DETERMINATION OF THE QUANTITY, QUALITY, AND LOCATION OF COASTAL GROUNDWATER DISCHARGE TO A MARINE EMBAYMENT: GREENWICH BAY, RHODE ISLAND

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FOR

CITY OF WARWICK, RHODE ISLAND

December, 1998

Abstract

As population increases in the coastal zone, many stresses occur in the coastal surface water environment. Anthropogenic pollution is a major cause of eutrophication throughout the world in both marine coastal and terrestrial water bodies. Nitrogen is the limiting nutrient in marine environments, and a major factor in causing eutrophication. Nitrogen is a major component of sewage effluent and is not totally removed from wastewater by conventional sewage disposal systems. Greenwich Bay, a small embayment in Rhode Island, is bounded by the highly populated cities of Warwick, and East Greenwich. As of 1992 only 40% of the residents of Warwick and 85% of East Greenwich residents were connected to public sewers.

A study was conducted to determine the effect sewering would have in reducing nitrogen loading to Greenwich Bay. This study included (1) delineation of the Greenwich Bay watershed, and subsequently the delineation of 23 sub-basins within the watershed; (2) development of a regional water budget; (3) development of a nitrogen budget/predictive model using a combination of ARCINFO geographic information systems (GIS) software, literature values for nitrogen inputs, and local population census data; (4) installation of semi permanent monitor wells to measure groundwater water quality; (5) measurement of direct groundwater coastal seepage water quality at sites determined by thermal infrared aerial imagery, and output from the nitrogen budget; and (6) prediction of the effect that sewering the entire Greenwich Bay watershed would have on nitrogen loading.

From the water budget analysis it is estimated that 55.9 million liters per day (15 million gallons per day) of groundwater discharges into Greenwich Bay or its contiguous coves, with an average nitrogen concentration of 6.6 mg/L, resulting in 369.9 kg per day of nitrogen entering Greenwich Bay from groundwater alone. Nitrogen concentrations in coastal discharge ranged from 4.2 mg/L for a relatively unpopulated area to 14.4 mg/L for areas of unsewered high residential density. Thermal infrared imagery and water quality sampling at low tide indicate high variability in the groundwater discharge pattern along the coastline. Especially noteworthy is the nitrogen loading to small, poorly flushed coves such as Brushneck Cove where groundwater discharge concentrations as high as 14.5 mg/L were measured, and the near shore water shows the effects of severe eutrophication.

It is predicted that complete sewering of the watershed would reduce the total nitrogen to 65.8 kg/day, a reduction of 82 percent. This is what will happen if everyone in the sub-basin connects to public sewers. As of the time when this paper was written, the connection to public sewers is optional. The Cities of Warwick and East Greenwich reserve the right to make such connections mandatory.

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1 INTRODUCTION

1.1 Statement of Research Problem

Many coastal surface water environmental impacts can be traced to the transport of contaminants via groundwater. As groundwater in a developed area travels to its discharge location it continuously accumulates various anthropogenic contaminants (Giblin and Gaines, 1990, Van den Brink and Zaadnoordijk, 1995). Human activities within the coastal watershed often produce nutrient rich waste products that directly enter waterways through runoff, or indirectly through groundwater which in turn discharges to streams and or directly into the receiving water causing what is called "cultural eutrophication" (Hantzsche and Finnemore, 1992, Valiela et al., 1992, Jorgensen and Richardson, 1996, Fuhs, 1974). Eutrophication, from the Greek "Eu" meaning well and "trope" meaning nourished, can be described as over stimulating a system with mineral nutrients such as phosphorus and nitrogen. On-site sewage disposal systems (OSSDs) are the highest ranking pollution source in terms of total volume of nutrient rich contaminated discharge to groundwater (Urish, 1991). Thirty to forty percent of the population of Rhode Island use OSSDs to treat and dispose of sanitary waste (Urish, 1991). Nitrogen is a major component of sewage effluent (Canter and Knox, 1985, Valiela et al., 1992, Hantzsche and Finnemore, 1992, Lapointe et al, 1990).

Adverse environmental effects along the coastline (Jorgensen and Richardson, 1996) occur mainly in;

- Semi enclosed seas,
- Fjords with sills that restrict exchange of water,
- Lagoons, bays, and harbors,
- Estuaries, and Coastal Rivers.

It should be noted that both in popular and scientific literature the term eutrophication has been frequently used to describe both the process of nutrient enrichment and the effects of enrichment. Eutrophication is the over nourishment of flora and can happen with or without the interference of man. Where the effect is from a developed area, it is more meaningful to call this process cultural eutrophication since cultural eutrophication suggests anthropogenic sources of the nutrient enrichment. The most common effect of eutrophication is the increase in biomass. Production (primarily growth) and loss (grazing, sedimentation, mortality and dilution) govern the amount of biomass present at any given time. New production is the only way to increase the presence of nitrogen in the water body. Regeneration is another form of production in which the nitrogen from the dying or dead plant life is recycled keeping it suspended within the eutrophic zone (Jorgensen and Richardson, 1996).

The factors that limit plant growth in marine waters are light, nutrient availability, and to a lesser degree temperature. Nitrogen is the limiting nutrient in a seasonally eutrophic body of salt water, due to the natural abundance of phosphorous, light and warm temperatures (Fuhs, 1974, Capone and Slater, 1990, Jorgensen and Richardson, 1996, Urish and Qanbar, 1997, Weiskel and Howes, 1991, Harman et al., 1996). An increase of nitrogen typically increases the total amounts of nutrients that can be utilized by the aquatic vegetation, thus dramatically increasing growth. The subsequent death and decay of the plant life reduces the oxygen levels in the water which in turn is reduces the habitability of the embayment.

Groundwater discharge to streams (baseflow) and along a shoreline has been identified as a primary source of nitrate-nitrogen entering coastal embayments (Urish & Qanbar, 1997, Jorgensen and Richardson, 1996, Capone and Slater, 1990, Giblin and Gaines, 1990). The form in which the nitrogen enters the embayment depends primarily upon the physical and hydrogeologic characteristics of the soil through which the groundwater passes through (Vesilind & Peirce, 1982, Giblin and Gaines, 1990, van den Brink and Zaadnoordijk, 1995). Different sediment types may reduce the nitrate-nitrogen concentration by a process called denitrification. Clean coarse-grained sediments will cause the nitrogen to remain relatively stable and conservative meaning little denitrification occurs, as where a soil rich in organic sediments will slow the flow as well as reduce concentrations of nitrate-nitrogen through denitrification (Fetter, 1993, Canter and Knox, 1986, Giblin and Gaines, 1990, van den Brink and Zaadnoordijk, 1995).

The ever increasing population throughout the coastal communities of the world, and in this case the cities that surround Greenwich Bay continue to cause a rise in the nitrogen concentration of the groundwater entering into Greenwich Bay (Jorgensen and Richardson, 1996, Valiela et al., 1992, Joubert and Gold, 1993). The large number of residences that remain dependent on the OSSDs within the Cities of Warwick and East Greenwich further increase this contamination. The population along the western shore of Greenwich Bay increased more than 70 percent between the years of 1960 and 1970 (Nowicki and McKenna, 1990), which can cause a great impact on an already stressed environment.

1.2 Study Objectives

The objectives of this study are to estimate the quantity, quality and the location of groundwater released into shallow coastal embayments around Greenwich Bay, Rhode Island. Performing the following tasks will fulfill the objectives.

1 Development of an area water budget to be used in the estimation of groundwater discharge quantities.

2 Development of a nitrogen budget for groundwater entering Greenwich Bay.

3 The use of thermal infrared aerial imagery to locate areas of concentrated shoreline groundwater discharge.

4 Measurements of coastal groundwater discharge quality.

5 Predictions of the effect of sewering on nitrogen loading to Greenwich Bay.

1.3 Location and Description of the Study Area

Greenwich Bay is located on the western side of Narragansett Bay, Rhode Island (Figure 1.1). Greenwich Bay is bounded on the north, east, and south by the City of Warwick, and on the west by the City of East Greenwich. Greenwich Bay discharges into Narragansett Bay to the south-southeast. Greenwich Bay has an area of 11.6 km^2 (4.5 mi^2). The mean depth of the bay is 2.0 meters (6.5 feet) with approximately 70 % of the bay being less than 3.0 meters (9.8 feet) in depth (Nowicki and McKenna, 1990). Greenwich Bay has five major coves along its perimeter, Apponaug, Brushneck, Buttonwoods, Greenwich, and Warwick (Figure 1.2).

1.3.1 Geography

The Greenwich Bay watershed coast line, which includes the Cities of Warwick, and East Greenwich, is a system of small coves, rivers, and streams. The land use around Greenwich Bay consists primarily of residentially developed land with small number of commercial development. Approximately 75% of the land in Warwick and 40% of the land in East Greenwich is zoned for high-density residential development, which allows for between one and eight houses per 4.047 hectares (1acre). As of 1985, only 10% of Warwick residents and 35% of East Greenwich residents were connected to public sewers (Nowicki & McKenna, 1990). As of 1992, the numbers changed to 40% for Warwick, and 85% for East Greenwich. The approximate area of the Greenwich Bay watershed is 5,356 hectares (13,235 acres) with approximately 18,692 houses, which means that

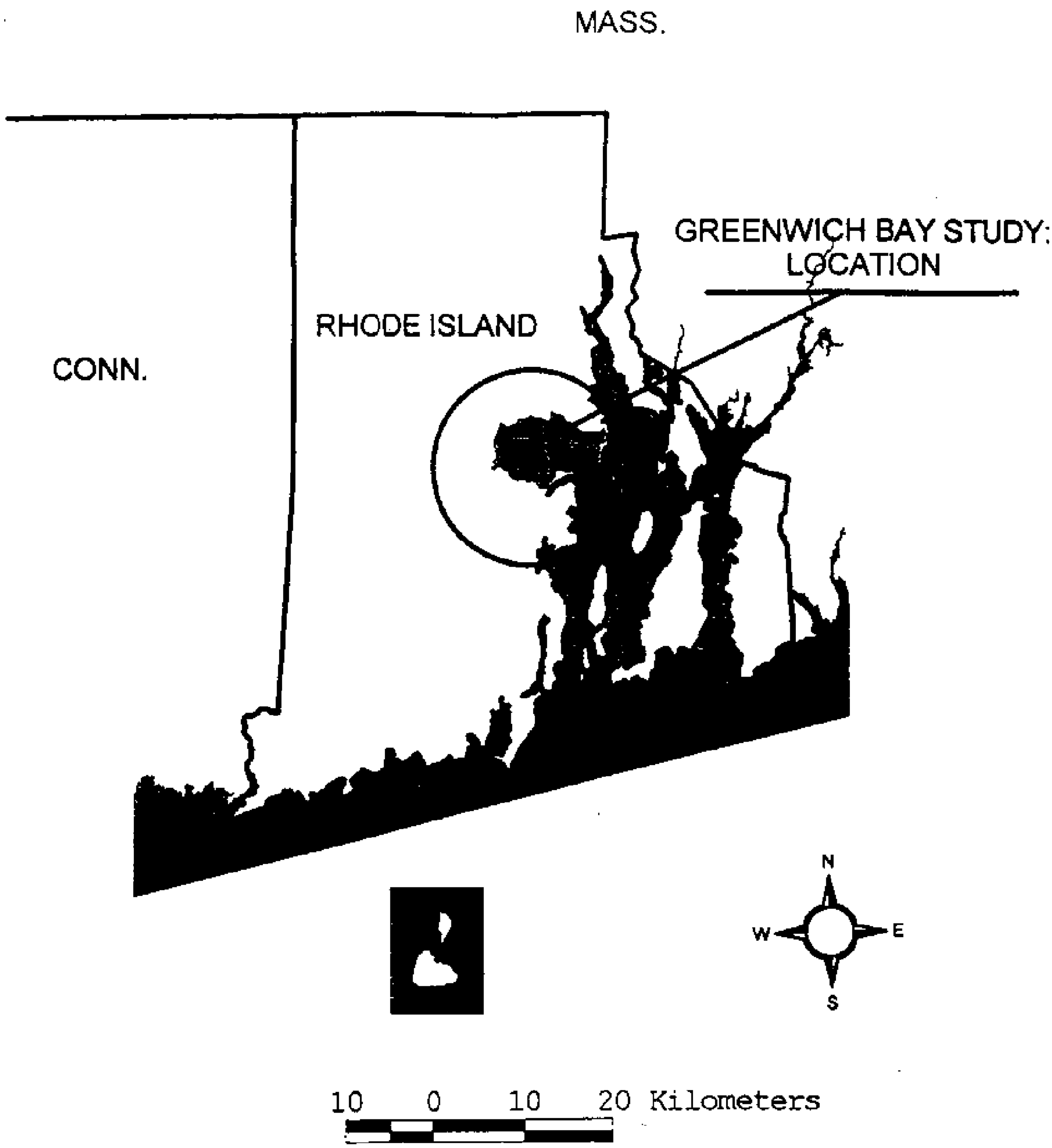
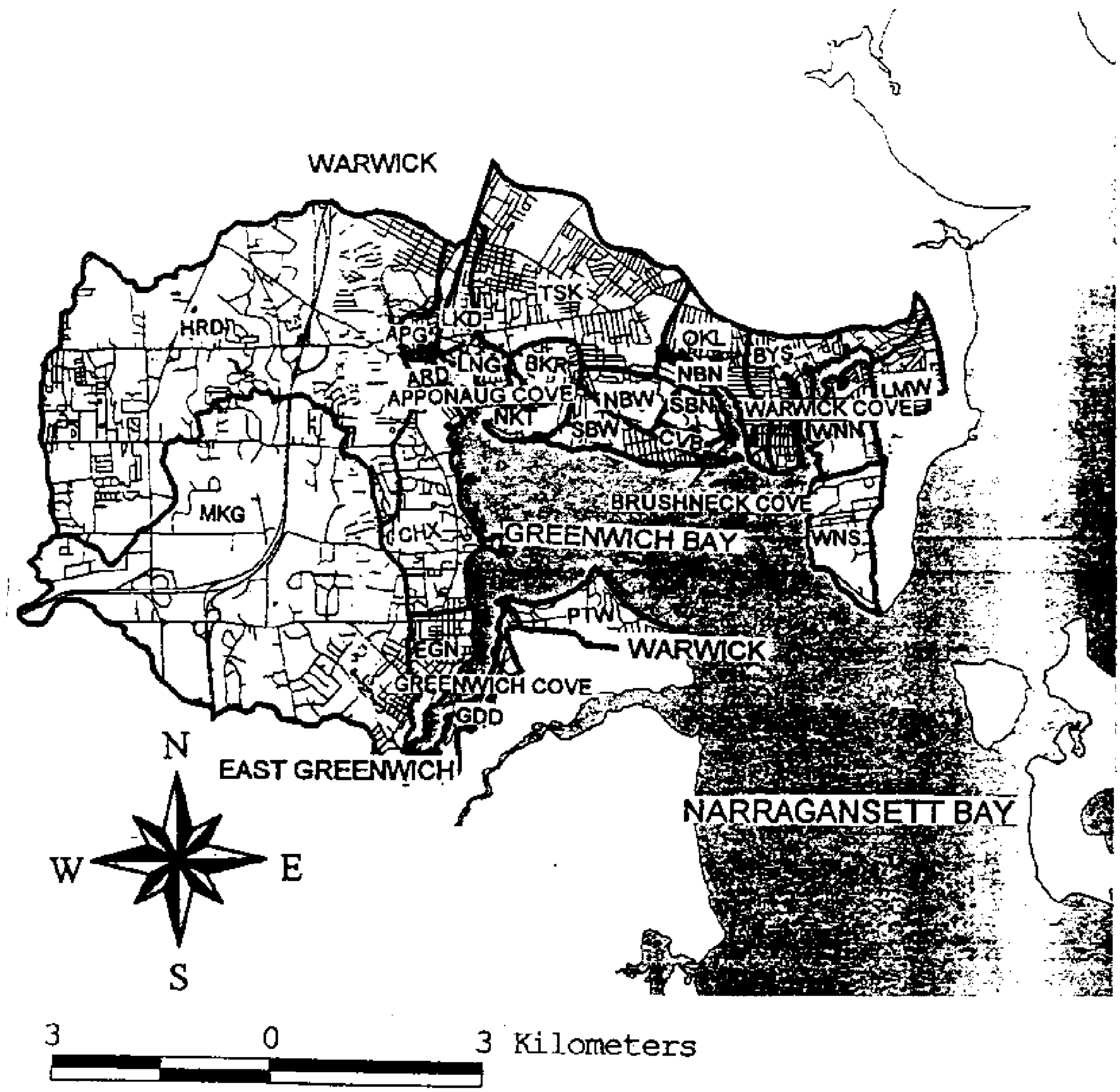


Figure 1.1 General location map of the study area



Apponaug (APG)
Arnold (ARD)
Baker (BKR)
Bayside (BYS)
Chepiwanoxet (CHX)
Cove Beach (CVB)
East Greenwich (EGN)
Goddard (GDD)
Hardig (HRD)
Lockwood (LKD)
Long (LNG)
Longmeadow (LMW)
Maskerchugg (MKG)
Nausauket (NKT)
North Brushneck (NBN)
North Buttonwoods (NBW)
Oakland (OKL)
Pottowomut (PTW)
South Brushneck (SBN)
South Buttonwoods (SBW)
Tuscatucket (TSK)
Warwick Neck North (WNN)
Warwick Neck South (WNS)

Figure 1.2 Greenwich Bay watershed and sub-basin delineation map there is more than one house per 4.047 hectares (1 acre) of land (more than 3 per hectare). The ground cover is mostly low vegetation consisting of grass and shrubs with larger trees on residential land and in parks (Nowicki and Mckenna, 1990).

1.3.2 Climate

The area surrounding Greenwich Bay has a marine type climate with a distinct winter and summer season. Narragansett Bay, Greenwich Bay, and the Atlantic Ocean moderate the temperature throughout the year. Extreme periods of heat and cold are short. The United States Weather Bureau collects climatological data at Theodore F. Green State Airport, this measuring station is outside the study area however it is close enough to give a reasonable approximation of precipitation in the Greenwich Bay study area. Figure 1.3a and 1.3b show thirty-year average monthly precipitation, and temperature data. The National Weather Bureau station is just north of the Greenwich Bay watershed, and is the best long term data collection station within a reasonable distance of this watershed. The study area receive an average of 106 cm (42.0 in) of precipitation per year, generally distributed evenly among the months. Extreme precipitation of records are the high record at 32.30 cm (12.74 in) in the month of April 1983, and the low of 0.99 cm (0.39 in) during the month of February, 1987. During the period of study, 1996-1998, annual precipitation was 122 cm (48.0 in) in 1996, 129 cm (50.8 in) in 1997, 133 cm (52.5 in) in 1998. The average temperature is 10.3 °C (50.6 °C). January is the coolest month of the year with

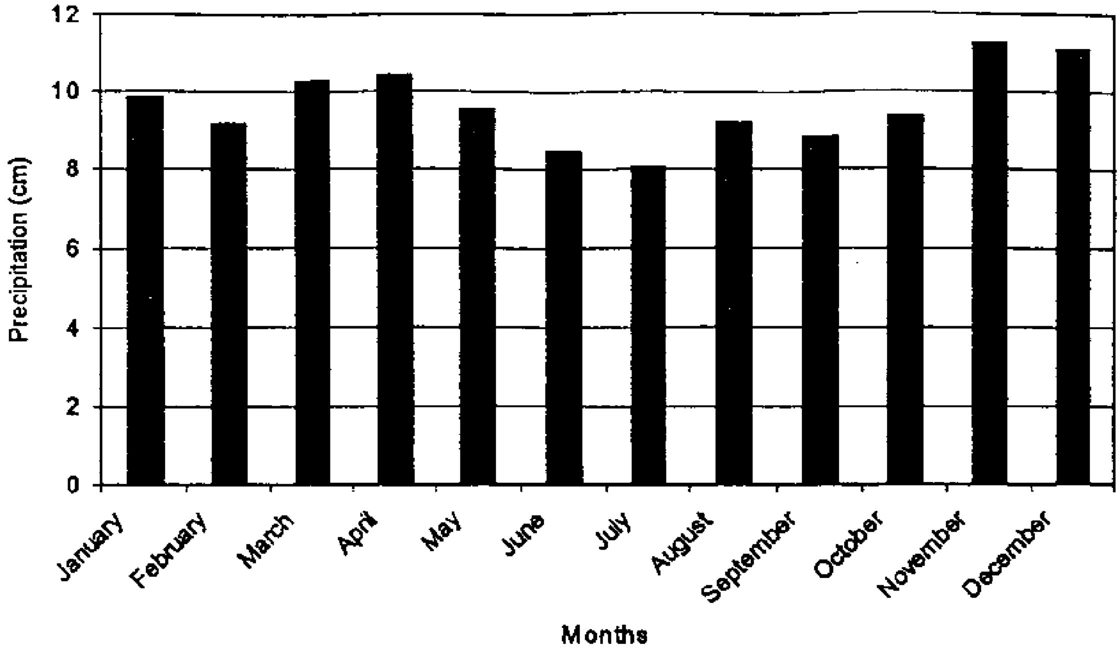


Figure 1.3a Average Precipitation for Warwick, Rhode Island (1948-1995)

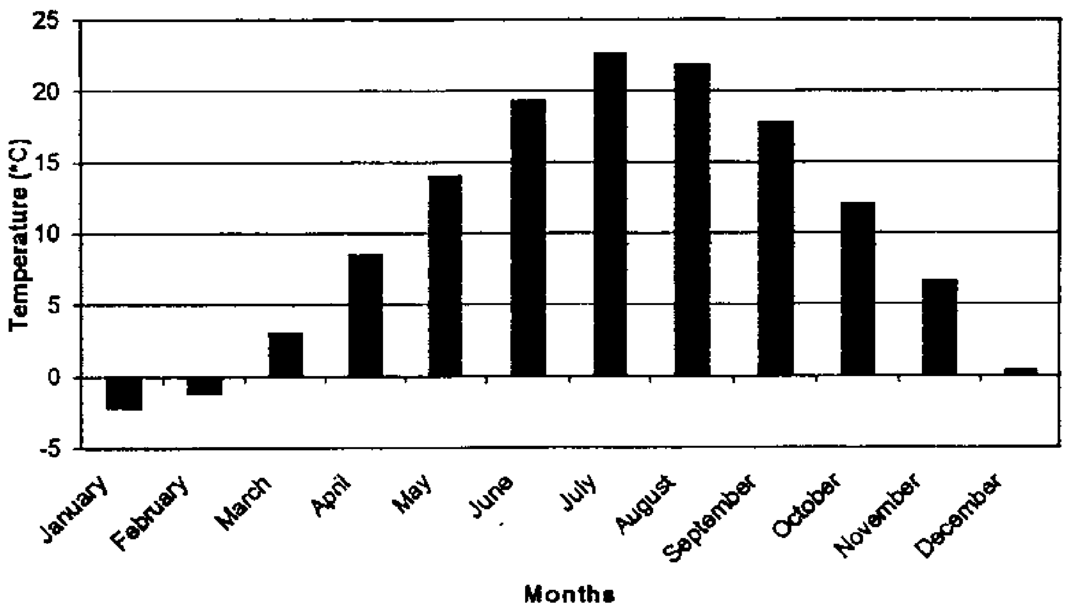


Figure 1.3b Temperature 30 Year Average for Warwick, Rhode Island (1961-1990)

an average temperature ranging from –6.05° C to 2.77° C (21.1 ° F to 37.0 ° F), where as July (warmest temperature) temperature ranges from 17.55 ° C to 27.77 ° C (63.3 ° F to 82.0 ° F) (Figure 1.3b) (Hoare, R. 1996).

1.3.3 Watershed Topography

The study area contains hills and valleys with elevations ranging from sea level to 107 meters (350 feet). There are a number of coves, and coastal wetlands surrounding the Bay. Along the coast of Greenwich Bay, and its contiguous coves, the topography plays an important role in the operation of an OSSD.

