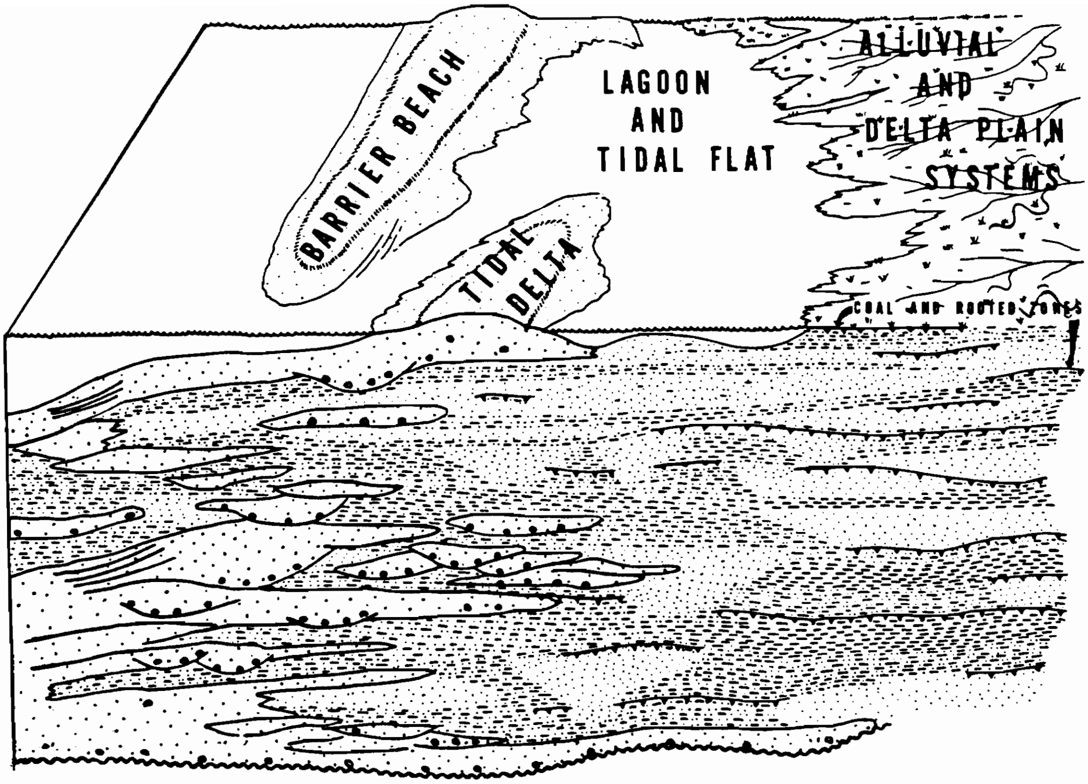

Figure 3.13. Schematic diagram representing alluvial deposition in coastal area (from Miller 1974).

Table 3.9. Mean nutrient concentrations and salinity of wells at Steelman's Landing study site (Some data courtesy Dr. William Reay).

Well	stat	NH_4	NO_2	NO_3	PO_4	sal
FF1	mean std. n	1.74 0.84 11	0.06 0.16 12	733.98 226.10 13	0.24 0.18 12	0.166 0.010 5
FF2	mean std. n	2.86 1.79 11	0.04 0.12 13	566.63 164.90 11	0.83 0.67 13	0.187 0.051 5
FF3	mean std. n	2.01 1.39 11	0.02 0.06 14	1.93 1.90 13	0.30 0.20 12	0.244 0.011 5
MF1	mean std. n	13.21 5.32 8	0.31 0.64 8	1.35 1.39 9	1.32 0.33 9	1.616 1.316 8
MF2	mean std. n	5.28 3.78 8	0.05 0.08 8	1.23 1.86 9	2.51 0.48 9	0.392 0.786 8
MM1	mean std. n	21.14 2.92 7	0.07 0.11 8	1.18 1.00 8	0.59 0.17 8	3.938 2.944 8
MM2	mean std. n	9.00 3.22 7	0.03 0.09 8	0.58 0.98 8	2.73 0.47 8	0.438 0.916 8
FM1	mean std. n	19.71 5.52 7	0.17 0.18 7	0.37 0.25 8	0.95 1.34 8	5.045 0.518 8
FM2	mean std. n	9.21 6.01 7	0.02 0.05 8	0.31 0.34 8	2.28 0.99 8	0.261 0.222 8
LO-1	mean std. n	6.49 2.58 6	0.31 0.48 7	0.23 0.23 7	1.65 1.45 7	25.017 0.897 7

Table 3.9. (continued) Mean nutrient concentrations and salinity of wells at Steelman's Landing study site.

well	stat	NH_4	NO_2	NO_3	PO_4	sal
LO-2	mean std. n	8.70 5.58 6	0.01 0.02 7	0.42 0.17 7	2.90 1.29 7	0.340 0.190 7
OS1-1	mean std. n	nd	1.48 1	0.00 1	nd	0.401 0.192 2
OS1-2	mean std. n	nd	0.00 1	0.35 1	3.5 1	0.156 0.049 2
OS2-1	mean std. n	nd	0.00 1	0.31 1	3.20 1	23.241 1.776 2
OS2-2	mean std. n	nd	0.00 1	0.00 1	3.09 1	0.330 1
OS3-1	mean std. n	25.76 9.39 2	0.03 0.06 3	0.33 0.07 3	3.28 2.58 3	6.273 0.682 3
OS3-2	mean std. n	7.93 0.33 2	0.00 0.00 3	0.36 0.13 3	1.98 0.54 3	0.237 0.059 3
OS4	mean std. n	24.57 1	0.11 0.12 2	0.03 0.04 2	6.09 8.61 2	30.14 1.53 2

3.4 Discussion

The saltwater-freshwater transition zone was identified as a 400m-wide area beneath the intertidal zone in Magothy Bay. Seepage meter studies described a band of fresh SGWD near the shoreline and a band of saline SGWD farther offshore. Deeper monitoring wells containing fresh water located across the saltmarsh to approximately 420m offshore indicated freshwater movement through the system to that point. A deep well 550m offshore containing saline water was located on the saline side of the transition zone. The lens of freshwater flowed beneath the saltmarsh and nearshore area until it contacted the most landward tip of the salinity wedge. At this point a the vertical flow component increased and fresh groundwater was forced toward the surface. As freshwater approached the sediment-water interface, it interacted with saline interstitial water in the sediments which increased its salinity. The discharging water collected in seepage meters represented a mixture of the deeper lying freshwater and salty bay water which had diffused down into the sediments.

At the saltmarsh portion of the study site, the nutrient concentrations were much lower than those at the field-forest interface. Monitoring wells across the saltmarsh into the offshore area were relatively low in nutrients at all depths. Seepage meter studies suggested that discharging water was relatively nutrient free, while monitoring wells below the discharge area indicated that the low nutrient water collected in seepage meters was characteristic of groundwater in the system.

Site specific geology played a very important part in the location of the transition zone and its relationship to the saltmarsh community overlying the freshwater flow system. Continuous core analysis of core 1 revealed no significant increases in silt or clay size particles at depths other than those at the surface corresponding with increased organic matter. This suggested that groundwater flowed through the forest without inhibition due to confining units. Core 2 revealed a layer of increased silt and clay at a depth of approximately six meters which did not correspond with increased organic matter. This layer of decreased permeability may have served as a confining unit at this portion of the study site. The horizontal extent of this layer of increased silt and clay is unknown because it failed to appear in either core 1 from the forest or core 3 from the offshore area. The layers of silt and clay size particles contained in core 3 were not thought to be continuations of the layer found in core 2 because they were not of similar thickness or silt and clay content.

The freshwater lens below the saltmarsh was overlaid by a surficial perched saline aquifer which supported the saltmarsh ecosystem. The saltmarsh system was actually an unstable system where denser saline water was located atop the freshwater flowing below. Concentration of salt on the marsh surface was caused by periodic tidal inundation and evaporation of seawater from the marsh surface during high tide or wind blown sea spray across the marsh surface.

A comparison of horizontal and vertical hydraulic gradients indicates that vertical hydraulic gradients were approximately one order of magnitude greater than horizontal hydraulic gradients across the saltmarsh and nearly two orders of magnitude greater in the offshore area. This suggests that there was a greater tendency for groundwater flow upward toward the surface than in the horizontal direction. However, several factors may have prevented the upward movement of deep groundwater. These factors discussed previously, may have included site geology, which may include a layer of reduced permeability as suggested by core 2. Also, density differences in surface water of higher salinity may have formed a density barrier preventing upward migration of deep freshwater.

An error analysis of horizontal hydraulic gradients was conducted. Due to the large horizontal distance encompassed by the study area, it was necessary to move the transit several times during well leveling. Due to the small horizontal hydraulic gradients encountered in the offshore area, analysis of total possible error due to measuring well elevations was considered. A worst-case error of 0.01 feet which was the smallest increment of measure on the story pole, was allowed for each move of the transit. A difference in the horizontal hydraulic gradient on the order of 1×10^{-5} m/m was calculated between the marsh-forest and offshore 3 well clusters and marsh-forest and offshore 4 well clusters. This suggests that the horizontal hydraulic gradients reported on the order of 0.0001m\m are measurable values, not errors associated with elevation differences and associated large horizontal distances between wells.

In addition to density differences between water of the perched saline saltmarsh surface aquifer, Valeila and Teal (1979) reported layers of reduced permeability were common on a saltmarsh surface as a result of decomposition of organic matter. These silt and clay sized organic particles formed a barrier to vertical and horizontal flow.

Water in the last onshore 1 well showed a strong tidal influence, as reflected by the reaction of well head to change in the tide (Figure z). The rapid change of hydraulic head in both the last onshore 1 and last onshore 2 wells in response to tidal fluctuation, combined with the salinity of the shallow well and proximity to shoreline suggested that actual seawater permeated the sediments at the shoreline, not just saline groundwater penetrating slowly downward from the surface.

Nutrient analyses of monitoring well water samples and geologic characteristics of study site soils and sediments were used to determine the role of groundwater in supplying nutrients to the overlying, highly productive saltmarsh plant community. Nitrate, the form of nitrogen used by plants, was very low in the saltmarsh portion of the study site. Elevated ammonia and phosphate, characteristic of the saltmarsh surface reflect decomposition of organic matter and reduction of oxidized nutrient forms, although the increase in phosphate was small compared to that of ammonia. Valeila and Teal (1979) indicated that wetlands generally import oxidized and particulate nitrogen forms and export reduced forms into coastal zones.

Fresh groundwater discharged at the marsh-forest interface as a result of elevational changes between the forest and marsh. Horizontal subsurface flow in the shallow water table beneath the forest proceeded until lowered surface elevation caused it to discharge. Freshwater reaching the marsh surface affected the plant zonation as related to salinity tolerance of each species. This discharging, low nutrient freshwater influenced the surface salinity of the high marsh area.

Low nutrient concentrations in monitoring well samples, and site specific flow patterns which prevented much of the groundwater flowing beneath the saltmarsh to come in contact with the saltmarsh, indicated that groundwater did not sustain the saltmarsh plant community at this site.

IV. Creek Base Flow

4.1 Introduction

Nutrient concentrations in grab samples obtained from several small creeks indicated that large concentrations of nutrients can be found in drainage from agricultural areas. Previous research by Simmons et al. (1991) indicated nitrate levels in four groundwater derived creeks averaged 140-800μmol/l. A seasonal variation, specifically due to the effects of temperature on biota was expected to greatly influence nutrient movement through the system. Peverly (1982) indicated that 80-90% of the annual nitrogen loads were carried by Oak Orchard Creek in New York between December and April, and that little nutrient transport occurred in late summer and fall. Temperature dependent rates of nitrate reduction by denitrification reported in incubated stream sediments at 11°C were only 45% of losses at 20° (Hill, 1983 as cited in Warwick and Hill, 1988).