The topography around Greenwich Bay when combined with the soil type, depth to impervious surfaces, slow percolation rates, and high water table make much of the area poorly suited for OSSD systems. The placement of an OSSD system in an area with these attributes can lead to lateral seepage, erosion, and sedimentation. The seepage of groundwater along steep hillsides, which in some cases extend to the upper beach, can reach the Bay in a very short time and with little attenuation. Groundwater can also reach the Bay as seepage entering storm drains, as watershed stream flow, or combining with surface runoff during a rain event prior to entering the Bay.

There are areas along the coastlines of Greenwich Bay and its coves that have moderate to steep sloping hills that extend to the upper beach. These areas can be found along the east and western shorelines of Apponaug Cove, and the eastern edge of Greenwich Cove (Warwick Department of Planning, 1994). The eastern edge of Greenwich Cove is relatively unpopulated. However, both the east and western shorelines of Apponaug Cove are moderate to densely populated.

1.3.4 Geology

The geology of the area was examined to better understand the function of septic systems, and the nature and direction of flow to the Bay. The area around the bay has a mixture of glacial outwash, and glacial till. The glacial outwash is comprised of well sorted, stratified sand and gravel deposited by glacial melt water. These areas have fast percolation rates and provide quick diffusion of septic effluent. Although outwash has a high coefficient of storage, and yield of groundwater, it also has a high potential for contamination when the groundwater table is close to the land surface. The glacial till on the other hand is made up of poorly sorted boulders, gravel, sand and silt. The till areas have bedrock beneath them at shallow depths. This type of soil is poorly suited for OSSDs for a number of different reasons. Factors that adversely effect the proper absorption and filtration of septage are:

1 Low percolation rates.

2 Partially cemented fine-grained sands (hardpan) within the till.

3 Large boulders and cobbles that reduce the filtration distances for septage.

4 Till also has a tendency to clog causing a failure of the septic system.

Another geological problem in the area is that in some places the bedrock is very shallow. Because there is no extensive spatial area available for purification of wastewater, there is a tendency for the material to surface prematurely, or discharge through fractures directly into water bodies.

1.3.5 Groundwater Fluctuations and Tidal Effect

Another hydrologic feature of the area affecting coastal groundwater discharge into the Bay is tidal behavior. Greenwich Bay has a semi-diurnal tidal cycle with the principal variations following the changes in the moon's phase and the changes in the season. The tidal range is approximately 2 meters (6.1 ft). Tidal fluctuation tends to have the greatest impact on the parts of an aquifer system located next to tidal bodies. These effects are short-term fluctuations in the head due to the tide. The amplitude and fluctuation is greatest at the coast and diminishes as further inland (Fetter, 1994). The elevation change within the aquifer system affects the houses that rely on OSSDs for disposal of their wastewater and are located in areas that have gentle slopes at the upper beaches of Greenwich Bay and its coves. These elevation changes reduce the distance from the bottom of the soil absorption field and the groundwater surface; thus, restricting physical, biological, and chemical processes that purify the wastewater.

2 METHODS

2.1 Delineation of watershed/ basin/ and sub-basins

Delineation of the Greenwich Bay watershed was accomplished using United States Geological Survey (USGS) topographic maps of Crompton, East Greenwich, and Bristol Quadrangles. The watershed was defined by determining watershed divides or topographic features that determine the direction in which precipitation will travel after it reaches land. Water will travel from high elevation to low elevation regardless of whether it is above land surface, or along the water table. The watershed for groundwater was determined on the same principles as a watershed for surface water using surface topography. While it is recognized that surface water watershed divides are not the same as groundwater watershed divides, it is a reasonable approximation, given the lack of detailed groundwater elevations in the area.

The watershed was sub-divided into 23 sub-basins as shown in Figure 1.2. The 23 sub-basins were then characterized by the location of the terrestrial water discharges, i.e. discharge to the head of a cove, or along the shoreline of the bay. The area of all the sub-basins as well as the total water-shed area was determined using a planimeter, and using a geographic information system (GIS). The area was first digitized into the GIS format, and then manipulated to calculate the areas of each sub-basin. The GIS calculations were used throughout this paper as there was a good correlation between the two methods of calculation. The sub-basin areas range in size from 3.96 ha (9.79 acres) within South Brushneck to 1580 ha (3904 acres) within Hardig Brook.

2.2 Develop Water Budget

In order to understand the hydrology and evaluate the role of groundwater on the Greenwich Bay study area, a steady state water budget was developed. A water budget takes into account all the water entering the watershed, and the means by which it enters the Bay. A general equation, Equation 2.1, for a hydrologic budget model, rearranged from that given by Viessman & Lewis (1996);

$$G = P - R - E - T \pm \Delta S. \tag{2.1}$$

Where

P is precipitation

R is surface runoff

G is groundwater flow

E is evaporation

T is transpiration

ΔS is change in storage

Since in the Greenwich Bay watershed most people depend on public water supplies from outside the watershed, an imported water term (I) is added to the equation 2.1. Additionally, to produce a steady state equation, ΔS is set to zero. The working equation for the sub-basin of this study is.

$$G = P + I - E - T - R \tag{2.2}$$

The equation then states that "water in" equals "water out". Therefore groundwater flow (G) must be equal to groundwater recharge and ultimately groundwater discharge to the Bay. Based on area climatological data (Internet Weather Service 1998, Rosenshein et al., 1968, Hoare, R, 1996, National

Climatic Data Center 1995, Allen et. al., 1966), it is estimated that there is an average annual precipitation of 106 cm (42.0 in). Groundwater recharge ranged from 25 to 53 cm (10 to 21 inches) in a 23 year study of the Potowomut River sub-basin just to the south of the Greenwich Bay sub-basin (Rosenshein, R.S. et al, 1968). Therefore an average value of 38.1 cm (15 in) was used as the value for recharge throughout the Greenwich Bay Watershed. This annual average is a reasonable estimation due to the proximity of the Potowomut study area to the Greenwich Bay watershed. This annual average does not represent the variability of seasonal flow, i.e. low flow summer months when water table is low and high flow spring months when the water table is high (Millham and Howes, 1994). The imported water term is only applicable for houses within the sub-basins not currently connected to public sewers. All values of nitrogen loading are calculated from this annual groundwater recharge value. The values that are presented in daily loading were calculated by dividing the annual average value by 365 days.

2.3 Development of the Nitrogen Budget

Because eutrophication is one of the issues that face the economic and environmental health of Greenwich Bay a means of quantifying the nitrogen concentration of the groundwater entering the bay was employed. There has been extensive work in the development and use of models to forecast the quantity and quality of groundwater in coastal areas (Frimpter, et al. 1988, Eichner and Cambareri 1991, Joubert, et al. 1996). Based on the concepts described by Eichner and Cambareri (1991), a spreadsheet model was developed and used to estimate nitrogen concentrations of groundwater within the Greenwich Bay watershed. The spreadsheet model was also used to make predictions of nitrogen concentrations in groundwater in areas of the watershed planned for sewering. The model results were then used to estimate groundwater nitrogen loading to streams and direct groundwater discharge to Greenwich Bay. The following assumptions have been made when using this model;

The USGS estimates that each person uses an average of 265 liters of water per day (USGS, 1990). Wastewater concentration of nitrogen leaching to groundwater can range from 30.5 mg/L to 53.3 mg/L as measured by Gold (1990). A conservative estimate was chosen to represent groundwater concentrations leaching from septic tanks in the Greenwich Bay watershed. This concentration is 45 mg/L nitrate-nitrogen (Canter and Knox, 1978). When the concentration of nitrate-nitrogen is divided by the average water use, 11.925 grams of nitrogen per person per day is the resultant. Nixon estimated 11.8 g of nitrogen per person per day enters the groundwater through septic systems(Nowicki and Mckenna, 1990). The difference in these two references is approximately one percent. Roof size 185.8 m^2 (2000 ft^2) (Eichner & Cambareri, 1991). Roof runoff concentration is equal to 0.75 mg/L nitrate-nitrogen (Eichner & Cambareri, 1991). The concentration of runoff from impervious surfaces was measured to range from 0.4 mg/L t 1.8 mg/L (Eichner and Cambareri, 1991). Because less accumulation occurs on rooftops compared to paved surfaces, less than half the maximum was used as the concentration for rooftops. Ten percent of the sub-basin is impervious (conservative estimate). Because such a low number was chosen as impervious, ninety percent of the runoff from these surfaces was used as recharge to groundwater. Pavement runoff concentration is 1.5 mg/L nitrate-nitrogen. As stated previously the range is from 0.4 mg/L to 1.8 mg/L for impervious surface runoff (Eichner and Cambareri, 1991). A lawn size average was chosen to equal approximately 465 m^2 (5000 ft^2). Application rates for fertilizer added to lawn was estimated at 1.4 Kg/yr (3 lb/yr), the application rates can range from 1 Kg/yr (2.2 lb/yr) to 1.4 Kg/yr (3 lb/yr). Due to the diverse economic characteristics of Warwick, West Warwick, and East Greenwich only 50 percent of the homes were estimated to use fertilizer. Because of the uptake from the vegetative zone in the soil, only 25 percent of the fertilizer is estimated to reach groundwater as per Eichner and Cambareri, 1991. All dry weather stream flow is considered to be groundwater flow. Climate data indicates that 38.1 cm/yr (15 in/yr) of precipitation becomes groundwater recharge (Rosenshein, et al., 1968). Nitrogen concentration in the atmosphere can range from 0.14 mg/L to 1.15 mg/L, a nitrogen concentration of 0.05 mg/L was chosen as a conservative estimate. It is recognized that a large amount of the nitrogen deposited from the atmosphere is removed in by the soil prior to entering groundwater, and that is why such a small amount was chosen as contribution from the atmosphere. Recharge (e.g., wastewater flows, precipitation, and imported water) and nitrate-nitrogen sources (e.g., septic wastes, fertilizers, atmospheric nutrients, and nutrients present in roof and other impervious surface runoff) within the watershed are well mixed prior to leaching to the groundwater. Although this assumption does not accurately represent the behavior of a groundwater plume it serves to simplify nitrate-nitrogen-loading calculations and is actually appropriate when dealing with low concentrations (Eichner & Cambareri, 1991).

Nitrogen was evaluated as the nutrient of primary interest because of its potential for contributing to eutrophic conditions in shallow and poorly flushed coastal regions in the bay (Portnoy et al., 1998). Calculations are made assuming that no loss or alteration of nitrogen takes place after the entry into the groundwater system. The on-site sewage disposal contributions are estimated based on unsewered homes obtained from the US Census Report of 1992. This information was integrated with sub-basin delineation's using ARCINFO software, part of the GIS. The total nitrate-nitrogen concentration was calculated by adding the loading due to wastewater, impervious surfaces, lawn, and natural deposition.

2.4 Thermal Infrared Imagery

Thermal infrared aerial imagery has been employed to identify specific areas of concentrated groundwater discharge along shorelines (Portnoy et al., 1998, Urish and Qanbar, 1997, Banks et al., 1996). This method maps surface temperatures of objects exposed to a super-cooled detector, which is typically mounted on a small aircraft. This can be very easily used to view temperature differences in waters along a coastal margin by measuring the difference in thermal spectral response of the water along the coast. Since groundwater is colder, approximately 10-15.6 °C (50-60 °F), than bay water which is approximately 21-23 °C (70-74 °F) in the summer, discharging fresh groundwater can be identified from the thermal infrared response. Additionally, when fresh groundwater enters a salt-water body it will tend to float on top because of its lighter density. This property enhances the ability of the thermal infrared method to detect the colder fresh groundwater. The greatest discharge of coastal groundwater takes place over a period of approximately two hours during low tide (Urish & Qanbar, 1997). Since coastal groundwater discharge takes place in a highly non-uniform manner, this delineation of fresh groundwater discharge is important so that the most affected shoreline can be identified and the most efficient groundwater quality sampling locations can be determined.

Spatial resolution of the thermal imagery was produced at 1 meter, and the spectral resolution was 1° C [Aero-Marine Surveys, Inc. August 24, 1997]. Surface water temperatures within the bay were ground-truthed during the flight throughout the bay and all the coves. The survey was run twice in order to distinguish between stationary coastal features, and moving groundwater plumes. Plumes, and other moving features appear in deferent places when images are captured at two different time periods.

2.5 Study Site Selection

The selection of the detailed study sites was made using the results of the water/nutrient budget spread sheet model, areas having a linear beach face discharge, and a strong thermal infrared aerial image contrast. Sites were chosen on the basis of sub-basin nitrate-nitrogen concentrations (high, medium and low) in groundwater, definitive topographic characteristics, and strong visible plumes distinguished using the thermal infrared aerial imagery.

2.6 Topographic Survey

Topographic elevations were measured using a Topcon Model AT-F2 automatic level. This equipment is accurate to within 0.003 meters. Arbitrary reference datum for elevation control were set at each of the sites, and then compared to tide level and time at which the measurement was taken. The land surface elevations were determined by closed loop level survey procedures.

2.7 Installation of Monitor Wells

Installation of monitor wells was accomplished by excavating to the water table with a hand auger, then driving 3.2 cm (1.25 inch) diameter 182 cm (72 inch) long well points by sledge. The well points have a 46 cm (18-inch) screen length with 250-micrometer (.0098) inch screen openings. These wells were driven into the upper beach zone so that the tops of the wells are above the level of high tide water preventing bay water from entering the wells. Elevations of the tops were established using standard leveling techniques. Each study site was assigned an arbitrary datum for monitor well, beach topography, and tide referencing.

2.8 Beach Hydrogeologic Parameters

Sediment samples were taken from the study sites within the discharge zones. Grain size distributions of these samples were determined using standard ASTM sieve analysis procedure. The results were then plotted as distribution curves and the effective grain size, median grain size, coefficient of uniformity, and porosity were determined. characteristics determined.

Falling head permeameter tests (Freeze & Cherry, 1979) were conducted on the samples to determine the effective hydraulic conductivity (K_e). This method involves passing water through the sample while measuring the drop in head (Equation A.1). All values were standardized to 20° C.

The hydraulic conductivity was also approximated for the samples using the Hazen method (Fetter 1994).

$$K = C\,(d_{10})^2 \qquad (2.3)$$

Where

K is the hydraulic conductivity (cm/s)

d_{10} is the effective grain size (cm)

C is a coefficient based on sand characteristics i.e. fine sand, well sorted

This equation is only effective where the effective grain size is between 0.1 and 3.0 mm. All samples fall within this range. The C value used was 80 for Oakland, 100 for Arnold, and 100 for Potowomut.

The porosity of the samples collected from the study sites were calculated using the "dry weight-volume" method. The "dry weight-volume" method involves oven drying and weighing a known volume of sample. Using an assumed value of 2.65 g/cm^3 as the specific density of the sample solids the volume of solids can be directly calculated. The volume of the voids is the total volume minus the volume of the solids. The porosity is the volume of the voids divided by the total volume. The porosity is an important characteristic for determining the storage and flow characteristics of a sediment.

2.9 Shoreline Profiles and Groundwater Quality Measurements

To obtain the distribution of salinity, nitrate-nitrogen and ammonia-nitrogen at the upper part of the water table and within the seepage areas, shallow water quality sampling was done along a beach transect at the low tide line at intervals of one to one and one half meters. Small excavations were dug along the beach transect, and allowed to fill with groundwater discharge from the land. Salinity was measured on site using a hand held salinity refractometer with automatic temperature compensation Model A366ATC. 80-ml samples were collected at each excavation for laboratory analysis of nitrogen and ammonia concentrations. Samples were preserved with H_2SO_4 and stored at 4° C until analyzed for ammonia (NH3-N) using the Automated Phenate Method and for nitrate-nitrogen plus nitrite-nitrogen (NO_3-N plus NO_2-N) using the Automated Cadmium Reduction Method. Samples were also collected from the monitor wells installed at two of the three sites (Oakland, and Arnold). I was not able to install a monitor well in the area of the Potowomut sub-basin with the greatest beach groundwater discharge. Nitrate-nitrogen was measured in the field using a Model N1-11 HACH test kit; this test kit has an accuracy of plus or minus 1.0 mg/L. This process was repeated at all three sites within the Greenwich Bay area. The data were then plotted and analyzed for trends in salinity, nitrogen, and ammonia.

2.10 Predicting Effects of Sewers

To predict the effects of sewering the sub-basins the budget model values of wastewater, are adjusted while all other variables remain constant. This procedure is done by reducing the amount of wastewater that is disposed of within the sub-basins of the Greenwich Bay watershed according to the sewering schedule designated by the City of Warwick Planning Department. It is envisioned that at the end of the first year after sewering begins 50% of the households would be hooked up; at the end of the second year 70%; and at the end of the third year 100%.

3 RESULTS AND DISCUSSION

3.1 Delineation of Watershed/basin/sub-basin

The watershed sub-basin area characteristics are detailed in Table 3.1. There is a distinction made between the sub-basin areas that have a linear discharge along a beach and the sub-basin areas that discharge into streams before reaching the coves or bay. The largest sub-basin areas such as Hardig, Maskerchugg, and Tuscatucket contribute the largest amounts of water. These areas contribute large stream discharges to the heads of Apponaug, Greenwich, and North Brushneck Coves respectively. The smaller areas such as South Brushneck and Cove Beach contribute relatively little water, and are shoreline discharges. The percentage of stream discharge area as compared to the

Table 3.1. Estimated average annual groundwater discharge into Greenwich Bay from sub-basin.

Sub-basin Name	Area of sub-basin (sqm.)	Linear feet of shoreline (m.)	Groundwater discharge into bay (cum/day/m)	Groundwater discharge into bay (cum/day)	stream discharge into bay (cum/day)
Apponaug (APG)	504,850 (SL)	790	0.66	530	
Arnold (ARD)	204,790 (SL)	1,850	0.12	215	
Baker (BKR)	883,690 (ST)				920
Bayside (BYS)	1,786,930 (SL)	7,810	0.24	1,865	
Chepiwanoxet (CHX)	2,822,100 (SL)	7,180	0.41	2,945	
Cove Beach (CVB)	90,290 (SL)	1,610	0.06	95	
East Greenwich (EGN)	1,076,580 (SL)	2,250	0.50	1,125	
Goddard (GDD)	703,390 (SL)	5,840	0.13	735	
Hardig (HRD)	15,798,430 (ST)				16,490
Lockwood (LKD)	511,510 (ST)				535
Long (LNG)	457,730 (SL)	790	0.60	480	
Longmeadow (LMW)	881,020 (ST)				920
Maskerchugg (MKG)	15,464,220 (ST)				16,140
Nausauket (NKT)	293,300 (SL)	1,350	0.23	305	
North Brushneck (NBN)	246,470 (SL)	1,850	0.14	255	
North Buttonwoods (NBW)	700,800 (ST)				730
Oakland (OKL)	1,254,820 (SL)	5,150	0.25	1,310	
Potowomut (PTW)	1,185,290 (SL)	7,630	0.16	1,235	
South Brushneck (SBN)	39,600 (SL)	1,190	0.03	40	
South Buttonwoods (SBW)	931,060 (SL)	3,670	0.26	970	
Tuscatucket (TSK)	5,190,940 (ST)				5,420
Warwick Neck North (WNN)	1,085,310 (SL)	5,950	0.19	1,135	
Warwick Neck South (WNS)	1,444,510 (SL)	4,950	0.30	1,510	
TOTALS	53,557,619	59,860	4.29	14,750	41,155

Notes: 1) In the column entitled "Area of sub-basin", SL indicates groundwater shoreline discharge and ST indicates dry weather groundwater discharge into a stream which subsequently discharges into the bay

2) Groundwater discharges are estimated average daily values based on 15 inches of groundwater recharge per year.

3) Where the sub-basin is contiguous to the shoreline the linear feet of shoreline through which the groundwater discharges is indicated as well as the quantity per linear foot.

4) Where the sub-basin groundwater discharges into a stream, the estimated single value of that discharge is indicated.

5) As a first estimate it is assumed that all residents get imported water supply at the rate of 265 liters per person per day and that for unsewerd houses this water becomes groundwater recharge (USGS 1990).

6) As a first estimate it is assumed that, because of large quantities of groundwater well pumping, there is no groundwater discharge into lower Greenwich Cove from the Hunt River Basin (Allen, W.B. 1956).

percentage of shoreline discharge area is 72% stream discharge and 28% shore line discharge.

3.2 Water Budget

Table 3.1 also shows the estimated groundwater discharge from the 23 sub-basins into Greenwich Bay. Approximately 26 % of the groundwater that discharges into Greenwich Bay is shore line discharge and 74 % is dry weather stream discharge. The percent of land area that discharges to streams, and the percent of the land area that makes up the shoreline groundwater discharge is approximately equal to the proportion of category of discharge from the Greenwich Bay watershed area. However areas with large populations will also have an increase in water due to the imported water that is used (265 Liters per person per day, this assumes that the person relies on an OSSD for wastewater disposal) entering the system as artificial recharge. This effect will be most significant for the Tuscatucket sub-basin. Tuscatucket has a fairly large area of 519 ha (1283 acres) and has a large population of residents who's homes are not connected to public sewers (6,037).

3.3 Results of the Nitrogen Budget

Combining each of the individual nitrogen inputs to each sub-basins area is an important first step in determining the total loading to the entire watershed. One of the largest inputs to all the sub-basin areas is the wastewater from domestic use. The wastewater loading to a sub-basin was determined using the following formula adapted from Frimpter, et al. (1988), and Cambareri, (1991).

$$N_{ww} = W_u * P * C_{ww} \qquad (3.1)$$

Where

N_{ww} is the nitrate-nitrogen loading due to wastewater (mg/day)

W_u is the water use per person per day (L/person-day)

P is the unsewered population of the sub-basin (persons)

C_{ww} is the nitrate concentration of the wastewater (mg/L)

In the case of the Oakland sub-basin, the water use (W_u)used is 265 liters per person per day, the population (P) is 2,024 people, and the nitrate concentration (C) is 45 milligrams per liter. This results in an estimated loading for the Oakland sub-basin of 24,135 grams per day of nitrate-nitrogen.

The next largest contributor to the nitrate-nitrogen is lawn fertilization. The percent of the population that uses fertilizer was assumed to be less than the 100 percent due to the use of fertilizer being income oriented. Due to the lack of definitive information of the fertilization habits of the residents of Warwick, an assumption was made that only 50 percent of the households fertilize their lawns. The nitrogen loading due to fertilizer was calculated using the formula adapted from Frimpter, et al. (1988), and Cambareri, (1991).

$$N_L = A_L * F_{AR} * L * H * k \qquad (3.2)$$

Where

N_L is the nitrogen loading due to lawn fertilization (g/d)

A_L is the area of the lawn (m^2)

F_{AR} is the fertilizer application rate ($g/yr/m^2$)

L is the percent that leaches to the groundwater

H is the number of houses in the sub-basin area, and

k is a constant that represents the percent of houses that use fertilizer

In the Oakland sub-basin the area of the lawn (A_L) is 464.5 m^2 (5000 ft^2), the fertilizer application rate (F_{AR}) is 1.36 kg (3 lbs) per year per 92.9 m^2 (1000 ft^2), the percent that leaches to the groundwater (L) is 25 percent (Cambareri, T.C., 1991), the number of houses (H) is 1,002 houses, and the percent of the houses that fertilize (k) is 50 percent of the houses. This estimates that 2.3Kg of nitrogen reaches the bay from fertilizer each day. This daily value was interpolated from a yearly average. Because grass growing is seasonal, fertilizer application is also seasonal therefore the 1.36-kg (3 lbs.) per year per 92.9 m^2 (1000 ft^2) is only applied within a few months. Although this suggests if there would be a greater seasonal loading due to fertilization, it is not always the case due to the relatively slow velocity at which groundwater moves.