DeLaune et al. (1977 as cited by Smith et al. 1985) determined that nitrogen is largely bound in the organic fraction of the sediment, and that burial of such nitrogen can be a significant loss to the system. Much of this nitrogen is then lost via denitrification in these anoxic sediments. During the growing season, vegetative uptake can be a means of nutrient removal from the system. Uptake and long-term storage of nutrients in woody material is the most important role of riparian vegetation, while short term storage occurs as nutrients are incorporated into leaves and other parts of deciduous trees (Lowrance et al. 1985). A 1980 study by Lowrance et al. (1985) on an agricultural area drained by a small creek indicated that denitrification and storage in woody vegetation accounted for more than six times as much removal of nitrogen from the area than loss through stream flow.

Terry and Nelson (1975) indicated no inhibition of denitrification in sediments with overlying water containing oxygen concentrations of three to five parts per million. Skerman et al. (1951) and Skerman et al. (1957, as cited by Terry and Nelson 1975) demonstrated the occurrence of denitrification in cultures aerated with 10% oxygen.

Terry and Nelson (1975) found denitrification occurring in sediments of Big Turkey Lake and Monroe Reservoir in Indiana at temperatures ranging from 5°-23°C, indicating that the process could occur year round in many areas. This was in contrast to the study of Nelson, Owens, and Terry (1973, as cited by Terry and Nelson 1975), which established that denitrification did not occur in river water incubated at 5°C. It was expected that the nutrient flow study of Wall's Landing Creek conducted in the winter would produce a relationship more closely resembling the pattern of dilution alone, while warmer spring temperatures would cause decreases in nutrients due to biological uptake by sediments, including benthic algae and denitrification, as well as by vascular plants.

4.2 Objectives

The specific objectives of this study were:

1. Determine a nitrate flux along Wall's Landing Creek.
2. Observe changes in nutrients and dissolved oxygen as affected by isolated sediments.
3. Contour nitrate and salinity concentrations in Magothy Bay around the mouth of Wall's Landing creek.
4. Plot nitrate concentrations vs. salinity of ambient grab samples to determine the effect of biological nutrient reduction mechanisms on creek water.
5. Determine the loss of nitrogen through the creek on an annual basis and relate that loss to the total amount of nitrogen added as commercial fertilizer applied to the agricultural portion of the Wall's Landing Creek watershed.

4.3 Methods

Nitrate flux was determined in Wall's Landing Creek at three points along the creek. The first was located approximately 50m into the forest from the marsh-forest interface. The second was located approximately 120m across the saltmarsh from the marsh-forest interface. The third was located at the mouth of Wall's Landing Creek at the edge of

Magothy Bay. Velocity and cross-sectional areas were used to calculate discharge (l/sec). Nutrient concentrations of ambient samples were used to establish an estimate of nitrate flux across each station.

The creek was divided into two sections, a forest section and a marsh section, by the three flux measurement stations. In both reaches of the creek, light and dark dome chambers were incubated in situ. In the forest section, four replicates and three replicates were performed during the February and May sampling exercises, respectively, while one each light and dark chamber was used at each other site along the marsh. Three measurements, designated T_0, T_1, and T_2, were taken at the start of incubation, and then following each of two- three hour incubation periods, respectively, in order to observe changes in nutrients, dissolved oxygen, and salinity as affected by the isolated sediments. At the end of the first incubation the domes were removed and replaced into the sediment with fresh creek water isolated inside. Nutrient measurements taken from domes were used to calculate bulk flux measurements across the sediments at each sampling site.

Bulk flux rates of nitrate and dissolved oxygen were calculated using the following equation:

$$BulkFlux = \frac{(C_i \times V_i) - (C_o \times V_o)}{T \times A}$$

where:

C_i= Final concentration in dome chamber (μmol/l).

V_i= Final volume of dome chamber + bag volume (l).

C_o= Initial concentration in dome chamber (μmol/l).

V_o= Initial volume of dome chamber (l).

T= Incubation time (hrs.)

A= Area of sediment covered by dome chamber (m^2).

Ambient bay water samples were collected in three concentric rings at thirty meter intervals radiating from a point at the mouth of the tidal creek. Nitrate and salinity concentrations in Magothy Bay were contoured around the mouth of the creek.

Plots of nitrate concentration vs. salinity of ambient creek water grab samples were prepared and resulting relationships analyzed for method of nutrient concentration reduction.

The watershed area which was drained by Wall's Landing Creek was calculated. From this total area, the amount of agricultural area included in the watershed was calculated. Average fertilization rates for the crops normally grown in rotation between the fields were used to estimate an annual input of nitrogen applied as commercial fertilizer. Creek nitrogen flux rates were used to determine an approximate percentage loss of nitrogen through the creek compared to total nitrogenous fertilizer applied.

4.4 Results

4.4.1 Dome Sites Site descriptions for location of domes were considered based on sediment type. Table 4.1 describes the location and sediment type of each dome site. Underlying sediments in the forest and marsh 1, marsh 2, and marsh 3 sites were primarily medium-coarse sands. Underlying sediments of the marsh 4 and marsh 5 site were composed mud similar to that of the overlying sediment.

4.4.2 Discharge into Domes Benthic dome chambers were equipped with collection bags to measure volumes of water entering the chambers by seepage through sediments on creek bottoms. Average seepage rates were expressed as $l/(m^2/hr)$ and presented in table 4.2. In addition to water collected in bags at each site, three wells, screened at two meter depths were installed at two meter intervals adjacent to each flux station to obtain hydraulic head measurements indicating horizontal flow towards the creek from the adjacent marsh. Positive horizontal hydraulic gradients ($\Delta h/\Delta l$) at the woods and marsh 2 sites, 0.004 and 0.010m/m, respectively, indicated that water flowed towards the creek channel from the surrounding area. Thick mud at the marsh 5 site clogged the well screening, and no hydraulic gradient could be determined at this site.

4.4.3 Bulk Flux Measurements Figures 4.1, 4.2, 4.3, 4.4, represent bulk flux measurements of dissolved oxygen and nitrate for both February and May sampling exercises. Figure 4.3 suggests that the system was primarily heterotrophic in nature as oxygen was consumed in all but one case. Reduced rates of oxygen uptake were present in the woods and marsh 2 sites, whereas two of three lower creek sites displayed increases in rates of oxygen consumption. Figure 4.4 represents bulk flux measurements of nitrate during the February sampling exercise. Dissolved oxygen flux rates from benthic dome samples in February and May indicated predominantly heterotrophic systems, as only two February and one May replicate dark domes showed oxygen production. Higher rates of dissolved oxygen uptake were reported at two sites in February. However, more consistent rates were reported across all stations in May.

Several nitrate samples from the February sampling exercise were inadvertently lost during processing and samples from only four stations were analyzed. Results from these stations were highly variable, indicating a net negative flux, or loss of nitrate to the sediments from stations in the forest, light dome at the marsh 2 site, and dark dome at the marsh 4 site. Small positive rates of nitrate flux, or increases in nitrate to the water column, were reported in dark domes at the marsh 2 site and light domes at the marsh 4 site. Both light and dark domes at the marsh 1 site showed positive nitrate flux rates. The higher rates of dissolved oxygen loss were concentration dependent. At low tide, when nitrate concentrations were higher, nitrate uptake was higher than at low tide when nitrate concentrations were low.

Nitrate flux rates from May suggested that nitrate uptake by sediments occurred at all marsh sites. The thick muds at sites 3,4, and 5 on the marsh were more conducive to nutrient uptake than those of the woods, marsh 1, or marsh 2 sites. Concentration dependent rates of nitrate reduction at the marsh 5 site are illustrated on figure 4.5. The rate of nitrate reduction as indicated on Figure 4.4 of site 5 appears lower than that of sites marsh 3 or marsh 4. This is a function of averaging the flux values taken from the two incubation periods.

Dissolved oxygen fluxes were similar in both February and May Sampling exercises. This suggests that a biological oxygen demand, specifically, respiration in the sediments occurred over a wide temperature range (~5-19°C), as recorded from ambient creek water temperatures. Chemical oxygen demand, including oxidation of H_2S, is also a possibility accounting for oxygen loss in isolated water samples. Approximately three times as much oxygen was consumed by domes in the woods during the May sampling than February (-98.7 mg/m^2/hr light, -143.0 mg/m^2/hr dark, and -33.9 mg/m^2/hr light, -28.9 mg/m^2/hr dark, for May and February, respectively).

<u>4.4.4 Offshore Nutrient and Salinity Contours</u> Figures 4.6, 4.7, 4.8, and 4.9 represent contour plots of ambient samples for nitrate and salinity for both February and May sampling exercises. Comparisons of nitrate and salinity contours from each respective sampling exercise indicate that they are approximately mirror images of each other. As salinity of each sample increased moving seaward from the mouth of the creek, nitrate concentration in the ambient water decreased. Figures 4.6 and 4.7 from February were taken under calm wind conditions. The nutrient plume resulting from creek water entering Magothy Bay traveled directly offshore, approximately perpendicular to the mouth of the creek. Figures 4.8 and 4.9 from the May sampling exercise show an off-centered plume, which flowed towards the northeast shore. This reflected the presence of a northeast wind at the time of sampling, which pushed the plume in that direction. Computer generated contour plots (Systat Inc., Evanston, IL) suggest that a nitrate signature from Wall's Landing Creek was detected more than 200 meters offshore. The plume of nitrate may be contained close to shore or may flow farther offshore depending on winds and/or tidal state.

4.4.5 Nitrate vs Salinity Relationships Figures 4.10 and 4.11 represent nitrate concentrations plotted against salinity of all ambient samples taken from stations along the creek and offshore area, including samples used for offshore contours for February and May sampling exercises respectively. Binomial regression data from both February and May samples was indicated by the curved, solid lines on the figures. Straight, dashed lines represent a relationship of dilution of creek water with seawater.

4.4.6 Fertilizer Loss into Creek Using discharge measurements and ambient creek water nitrate concentrations this study indicated that an amount of nitrate equal to approximately 17.6kg-N/day and 6.6kg-N/day (reached Magothy Bay by way of Wall's Landing Creek during the February and May sampling exercises, respectively. The drainage watershed of Wall's Landing Creek was estimated at approximately 286 hectares (712 acres) of agricultural farmlands. Crops grown in the watershed and their respective fertilization rates were as follows: potatoes and winter wheat approximately 141kg/hectare (personal communication Fred Diem, Virginia Cooperative Extension, Northampton County,VA). This rate of nitrogen application over the 286 hectares of agricultural watershed area equals approximately 40000kg of nitrogen added annually. Using estimates of Peverly (1982), that 80-90% of the annual nitrogen losses in a small creek occurred between December and April, an estimated 2500-3000kg nitrogen were lost annually through Wall's Landing Creek. This represents an annual loss of nitrogen is estimated between 8.7 and 10.5kg/ha/yr and loss on the order of 7-10% of applied commercial fertilizer.

Table 4.1. Descriptions of Dome Sites.

Site	Location	Sediment Description
Forest	100 meters into forest from marsh-forest interface	Leaves, twigs, needles. High organic matter
Marsh 1	50 meters into marsh from marsh-forest interface	Twigs, peat. High organic matter
Marsh 2	125 meters into marsh from marsh-forest interface	Mud with high percent grass. High organic matter
Marsh 3	200 meters into marsh from marsh-forest interface	Patchy shallow mud and sand with sand beneath mud areas.
Marsh 4	120 meters into marsh from edge of Magothy Bay	Deep mud, silty, black sediment
Marsh 5	Mouth of creek at edge of Magothy Bay	Deep mud, silty, black sediment

Table 4.2. Average Discharge of February and May Seepage into Dome Chambers by site groupings.

Site	Discharge ($l/m^2/hr$) February	Discharge ($l/m^2/hr$) May
Woods	0.82	3.72
Marsh 1,2	2.65	1.15
Marsh 3,4,5	0.73	0.32

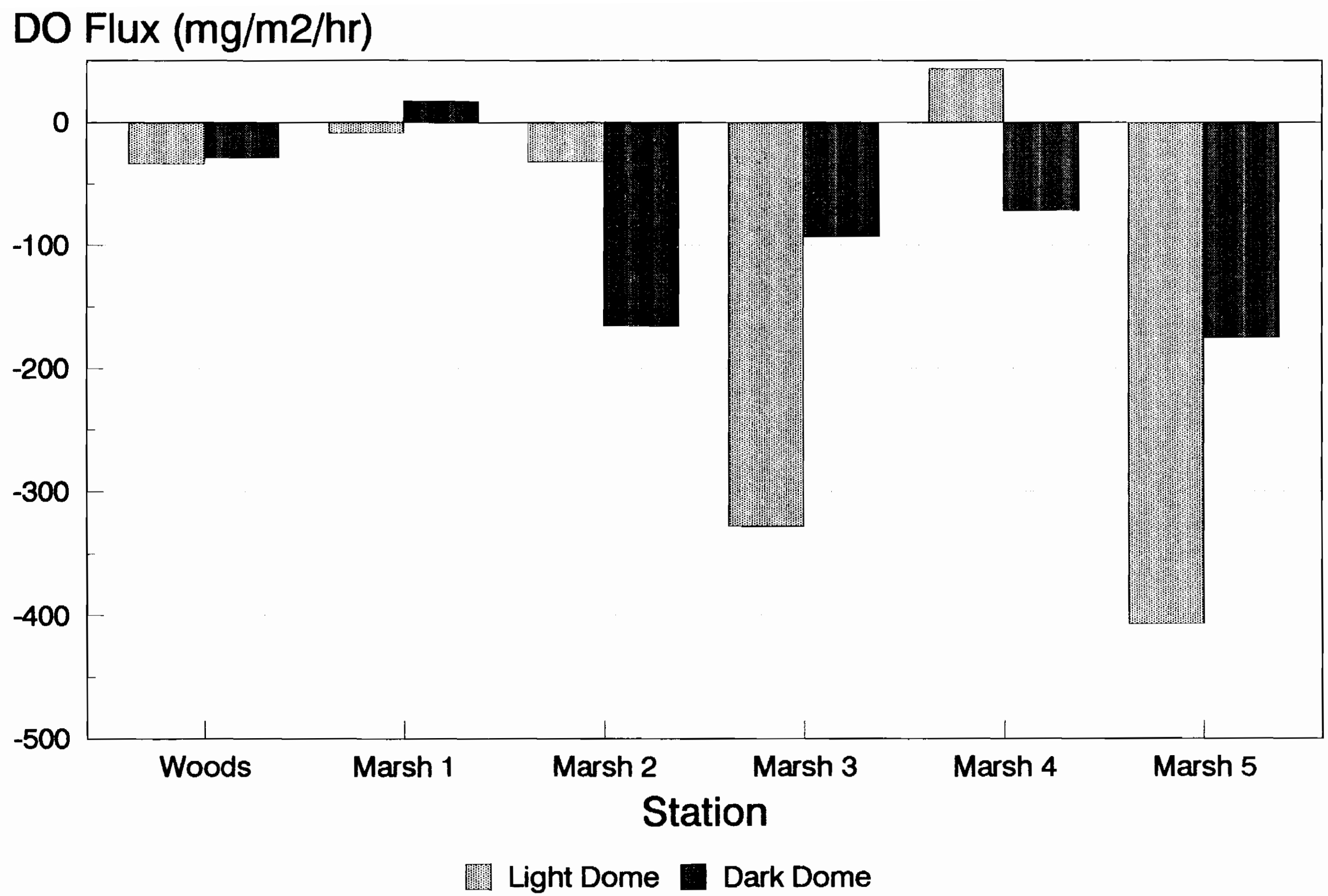

Figure 4.1. Dissolved oxygen bulk flux measurements for Wall's Landing Creek sites: February, 1993.

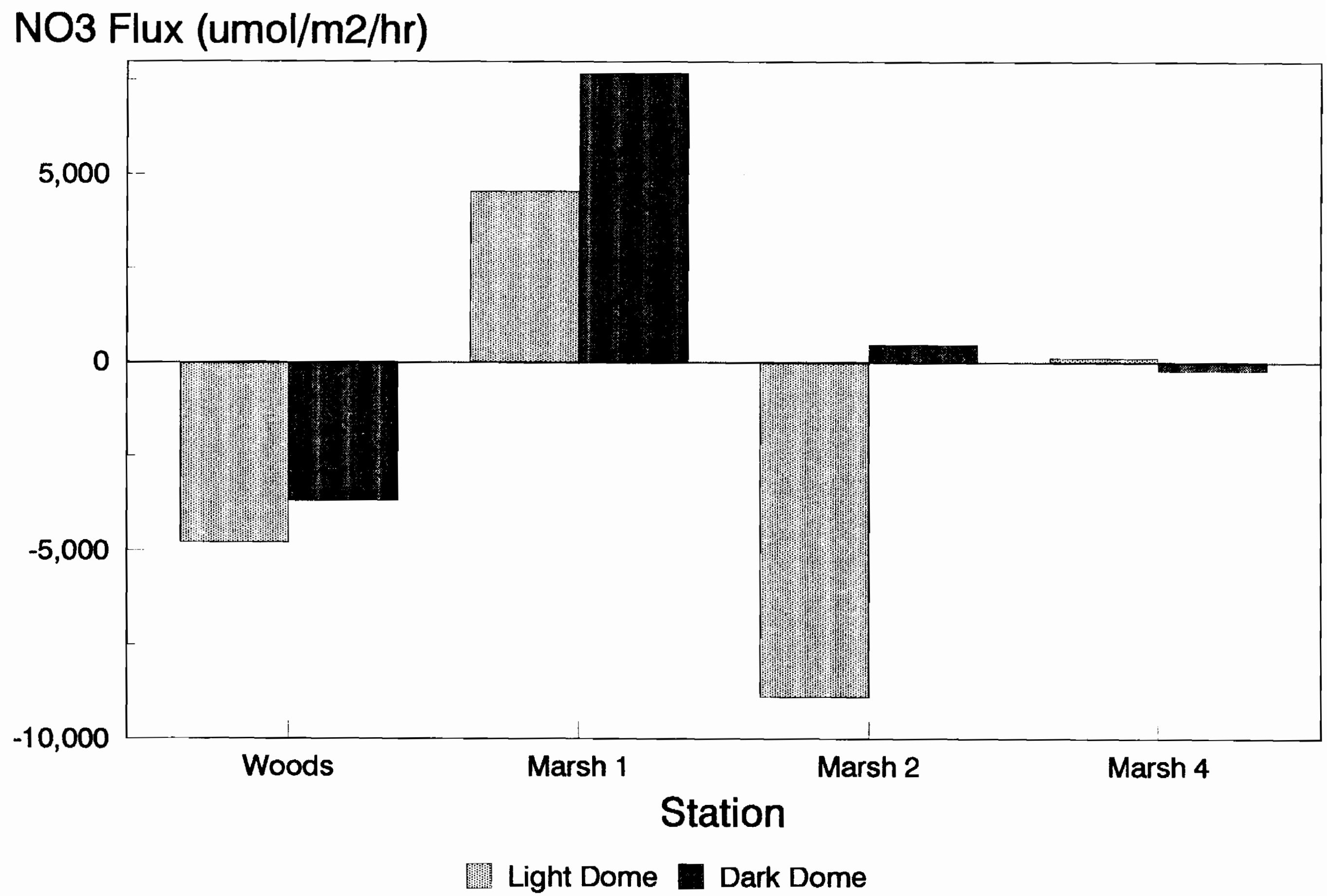

Figure 4.2. Nitrate bulk flux measurements for Wall's Landing Creek sites: February, 1993.

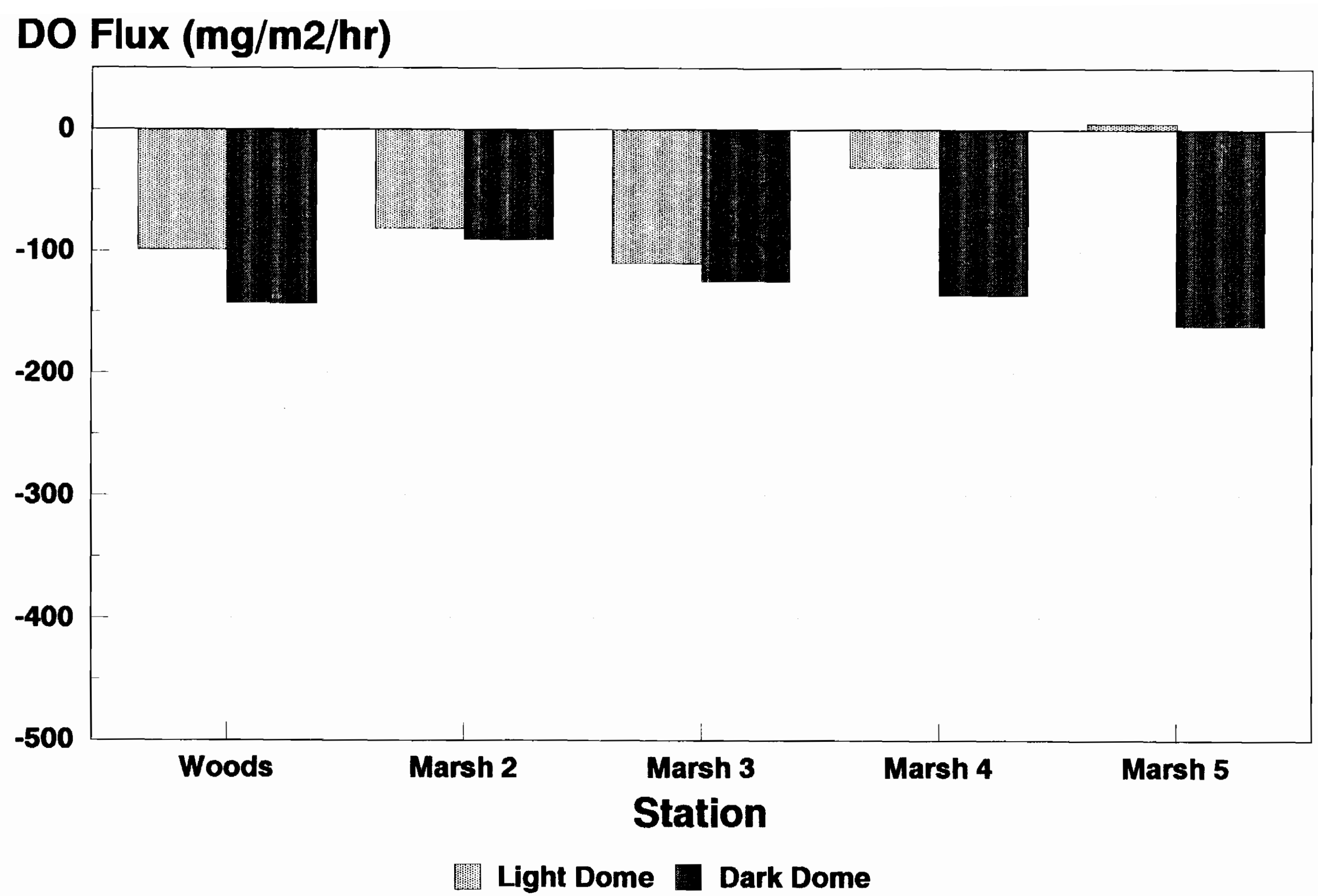

Figure 4.3. Dissolved oxygen bulk flux measurements for Wall's Landing Creek sites: May, 1993.