Roads and parking lots can have a large impact on groundwater quality as the dry weather buildup of nitrate-nitrogen on the surface can be dissolved in a rainstorm and leach into the groundwater. Although it is recognized that not all runoff becomes recharge, an estimated 90 percent of the runoff was used as groundwater recharge in these calculations. Therefore groundwater recharge from pavement runoff is 90 percent of 0.381 m (15 in) or approximately 0.343 m

(13.5 in). It is also assumed that 10 percent of the entire watershed is impervious; accordingly each sub-basin area was multiplied by 0.1. The impervious runoff loading was calculated in a spreadsheet using a formula adapted from Frimpter, et al. (1988), and Cambareri, (1991).

$$N_{ir} = A_s * R * C_{ir} \quad (3.3)$$

Where

N_{ir} is the nitrate-nitrogen loading due to recharge of runoff (g/D)

A_s is the area of the sub-basin that is impervious (m^2)

R is the amount of runoff that becomes groundwater recharge (m)

C_{ir} is the concentration of the runoff (g/L)

In the Oakland sub-basin, the impervious area (A_s) is 125,482 m^2 (1,350,725 ft^2) , the runoff that becomes groundwater recharge (R) is 0.343 m (13.5 in), the nitrate concentration (C) is 1.5 mg/L, and the total nitrate-nitrogen loading due to impervious runoff (N_{ir}) is equal to 176.85 g/d.

Roof runoff is another source of nitrate-nitrogen that may leach to the groundwater. The loading due to roof runoff is calculated using another formula adapted from Frimpter, et al. (1988), and Cambareri, (1991).

$$N_{rr} = A_r * R * H * C_{rr} \quad (3.4)$$

Where

N_{rr} is the nitrate-nitrogen loading due to recharge from roof runoff (g/d)

A_r is the roof area (m^2)

R is the recharge (m)

H is the number of houses

C_{rr} is the concentration of the roof runoff (mg/L)

In the Oakland sub-basin, the roof area (A_r) is 185.8 m^2 (2,000 ft^2), the recharge (R) is 0.343 m (13.5 in), the number of houses (H) is 1,002 houses, and the nitrate concentration (C_{rr}) is 0.75 mg/L. Therefore the nitrate-nitrogen loading (N_{rr}) due to roof runoff is 131 grams per day.

The last and final variable in the calculation of total nitrogen loading to Greenwich Bay is that of precipitation. Studies of nitrate-nitrogen levels in precipitation show that concentrations can be between 0.05 ppm (mg/L) to 1.15 ppm (mg/L) (Cambareri, 1991); however, Cambareri (1991) suggests that these concentrations can be taken up in the soil zone with little to no nitrate-nitrogen reaching the groundwater. Cambareri (1991) also suggests that the nitrate-nitrogen concentration from precipitation is so small in comparison to that from wastewater that it can be disregarded. Although it has been suggested that the atmospheric deposition of nitrate-nitrogen to groundwater is negligible, for the purpose of completeness the calculations were made using a formula adapted from Frimpter, et al. (1988), and Cambareri, (1991).

$$N_a = A_s * R * C_a \quad (3.5)$$

Where

N_a is the nitrate-nitrogen loading to groundwater from the atmosphere

(g/d)

A_s is the area of the sub-basin (m^2)

R is the recharge from precipitation (m)

C_a is the concentration of the precipitation (mg/L)

Using Oakland sub-basin data, the area (A_s) is 1,245,823 m^2 (13,507,254 ft^2) , the recharge is 0.381 m (15 in), and the concentration is 0.05 ppm (mg/L). The average value of concentration could have been used at this point however, because the soil zone can remove the nitrate concentration, the lowest value was used. The loading to groundwater due to atmospheric precipitation is 65.5 grams per day.

The total loading from the sub-basins can be calculated by adding all the individual loadings.

$$N_{tot} = N_{ww} + N_L + N_{lr} + N_{rr} + N_a \qquad (3.6)$$

Where

N_{tot} is the total loading (g/d)

The Oakland sub-basin total nitrogen loading estimated from this budget model is 18,194 grams of nitrogen per day. Calculations for each of the 23 sub-basins are provided in Appendix A. Results of the nitrogen budget indicate that the area that contributes the greatest amount of nitrogen enters Greenwich Bay through Tuscatucket Brook by dry weather flow. Although Hardig is the largest sub-basin, and it receives the largest loading due to atmosphere, and impervious surface runoff, it has a lower population density and therefore has a lower wastewater input. Tuscatucket the third largest sub-basin, is densely populated with much of the area covered with impervious surfaces. Tuscatucket is only 1/3 the size of the Hardig sub-basin, and has 1.5 times the contribution of nitrogen due to wastewater disposal. A large portion of the population in the Tuscatucket sub-basin is not currently connected to the pubic sewer system and depends on OSSD's for wastewater disposal. Wastewater, being the largest contributor of nitrogen to groundwater, is the determining factor when forecasting loading to Greenwich Bay. Table 3.2 provides a summary of the totals from the sub-basins within the Greenwich Bay watershed as estimated by the nitrogen budget model.

Sensitivity of the Nitrogen Budget

The budget is most effected by changes in the wastewater input. This input is not uniformly distributive throughout the watershed. While the significance of changing this component in each sub-basin can be important for point locations throughout Greenwich Bay, the sensitivity was determined over the entire watershed for simplicity. Changing this variable by 50 percent changes the total loading by $\pm$17 percent, and changing the wastewater variable by 100 percent changes the total by $\pm$78 percent. Conversely, an increase or decrease of all other variables (roof runoff, lawn fertilization, road runoff, atmospheric deposition) by 100 percent combined only changes the total loading to Greenwich Bay loading by 26 percent. Lawn fertilization is the next most

Table 3.2. Total estimated nitrogen loading for Greenwich Bay Watershed by sub-basin.

Sub-basin Name	Wastewater nitrogen loading (grams/day)	Lawn nitrogen loading (grams/day)	Atmosphere nitrogen loading (grams/day)	Road runoff nitrogen loading (grams/day)	Roof runoff nitrogen loading (grams/day)	Total nitrogen loading (grams/day)
Apponaug	1,870	465	25	70	25	2,455
Arnold	810	200	10	30	10	1,060
Baker	13,105	1,040	45	125	60	14,375
Bayside	24,050	2,510	95	250	140	27,045
Chepiwanoxet	13,760	2,005	145	400	115	16,425
Cove Beach	1,075	70	5	15	5	1,170
East Greenwich	3,520	2,370	55	150	130	6,225
Goddard	2,280	190	35	100	10	2,615
Hardig	48,450	12,990	825	2,225	730	65,220
Lockwood	8,250	695	25	70	40	9,080
Long	6,535	500	25	65	30	7,155
Longmeadow	8,910	640	45	125	35	9,755
Maskerchugg	42,060	7,385	805	2,180	415	52,845
Nausauket	4,030	295	15	40	45	4,425
North Brushneck	2,815	185	15	35	10	3,060
North Buttonwoods	8,370	555	35	100	30	9,090
Oakland	24,135	2,335	65	175	130	26,840
Potowomut	3,970	335	60	165	20	4,550
South Brushneck	465	305	0	5	15	790
South Buttonwoods	9,075	740	50	130	40	10,035
Tuscatucket	71,990	6,780	270	730	380	80,150
Warwick Neck Nortł	11,245	735	55	150	40	12,225
Narwick Neck Soutł	2,695	275	75	205	15	3,265
Sub-basin Totals	313,465	43,600	2,780	7,540	2,470	369,855

Notes: 1) Nitrogen loading based on Field Evaluation of Nitrogen Removal Septic Systems for Coastal Communities (Gold, A.J., et al., 1990) Methodology and recommendations based on the CapeCod Commision Nitrogen Loading Technical Bulletin 91-001 (1991).

sensitive variable contributing to 23 of the 26 percent change.

Measured Values Vs. Estimated Values

Water quality and quantity of stream discharge were measured for the Hardig Brook (DeMello, A.C., 1996). The values were compared to the values obtained through the use of the nitrogen budget model. The nitrogen budget estimates a fifty percent higher concentration than that represented by DeMello, (1996). Measured Stream flow data was twenty percent lower than the value estimated by the water budget. The reasons for such differences could by the time in which measurements were made, and weather conditions prior to sample collection. The average nitrogen concentration, estimated by the nitrogen budget model, was 3.0 mg/L. The average concentration, measured during dry weather surveys completed by DeMello (1996), indicated an average nitrate-nitrogen concentration of 1.5 mg/L. When values were chosen for the nitrogen budget model, conservative numbers were used in the intentions of over estimating the anthropogenic nitrogen loading.

3.4 Thermal Infrared Imagery

Thermal infrared surveys of Greenwich Bay and its coastal regions were accomplished in August 1997. Two survey runs were made on both dates to distinguish between a moving fresh water discharge plume and fixed coastal features. In order to optimize conditions for high quality results the flights were made in the early evening during low tide when the contrast in temperature was the greatest, and there was little to no direct solar effects. It was also essential that the survey runs are made during a low tide period when the coastal groundwater discharge is greatest. Graphs showing conditions of tide and water temperature for the August 24, 1997 survey are provided as Figure 3.1. The photo runs were made during the time period of 7:00 to 9:00 P.M. shortly after sunset to minimize the effects of solar reflection. The fresh groundwater bay-water temperature contrast was approximately 7.8 °C (14 °F). The thermal infrared images show areas of major groundwater discharge in Warwick Cove, Brushneck Cove, Apponaug Cove, and Greenwich Cove as well as some points which discharge directly into the bay along the northwestern point of Potowomut neck, and southeast of Baker Creek (Appendix B). As an example, Figures 3.2a and 2b are thermal infrared images of Brushneck Cove taken approximately one hour apart. In this figure the dark plumes emanating from the shoreline define the colder less dense fresh groundwater. The plumes are most evident along the western shore and north central part of the cove. The time lapse shows a movement of the plumes north and into the cove rather than south and out to the bay. This type of movement makes it easier to identify the behavior of the plumes over a period of time.

3.5 Study Site Selection

Specific sites were selected for detailed study. These are Oakland Site, Arnold Site, and Potowomut Site (Figure 3.3). The results of the hydrogeologically significant parameters such as grain size, porosity, and

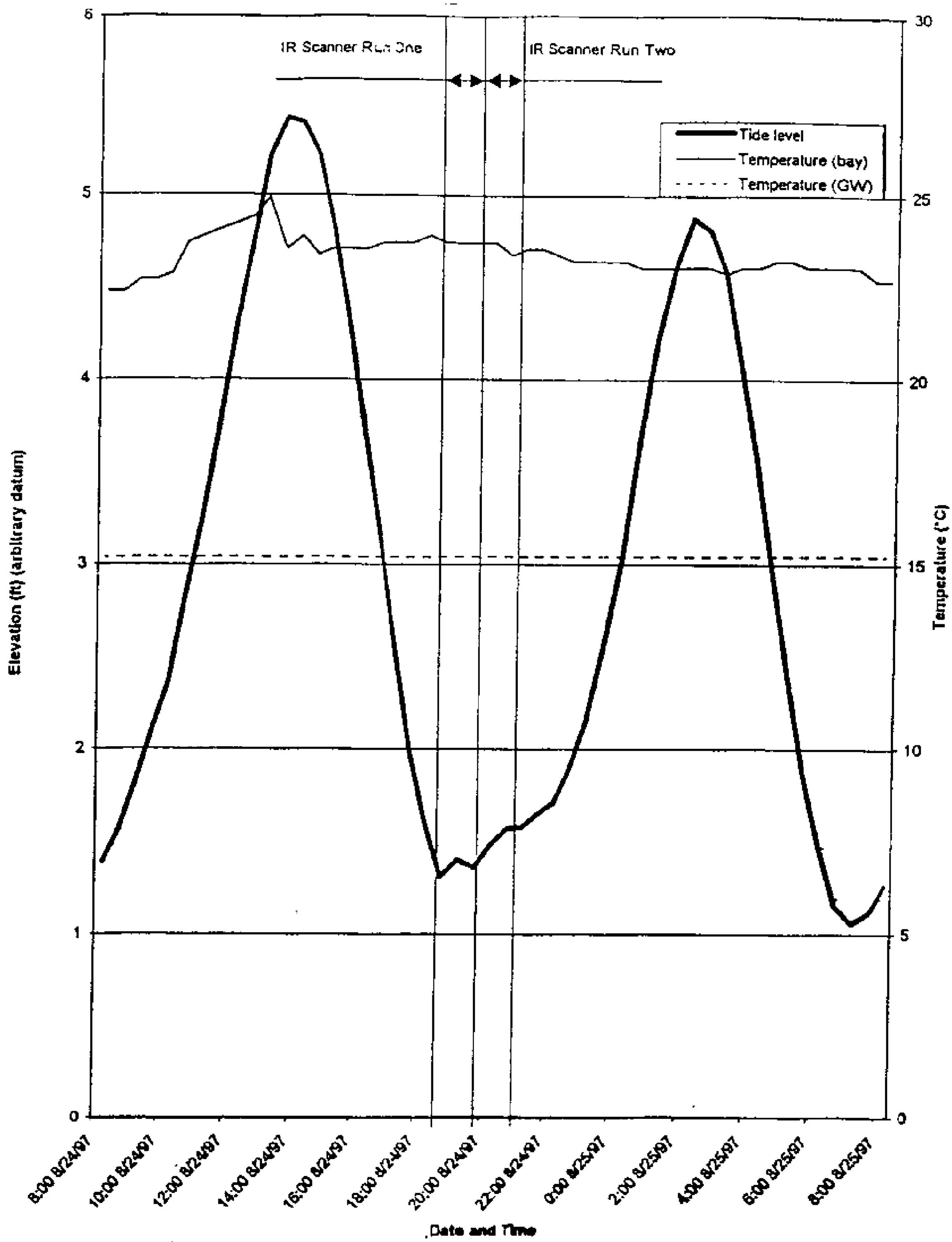
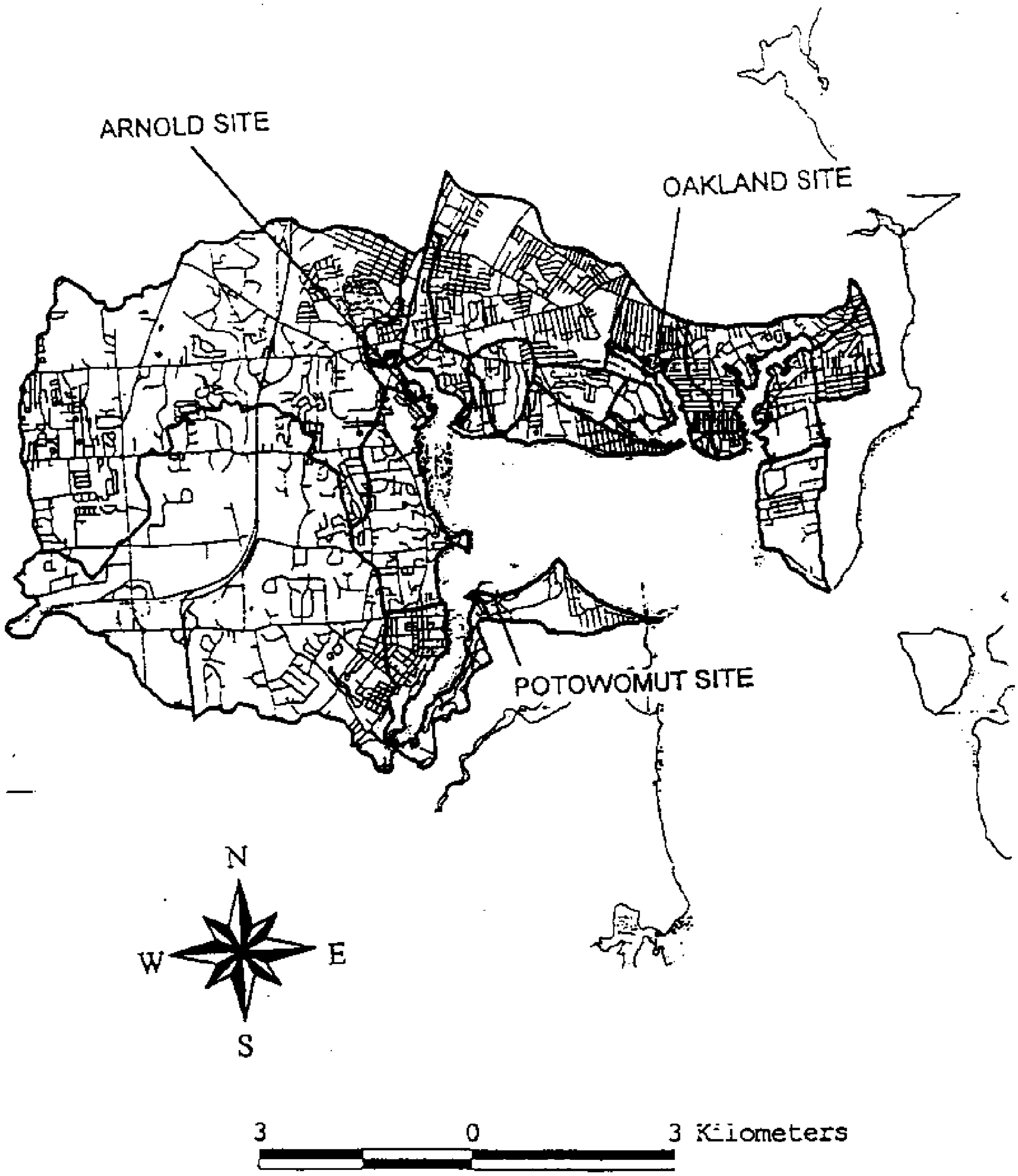


Figure 3.1 Tide level and water temperature conditions during thermal infrared aerial survey of August 24, 1997

3.2a Thermal Infrared Aerial Image Oakland Site
Run one taken at 19:39 August 24, 1997
Scale 1:10,200

3.2b Thermal Infrared Aerial Image Oakland Site
Run two taken at 20:40 August 24, 1997
Scale 1:10,200

Figure 3.2 a & b Thermal Infrared Aerial Imagery of Oakland Site (Brushneck Cove) August 24, 1997 two runs taken at 19:39 and 20:40 respectively.



3.3 Specific sites for field study

hydraulic conductivity is shown in Table 3.3. Detailed grain size analysis results and hydraulic conductivity test results are contained in Appendix C.

Table 3.3 Site Soil Parameters Summary

SITE (LOCATION)	GRAIN SIZE D_{10} (mm)	D_{50} (mm)	Cu (1)	Cc (2)	POROSITY	HYDRAULIC CONDUCTIVITY (m/day)
A (Oakland)	0.10	0.22	2.35	1.30	32.8	16.24
B (Arnold)	0.25	0.80	4.00	1.00	33.8	108.84
C (Potowomut)	0.35	0.90	3.42	1.01	34.3	90.72

Notes: 1) Cu is uniformity coefficient equal to D_{60}/D_{10}
2) Cc is correlation coefficient equal to $D_{30}/D_{10}D_{60}$

There was a wide variation in grain size and hydraulic conductivity between the three sites. The effective grain sizes were 0.1mm at the Oakland Site, 0.25 at the Arnold Site, and 0.35 mm at the Potowomut Site. Hydraulic conductivity ranged from 16 m/day at the Oakland Site to 108 m/day at the Arnold Site, with 90 m/day at the Potowomut Site. The hydraulic conductivity determinations for the three sites as approximated by the Hazen Method is 7 m/day for Oakland Site, 54 m/day for Arnold Site, and 105 m/day for Potowomut Site. The approximation for the Oakland and Arnold Sites are roughly half the value measured in the falling head permeameter test, as for the Potowomut Site, the value is 15 m/day higher.

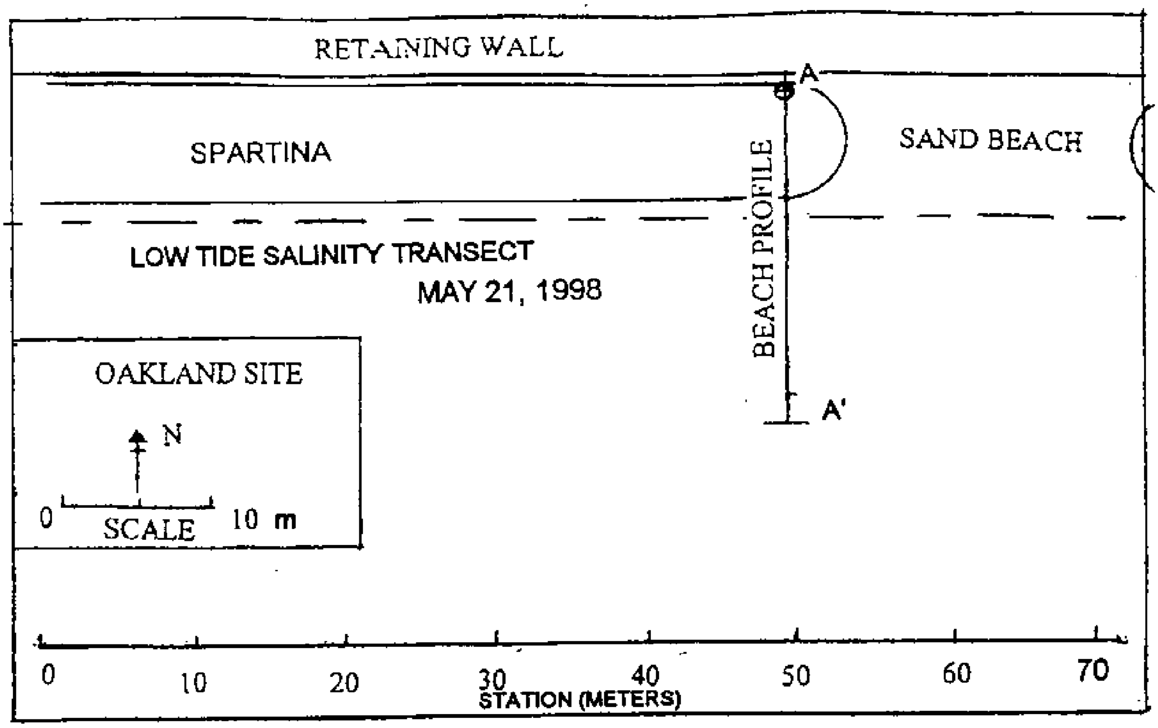
The porosity of the samples from the three sample locations indicate relatively little difference between samples.

3.5.1 Oakland Site

This site is located on the northeastern side of Brushneck Cove and can be accessed by taking Canfield Avenue off West Shore Road in Warwick. This site has a shallow sloping beach. A boundary of retaining walls defines the upper beach face, and almost the entire inter-tidal zone is covered with vegetation. Photographs looking along the beach and perpendicular to the beach are shown in Figure 3.4. There is a sharp transition in the beach sediments that range from a medium to fine grained sand at the point of groundwater discharge, to an organic mud, which lines the bottom of the cove. The discharge of groundwater most likely forced the fine-grained sediments from the groundwater discharge zones leaving a more coarse grained sand. The organic material found at the bottom of the cove is most likely from deposition of decomposed flora that has accumulated over many years. A plan view and beach profile of the Oakland Site are presented in Figure 3.5. Thermal infrared images of the Oakland Site are presented in Figures 3.2a and 3.2b. The thermal infrared images in Figure 3.2a and 3.2b are images of the entire Brushneck Cove. The

Figure 3.4 a Oakland Site: Beach Face Looking East

Figure 3.4 b Oakland Site: Beach Face Looking West



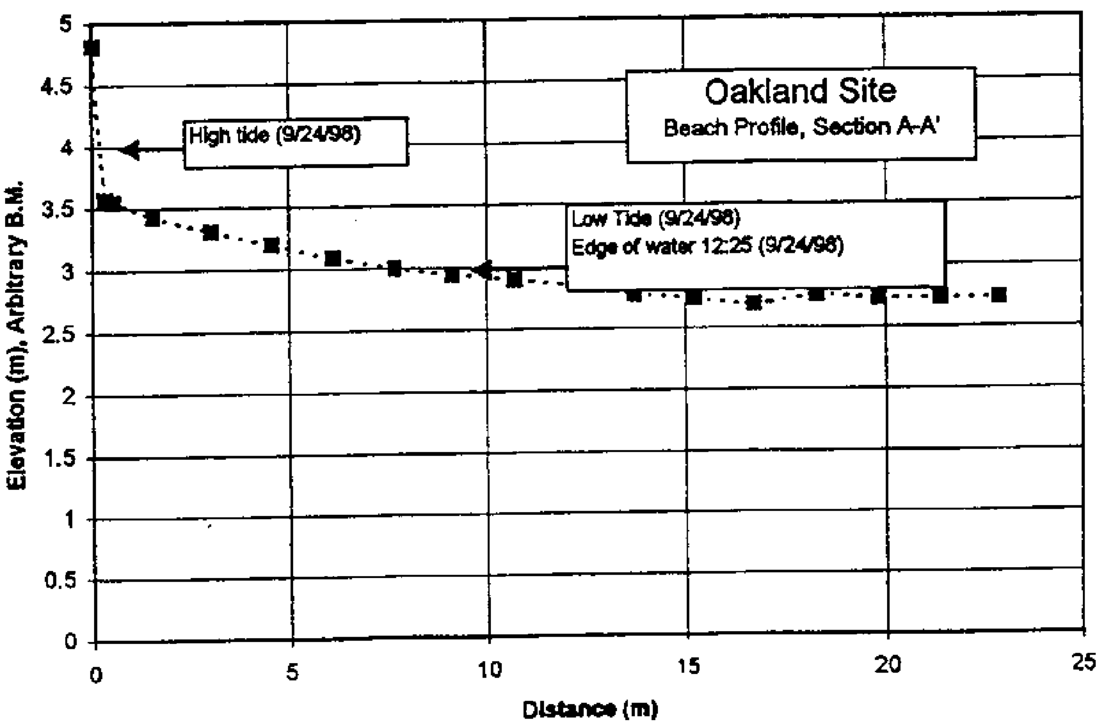


Figure 3.5 **Plan view and beach profile of Oakland Site**

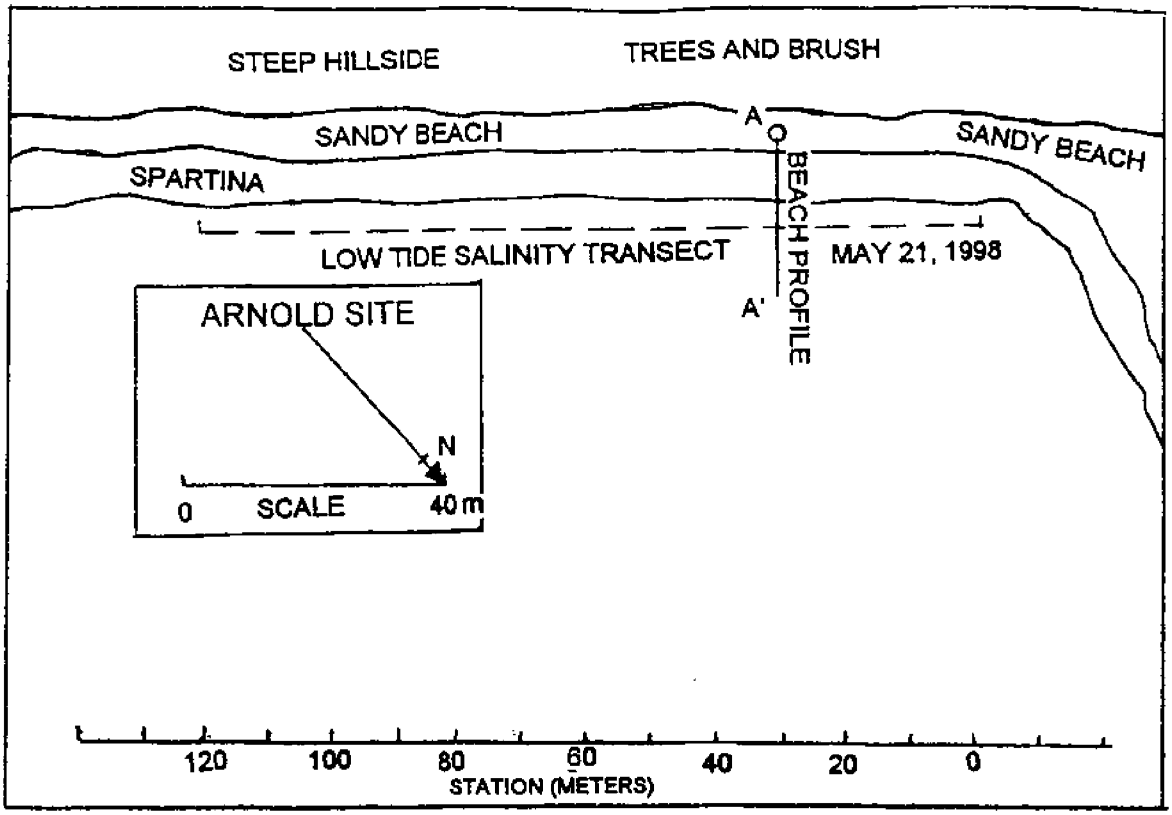
lighter areas represent the warmer surface water of Brushneck Cove. The darker areas are terrestrial features except for the finger shaped appendages that protrude into the bay. These darker areas in the cove are discharge plumes created by fresh, cold, less dense groundwater floating on top of the warmer saline cove water. The area to the north is where the Oakland site survey was completed. The first survey run image shows a slight discharge from the beach face. The second survey run shows a larger plume emanating from the beach face and moving outward towards the center of the cove. This is one of the major reasons this site was chosen for a detailed site assessment.

3.5.2 Arnold Site

This site is located on the southwestern portion of Apponaug Cove and can be accessed from Post Road, Warwick, Rhode Island. This site also has a shallow beach slope, and the lower inter-tidal zone is covered with vegetation. The upper beach is bounded by a large hill. The upper inter-tidal zone is almost entirely covered with vegetation. Photographs looking along the beach and perpendicular to the beach are shown in Figure 3.6. As with the previous site (Oakland), this site also has a transition in bottom sediment composition. The material that makes up the beach is a sandy soil rich in organic matter, the material that lies just off shore is a thick organic material with very little sand. A plan view and beach profile of the Arnold Site are presented in Figure 3.7. Thermal infrared images of the Arnold Site are presented in Figures 3.8a and 3.8b. The thermal infrared images in Figure 3.8a and 3.8b are images of

Figure 3.6 a Amold Site: Beach Face Looking South

Figure 3.6 b Amold Site: Beach Face Looking South



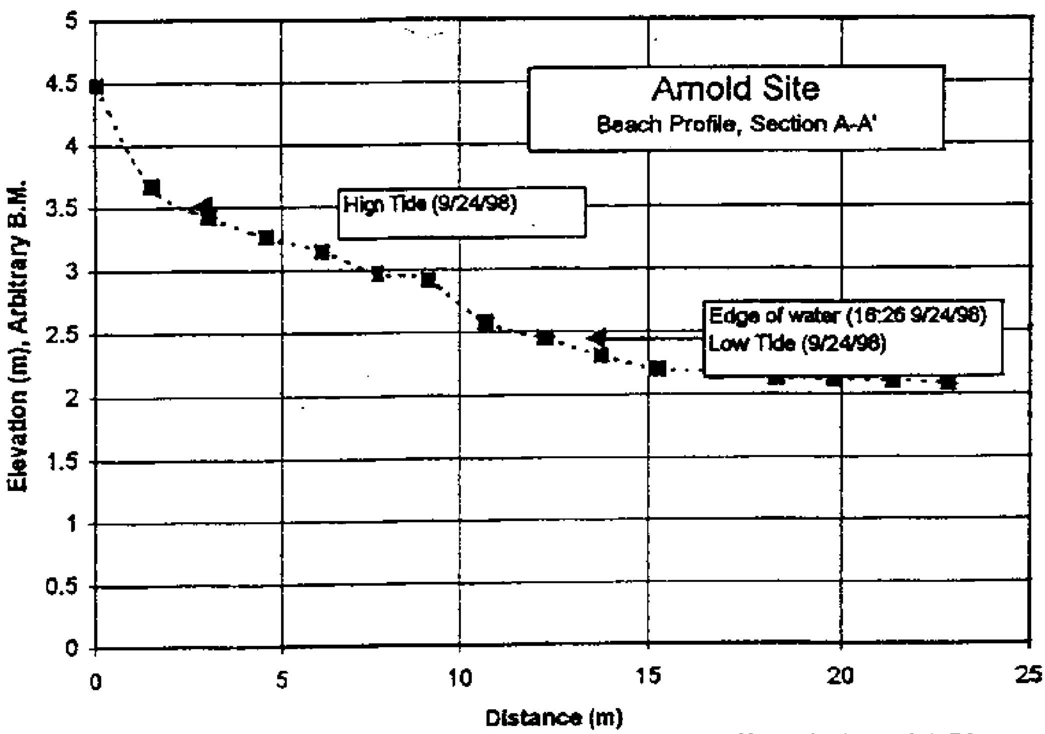
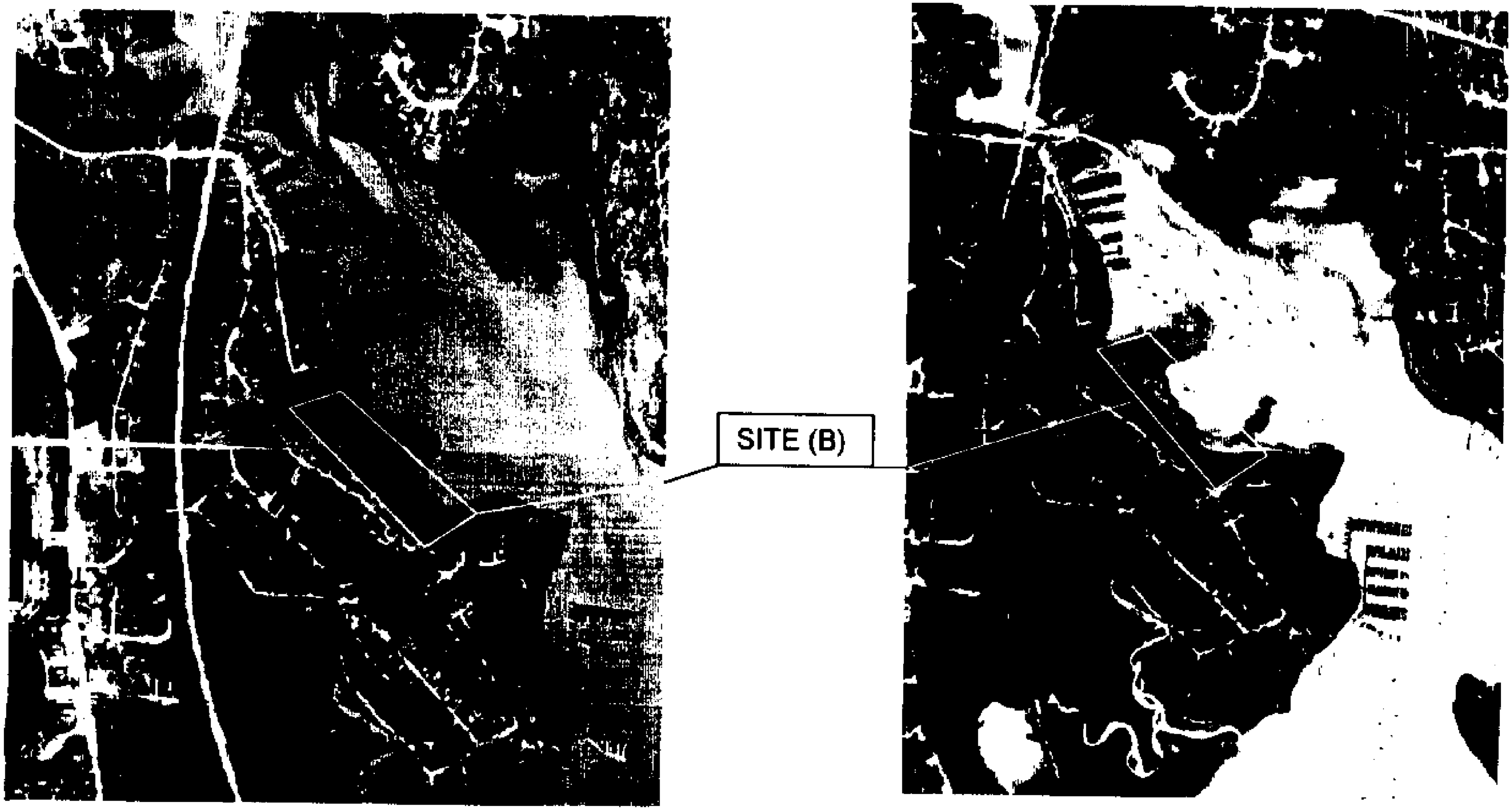


Figure3.7 Plan view and beach profile of Arnold Site



3.8a Thermal Infrared Aerial Image Arnold Site
Run one taken at 19:11 August 24, 1997
Scale 1:16,000

3.8b Thermal Infrared Aerial Image Arnold Site
Run two taken at 20:12 August 24, 1997
Scale 1:16,000

Figure 3.8 a & b Thermal Infrared Aerial Imagery of Arnold Site (Apponaug Cove) August 24, 1997 two runs taken at 19:11 and 20:12 respectively.

Apponaug Cove. The lighter areas, as in the images from the Oakland Site, represent warmer surface water of Apponaug Cove. The darker areas are terrestrial features. The shady dark areas that protrude into the cove water is a colder discharge of fresh groundwater. The movement of the discharge plume as well as the strength of the discharge is time dependent, and therefore visible in the thermal infrared images due to the two survey runs taken at an interval of approximately one hour. The Arnold Site is located in the middle western section of the cove in the thermal infrared imagery. There is a good size plume emanating from the shore line of this area. The movement of the discharge plume from the Arnold Site appears to be moving in the north east direction. In the second survey run the plume is not as distinctive therefore two possibilities exist. The discharge may be slowing due to a change in the direction of the tide, or there is more mixing taking place as the discharge move further into the cove.

3.5.3 Potowomut Site

The study area is located on the beach of Goddard State Park located on Potowomut Neck in the south part of Greenwich Bay. This site is located in the southern most part of the City of Warwick. East Greenwich to the west and North Kingstown borders Potowomut Neck to the south. The beach area has no vegetation, and can be totally covered with water at an extremely high spring tide. Photographs looking along the beach and perpendicular to the beach are presented in Figure 3.9. The beach sediments, as well as the bottom sediments are of a sandy quartzite material. A plan view and beach profile of the

Figure 3.9 a Potowomut Site: Beach Face looking East

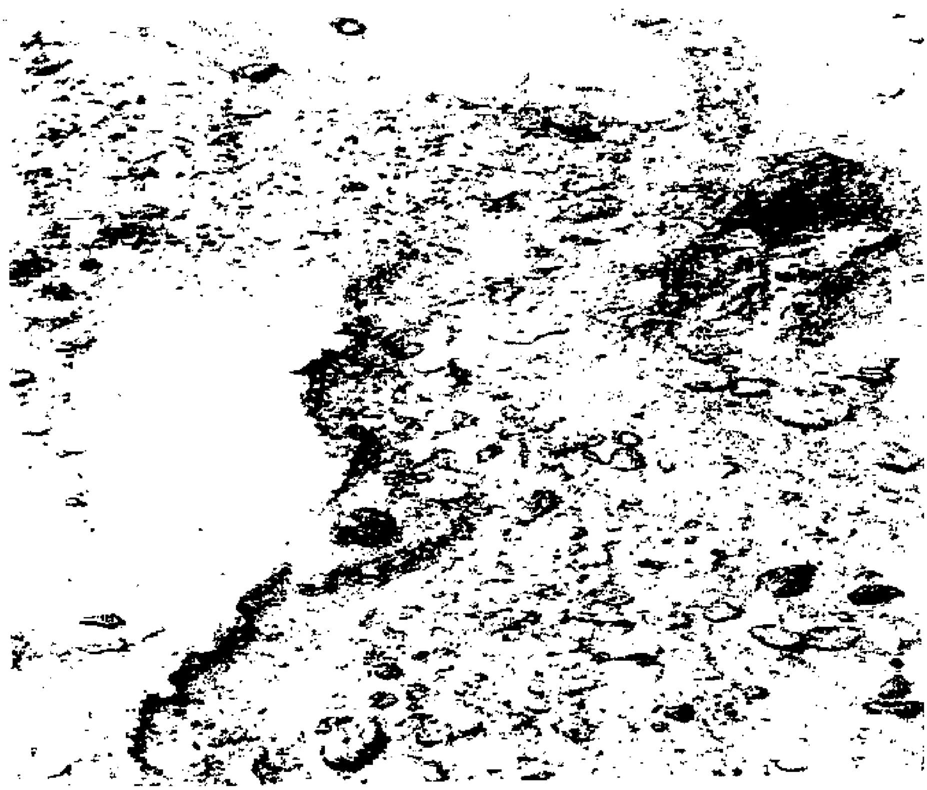


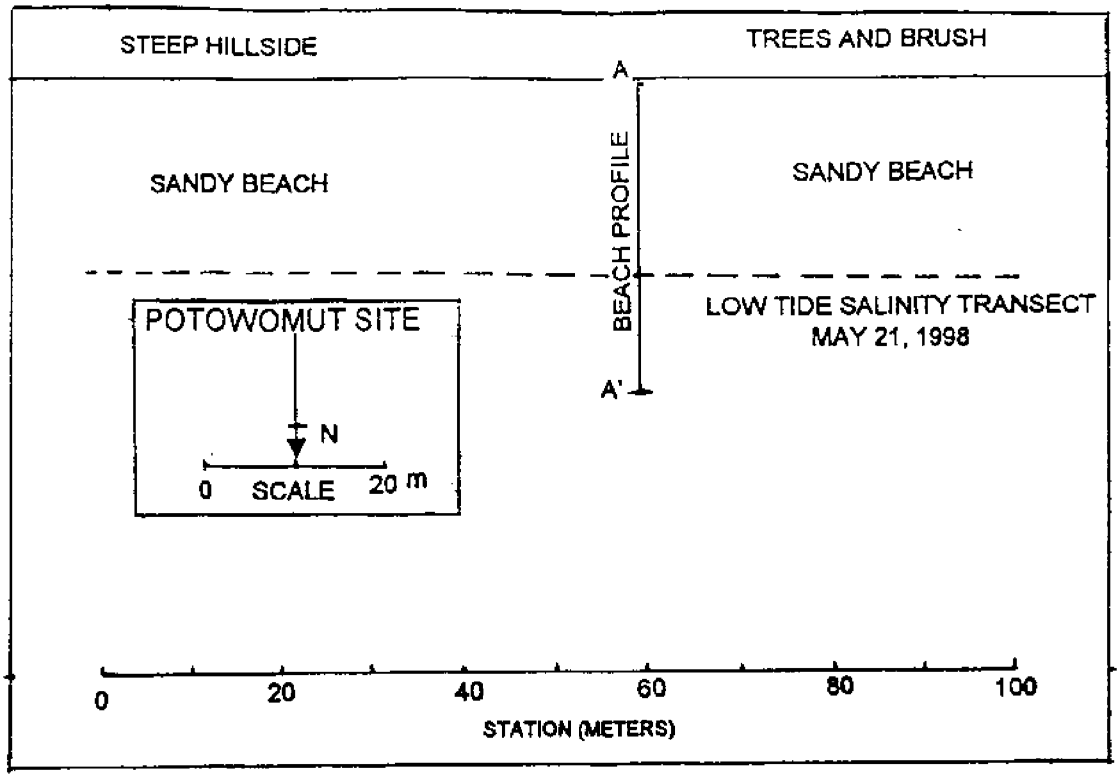
Figure 3.9 b Potowomut Site: Rivulet caused by discharging water

Potowomut Site are presented in Figures 3.10. Thermal infrared images of the Goddard site are presented in Figures 3.11a and 3.11b. The thermal infrared image in Figures 3.11a shows the northern end of Greenwich Cove. To the right of the Greenwich Cove is the very northwestern tip of Potowomut Neck, and to the left is East Greenwich (Chepiwanoxet Neck protrudes into the Bay). In Figure 3.11b is the northwestern tip of Potowomut Neck. The Potowomut Site is located on the northwestern tip of Potowomut Neck, and encompasses the discharge plume that emanates from the tip of Potowomut Neck. The interesting thing about the plume is that it appears to be the strongest discharge along the entire beach face of the Potowomut sub-basin area.

3.6 Measured Salinity, Nitrogen, and Ammonia at the Three Study Sites

The following are the salinity, nitrogen, and ammonia results that were collected at equal distance intervals along the beach line at low tide. The data from transects are presented as plots for each of the three sites. Tabular data is presented in Appendix D.

Oakland Site (A) Salinity beach line transects (Figure 3.12) were taken at low tide in two different seasons, spring and summer (May 21, 1998 and September 4, 1998). The profile indicates low salinity along the length of the transect. There are zones within this profile, which have salinity values of 0 ppt indicating point discharge of fresh groundwater. The low salinity values throughout the transect indicates that there is a substantial amount of fresh groundwater discharging along the entire length of the transect. A large



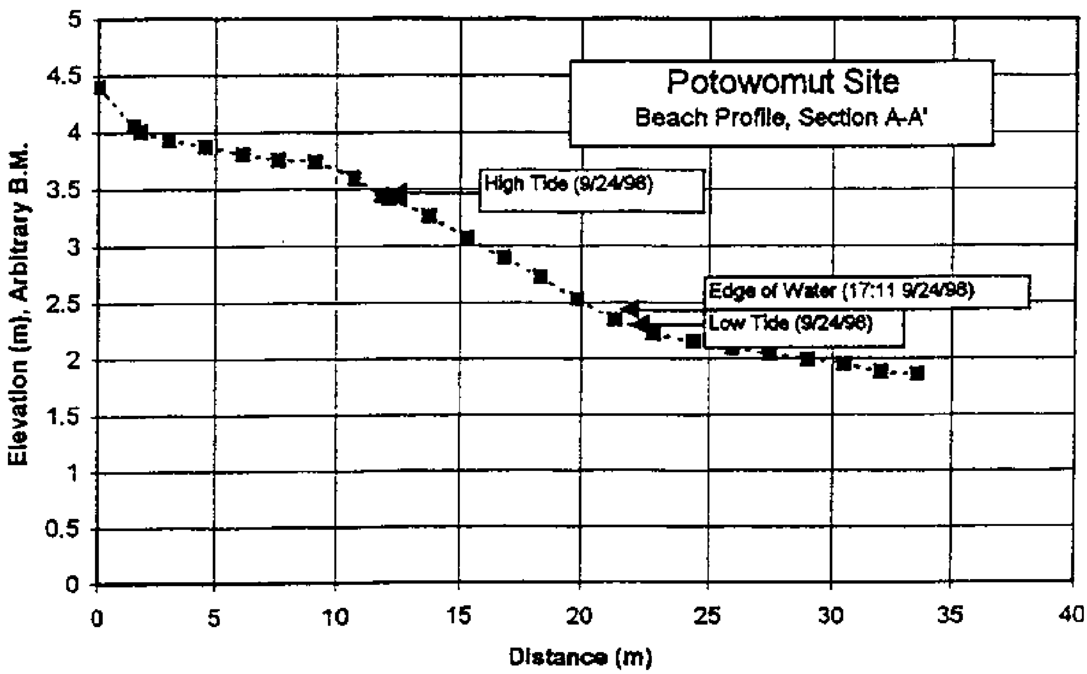
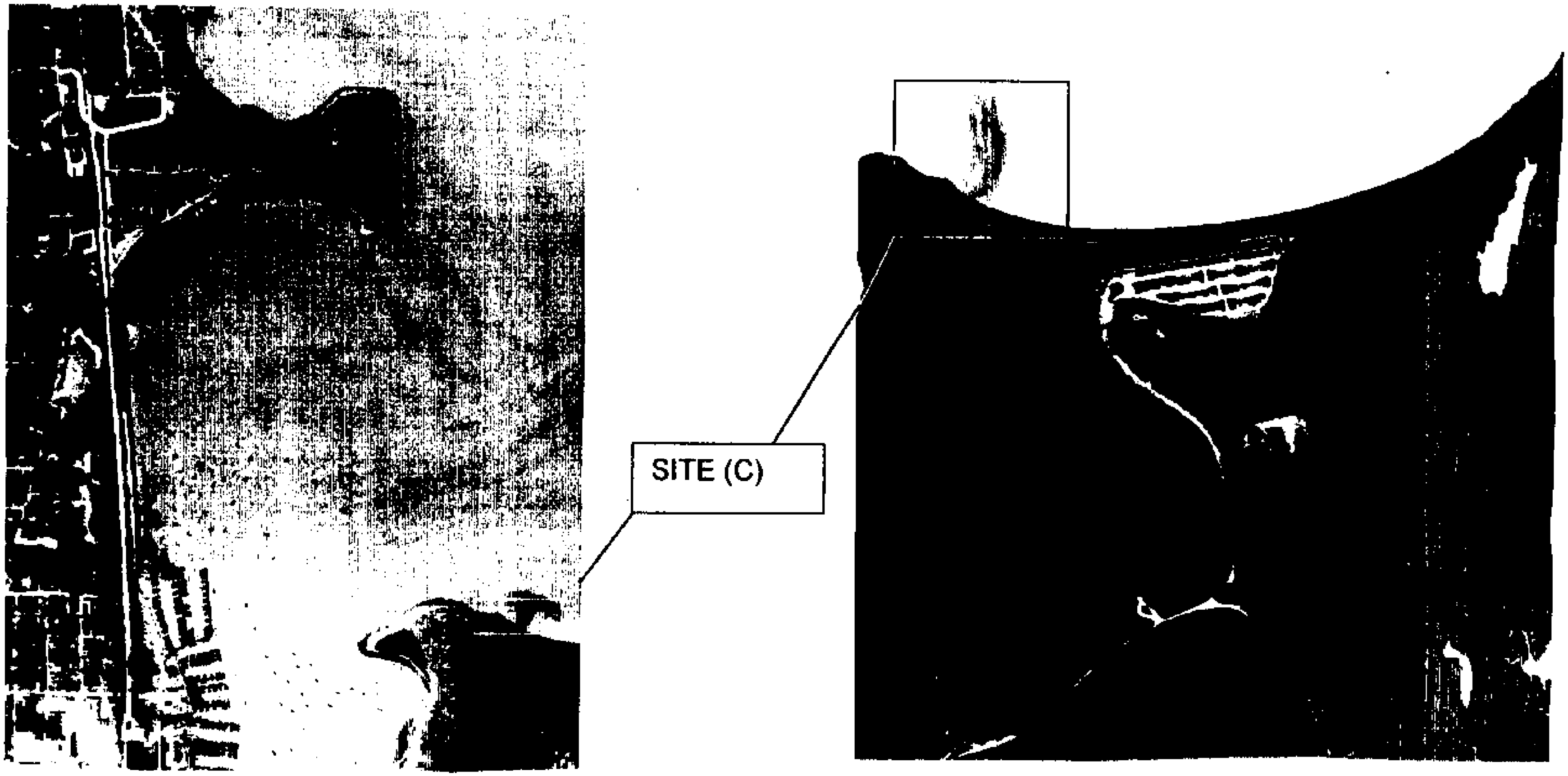


Figure 3.10 Plan view and beach profile of Potowomut Site



3.11a Thermal Infrared Aerial Image Potowomut Site
Run one taken at 19:17 August 24, 1997
Scale 1:10,000

3.11b Thermal Infrared Aerial Image Potowomut Site
Run two taken at 20:22 August 24, 1997
Scale 1:60,000

Figure 3.11 a & b Thermal Infrared Aerial Imagery of Potowomut Site August 24, 1997 two runs taken at 19:17 and 20:22 respectively.