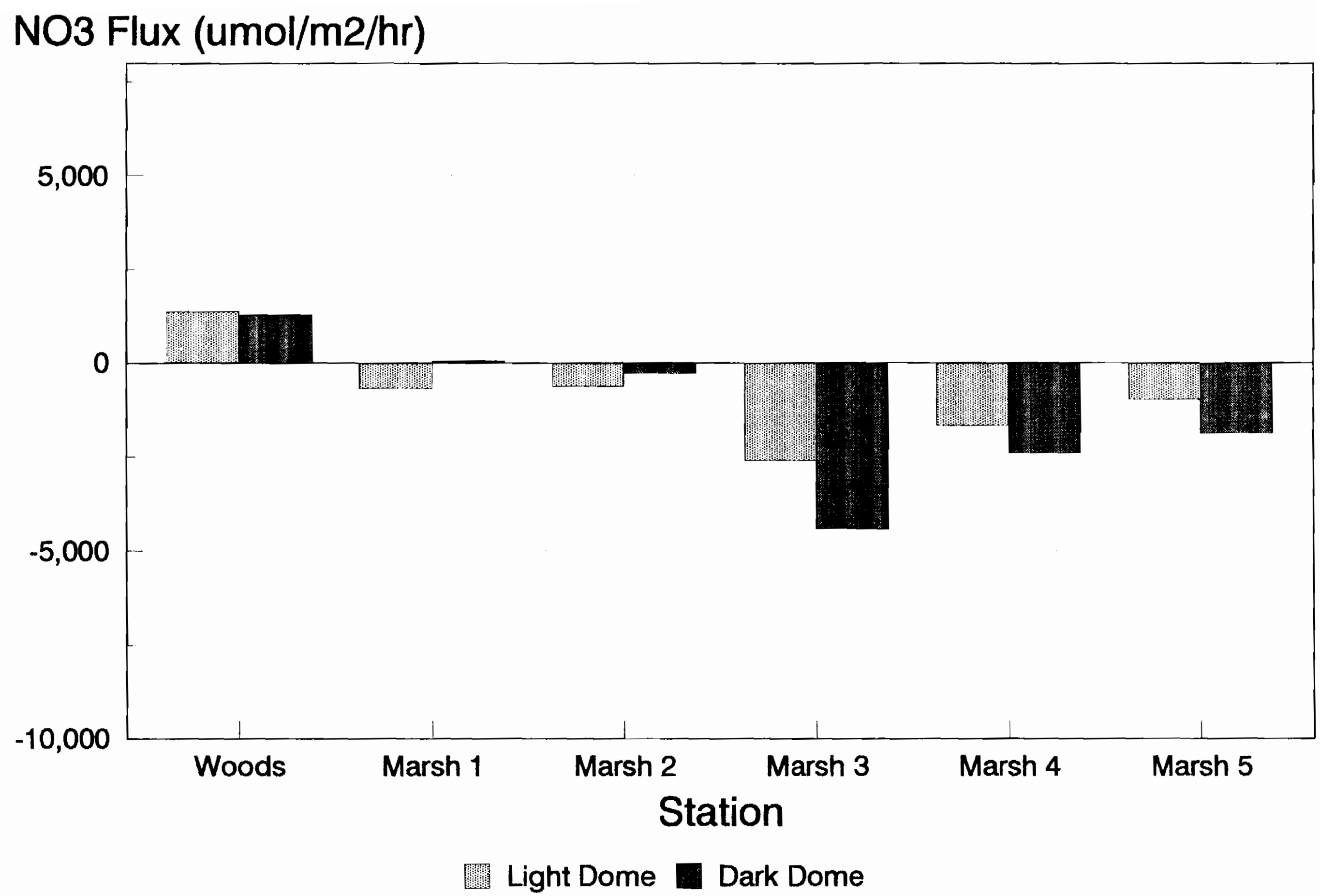

Figure 4.4. Nitrate bulk flux measurements for Wall's Landing Creek sites: May, 1993.

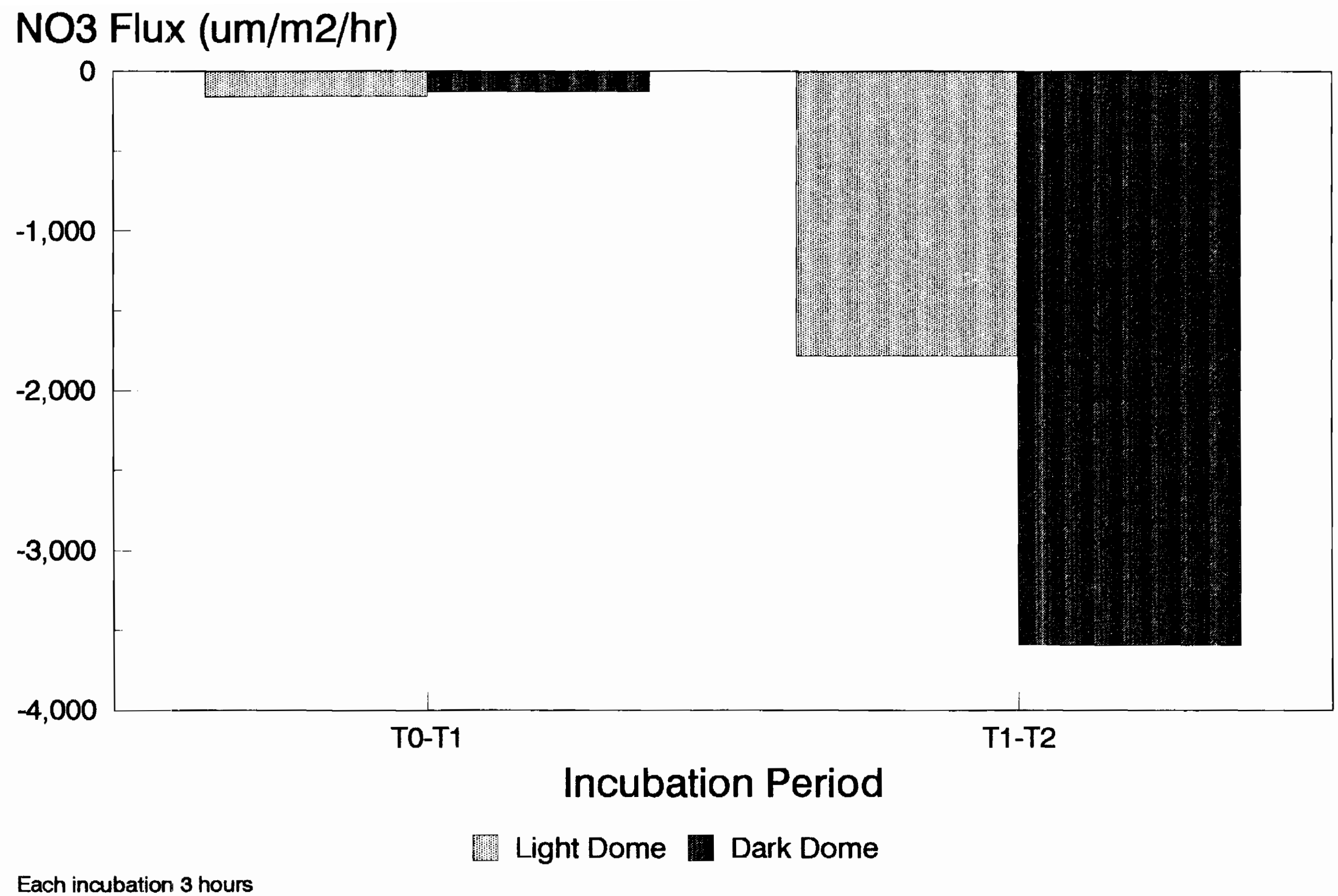

Figure 4.5. Bulk flux measurements from two- three hour incubation periods from marsh site 5 indicating concentration dependence of sediments for nitrate uptake.

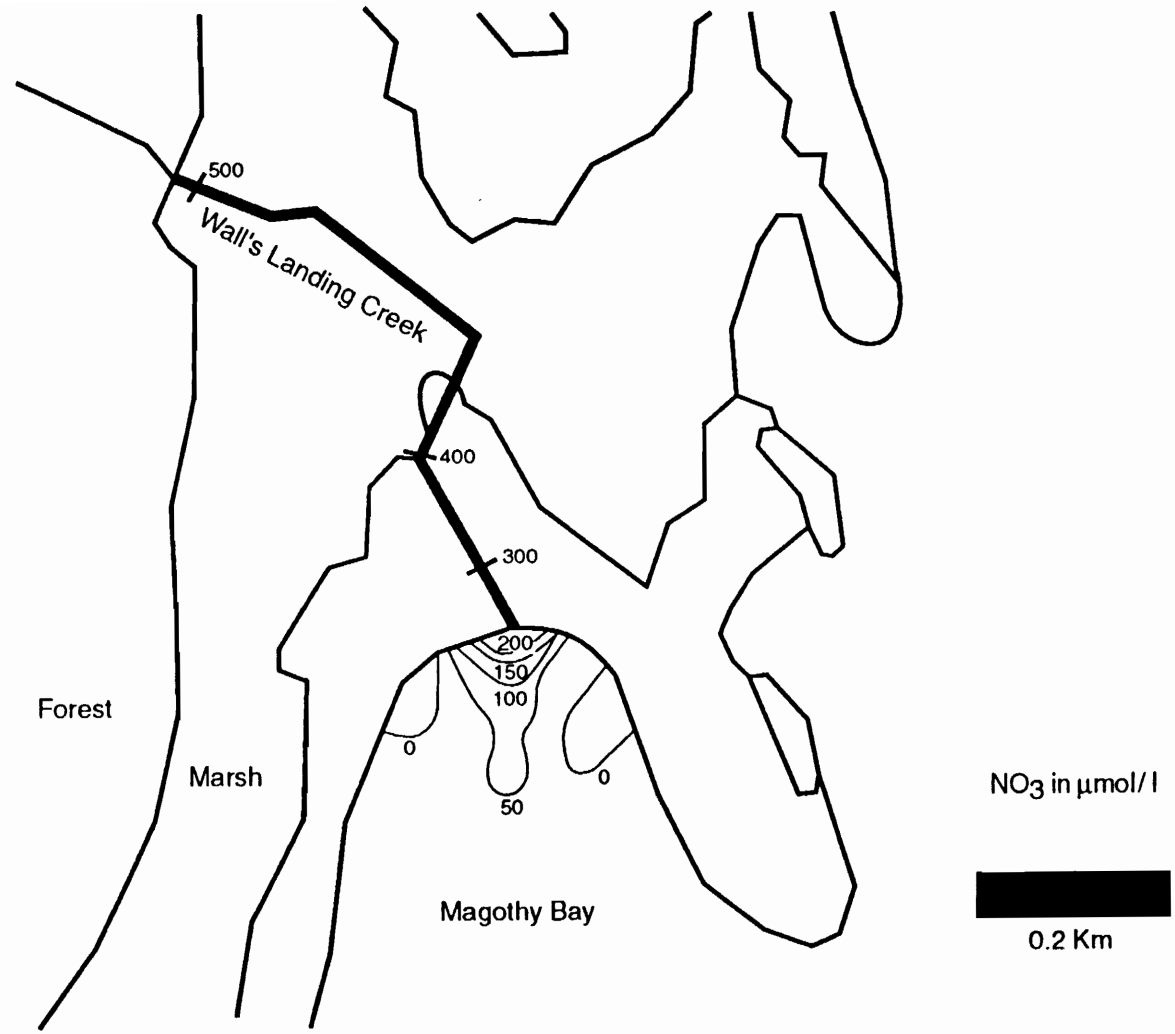

Figure 4.6. Offshore nitrate contour: February, 1993. Wall's Landing Creek entering Magothy Bay.

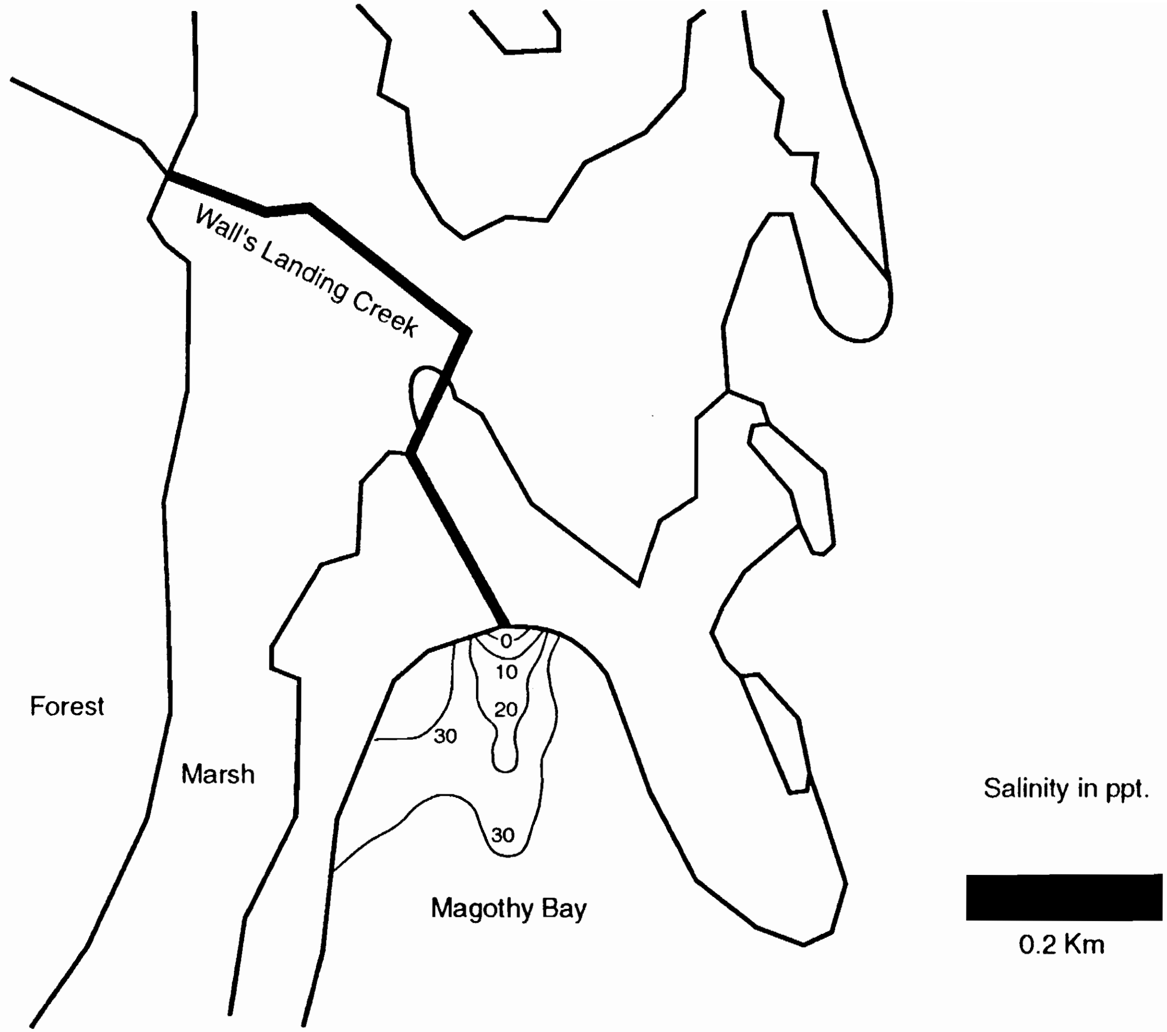

Figure 4.7. Offshore salinity contour: February, 1993. Wall's Landing Creek entering Magothy Bay.

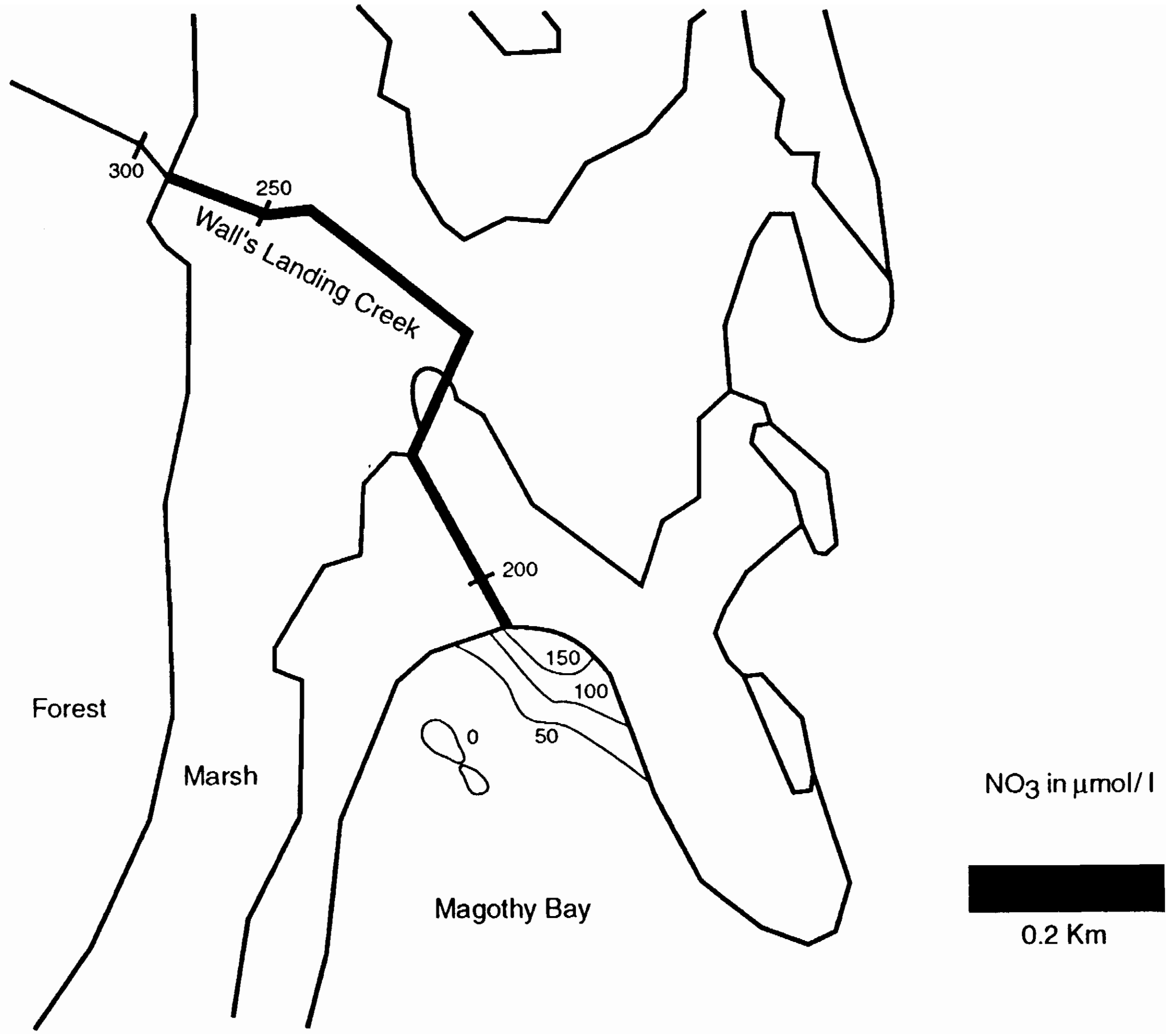

Figure 4.8. Offshore nitrate contour: May, 1993. Wall's Landing Creek entering Magothy Bay.

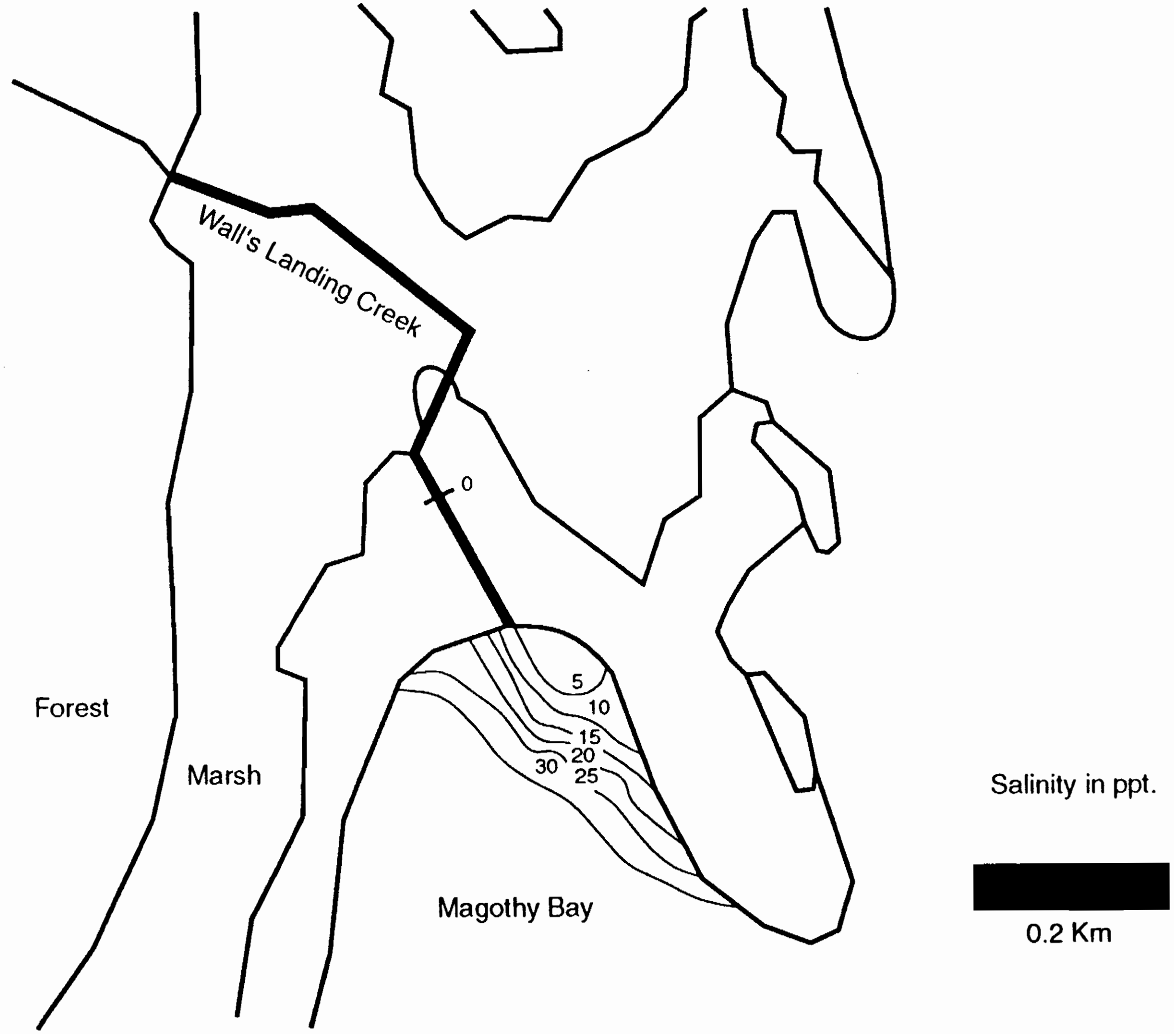

Figure 4.9. Offshore salinity contour: May, 1993.
Wall's Landing Creek entering Magothy Bay.