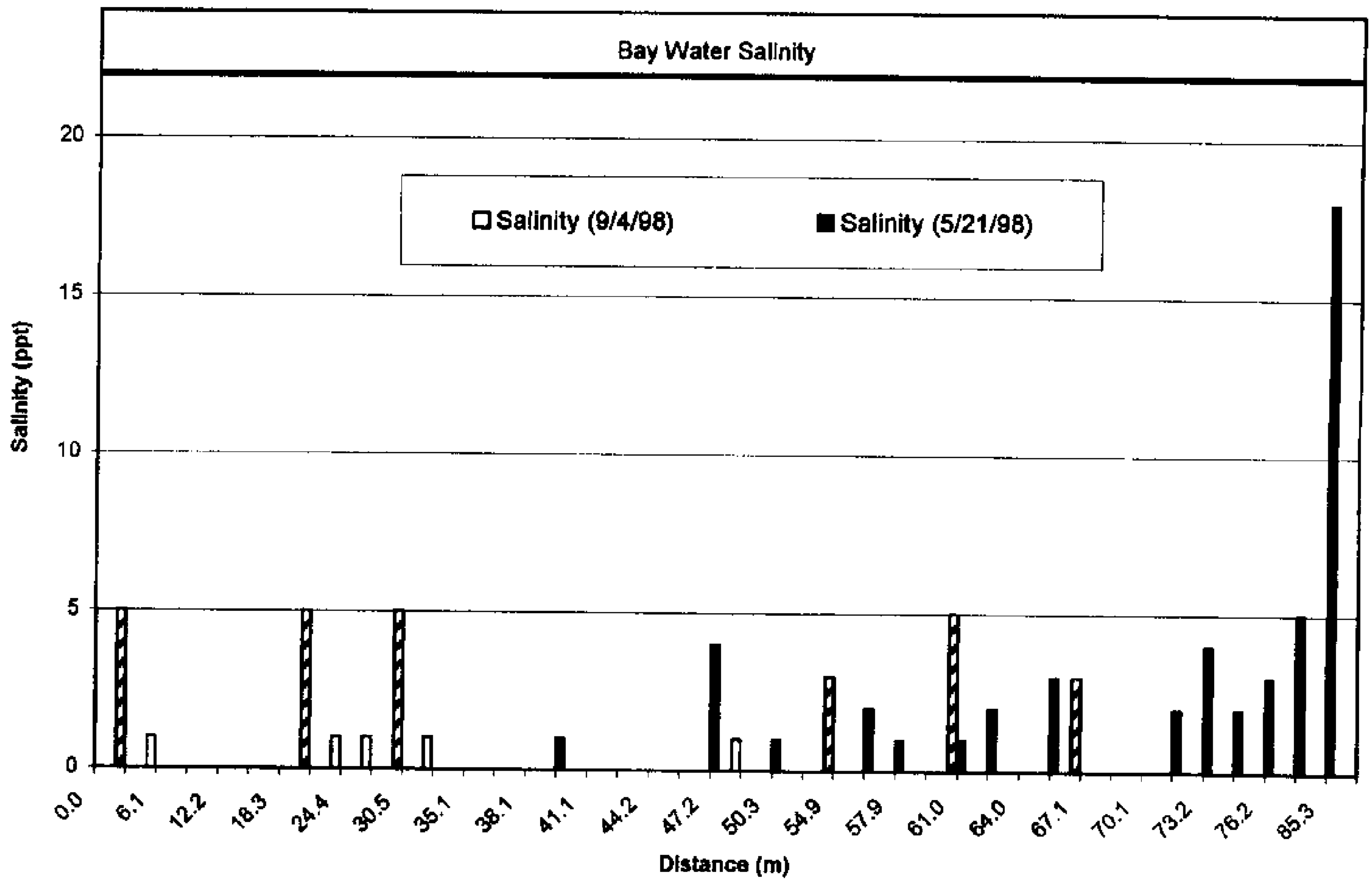


Figure 3.12 Oakland Beach Site (A) low tide line salinity transects

difference in the salinity from spring to summer would indicate a seasonal discharge due to precipitation, however there was not a large variation in salinity between the two seasons indicating that seasonal variability does not play an important role in groundwater discharge in this area.

The nitrogen transects (Figures 3.13a and 3.13b) show relatively high concentrations of nitrogen (NO_3 and NO_2) throughout the beach. Ammonia levels for May 21, 1998 are very low indicating that most of the nitrogen in the groundwater enters the bay in the form of nitrate or nitrite. 20 percent of the samples taken from the Oakland Site had concentrations of nitrate expressed as nitrogen that exceed the United States Environmental Protection Agencies (USEPA) standard for potable water. The USEPA's standard for nitrate nitrogen concentration in potable water is 10 mg/l NO_3-N. Almost 80 percent of the samples show elevated nitrogen levels exceeding 5 mg/L. Concentrations of nitrate-n in groundwater samples extracted from the monitor well, as determined by field analysis using HACH test kits, measured 14 mg/L and 16 mg/L respectively.

Arnold Site (B) A salinity beach line transect (Figure 3.14) completed in spring, shows low salinity over the entire transect with an increase in salinity as you move closer to the main bay away from the influence of Hardig Brook. Although the salinity transect was only done once, it was completed on May 21, 1998 and there had been no precipitation for days prior to the sampling.

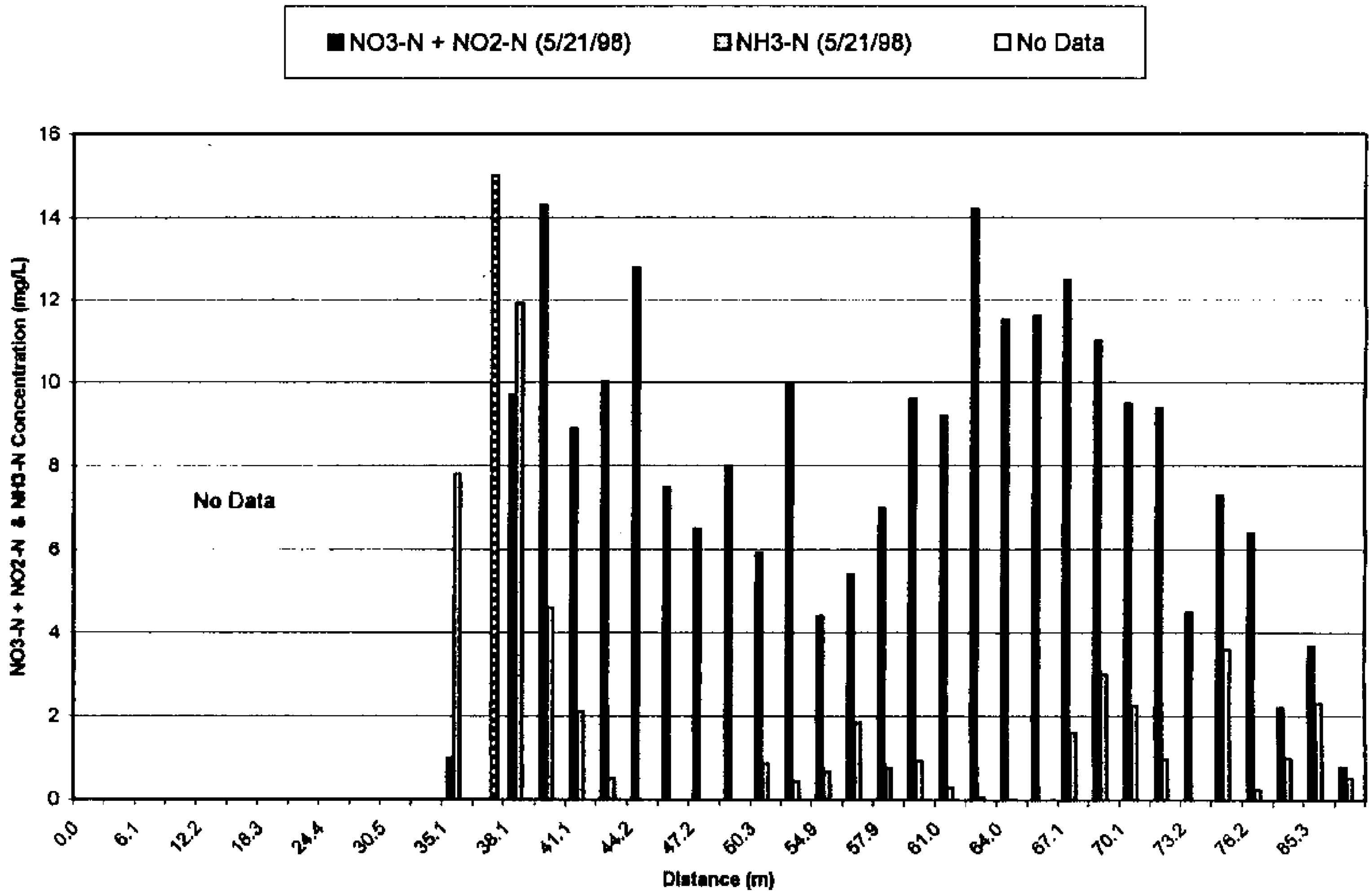


Figure 3.13a Oakland Site (A) NO3-N +NO2-N & NH3-N transects (May 21, 1998)

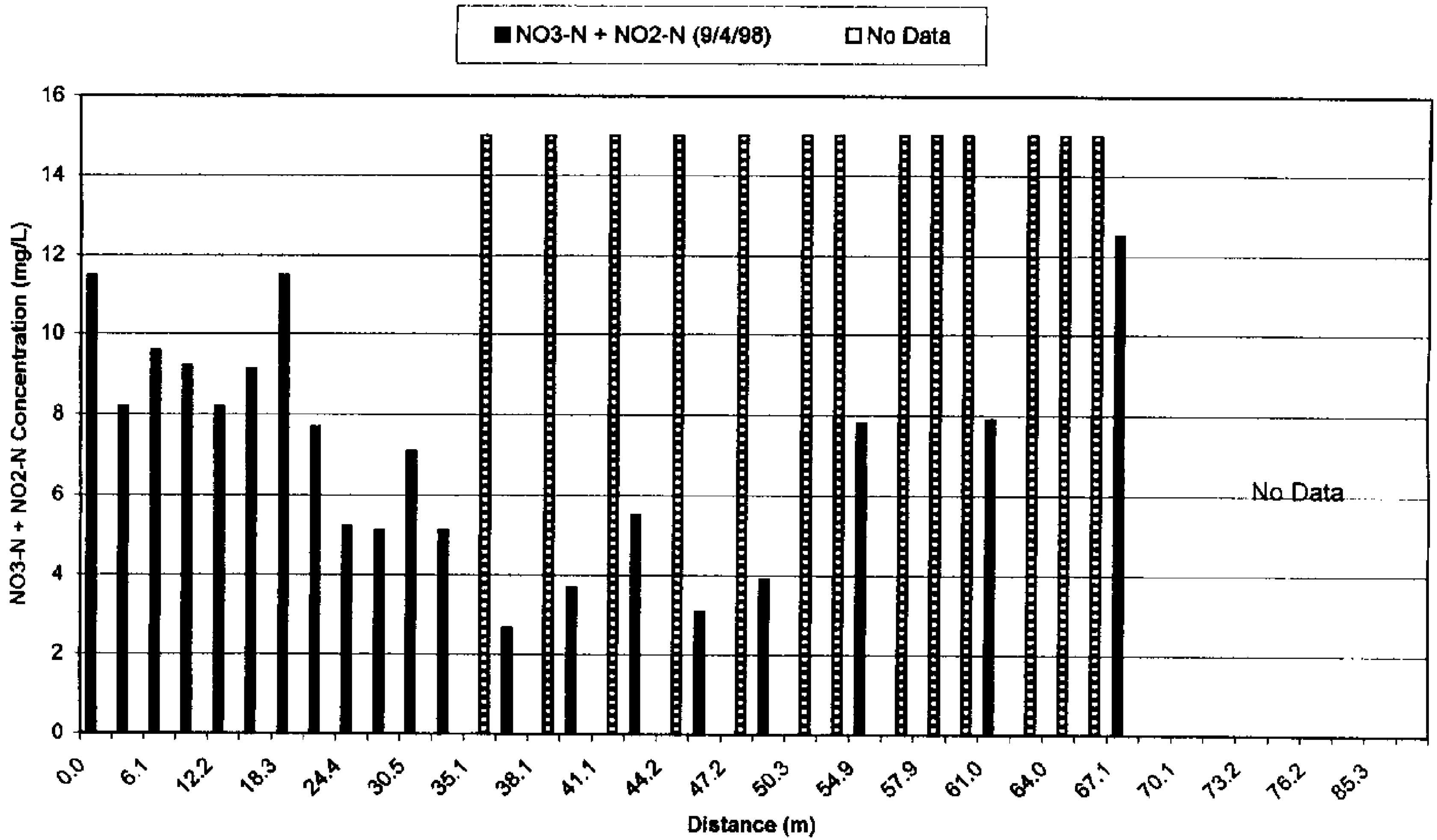


Figure 3.13b Oakland Site (A) low tide line (NO3-N+NO2-N) transects (September 4, 1998)

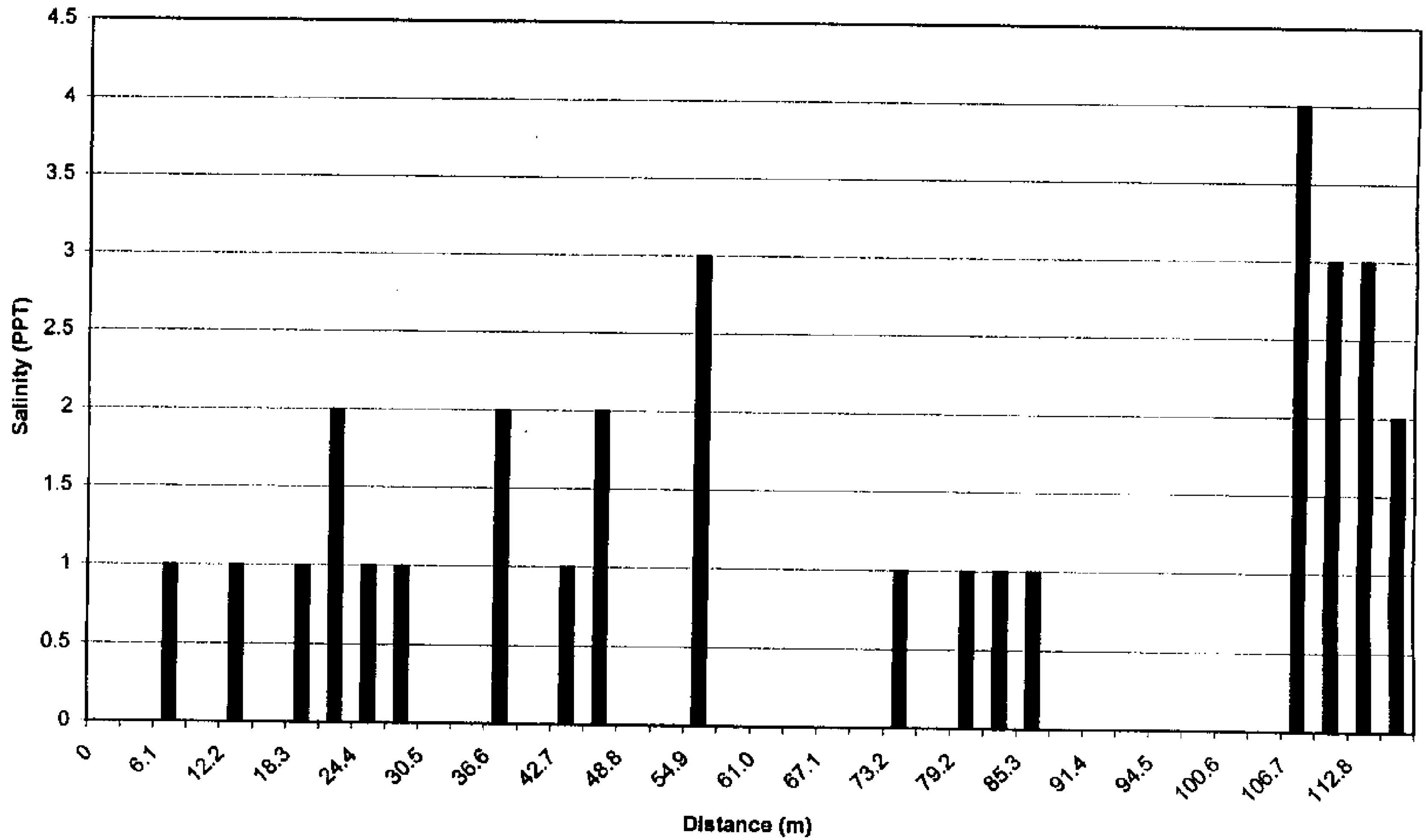


Figure 3.14 Arnold Site (B) low tide line salinity transect (May 21, 1998)

Therefor the prolific discharge of water emptying out of the beach as well as the low salinity values of this discharge indicates a point or points discharge of groundwater from the land.

Nitrogen levels (Figure 3.15) were high throughout the transect. Only one sample exceeded the USEPA standard of 10 mg/l NO3-N for potable waters, however all but two of the samples were above 5 mg/L indicating a large loading of nitrogen to the groundwater in this area. As with the Oakland Site ammonia (NH_3-N) levels remained low, not exceeding 1 mg/L.

Potowomut Site (C) A salinity beach line transect (Figure 3.16), done in late spring and early summer, shows a discharge of brackish water throughout most of the transect. This may indicate large amounts of Bay water infiltrating into the beach at high tide and mixing with the fresh groundwater, then discharging as a mixed salinity concentration at low tide. This low tide discharge enters the Bay in narrow discharge zones in the same manner as fresh groundwater discharges.

Nitrate-N + nitrite-N concentrations as well as ammonia-N concentrations (Figure 3.17) were very low in this area. This area was chosen because of its lack of anthropogenic inputs such as septage, and fertilizer. Values ranged from 0 to 1.5 mg/L, in fact 70 percent of the concentrations of nitrate + nitrite were less than 0.2 mg/L. As for ammonia, the concentrations were higher indicating a

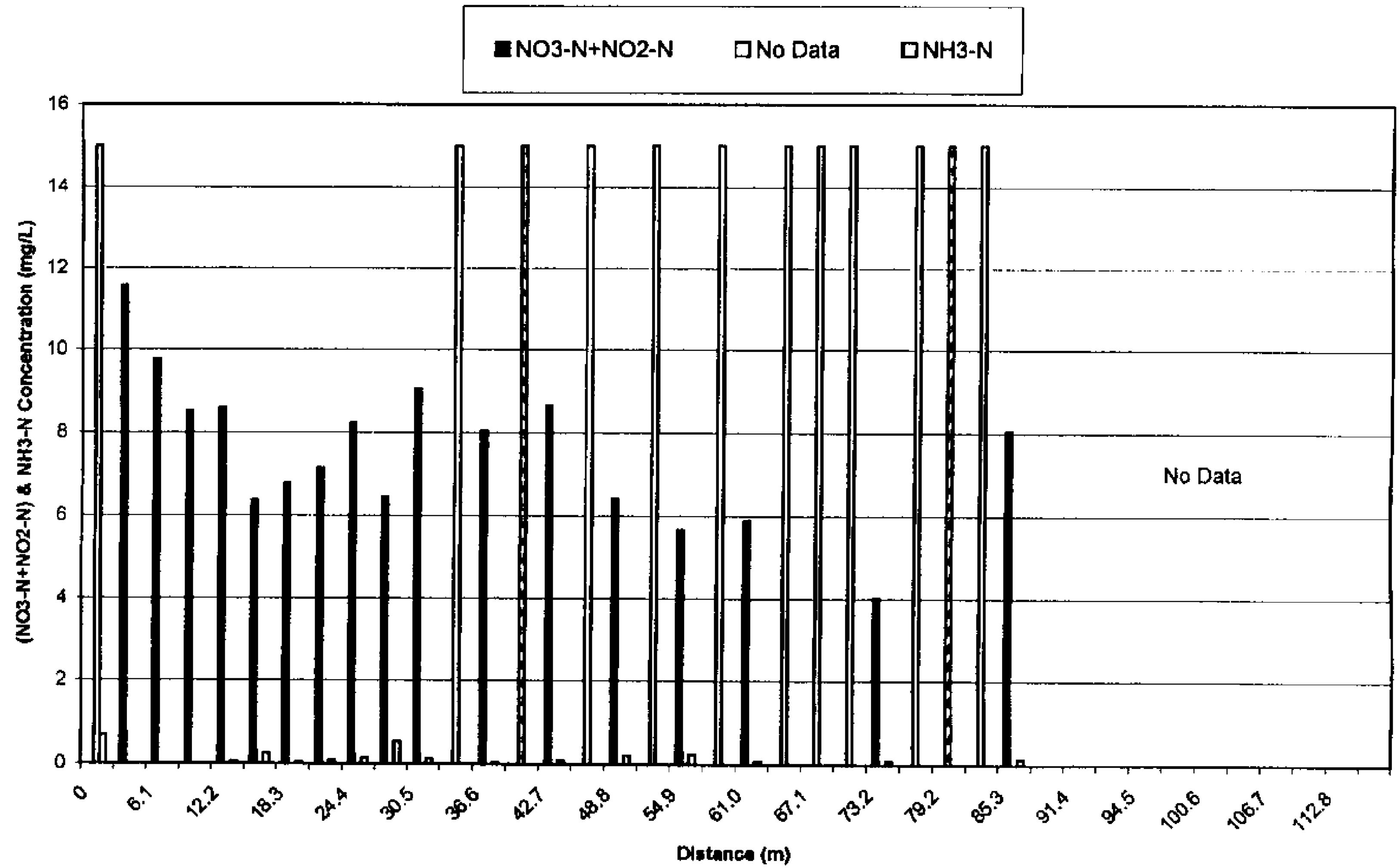


Figure 3.15 Arnold Site (B) low tide line (NO3-N+NO2-N) & NH3-N transects (May 21, 1998)

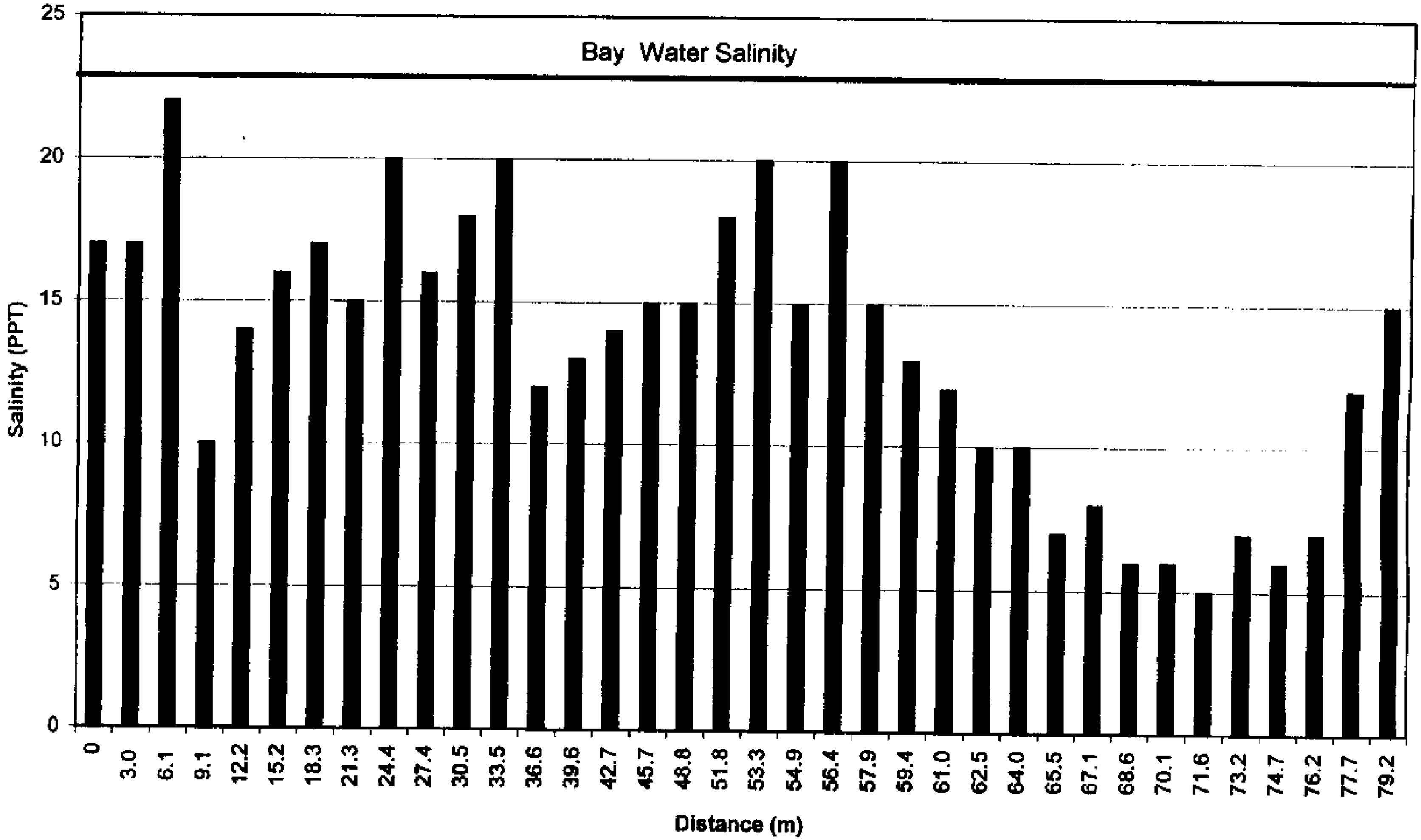


Figure 3.16 Potowomut Site (C) low tide line salinity transect (May 21, 1998)

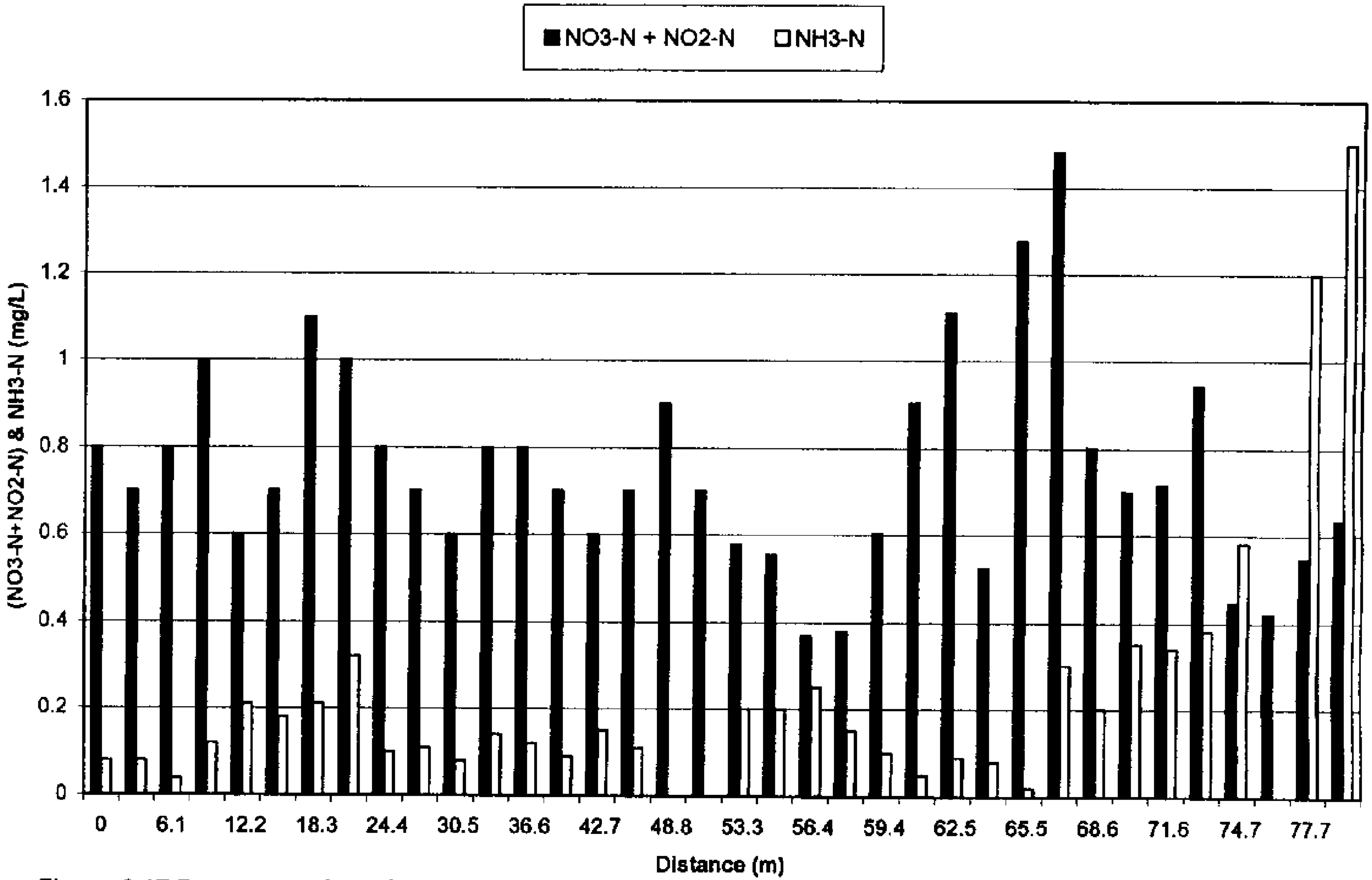


Figure 3.17 Potowomut Site (C) low tide line (NO3-N+NO2-N) and NH3-N transects
(May 21, 1998)

possible denitrification process in route to discharging along the beach.

3.7 Predicted Sewering Results

Based on the information on planned sewering locations from the Warwick City Planning Department, it is envisioned that with 100% sewering the nitrogen loading to the Bay from groundwater discharge would be reduced by approximately 80%. The greatest benefit would be in the South Brushneck sub-basin where the loading would be reduced by 90.0%. As would be expected, the area that would benefit least form total sewering is the Hardig sub-basin, which would see a reduction of 65% of the present total nitrogen loading, due to its large area and low population density. The percent reduction for all sub-basin areas as well as total reduction of nitrogen loading over the entire watershed is shown in Table 3.4. The reduction in concentration is shown graphically in Figure 3.18.

3.8 Relationship of Salinity and Nitrogen in Beach Groundwater Discharge

Groundwater samples were taken and tested for nitrogen (NO_3-N + NO_2-N) content. The results were evaluated for patterns of salinity-nitrogen concentration spatially. These samples were taken along the beach low tide transect lines at each of the three sites.

The data was plotted to evaluate a relationship between salinity and nitrogen. The data was also used to normalize all the nitrogen concentration

Table 3.4 Percent reduction in groundwater nitrogen due to the City of Warwicks' sewering plan

Sub-basin Name	Percent Reduction After First Year	Percent Reduction After Second Year	Percent Reduction After Third Year
Apponaug	14.8	35.7	67.1
Arnold	14.9	36.0	67.6
Baker	19.2	46.3	86.9
Bayside	18.5	44.6	83.7
Chepiwanoxet	16.9	40.9	76.8
Cove Beach	19.6	47.2	88.6
East Greenwich	10.0	24.2	45.4
Goddard	17.9	43.3	81.3
Hardig	14.3	34.6	65.0
Lockwood	19.1	46.0	86.4
Long	19.2	46.4	87.2
Longmeadow	19.2	46.4	87.1
Maskerchugg	15.8	38.0	71.4
Nausauket	19.3	46.6	87.6
North Brushneck	19.4	46.9	88.2
North Buttonwoods	19.4	46.9	88.1
Oakland	18.8	45.3	85.1
Potowomut	17.9	43.3	81.4
South Brushneck	19.8	47.9	90.0
South Buttonwoods	18.9	45.7	85.8
Tuscatucket	18.7	45.2	85.0
Warwick Neck North	19.4	46.8	88.0
Warwick Neck South	16.6	40.1	75.3
Total reduction	17.3	54.8	78.3

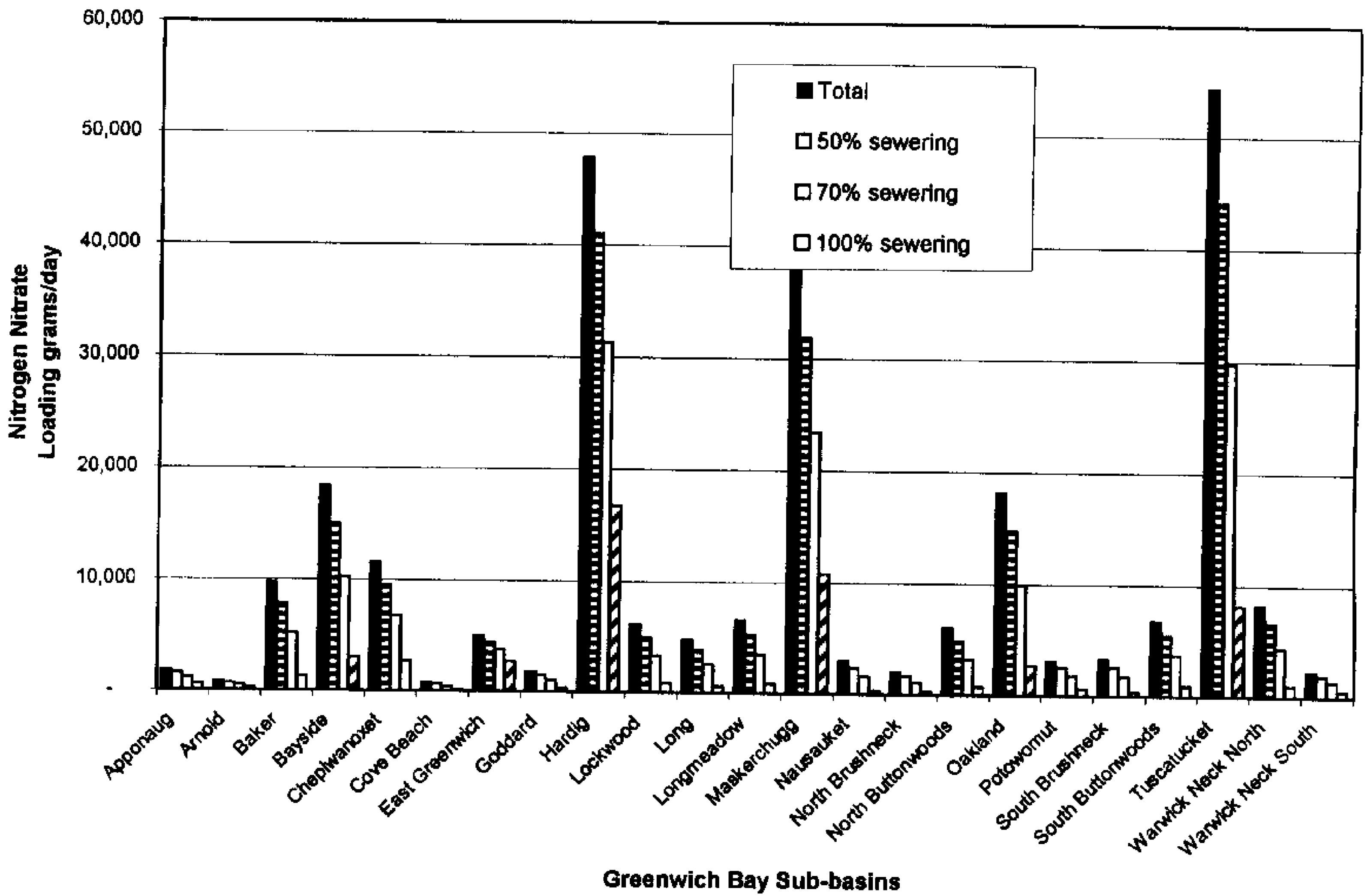


Figure 3.18 Reduciton of nitrogen with addition of sewering

results to fresh water equivalent. The average nitrogen concentration, relative to the base of fresh water occurs when salinity equals zero. This assumes that a fresh water nitrogen concentration is uniform for all samples and all sites. This assumption may not be accurate depending on the proximity the sample was taken as to a nitrogen source (Valiela et al., 1992, Urish and Qanbar, 1997). Figures 3.19, 3.20, and 3.21 represent the salinity nitrogen relationship for the Oakland, Arnold, and Potowomut Sites respectively. There are two lines plotted on each figure, the solid line is the line of best fit for all the sample points, while the dashed line is the high concentration envelope. Table 3.5 summarizes the results of this analysis along with the results of the nitrogen budget for each of the three study sites.

Oakland Site (A). The Oakland Site data shows high concentrations of nitrate plus nitrite-nitrogen, a plot of nitrate plus nitrite-nitrogen concentration verses salinity is shown in Figure 3.19. Nitrate plus nitrite-nitrogen concentrations are in the high range of 14 mg/l to 14.5 mg/l at one of the points, although there appears to be a uniform distribution of high nitrate plus nitrite-nitrogen levels along the entire beach area, even when the fresh groundwater contribution is low. Ammonia-nitrogen levels only exceed nitrogen levels in one of the samples, this may indicate that there is a wastewater source not far from the discharge location, this source can be an OSSD from a residence located along the beach. In the case of Oakland the high measured values are within two percent of the estimated nitrogen concentration.

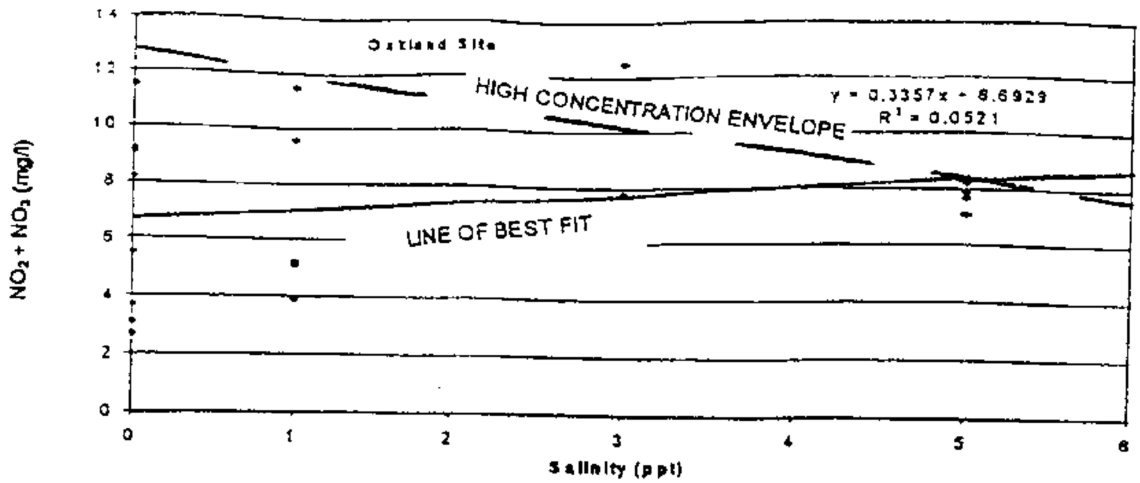


Figure 3.19 Oakland Site (A) scatter plot of nitrogen vs. salinity

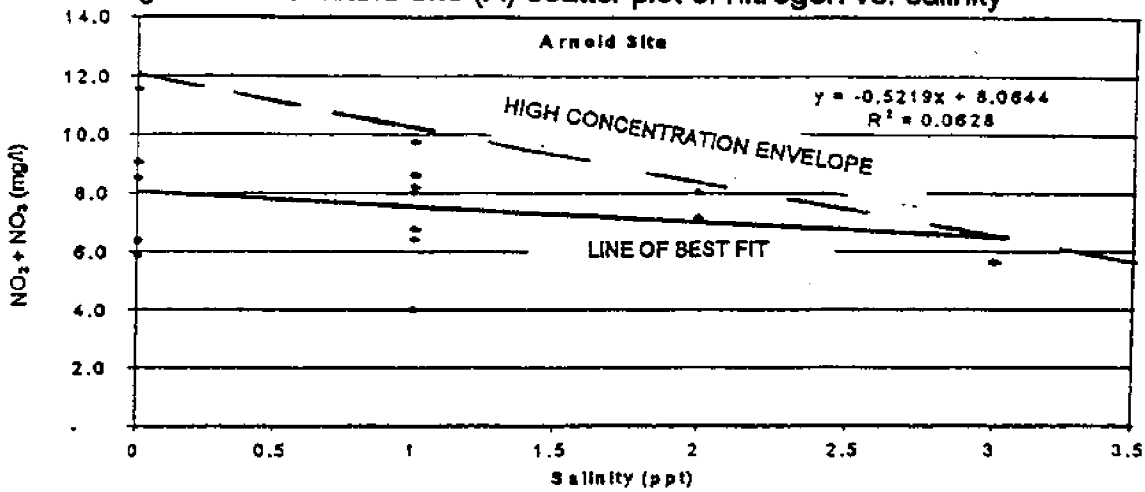


Figure 3.20 Arnold Site (B) scatter plot of nitrogen vs. salinity

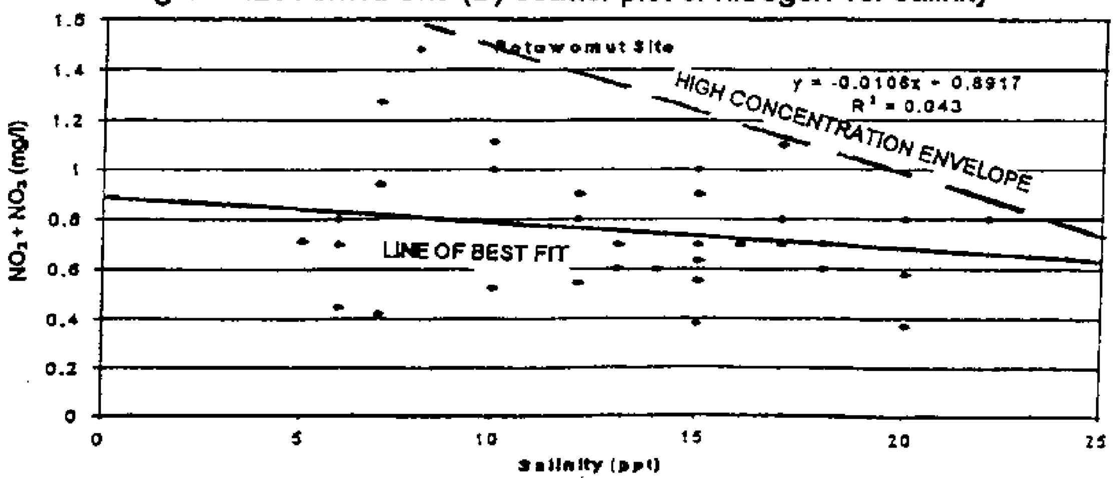


Figure 3.21 Potowomut Site (C) scatter plot of nitrogen vs. salinity

Arnold Site (B). At this site nitrate plus nitrite-nitrogen are plotted verses salinity in Figure 3.20. Nitrate plus nitrite-nitrogen concentrations are again in the high range 5 mg/l to 11.5 mg/l. Ammonia-nitrogen concentrations are uniformly low throughout the transect indicating that the contribution of nitrogen to the Cove is from sources distant to the shore. At the Arnold Site, the measured high value is over three times the estimated value; this may be because the beach groundwater discharge is not truly representative of the sub-basin.

Potowomut Site (C). At this site data from the nitrate plus nitrite-nitrogen are plotted against salinity in Figure 3.21. Nitrate plus nitrite-nitrogen concentration and ammonia concentrations are low ranging from 0.38 mg/l to 1.50 mg/l and 0.0 to 1.50 respectively. The low-level contribution of nitrogen throughout the transect is distributed uniformly. The area where the higher ammonia-nitrogen levels occur is the area with the freshest discharge. In the case of Potowomut the high measured value for nitrogen is within 25 percent of the estimated value.

4 CONCLUSIONS

It is apparent from the salinity low tide line transects and from the thermal infrared imagery that there is a significant fresh groundwater discharging into

Greenwich Bay, but that this discharge is non-uniform along the coastline. The area water budget indicates that there is approximately 55.9 million liters (15 million gallons) of water discharged each day on an annual basis. One third of groundwater discharge to Greenwich Bay is shoreline discharge while the remaining two thirds is groundwater discharges through stream during dry weather flow.