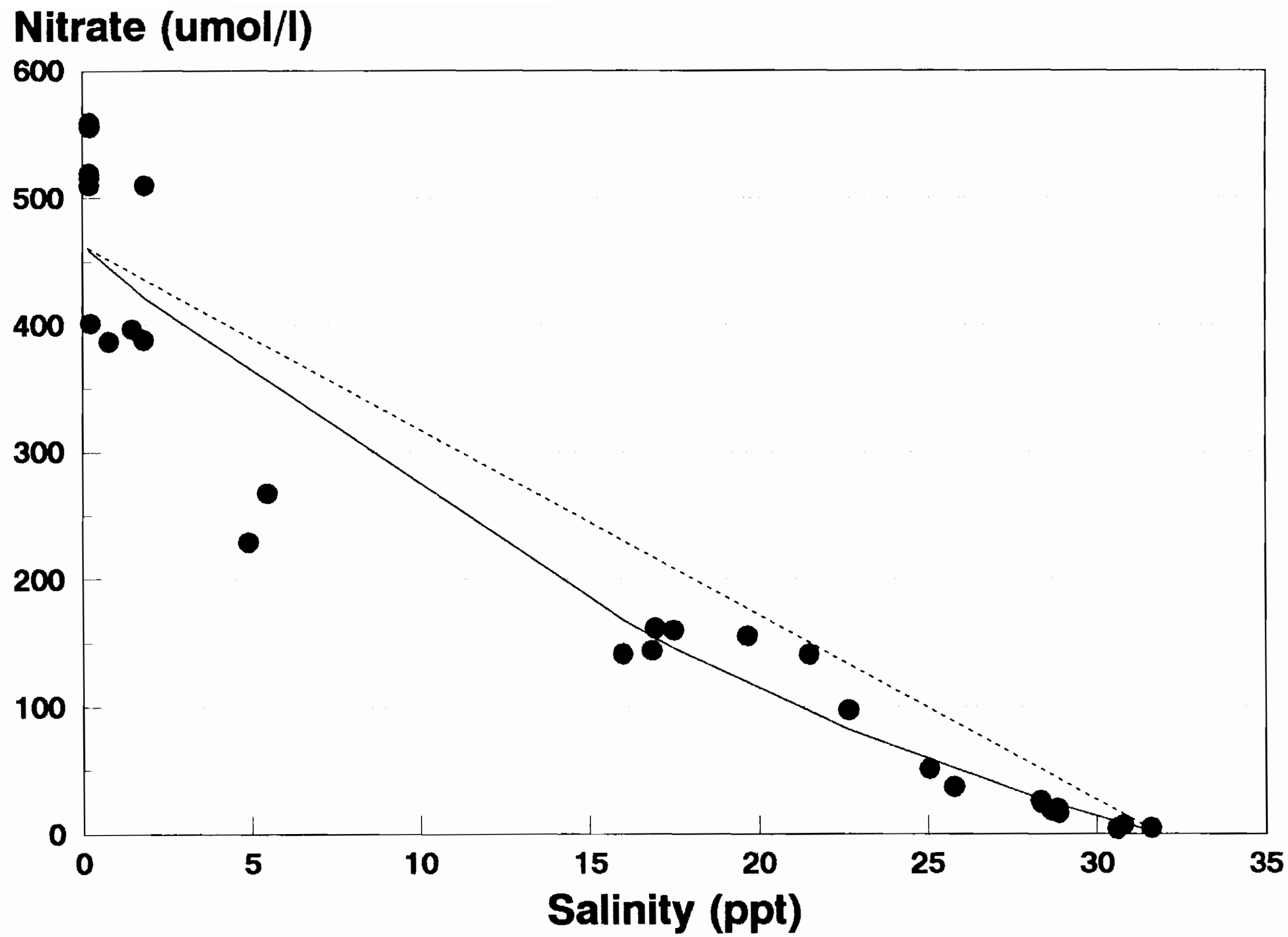

Figure 4.10. Nitrate vs. salinity relationship: February, 1993. Dashed line indicates dilution of nitrate by seawater. Solid line indicates regression of nitrate and salinity values.

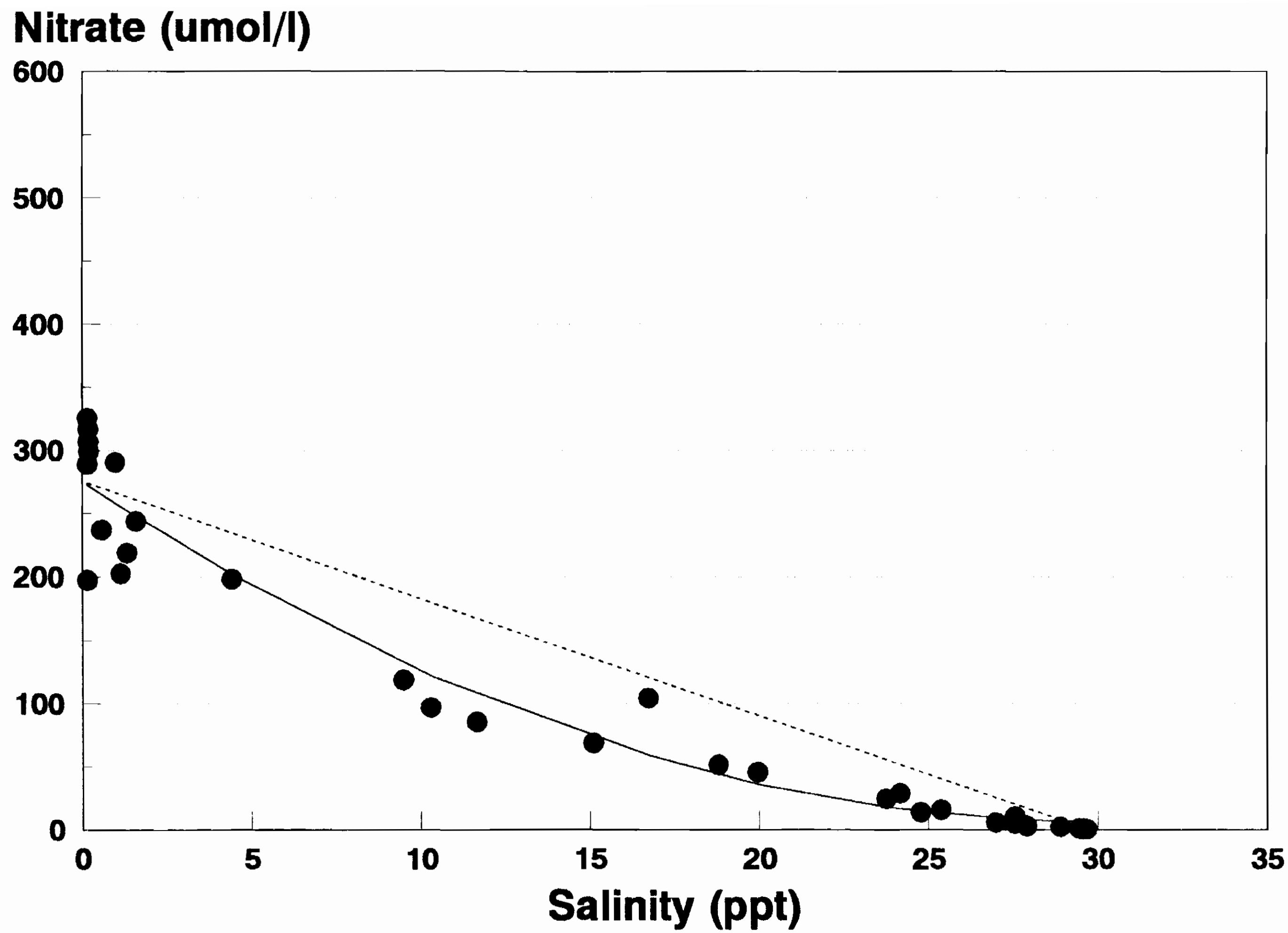

Figure 4.11. Nitrate vs. salinity relationship: May, 1993. Dashed line indicates dilution of nitrate by seawater. Solid line indicates regression of nitrate and salinity values.

4.5 Discussion

Under conditions encountered in Wall's Landing Creek, which included a short residence time in the creek channel and failure of any substantial algal mat to accumulate which could contribute to nutrient uptake, creekwater proceeded essentially unaffected by biological nutrient reduction mechanisms.

Residence time for nutrients flowing in Wall's Landing Creek was estimated at 2.75-4.5 hours from the time of entry, in the upland agricultural field area, to the time of release into Magothy Bay. The short residence time partially limited action by biological components, such as uptake by vascular plants, benthic algae,or other microorganisms, or denitrification, when compared to areas where water may pool such as irrigation ponds. Nutrient and/or light limitations may also exist, which prevent the growth of a substantial algal biofilm. The creek base flow study indicated that high nitrate concentrations moving at a high velocity through an essentially bare channel allowed little chance of nutrient load reduction.

Bulk flux of dissolved oxygen and nitrate suggested that sediments, as isolated by benthic dome chambers, had the potential for removal of nitrate and oxygen. Nutrient reduction occurred at a much higher rate from isolated waters than from ambient creek waters. However, disturbance of sediment during installation of dome chambers may have also enhanced dissolved oxygen and nitrate uptake by stirring up lower lying layers of anoxic sediments. These sediments, normally starved for oxygen and nitrate could have contributed to measured uptakes in dome chambers.

Analysis of nitrate concentration reduction from ambient creek samples suggests a pattern similar to conservation of nitrate with increasing salinity. Strict adherence to the dashed line representing a conservative relationship would indicate that dilution of ambient creek water with seawater was the sole process of reduction of nitrate concentrations. Deviation from this is represented by binomial regression data from both February and May samples. Analysis of the P-value from a binomial regression of February data suggests that it is not significantly different from a linear relationship ($P= 0.077$). This suggests that nitrate reduction was not significantly different from straight dilution. The P-value from the binomial regression of May sampling showed significance, ($P= 0.00$) indicating that it was different from that of a linear relationship. This suggests that there was a slight difference between the actual reduction of nitrate, as compared to dilution, which was attributed to biological factors. Included amoung these factors may be uptake of nitrate by vascular plants, algae, or microorganisms for use as a nutrient, or removal by an anoxic system for use during denitrification as a terminal electron acceptor.

The nitrogen losses through Wall's Landing Creek were consistent with those reported by Jacobs and Gilliam (1985 as cited by Jacobs and Gilliam 1985) from a North Carolina Coastal Plain watershed of 10-55kg/ha/yr. Losses of commercial fertilizer through groundwater into creeks are prevalent and may be unavoidable. The permeable nature of Coastal Plain soils make leaching of nutrients into groundwater inherent in the system. However, adherence to best management practices may provide opportunities for reduction of nutrients in groundwater before reaching sensitive marine environments.

This tidal creek and many others similar on Virginia's Eastern Shore may contribute significant quantities of nutrients to marine habitats. The creek base flow study emphasizes the importance of managing groundwater nutrient loads, through maintenance of adequate riparian vegetation, prior to reaching surface waters.

V. General Discussion and Summary

Nutrient rich water flowing below ground is subject to many biological nutrient reduction mechanisms, including microbial transformations such as denitrification or nitrification, or uptake by vegetation. However, upon reaching the creek channel, seaward flow of high nutrient water proceeded essentially uninhibited due to the short or nonexistent contact time of nutrients with these reduction processes. Nutrient and oxygen transformations in isolated benthic dome chambers suggested that biological processes in the sediments had the potential for nutrient reduction, if contact had occured. Rapid movement of creekwater allowed for little heterotrophic nutrient reduction. In addition, the amount of nitrate actually contacting the creek channel sediments in comparison to total volume of creek water, was not enough to reduce ambient creek nitrate concentrations significantly from a pattern of physical dilution alone.

The upland region of this system was highly susceptible to surface inputs of commercial fertilizers. Conditions conducive to denitrification existing in the forest, as well as vegetation and physical dilution contributed to the loss of nitrate from shallow water table aquifers. Some nitrate which escaped biological reduction into deeper flow patterns appears to be travelling slowly as a plume beneath the forest. This plume has not yet reached the saltmarsh portion of the study site. Low nutrient groundwater in the saltmarsh and offshore areas reflects the pristine conditions which were characteristic of the system prior to human influence.