The nitrogen budget estimates a total loading of 369.9 Kg of nitrogen to the Bay per day. The budget (model) also predicts that the largest contributor of nitrogen per unit area is the Oakland sub-basin discharging an average 215 grams nitrogen per hectare per day. The next largest contributor, according to the budget, was the South Brushneck sub-basin having a loading of 200 grams nitrogen per hectare per day. The lowest contributor of nitrogen comes from the Warwick Neck South, which discharges 23 grams nitrogen per hectare per day. Although the Warwick Neck South sub-basin has the lowest input of nitrogen according to the model, an alternate sample site was chosen for easier accessibility. The Warwick Neck South sub-basin does not have ready access since much of the waterfront is private property. The Potowomut sub-basin contributes 38 grams nitrogen per hectare per day, and was chosen as the alternate site. The Arnold sub-basin also has a fairly low contribution, 52 grams nitrogen per hectare per day, has a definitive groundwater plume discharging into the Bay as shown in the thermal infrared image. It contain a large number of unsewered houses, and has interesting characteristics such as the steep sloping hills. Because of these characteristics, this was selected as a detailed sampling site.

Thermal infrared aerial imagery was very helpful in locating areas in which to conduct detailed studies. The three study sites were chosen on the basis of thermal infrared imagery, which showed large and definitive groundwater discharge into the Bay, and a site survey in which certain beach face characteristics such as lack of vegetation, residential density, and discharge rivulets occurred along the discharge zone at low tide line. Another major consideration was the nitrogen budget model output. Thermal infrared aerial imagery is a cost-effective means of selecting specific areas in which detailed groundwater surveys can be made. The use of this technology can reduce the expensive cost of sampling areas in which there is a lack of groundwater discharge.

Comparison of the nitrogen levels in the area in which the site-specific studies were conducted compared to the predicted values from the nitrogen budget shows some disparities. The Oakland Site was identified as a major contributor by the budget with the Arnold site identified as a lesser contributor, and the Potowomut Site identified as a least contributor of the three. The average values obtained from field sampling compared to the predicted values are shown in Table 3.5. Because the groundwater samples taken from each site are from very specific locations, the comparison of the estimated versus the measured has to be looked at with all the factors that affect the quality of the water. The variability may be seasonally and time dependent. The estimates for

Table 3.5 Nitrogen Concentrations at Sites:

SITE	ESTIMATED NITROGEN	MEASURED NITROGEN	
		AVERAGE	HIGH
	(mg/l)	(mg/l)	(mg/l)
Oakland (A)	13.88	6.75	13.50
Arnold (B)	3.59	8.00	12.00
Potowomut	2.52	0.90	1.95

Notes:

1. Estimates are based on annual water and nitrogen budgets.
2. Measured values are based on nitrogen water quality field data normalized to fresh water equivalents using plots of nitrogen versus salinity (Figures 3.19, 3.20, and 3.21)
3. It Should be noted that the "estimated nitrogen" concentration is for total sub-basin area, while the "measured nitrogen" concentration is for samples from a specific beach discharge location, which may not be representative of the entire sub-basin.

the Oakland sub-basin as with all the sub-basins were made using conservative values for loading in order not to underestimate the loading of nitrogen to Greenwich Bay. The estimated value of nitrogen concentration for the Oakland, and Potowomut Sites were 13.9 mg/l, and 2.5 mg/l respectively. These values fall slightly above the measured high concentrations obtained in the field studies. This is an acceptable condition for the budget model to over estimate the loading , however, the Arnold Site was severely underestimated. The Arnold sub-basin estimation for nitrogen concentration in the discharging groundwater is 3.59 mg/l, and the measured average, and high concentration values were 8.00 mg/l and 12.0 mg/l respectively. Possibilities for such high numbers in the Arnold Site are the topographic characteristics of the area, and that the groundwater discharge plume does not completely represent the entire sub-basin. The residents that live along the coast of the Arnold sub-basin area located on a large hill that slopes very steeply before leveling out at the upper tide line. The area is very poorly suited for OSSDs due to the topography, and the proximity to Apponaug Cove. The wastewater does not have enough time to purify prior to entering Apponaug Cove.

Sewering the entire Greenwich Bay watershed would have a profound effect on the quality of groundwater entering the Bay. The sewering would result in an approximate 80 percent reduction of total nitrogen loading to Greenwich Bay. However, the only way in which this reduction will take place is if the residents within the Greenwich Bay watershed are willing to voluntarily connect their houses to the public sewer system. The City of Warwick has the option of large number of people in the watershed do not voluntarily connect their houses to public sewers.

5 Recommendations for Additional Study

1. Continue to monitor groundwater quality in the monitor wells installed in the Oakland and Arnold Sites.
2. Identify other major discharge areas using thermal infrared aerial imagery for detailed site analysis.
3. Install additional groundwater quality monitor wells in areas identified as major groundwater discharge locations.
4. Compare the nitrogen budget model projected reductions in loading to Greenwich Bay with data collected from monitor wells.

6 ACKNOWLEDGEMENTS:

The authors wish to acknowledge the support of the City of Warwick, the University of Rhode Island Sea Grant Program and the United States Department of Defense for the financial support that made this project possible. Additionally, the cooperation of the people of the City of Warwick and the collaboration of many other investigators of the University of Rhode Island Greenwich Bay Collaborative are greatly appreciated.

REFERENCES CITED

Ahearn, C., R. Bernardo, C. Deacutis, and C. Volkay-Hilditch, 1990, The State of the State's Waters- Rhode Island, A Report to Congress, pp. IV.A-1 – IV.D-4.

Allard, M., 1998, Greenwich Bay, http://seagrant.gso.uri.edu/G_Bay, Rhode Island Sea Grant Communications Office, University of Rhode Island Narragansett Bay Campus, Narragansett, RI.

Allen, W.B., 1956, Ground-Water Resources of the East Greenwich Quadrangle, Rhode Island, Geological Bulletin No.8, United States Geological Survey pp. 1-56.

Allen, W.B., G. W. Hahn, and R.A. Brackley, 1966, Availability of Ground Water Upper Pawcatuct River Basin Rhode Island, Geological Survey Water-Supply Paper 1821, United States Government Printing Office, Washington, DC, pp. 22-25.

APHA, AWWA, WPCF, Standard Methods for the Examination of Water and Wastewater, 17th Edition, 1989, pp. 4-80 – 4-81, 4-87 – 4-88.

Cambareri, T.C. and E.M. Eichner, 1998, Watershed Delineation and Ground Water Discharge to a Coastal Embayment, Ground Water Vol. 36, No.4, pp. 626-634.

Canter, L.W. and R.C. Knox, 1986, Septic Tank System Effects on Ground water Quality, Lewis Publishers Inc, Chelsea, MI, pp.53-55, 76-79.

Capone, D.G. and J.M. Slater, 1990, Interannual patters of water table height and groundwater derived nitrate in nearshore sediments, Biogeochemistry 10: pp. 277-288.

Demello, A.C.V., 1996, Hardig Brook Water Quality Assessment: Identification of Point and Nonpoint Source Pollution, University of Rhode Island Master of Science Thesis, pp.41-84.

Dickerman, D.C. and P.M. Barlow, 1997, Map Showing Water-Table Conditions and Stream-Aquifer Interaction in the Hunt-Annaquatucket-Pettaquamscutt Aquifer, Central Rhode Island, October 7-9, 1996, Water-Resources Investigations Report 97-4167.

Dickerman, D.C. and M.M. Ozbilgin, 1985, Hydrogeology, Water Quality, and Ground-Water Development Alternatives in the Beaver-Pasquiset Ground-Water Reservoir, Rhode Island, United States Geological Survey, Water-Resource Investigations Report 85-4190.

Eichner, E.M. and T.C. Cambareri, 1991, Nitrogen Loading, Technical Bulletin 91-001, Cape Code Commission Water Resource Office, Barnstable, MA., pp. 1-14.

Fetter, C.W., 1999, Contaminant Hydrogeology, Prentice Hall, Upper Saddle River, NJ, p 292.

Fetter, C.W., 1994, Applied Hydrogeology, Prentice Hall, Upper Saddle River, NJ, pp. 82-88, 364-377.

Freeze, R.A. and J.A. Cherry, 1979, Groundwater, Prentice-Hall, Inc. Englewood Cliffs, NJ, pp.413-416.

Fuhs, G.W., 1974, Nutrients and Aquatic Vegetation Effects, Journal of The Environmental Engineering Division, ASCE, Vol. 100, No. EE2, Proc. Paper 10453, pp. 269-278.

Giblin, A.E. and A.G. Gaines, 1990, Nitrogen inputs to a marine embayment: The importance of groundwater, Biogeochemistry 10, pp. 309-328.

Gold, A.J., G.W. Loomis, and B.E. Lamb, 1990, Final Project Report For Field Evaluation Of Nitrogen Removal Septic Systems For Coastal Communities, Current Report The Narragansett Bay Project, pp. 1-27.

Hantzsche, N.N. and E.J. Finnemore, 1992, Predicting Ground-Water Nitrate-Nitrogen Impacts, Ground Water Vol. 30, No. 4, pp.490-499.

Harman, J., W.D. Robertson, J.A. Cherry, and L. Zanini, 1996, Impacts on a Sand Aquifer from an Old Septic System: Nitrate and Phosphate, Ground Water Vol. 34, No.6 pp. 1105-1113.

Hoare, R., 1996, Climate Data, http://WWW.worldclimate.com

Jorgensen, B.B. and K. Richardson, 1996, Eutrophication in Coastal Marine Ecosystems, Coastal and Estuarine Studies, American Geophysical Union, Washington D.C., pp. 1-17.

Joubert, L.B., D.Q. Kellogg, A.J. Gold, A. Mandeville, and W. DeLeo, 1996,Water Quality Impacts of Changing Land Use on Block Island, Rhode Island, Project # 92-EWQI-9040, Town of New Shoreham and USDA Cooperative State Research Education Extension Service, pp.1-8.

Joubert, L.B. and A.J. Gold, 1993, Watershed Land Use and Water Quality: A Guide for Local Officials, Natural Resource Facts Sheet No. 93-5.

Lapointe, B.E., J.D. O'Connell, and G.S. Garrett, 1990, Nutrient coupling between on-site sewage disposal systems, groundwaters, and nearshore surface waters of the Florida Keys, Biogeochemistry 10, pp.289-307.

Likens, G.E., 1972, Nutrients and Eutrophication: The Limiting-Nutrient Controversy, American Society of Limnology and Oceanography, Inc., Allen Press Inc., Lawrence, KS, p. 3.

Millham, N.P. and B.L. Howes, 1994, Nutrient Balance of a shallow coastal embayment: I. Patterns of groundwater discharge, Marine Ecology Progress Series, Vol. 112: pp. 155-167.

Nowicki, B.L. and J.H. McKenna, 1990, A Preliminary Assessment of Environmental Quality in Greenwich Bay, Rhode Island, Final Report to the Narragansett Bay Project, pp. 1-31.

Oberdorfer, J.A., M.A. Valentino and S.V. Smith, 1990, Groundwater contribution to the nutrient budget of Tomales Bay, California, Biogeochemistry 10: Academic Publishers, Netherlands, pp. 199-216.

Portnoy, J.W., B. Norwicki, T.C. Roman, and D.W. Urish, 1998, The Discharge of Nitrate-contaminated Groundwater from Developed Shoreline to Marsh-fringed Estuary, Water Resources Research, Vol. 34, No. 11 pp. 3095-3104.

Rosenshein, J.S., J.B. Gonthier, and W.B. Allen, 1968, Hydrologic Characteristics and Sustained Yield of Principal Ground-Water Units Potowomut-Wickford Area Rhode Island, Geological Survey Water-Supply Paper 1775, United States Government Printing Office, Washington DC, pp. 1-18.

Todd, D.K., 1980, Groundwater Hydrology, John Wiley & Son, New York Chichester Brisbane, Toronto, pp. 316-346.

Urish, D.W., 1991, Rhode Island Site-Suitability Assessment Manual for Large Flow and Multiple Flow On-Site Sewage Disposal Systems, Rhode Island Department of Environmental Management, pp.17-23.

Urish, D.W. and E.K. Qanbar, 1997, Hydrologic Evaluation of Groundwater Discharge Nauset Marsh, Cape Code Massachusetts, Department of the Interior National Park Service New England System Support Office, Natural Resource Management and Research, Boston, MA, pp. 1-65.

U.S. Geological Survey, http://www.usgs.gov/, January 7, 1999.

Valiela, I, K. Foreman, M. LaMontagne, D. Hersh, J. Costa, P. Peckol, B. DeMeo-Anderson, C. D'Avanzo, M. Babione, C. Sham, J. Brawley, and K. Lajtha, 1992, Couplings of Watershed and Coastal Waters: Sources and Consequences of Nutrient Enrichment in Waquoit Bay, Massachusetts, Estuarine Research Federation Vol. 15, No 4, pp. 443-457.

Van den Brink, C. and W.J. Zaadnoordijk, 1995, Evaluation of Ground-Water Contamination from Nonpoint Sources: A Case Study, Ground Water, Vol. 33, No. 3, pp. 356-365.

Vesilind, P.A. and J.J. Peirce, 1982, Environmental Engineering, Ann Arbor Science, Ann Arbor MI, pp. 33-37.

Viessman, W. and G.L. Lewis, 1996, Introduction to Hydrology, HarperCollins College Publishers, New York, NY, p 9.

Warwick Department of Planning, 1994, Strategic Plan for the Reclamation of Greenwich Bay, Warwick, RI: City of Warwick, pp. 7-26.

Weiskel, P.K. and B.L. Howes, 1991, Quantifying Dissolved Nitrogen Flux Through a Coastal Watershed, Water Resources Research, Vol. 27, No. 11, pp. 2929-2939.

APPENDIX A

COPY OF NITROGEN-NITRATE BUDGET CALCULATIONS

Unsewered population in sub-basin areas.

Sub-basin Name	Sub-basin Area (sqft)	Unsewered area in Sub-basin (sqft)	Unsewered houses in Sub-basin (#)	Number of residents in houses that are Unsewered in Sub-basin (#)
Apponaug (APG)	5,434,358	4,890,922	61	157
Arnold (ARD)	2,204,427	2,204,427	40	68
Baker (BKR)	9,512,274	9,512,274	403	1,099
Bayside (BYS)	19,234,952	12,887,418	766	2,017
Chepiwanoxet (CHX)	30,377,773	30,377,773	550	1,154
Cove Beach (CVB)	971,904	971,904	29	90
East Greenwich (EGN)	11,588,590	6,953,154	152	295
Goddard (GDD)	7,571,457	7,571,457	80	191
Hardig (HRD)	170,058,425	127,543,819	1,715	4,063
Lockwood (LKD)	5,506,024	5,506,024	258	692
Long (LNG)	4,927,101	4,927,101	197	548
Longmeadow (LMN)	9,483,510	9,483,510	261	747
Maskerchugg (MKG)	166,460,915	158,137,869	1,541	3,527
Nausauket (NKT)	3,157,196	3,157,196	119	338
North Brushneck (NBN)	2,653,048	2,653,048	79	236
North Buttonwoods (NBW)	7,543,626	7,543,626	237	702
Oakland (OKL)	13,507,254	6,753,627	738	2,024
Potowomut (PTW)	12,758,790	12,758,790	141	333
South Brushneck (SBN)	426,248	426,248	130	388
South Buttonwoods (SBW)	10,022,151	10,022,151	306	761
Tuscatucket (TSK)	55,876,639	53,082,807	2,320	6,037
Warwick Neck North (WNN)	11,682,521	10,514,269	314	943
Warwick Neck South (WNS)	15,549,097	13,994,187	103	226

Notes 1) "Unsewered area" estimated from inspection of area sewer maps.

2) Number of "unsewered houses" obtained from U. S. census report of 4/1992.

3) Number of people who live in houses not currently sewered was obtained from U. S. census report of 4/1992.

Wastewater contribution calculation

A Sub-basin Name	B Concentration of Nitrogen mg/l	C Wastewater Volume of Water l/cap/day	D Load of nitrogen grams/cap/day	E nitrogen input per sub-basin grams/day	F Unsewered residents in Sub-basin #
Apponaug	45	265	11.925	1872	157
Arnold	45	265	11.925	811	68
Baker	45	265	11.925	13106	1,099
Bayside	45	265	11.925	24053	2,017
Chepiwanoxet	45	265	11.925	13761	1,154
Cove Beach	45	265	11.925	1073	90
East Greenwich	45	265	11.925	3518	295
Goddard	45	265	11.925	2278	191
Hardig	45	265	11.925	48451	4,063
Lockwood	45	265	11.925	8252	692
Long	45	265	11.925	6535	548
Longmeadow	45	265	11.925	8908	747
Maskerchugg	45	265	11.925	42059	3,527
Nausauket	45	265	11.925	4031	338
North Brushneck	45	265	11.925	2814	236
North Buttonwoods	45	265	11.925	8371	702
Oakland	45	265	11.925	24136	2,024
Potowomut	45	265	11.925	3971	333
South Brushneck	45	265	11.925	4627	388
South Buttonwoods	45	265	11.925	9075	761
Tuscatucket	45	265	11.925	71991	6,037
Warwick Neck North	45	265	11.925	11245	943
Warwick Neck South	45	265	11.925	2695	226

NOTES

1. Calculations were made using the following column related formula

"D=(C*B/1000)" "E=(D*F)"

Lawn Contibution

A Sub-basin Name	C Houses in sub-basin #	D Average lot size area Sqft	E Average lawn area Sqft	F lawn nitrogen Concen. lb/1000sqft	G yearly lawn nitrogen loading grams/day
Apponaug	200	10,000	5,000	3	466
Arnold	85	10,000	5,000	3	198
Baker	446	10,000	5,000	3	1,040
Bayside	1,076	10,000	5,000	3	2,509
Chepiwanoxet	860	10,000	5,000	3	2,006
Cove Beach	29	10,000	5,000	3	68
East Greenwich	1,016	10,000	5,000	3	2,370
Goddard	81	10,000	5,000	3	189
Hardig	5,569	10,000	5,000	3	12,988
Lockwood	299	10,000	5,000	3	697
Long	214	10,000	5,000	3	499
Longmeadow	274	10,000	5,000	3	639
Maskerchugg	3,167	10,000	5,000	3	7,386
Nausauket	126	10,000	5,000	3	294
North Brushneck	79	10,000	5,000	3	184
North Buttonwoods	239	10,000	5,000	3	557
Oakland	1,002	10,000	5,000	3	2,337
Potowomut	144	10,000	5,000	3	336
South Brushneck	131	10,000	5,000	3	306
South Buttonwoods	318	10,000	5,000	3	742
Tuscatucket	2,907	10,000	5,000	3	6,780
Warwick Neck North	315	10,000	5,000	3	735
Warwick Neck South	117	10,000	5,000	3	273

Notes

1. Calculations were made using the following column related formula G=(E*F/1000/365*454*0.25*C*.5)
2. 365 days, 454 grams/lb, 25% leaching, 50% of houses apply fertilizer

Atmospheric contribution calculation
(B*C/12*28.32/365*D/1000)
12 in/ft, 28.32 l/cuft, 365 days

A Sub-basin Name	B Sub-basin Area Sqft	C Atmosphere Percipitation in/year	D Atmosphere nitrogen Concentration mg/l	E Atmosphere nitrogen loading grams/day
Apponaug	5,434,358	15	0.05	26.35
Arnold	2,204,427	15	0.05	10.69
Baker	9,512,274	15	0.05	46.13
Bayside	19,234,952	15	0.05	93.28
Chepiwanoxet	30,377,773	15	0.05	147.31
Cove Beach	971,904	15	0.05	4.71
East Greenwich	11,588,590	15	0.05	56.20
Goddard	7,571,457	15	0.05	36.72
Hardig	170,058,425	15	0.05	824.67
Lockwood	5,506,024	15	0.05	26.70
Long	4,927,101	15	0.05	23.89
Longmeadow	9,483,510	15	0.05	45.99
Maskerchugg	166,460,915	15	0.05	807.22
Nausauket	3,157,196	15	0.05	15.31
North Brushneck	2,653,048	15	0.05	12.87
North Buttonwoods	7,543,626	15	0.05	36.58
Oakland	13,507,254	15	0.05	65.50
Potowomut	12,758,790	15	0.05	61.87
South Brushneck	426,248	15	0.05	2.07
South Buttonwoods	10,022,151	15	0.05	48.60
Tuscatucket	55,876,639	15	0.05	270.96
Warwick Neck North	11,682,521	15	0.05	56.65
Warwick Neck South	15,549,097	15	0.05	75.40

Notes
1. Calculations were made using the following column related formula
E=B*C/12*28.32/365*D/1000

Contribution of nitrogen from impervious surface runoff
Paved runoff contribution

A Sub-basin Name	B Paved area (sqft)	C Load from road runoff (grams/day)	D Houses in Sub-basin (#)	E Load from roof runoff (grams/day)
Apponaug	543,436	71.15	200	26.19
Arnold	220,443	28.86	85	11.13
Baker	951,227	124.55	446	58.40
Bayside	1,923,495	251.85	1,076	140.88
Chepiwanoxet	3,037,777	397.74	860	112.60
Cove Beach	97,190	12.73	29	3.80
East Greenwich	1,158,859	151.73	1,016	133.03
Goddard	757,146	99.13	81	10.61
Hardig	17,005,843	2,226.60	5,569	729.16
Lockwood	550,602	72.09	299	39.15
Long	492,710	64.51	214	28.02
Longmeadow	948,351	124.17	274	35.88
Maskerchugg	16,646,092	2,179.50	3,167	414.66
Nausauket	315,720	41.34	126	16.50
North Brushneck	265,305	34.74	79	10.34
North Buttonwoods	754,363	98.77	239	31.29
Oakland	1,350,725	176.85	1,002	131.19
Potowomut	1,275,879	167.05	144	18.85
South Brushneck	42,625	5.58	131	17.15
South Buttonwoods	1,002,215	131.22	318	41.64
Tuscatucket	5,587,664	731.60	2,907	380.62
Warwick Neck North	1,168,252	152.96	315	41.24
Warwick Neck South	1,554,910	203.59	117	15.32

Notes
1) Concentration of nitrogen (1.5 mg/l for roads, 0.75 mg/. for roofs) obtained from Technical Bulletin 91-001, 1991, "Nitrogen Loading", by: Eichner E.M.and Cambareri T.C. ,Water Resource Office, Cape Cod Commission, Barnstable, MA.
2) Impervious areas broken into two groups, paved and roofs. average roof size is estimated at 2000 sqft. paved surface area was estimated through visual inspection to be approximately 10%.
3) Recharge from runoff to groundwater estimated to be 90% of total groundwater recharge.
4) Calculations were made using the following column related formula (2000*D*13.5/12*28.32/365/1000*0.75)
2000 sqft roof size, 0.75 mg/L concentration for roof runoff

Total nitrogen loading for Greenwich Bay Watershed by sub-basin with the additional 50% of the residents sewered

Sub-basin Name	Wastewater nitrogen loading (grams/day)	Lawn nitrogen loading (grams/day)	Atmosphere nitrogen loading (grams/day)	Road runoff nitrogen loading (grams/day)	Roof runoff nitrogen loading (grams/day)	Total nitrogen loading (grams/day)
Apponaug	936	466	26	71	26	1,526
Arnold	405	198	11	29	11	654
Baker	6,553	1,040	46	125	58	7,822
Bayside	12,026	2,509	93	252	141	15,022
Chepiwanoxet	6,881	2,006	147	398	113	9,544
Cove Beach	537	68	5	13	4	625
East Greenwich	1,759	2,370	56	152	133	4,469
Goddard	1,139	189	37	99	11	1,474
Hardig	24,226	12,988	825	2,227	729	40,994
Lockwood	4,126	697	27	72	39	4,961
Long	3,267	499	24	65	28	3,883
Longmeadow	4,454	639	46	124	36	5,299
Maskerchugg	21,030	7,386	807	2,180	415	31,817
Nausauket	2,015	294	15	41	17	2,382
North Brushneck	1,407	184	13	35	10	1,649
North Buttonwoods	4,186	557	37	99	31	4,910
Oakland	12,068	2,337	66	177	131	14,778
Potowomut	1,986	336	62	167	19	2,569
South Brushneck	2,313	306	2	6	17	2,644
South Buttonwoods	4,537	742	49	131	42	5,501
Tuscatucket	35,996	6,780	271	732	381	44,158
Warwick Neck North	5,623	735	57	153	41	6,608
Warwick Neck South	1,348	273	75	204	15	1,915
Total input						215,207