Conditions described by this study may not be applicable to all sites on the Delmarva Peninsula. Horizontal distance, soil type, vegetation characteristics, and elevation may make some sites along the Atlantic shoreline more similar than those encountered along shorelines facing the Chesapeake Bay. Site hydrologic conditions should be considered on an individual basis when efforts are made to estimate nutrient flux to coastal marine environments.

V. Management Implications

The need exists to identify the location of the freshwater-saltwater transition zone in any aquifer system which is affected by anthropogenic activities. In shallow water table aquifers such as the Columbia aquifer, as well as other highly permeable coastal plain aquifers, surface inputs can reach groundwater very quickly. Groundwater affected by human activities will eventually reach offshore areas and may impact marine environments. A supply of nutrients can lead to algal blooms which significantly reduce light penetration in the water column and cause a portion of the body of water to become anoxic. Also algae in the water column can be deposited on the bottom and kill sensitive organisms. Chemicals applied to upland areas in the form of pesticides or those reaching groundwater by accident such as through spills also have the potential to reach sensitive offshore areas.

The extensive, highly dendritic shoreline of the Chesapeake Bay makes it especially susceptible to influence of adjacent land use activities. The presence of highly permeable sediments as well as the low land surface elevations contribute to rapid travel times from land surfaces to groundwater, and to offshore areas.

In deeper aquifers, where withdrawals of groundwater are used for municipalities or manufacturing, maintaining the transition zone is important to prevent saltwater intrusion.

Volumes of freshwater withdrawals must be managed in order to keep the freshwater head higher than that of saltwater below. Excessive withdrawals can break the balance, allowing saline groundwater to replace freshwater in the aquifer. Only through replacement of freshwater to drive the saltwater back out of the aquifer, can the aquifer slowly become occupied by freshwater. Knowledge of the location of the transition zone is also important for determining the usefulness of marsh areas for nutrient removal from groundwater. Marsh systems are well known for their ability to remove nutrients from waters which come in contact. Both marsh plants and the sediments and soils associated with the marsh provide a means of nutrient removal by plant uptake or by denitrification. However, the site specific hydrology which determines the flow of groundwater through the marsh system is important to be sure that the groundwater in question actually comes in contact with the biological nutrient reduction mechanisms present in the marsh.

Management practices which could possibly reduce nutrient loads prior to the nutrients reaching these creek channels include reducing fertilization rates to optimal levels in agricultural soils as monitored by periodic testing of soils. Maintaining a vegetative buffer zone between any anthropogenically impacted upland area and any body of water can help reduce nutrient loads prior to their reaching the body of water. In areas where nutrients have already reached water, increased contact time with biological nutrient removal mechanisms can reduce nutrient loads. Holding ponds located adjacent to livestock runoff areas normally have anoxic sediments in which denitrification can occur. Characteristically high nitrate in this water, carbon supplied by the incomplete breakdown of plant material in the livestock diet, and the high biological oxygen demand placed on such a pond provides conditions very conducive to nitrogen removal via denitrification (Miller et al. 1985). Also, algae in the water column can remove nutrients from runoff water. In areas such as the Steelman's Landing site, installation of irrigation ponds can also allow groundwater to pool and come into contact with sediments, algae or bacteria in the water column, or provide vegetation in and around the pond's edges with nutrients for growth. Leaf litter and dead vegetation in the pond also provide organic carbon necessary for denitrification.

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Appendix 1. Relative grain size percentages and ash free dry weight by depth: Core 1: forest.

Depth (m)	%Gravel	% Sand	%Silt	%Clay	AFDW%
0.0-0.1	0.00	67.71	25.40	6.89	11.72
0.1-0.2	0.00	53.39	37.68	8.94	4.35
0.2-0.3	0.00	50.58	38.50	10.92	0.94
0.3-0.4	0.06	47.60	38.32	14.02	1.18
0.4-0.5	0.05	48.24	36.56	15.15	1.25
0.5-0.6	0.00	63.06	20.70	16.24	1.34
0.6-0.7	0.00	75.99	8.44	15.57	1.29
0.7-0.8	0.00	83.77	3.68	12.55	1.14
0.8-0.9	0.00	91.41	0.97	7.62	1.00
0.9-1.0	0.00	95.84	2.32	1.84	0.67
1.0-1.1	0.00	99.40	0.60	0.00	0.33
1.1-1.2	0.11	99.31	0.58	0.00	0.31
1.2-1.3	0.00	99.73	0.27	0.00	0.28
1.3-1.4	0.00	100.00	0.00	0.00	0.36
1.4-1.5	0.00	100.00	0.00	0.00	0.50
1.5-1.6	0.00	97.40	2.18	0.42	0.87
1.6-1.7	0.00	80.96	3.00	16.04	0.87
1.7-1.8	0.00	87.80	2.88	9.32	1.12
1.8-1.9	0.00	83.47	5.65	10.88	1.32
1.9-2.0	0.00	79.52	8.30	12.17	1.27
2.0-2.1	0.00	70.58	18.05	11.38	1.68
2.1-2.2	0.00	74.79	18.82	6.40	0.76
2.2-2.3	0.00	98.59	0.68	0.73	0.24
2.3-2.4	0.00	99.17	0.27	0.55	0.33
2.4-2.5	0.00	99.16	0.07	0.77	0.29
2.5-2.6	0.00	99.32	0.19	0.49	0.20
2.6-2.7	0.00	86.66	3.15	10.20	0.20
2.7-2.8	0.00	80.93	6.52	12.55	0.28
2.8-2.9	0.00	73.10	10.91	15.99	0.33
2.9-3.0					0.26
3.0-3.1					0.33
3.1-3.2					0.22
3.2-3.3	0.00	99.16	0.29	0.54	0.23
3.3-3.4	0.00	99.05	0.08	0.87	0.25
3.4-3.5	0.00	99.29	0.20	0.51	0.30
3.5-3.6	0.00	99.77	0.16	0.07	0.31
3.6-3.7	2.14	97.30	0.56	0.00	0.00
3.7-3.8	0.00	99.93	0.07	0.00	0.24
3.8-3.9	1.61	98.37	0.01	0.00	1.10
3.9-4.0	3.48	96.26	0.00	0.26	0.21
4.0-4.1	3.49	96.20	0.26	0.05	0.22
4.1-4.2	22.02	77.71	0.26	0.01	1.40
4.2-4.3	64.50	35.45	0.05	0.00	0.21
4.3-4.4	47.80	51.81	0.34	0.05	0.43

Appendix 1. (Continued). Core 1.

Depth (m)	%Gravel	%Sand	%Silt	%Clay	AFDW%
4.4-4.5	46.78	52.45	0.00	0.77	0.20
4.5-4.6	31.30	68.26	0.44	0.00	0.18
4.6-4.7	40.98	58.11	0.91	0.00	0.23
4.7-4.8	48.67	50.44	0.89	0.00	0.24
4.8-4.9	24.15	72.52	3.04	0.30	0.84
4.9-5.0	0.00	90.14	8.78	1.06	0.94
5.0-5.1	0.00	87.27	12.51	0.21	0.94
5.1-5.2	0.00	90.69	9.31	0.00	1.20
5.3-5.3	0.00	78.24	21.48	0.28	0.91
5.3-5.4	0.00	97.26	2.47	0.27	0.66
5.4-5.5	0.00	97.68	1.77	0.55	0.70
5.5-5.6	0.00	97.62	1.86	0.52	0.79
5.6-5.7	0.00	97.95	2.05	0.00	0.82
5.7-5.8	0.00	98.27	1.24	0.49	0.79
5.8-5.9	0.00	96.32	3.26	0.42	0.81
5.9-6.0	0.00	96.66	2.34	1.12	1.10
6.0-6.1	0.00	96.98	2.53	0.49	
6.1-6.2	0.00	98.17	1.80	0.03	
6.2-6.3	0.00	93.41	4.51	2.08	
6.3-6.4	0.00	88.27	5.26	6.47	
6.4-6.5	0.00	92.48	6.54	0.99	
6.5-6.6	0.00	91.59	7.85	0.56	
6.6-6.7	0.00	90.80	8.11	1.10	
6.7-6.8	0.00	87.45	11.18	1.37	
6.8-6.9	0.00	92.72	6.51	0.77	
6.9-7.0	0.18	94.21	4.56	1.05	
7.0-7.1	0.00	96.82	2.51	0.67	
7.1-7.2	0.00	95.99	1.90	2.11	
7.2-7.3	0.00	95.84	2.94	1.21	
7.3-7.4	0.00	94.83	4.24	0.93	
7.4-7.5	0.00	96.18	2.48	1.34	
7.5-7.6	0.00	92.47	5.39	2.13	
7.6-7.7	0.00	92.22	5.69	2.09	
7.7-7.8	0.00	96.24	2.78	0.98	
7.8-7.9	0.00	95.05	4.96	0.00	
7.9-8.0	0.00	92.36	7.26	0.38	
8.0-8.1	0.00	88.97	11.03	0.00	
8.1-8.2	0.00	94.75	5.25	0.00	
8.2-8.3	0.00	98.09	1.91	0.00	

Appendix 1. Relative grain size percentages and ash free dry weight by depth: Core 2: last onshore.

Depth (m)	%Gravel	%Sand	%Silt	%Clay	AFDW%
0.0-0.1	0.00	84.47	6.48	8.89	3.42
0.1-0.2	0.00	98.69	0.71	0.60	11.07
0.2-0.3	0.00	84.20	9.20	6.60	1.41
0.3-0.4	0.00	97.38	1.77	0.85	1.53
0.4-0.5	0.00	96.68	2.15	1.17	1.83
0.5-0.6	0.00	55.50	28.03	16.46	1.98
0.6-0.7	0.00	57.60	25.97	16.42	1.66
0.7-0.8	0.00	59.19	22.15	18.66	1.50
0.8-0.9	0.00	63.93	21.14	14.93	1.42
0.9-1.0	0.00	74.04	14.41	11.56	1.20
1.0-1.1	0.00	79.18	9.35	11.47	1.24
1.1-1.2	0.00	86.62	6.20	7.17	2.49
1.2-1.3	0.00	63.10	22.07	14.82	1.51
1.3-1.4	0.00	57.32	24.76	17.92	1.29
1.4-1.5	0.00	58.40	24.52	17.07	1.18
1.5-1.6	0.00	58.34	25.00	16.66	1.29
1.6-1.7	0.00	65.79	18.82	15.39	0.97
1.7-1.8	0.00	73.30	12.55	14.15	1.19
1.8-1.9	0.00	77.73	7.96	14.31	1.49
1.9-2.0	0.00	85.23	2.63	12.14	1.34
2.0-2.1	0.00	91.67	2.36	5.97	0.89
2.1-2.2	0.08	93.20	2.51	4.22	0.74
2.2-2.3	0.00	99.31	4.55	2.14	0.84
2.3-2.4	0.00	99.20	0.41	0.38	0.42
2.4-2.5	0.00	99.14	0.45	0.41	0.62
2.5-2.6	0.31	94.56	4.28	0.85	0.54
2.6-2.7	0.00	89.57	7.60	2.83	0.65
2.7-2.8	0.00	99.18	0.42	0.40	0.64
2.8-2.9	0.07	99.56	0.36	0.00	0.43
2.9-3.0	0.29	99.30	0.41	0.00	0.84
3.0-3.1	0.00	99.62	0.38	0.00	0.48
3.1-3.2	0.06	99.04	0.45	0.00	0.69
3.2-3.3	6.26	89.03	3.37	1.34	0.79
3.3-3.4	1.41	97.32	0.45	0.81	0.85
3.4-3.5	6.17	91.71	1.97	0.15	0.99
3.5-3.6	0.56	97.61	1.22	0.61	0.88
3.6-3.7	0.00	97.45	1.55	1.00	1.03
3.7-3.8	0.56	96.56	1.56	1.32	0.59
3.8-3.9	0.52	96.98	0.86	1.64	0.69
3.9-4.0	0.12	99.06	0.42	0.38	0.68
4.0-4.1	0.11	97.10	2.17	0.62	0.49

Appendix 1. (Continued). Core 2.

Depth (m)	%Gravel	%Sand	%Silt	%Clay	AFDW%
4.1-4.2	0.05	98.99	0.13	0.83	0.52
4.2-4.3	3.22	90.28	4.33	2.17	0.44
4.3-4.4	6.83	91.26	1.79	0.12	0.69
4.4-4.5	2.11	74.90	12.75	10.24	0.59
4.5-4.6	1.03	97.86	1.05	0.07	0.50
4.6-4.7	0.00	13.82	55.83	30.28	0.59
4.7-4.8	0.22	84.91	14.02	0.85	0.66
4.8-4.9	9.86	78.45	7.32	4.37	0.54
4.9-5.0	2.58	84.39	12.36	0.66	0.21
5.0-5.1	13.63	86.05	0.42	0.00	0.48
5.1-5.2	0.14	13.87	57.94	28.05	0.00
5.3-5.3	0.20	19.73	30.72	49.35	0.06
5.3-5.4	0.00	3.49	22.42	74.09	
5.4-5.5	0.00	8.82	47.20	43.97	0.42
5.5-5.6	0.00	0.77	28.98	70.25	0.33
5.6-5.7	3.23	56.62	36.03	4.11	0.24
5.7-5.8	5.99	83.92	6.36	3.73	0.62
5.8-5.9	7.06	86.33	4.98	1.63	
5.9-6.0	4.44	86.38	6.37	2.80	
6.0-6.1	6.48	87.45	4.44	1.64	
6.1-6.2	29.83	67.19	2.10	0.88	
6.2-6.3	14.56	82.55	2.66	0.23	
6.3-6.4	8.63	87.28	3.28	0.82	
6.4-6.5	9.15	87.38	3.45	0.02	
6.5-6.6	5.39	87.76	3.01	3.85	
6.6-6.7	7.36	86.60	3.02	3.02	
6.7-6.8	17.54	75.84	3.04	3.58	
6.8-6.9	6.59	85.34	3.35	4.73	
6.9-7.0	11.16	83.00	1.94	3.91	
7.0-7.1	8.57	85.01	2.67	3.75	
7.1-7.2	23.42	71.23	2.47	2.87	
7.2-7.3	51.73	42.81	3.42	2.03	
7.3-7.4	32.81	61.51	3.74	1.94	
7.4-7.5	14.58	81.90	2.15	1.37	
7.5-7.6	11.28	83.73	3.84	1.15	
7.6-7.7	6.07	87.25	5.03	1.65	
7.7-7.8	11.54	83.99	3.55	0.91	
7.8-7.9	1.73	94.18	2.70	1.40	
7.9-8.0	22.23	74.78	2.57	0.41	
8.0-8.1	8.82	85.90	5.17	0.11	

Appendix 1. Relative grain size percentages and ash free dry weight by depth: Core 3: offshore.

Depth (m)	%Gravel	% Sand	%Silt	%Clay	AFDW%
0.0-0.1	0.11	56.76	23.39	19.74	3.16
0.1-0.2	0.20	59.02	24.04	16.75	2.55
0.2-0.3	0.57	57.17	25.31	16.97	3.13
0.3-0.4	0.48	58.66	23.89	17.14	2.92
0.4-0.5	1.65	56.39	24.83	17.14	2.63
0.5-0.6	0.06	66.57	19.90	13.47	2.64
0.6-0.7	0.20	59.46	25.54	14.81	2.85
0.7-0.8	0.03	54.75	27.16	18.06	3.17
0.8-0.9	1.61	46.17	28.39	23.82	4.23
0.9-1.0	0.16	40.20	32.87	26.77	2.67
1.0-1.1	0.12	43.59	32.65	23.64	2.54
1.1-1.2	3.31	48.29	27.39	21.01	3.13
1.2-1.3	0.05	41.43	31.78	26.73	0.45
1.3-1.4	0.07	66.85	18.15	14.93	0.47
1.4-1.5	0.00	93.83	4.32	1.85	0.32
1.5-1.6	0.00	96.03	3.25	0.72	0.34
1.6-1.7	0.00	96.08	3.92	0.00	0.51
1.7-1.8	0.10	96.94	2.96	0.00	0.38
1.8-1.9	0.19	96.04	3.29	0.49	0.34
1.9-2.0	2.36	94.30	3.34	0.00	
2.0-2.1	0.07	96.43	3.33	0.17	
2.1-2.2	0.00	96.42	3.52	0.07	
2.2-2.3	0.00	97.17	2.15	0.68	
2.3-2.4	0.00	97.28	2.39	0.34	
2.4-2.5	0.00	96.70	3.06	0.25	
2.5-2.6	0.00	96.86	2.56	0.58	
2.6-2.7	1.37	96.15	1.73	0.76	
2.7-2.8	4.75	92.40	2.11	0.74	
2.8-2.9	0.00	97.11	2.89	0.00	
2.9-3.0	0.08	96.10	3.26	0.56	
3.0-3.1	0.03	96.66	3.03	0.28	
3.1-3.2	0.00	96.30	2.74	0.96	
3.2-3.3	0.22	96.25	2.95	0.58	
3.3-3.4	1.93	95.36	2.67	0.05	
3.4-3.5	2.46	96.32	1.22	0.00	
3.5-3.6	4.58	92.76	2.66	0.00	
3.6-3.7	2.02	94.12	2.94	0.92	
3.7-3.8	0.64	94.92	3.89	0.55	
3.8-3.9	1.70	94.42	3.41	0.47	
3.9-4.0	4.20	92.21	3.43	0.16	
4.0-4.1	0.52	96.08	2.73	0.66	
4.1-4.2	0.00	96.16	3.10	0.74	
4.2-4.3	1.00	95.11	3.59	0.31	

Appendix 1. (Continued). Core 3.

Depth (m)	%Gravel	%Sand	%Silt	%Clay
4.3-4.4				
4.4-4.5	0.19	96.32	2.54	0.96
4.5-4.6	0.06	96.22	3.22	0.50
4.6-4.7	0.19	97.90	1.91	0.00
4.7-4.8	12.62	85.58	1.80	0.00
4.8-4.9	17.52	80.02	2.46	0.00
4.9-5.0	24.15	72.15	3.47	0.23
5.0-5.1	2.46	93.85	3.69	0.00
5.1-5.2	0.12	93.31	6.57	0.00
5.2-5.3	0.00	94.07	5.93	0.00
5.3-5.4	0.06	94.47	5.48	0.00
5.4-5.5	0.07	92.13	6.32	1.47
5.5-5.6	0.43	79.57	18.02	1.98
5.6-5.7	0.24	93.95	5.16	0.65
5.7-5.8	0.13	93.86	5.19	0.83
5.8-5.9	0.43	94.75	4.03	0.79
5.9-6.0	0.00	90.47	8.59	0.94
6.0-6.1	0.00	76.10	20.67	3.24
6.1-6.2	4.26	47.34	32.04	16.35
6.2-6.3	0.07	57.75	36.83	5.36
6.3-6.4	0.06	39.67	32.37	27.91
6.4-6.5	7.33	84.80	6.56	1.32

PROFESSIONAL VITA
of
HOWARD C. NIPPERT

September 1993

CAREER GOAL: College Professor.

PERSONAL:

Birthdate:	July 15, 1965
Birthplace:	Warwick, New York
Height:	5 feet, 6 inches
Weight:	123 lbs.
	No physical defects
Marital Status:	Single

PRESENT ADDRESS:

Home: 2467 Cypress Lane
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EDUCATION:

1993 M.S., Biology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Thesis: *Investigation of Salinity and Nutrient Characteristics of Two Groundwater Based Flow Systems on Virginia's Eastern Shore.*

1988 B.S., Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

PRESENT POSITION:

Instructor of Biology, Radford University.

Research Assistant, Virginia Polytechnic Institute and State University.

EMPLOYMENT:

1993 Graduate Teaching Assistant. Honors Freshman Biology Laboratory. Biology Dept., VPI&SU.

1992 Graduate Teaching Assistant. Freshwater Ecology Laboratory. (Seniors and graduate students) Biology Dept., VPI&SU.

1991-1992 Graduate Research Assistant. Investigation of freshwater-saltwater transition zone on Virginia's Eastern Shore, for Virginia Division of Soil and Water Conservation. Dr. G.M. Simmons, Jr., Biology Dept., VPI&SU.

1990-1991 Laboratory Technician. Effectiveness of a mesic forest in the reduction of nutrients from agricultural ground water drainage, for Virginia Division of Soil and Water Conservation. Dr. G.M.Simmons, Jr., Biology Dept., VPI&SU.

REPORTS:

Nippert,H., *Is the A-1 Fermentation Method for Evaluation of Shellfish Growing Areas Adequate?* Unpublished report to Division of Shellfish Sanitation, Virginia Department of Health, May 1993.

Nippert,H., Location and quantification of the freshwater-saltwater transtion zone in an unconfined aquifer on Virginia's Eastern Shore. In Simmons,G.M., Unpublished, *Annual Report to the Virginia Department of Conservation and Historic Resources*, July 1992.

Nippert,H., Effectiveness of a mesic forest in reduction of nutrients from agricultural ground water drainage. In Simmons,G.M., Nippert,H., Reay,W., Smedley,S., and Gallagher,D.L., *Submarine Groundwater Discharge Coupling Land/Water Ecosystems,* Unpublished Report to Virginia Division of Soil and Water Conservation, August 1991.

TEACHING EXPERIENCE:

1993 Instructor of Biology. Principles of Biology. Lecture and Laboratory. Biology Dept., Radford University.

1993 Graduate Teaching Assistant. Honors Freshman Biology Laboratory. Biology Dept., VPI&SU.

1993 Substitute Lecturer for Dr. G.M. Simmons, Jr., General Biology., VPI&SU.

1992 Graduate Teaching Assistant. Freshwater Ecology Laboratory. Biology Dept., VPI&SU.

1992 Lecturer on groundwater quality and water chemistry for accelerated high school students. Center for Talented Youth. VPI&SU.

1992-1993 Lectures on groundwater monitoring, monitoring well installation, and limnological analyses, to senior and graduate civil engineering classes (Environmental Sampling and Monitoring, CE5724 and Dynamics of Groundwater, CE5374).

1992 Completed Virginia Tech Fall Graduate Teaching Assistant Seminar. August 17-19.

PROFESSIONAL PRESENTATIONS:

1993 April, 1993. 6th Annual Virginia Water Resources Conference, Richmond, VA. *The Freshwater-Saltwater Transition Zone and it's Relationship to a Natural Saltmarsh on Virginia's Eastern Shore.*

1993 April, 1993 Ecology and Environmental Biology Seminar, *The Freshwater-Saltwater Transition Zone and it's Relationship to a Natural Saltmarsh on Virginia's Eastern Shore.* Biology Dept. VPI&SU.

ADDITIONAL INFORMATION:

1993 United States National Marathon Team, World University Games.

1991-1993 Assistant Men's Cross-Country Coach, VPI&SU.

1992 Member U.S.A. Track and Field National Half Marathon Team Champions, Blue Ridge Asics Mountain Runners.

1991 1st, Virginia State 8K Championships.

1987 Member 4th Place Team, NCAA Division I Cross-Country Championships, VPI&SU.

REFERENCES:

Dr. G.M. Simmons, Jr., Department of Biology, Derring Hall, VPI&SU.

Dr. A.L. Buikema, Department of Biology, Derring Hall, VPI&SU.

Mr. Steve Taylor, Men's Head Cross-Country Coach, VPI&SU Athletic Department, Cassell Coliseum.

Dr. J.R. Webster, Department of Biology, Derring Hall, VPI&SU.