Total nitrogen loading for Greenwich Bay Watershed by sub-basin with the additional 70% of the residents sewered

Sub-basin Name	Wastewater nitrogen loading (grams/day)	Lawn nitrogen loading (grams/day)	Atmosphere nitrogen loading (grams/day)	Road runoff nitrogen loading (grams/day)	Roof runoff nitrogen loading (grams/day)	Total nitrogen loading (grams/day)
Apponaug	562	466	26	71	26	1,152
Arnold	243	198	11	29	11	492
Baker	3,932	1,040	46	125	58	5,201
Bayside	7,216	2,509	93	252	141	10,211
Chepiwanoxet	4,128	2,006	147	398	113	6,792
Cove Beach	322	68	5	13	4	411
East Greenwich	1,055	2,370	56	152	133	3,766
Goddard	683	189	37	99	11	1,019
Hardig	14,535	12,988	825	2,227	729	31,304
Lockwood	2,476	697	27	72	39	3,311
Long	1,960	499	24	65	28	2,576
Longmeadow	2,672	639	46	124	36	3,517
Maskerchugg	12,618	7,386	807	2,180	415	23,405
Nausauket	1,209	294	15	41	17	1,576
North Brushneck	844	184	13	35	10	1,086
North Buttonwoods	2,511	557	37	99	31	3,235
Oakland	7,241	2,337	66	177	131	9,951
Potowomut	1,191	336	62	167	19	1,775
South Brushneck	1,388	306	2	6	17	1,718
South Buttonwoods	2,722	742	49	131	42	3,686
Tuscatucket	21,597	6,780	271	732	381	29,760
Warwick Neck North	3,374	735	57	153	41	4,359
Warwick Neck South	809	273	75	204	15	1,376
Total input						151,680

Table 6. Total nitrogen loading for Greenwich Bay Watershed by sub-basin with the additional 100% the residents sewered

Sub-basin Name	Wastewater nitrogen loading (grams/day)	Lawn nitrogen loading (grams/day)	Atmosphere nitrogen loading (grams/day)	Road runoff nitrogen loading (grams/day)	Roof runoff nitrogen loading (grams/day)	Total nitrogen loading (grams/day)
Apponaug	-	466	26	71	26	590
Arnold	-	198	11	29	11	249
Baker	-	1,040	46	125	58	1,269
Bayside	-	2,509	93	252	141	2,995
Chepiwanoxet	-	2,006	147	398	113	2,663
Cove Beach	-	68	5	13	4	89
East Greenwich	-	2,370	56	152	133	2,710
Goddard	-	189	37	99	11	335
Hardig	-	12,988	825	2,227	729	16,768
Lockwood	-	697	27	72	39	835
Long	-	499	24	65	28	616
Longmeadow	-	639	46	124	36	845
Maskerchugg	-	7,386	807	2,180	415	10,787
Nausauket	-	294	15	41	17	367
North Brushneck	-	184	13	35	10	242
North Buttonwoods	-	557	37	99	31	724
Oakland	-	2,337	66	177	131	2,710
Potowomut	-	336	62	167	19	584
South Brushneck	-	306	2	6	17	330
South Buttonwoods	-	742	49	131	42	963
Tuscatucket	-	6,780	271	732	381	8,163
Warwick Neck North	-	735	57	153	41	985
Warwick Neck South	-	273	75	204	15	567
Total input						56,390

Table Total nitrogen loading for Greenwich Bay Watershed by sub-basin with the additional 50% 70% and 100% sewering

Sub-basin Name	Current sewering Total nitrogen loading (grams/day)	50% sewering Total nitrogen loading (grams/day)	70% sewering Total nitrogen loading (grams/day)	100% sewering Total nitrogen loading (grams/day)
Apponaug	1,872	1,526	1,152	590
Arnold	811	654	492	249
Baker	13,106	7,822	5,201	1,269
Bayside	24,053	15,022	10,211	2,995
Chepiwanoxet	13,761	9,544	6,792	2,663
Cove Beach	1,073	625	411	89
East Greenwich	3,518	4,469	3,766	2,710
Goddard	2,278	1,474	1,019	335
Hardig	48,451	40,994	31,304	16,768
Lockwood	8,252	4,961	3,311	835
Long	6,535	3,883	2,576	616
Longmeadow	8,908	5,299	3,517	845
Maskerchugg	42,059	31,817	23,405	10,787
Nausauket	4,031	2,382	1,576	367
North Brushneck	2,814	1,649	1,086	242
North Buttonwoods	8,371	4,910	3,235	724
Oakland	24,136	14,778	9,951	2,710
Potowomut	3,971	2,569	1,775	584
South Brushneck	4,627	2,644	1,718	330
South Buttonwoods	9,075	5,501	3,686	963
Tuscatucket	71,991	44,158	29,760	8,163
Warwick Neck North	11,245	6,608	4,359	985
Warwick Neck South	2,695	1,915	1,376	567
Total input	317,634	215,207	117,519	56,390

APPENDIX B

BEACH SEDIMENT SAMPLE ANALYSIS

GRAIN SIZE ANALYSIS—MECHANICAL

Project: C.?.?. Project Job No.: —

Location of Project: [illegible] Site ④ Boring No.: 1 Sample No.: 1

Description of Soil: Fine Sand Depth of Sample: 1 m.

Tested By: ALG Date of Testing: 11/23/98

Soil Sample Size (ASTM D1140-54)

Nominal diameter of largest particle	Approximate minimum mass of sample, g
No. 10 sieve	200
No. 4 sieve	500
3/4 in.	1500

Mass of dry sample + dish	694.55
Mass of dish	19.60
Mass of dry sample, M_s	674.95

Sieve analysis and grain shape

	Sieve no.	Diam. (mm)	Mass retained	% retained	% passing
4?8.30	6	2.35	6.8	1.0	99
434.50	16	1.18	8.0	1.1	97.9
370.95	40	0.425	26.4	3.9	94
35[illegible]	60	0.250	172.5	25.6	68.4
301.95	106	0.106	390.5	57.9	10.5
[illegible]	PAN		70.[illegible]	10.5	—

% passing = 100 − Σ % retained.

D_{60}: 0.235
D_{10} = 0.1
D_{30}: 0.175
D_{50}: 0.215

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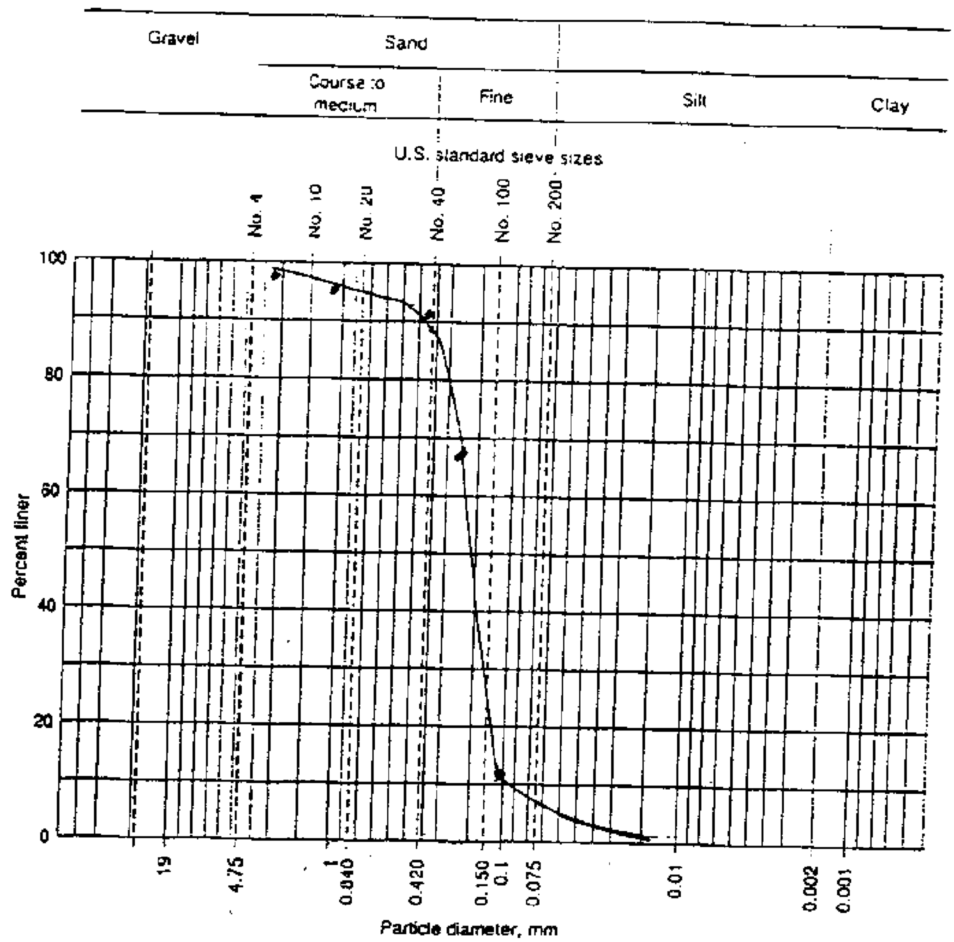
Project: G. Bay Project Job No. –

Location of Project: Oakland Site Boring No. 1 Sample No. 1

Tested By: ALG Date of Testing: 11/23/98



Visual soil description: Fine Sandy Soil w/ some pebbles light in color

Soil classification: well sorted, fine grained Sand

System:

D_{10} 0.1

D_{30} 0.175

D_{50} 0.215

D_{60} 0.235

$C_u = \frac{.235}{0.1} = 2.35$

$C_c = \frac{(.175)^2}{(.235)(0.1)} = 1.30$

Hazen method

$K = 80\,(0.01)^2 = 0.008$ cm/s ×

691 cm/day $\frac{m}{100\ cm}$ = 6.9 m/day

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GRAIN SIZE ANALYSIS—MECHANICAL

Project: G.Bay Project — Job No. —

Location of Project: Arnold site — Boring No. 1 — Sample No. 1

Description of Soil: Sandy gravel — Depth of Sample: 1 m

Tested By: ALG — Date of Testing: 11/23/96

Soil Sample Size (ASTM D1140-54)

Nominal diameter of largest particle	Approximate minimum mass of sample, g
No. 10 sieve	200
No. 4 sieve	500
3/4 in.	1500

Mass of dry sample + dish	739.50
Mass of dish	18.50
Mass of dry sample, M_s	721.00

Sieve analysis and grain shape

Sieve no.	Diam. (mm)	Mass retained	% retained	% passing
6	3.35	136.85	19.0	81
16	1.18	117.93	16.3	64.7
40	0.425	270.08	37.5	27.2
60	0.250	104.7	14.5	12.7
100	0.160	61.95	8.6	4.1
P200	-	29.55	4.1	—

% passing = 100 − Σ % retained.

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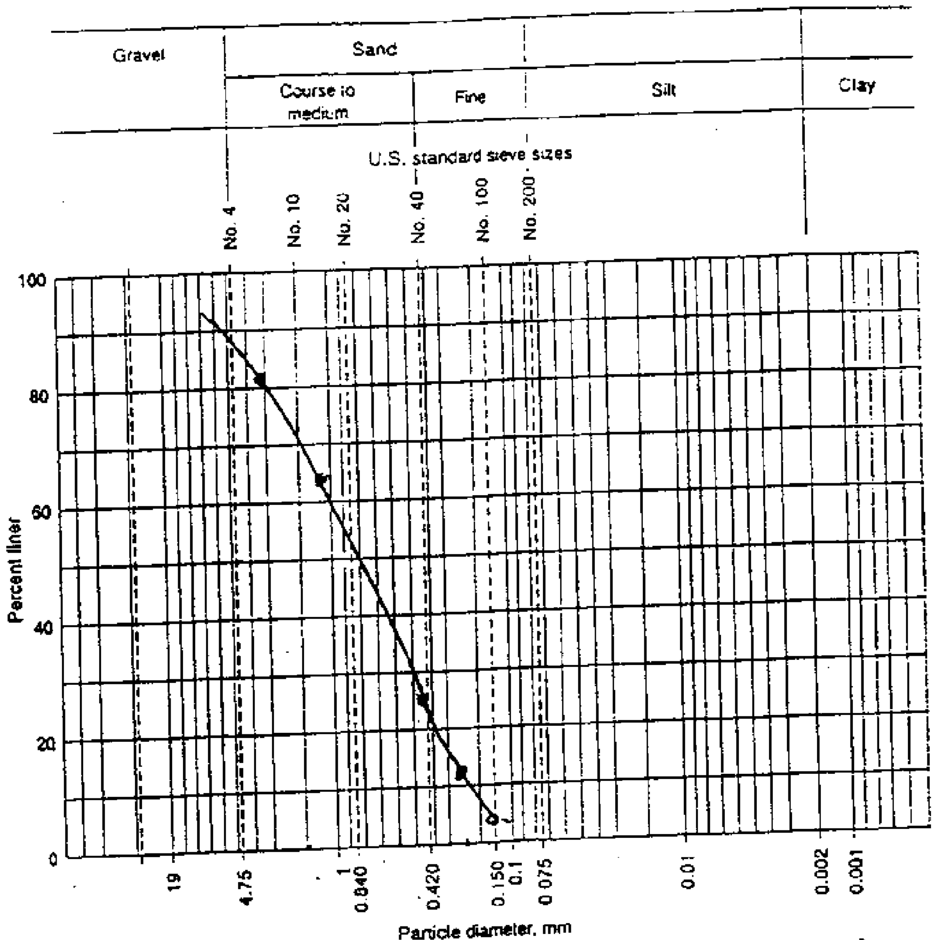
GRAIN SIZE DISTRIBUTION

Project: G. Bay   Job No.: –

Location of Project: Arnold Site (B)   Boring No.: 1   Sample No.: 1

Tested By: ALG   Date of Testing: 11/23/98



Visual soil description: Medium to Coarse Sandy Gravel
Dark in Color

Soil classification: Sample is fine with range of well sorted medium to fine grained sand

System

$D_{10} = 0.25$ $\quad C_u = \frac{1}{0.25} = 4$

$D_{30} = 0.5$ $\quad C_c = \frac{0.5^2}{.25} = 1$ $\quad k = C(d_{10})^2$

$D_{50} = 0.8$

$D_{60} = 1$

$k = 5$ cm

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GRAIN SIZE ANALYSIS—MECHANICAL

Data Sheet 5a

Project Greenwich Bay Job No. –

Location of Project Goddard Park Boring No. Plume C Sample No. 1

Description of Soil Coarse Grained Sand Depth of Sample 5 meters

Tested By Anthony Gorrick Date of Testing 7/27/98

Soil Sample Size (ASTM D1140-54)

Nominal diameter of largest particle	Approximate minimum mass of sample, g
No. 10 sieve	200
No. 4 sieve	500
3/4 in.	1500

Mass of dry sample + dish	641.10
Mass of dish	17.55
Mass of dry sample, M_s	623.45

Sieve analysis and grain shape

Sieve no. / G	Diam. (mm)	Mass retained	% retained	% passing
10 475.50	2.000	161.00	25.82	74.18
20 411.05	0.841	171.40	27.49	46.69
30 396.55	0.594	108.30	17.37	29.32
40 270.00	0.419	78.00	12.51	16.81
60 351.88	0.249	87.13	13.98	2.83
120 346.48	0.124	16.51	2.65	0.18
PAN 371.45		1.10	.18	0

% passing = 100 − Σ % retained.

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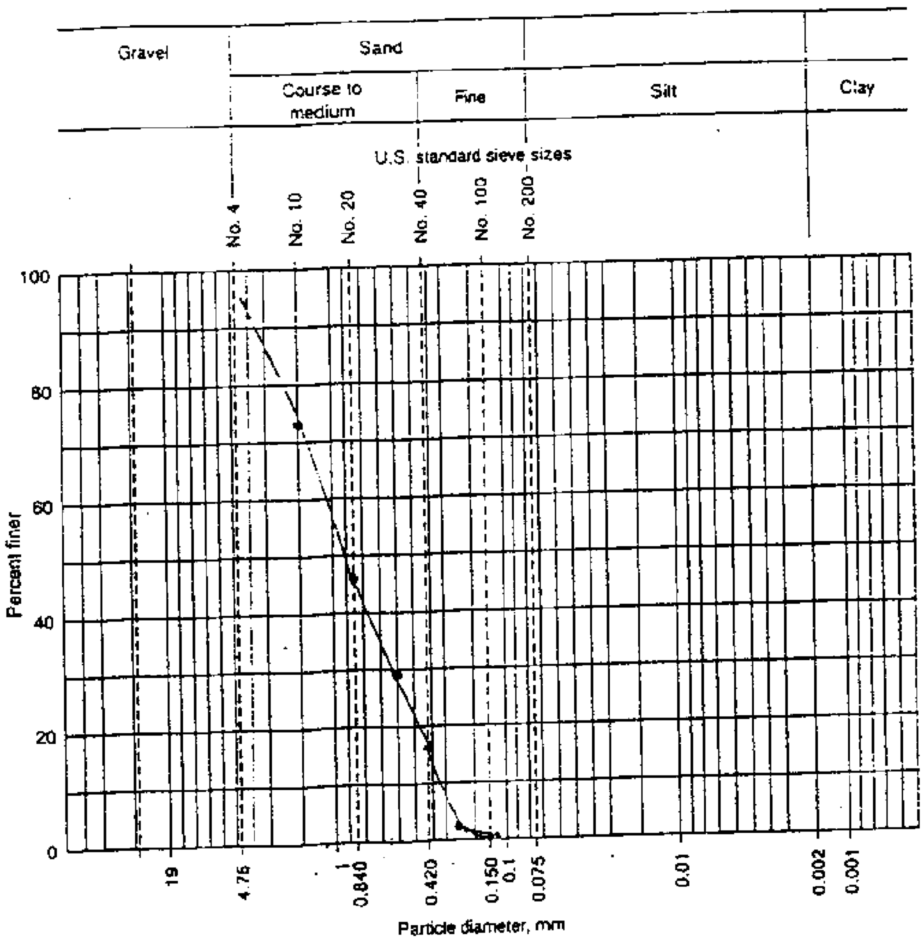
GRAIN SIZE DISTRIBUTION

Project: Greenwich Bay — Job No. –

Location of Project: Goddard Park — Boring No. Dune Crater — Sample No. 1

Tested By: A. G. — Date of Testing: 7/27/98



Visual soil description

Soil classification

System

$C_u = \frac{D_{60}}{D_{10}} = \frac{[illegible]}{0.35} = 3.42$

$C_c = [illegible] = 1.0$

$D_{50} = .9$

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COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head) — Data Sheet 11, 12

Project: Greenwich Bay — Job No. —

Location of Project: Oakland site

Description of Soil: Fine - Sand

Tested by: AL — Date of Testing: ______

Sample Dimensions: Diam. 3.81 cm; Area 11.40 cm²

Mass soil + pan init. 710.0 g — Ht. 16.0 cm

Mass soil + pan Final 385.1 g — Vol. 182.4 cm³

Mass of Sample 324.9 g — Density, ρ ___.565 g/cm³

V_s = 1??
 V_v = 19?.
 V_T = 5?.

Constant Head

h = ______ cm

Test data / *Test data used*

Test No.	t, s	Q, cm³	T, °C	Test No.	t, s	Q, cm³	T, °C
1							
2							
3							
4							
				Average[a]			

$k_T = \frac{QL}{Aht}$ = ______ = ______ cm/s

$\alpha = \eta_T/\eta_{20}$ = ______

$k_{20} = \alpha k_T$ = ______ cm/s

Falling Head

Standpipe = [burette, other (specify)] Cylinder — Area standpipe, a = 32.00 cm²

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t, s	Q_{in}, cm³	Q_{out}, cm³	T, °C	Test no.	h_1, cm	h_2, cm	t, s	T, °C
1	119	107	296	1.3		15°	1	109	87	852	15°
2	119	107	290				2	119	85.5	836	15°
3											
4											
							Average				

$\frac{0.011404}{0.010050} = 1.1347$

$\alpha = \eta_T/\eta_{20}$ = 1.135

$k_T = \frac{aL}{At}\ln\frac{h_1}{h_2}$ = $\frac{32 \times 16.2}{3.?? \times 296} \ln \frac{119}{107}$ = 0.0166 cm/s

$k_{20} = \alpha k_T$ = K_{20} = 1.135 x 0.0166 = 0.0188 cm/s

K 16.2? m PER DAY

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.
[b]Simplify by using the same h_1 and h_2 each time, so you can average t.

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COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head) Data Sheet 11. 12

Project: Greenwich Bay Job No. ______

Location of Project: Arnold site

Description of Soil: Sandy Gravel

Tested by: ALG Date of Testing: 11-2-98

Sample Dimensions: Diam. 3.81 cm; Area 11.40 cm^2

Mass soil + pan Init. 741.5 g; Ht. 16.00 cm

Mass soil + pan Final 421.5 g; Vol. 182.4 cm^3

Mass of Sample 320.0 g; Density, ρ 2.65 g/cm^3

$V_s = 120.75$

Constant Head

h = ______ cm

$n = 33.8$

Test data / *Test data used*

Test No.	t, s	Q, cm^3	T, °C	Test No.	t, s	Q, cm^3	T, °C
1							
2							
3							
4							
				Average[a]			

$k_T = \frac{QL}{Aht}$ = ______

= ______ cm/s

$\alpha = \eta_T/\eta_{20}$ = ______

$k_{20} = \alpha k_T$ = ______ cm/s

Falling Head

Standpipe = [burette, other (specify)] Cylinder Area standpipe, a = 24.00 cm^2

Test data[b] / *Test data used*

Test no.	h_1, cm	h_2, cm	t, s	Q_{in} cm^3	Q_{out} cm^3	T, °C	Test no.	h_1, cm	h_2, cm	t, s	T, °C
1	119	107	43			15		119	87	129	15
2	119	107	43			15		119	87	129	15
3											
4											
							Average				

$\alpha = \eta_T/\eta_{20}$ = 1.135

$k_T = \frac{aL}{At}\ln\frac{h_1}{h_2} = \frac{20.2}{3.43} \times \frac{16}{43} \times \ln\frac{119}{107}$ = 0.111 cm/s

$k_{20} = \alpha k_T$ = 1.135(0.111) = 0.126 cm/s

[a]Use averaged values only if there is a small difference in test temperature, say, 1–2°C.

[b]Simplify by using the same h_1 and h_2 each time, so you can average t.

K_{20} [illegible]

HAZEN [illegible]

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COEFFICIENT OF PERMEABILITY (Constant Head, Falling Head) Data Sheet 11, 12

Project: Brenwich Job No. —

Location of Project: Pitmount site

Description of Soil: Sandy / gravel

Tested by: ArG Date of Testing:

Sample Dimensions: Diam. 3.81 cm; Area 11.40 cm²

Mass soil + pan init. 449.1 g; Ht. 16.50 cm

Mass soil + pan Final 121.5 g; Vol. 188.1 cm³

Mass of Sample 327.6 g; Density, ρ ~~2.4~~ 2.05 g/cm³

$V_s = \frac{327.6}{2.65}$

$V_s = 123.62$

$V_v = 188.1 - 123.6$

$V_v = 64.5$

$n = 34.3$

Constant Head

h = ______ cm

Test data				*Test data used*			
Test No.	t, s	Q, cm³	T, °C	Test No.	t, s	Q, cm³	T, °C
1							
2							
3							
4							
				Average[a]			

$k_T = \frac{QL}{Aht}$ = ______ = ______ cm/s

$\alpha = \eta_T/\eta_{20}$ = ______

$k_{20} = \alpha k_T$ = ______ cm/s

Falling Head

Standpipe = {burette, other (specify)} Cylinder Area standpipe, a = 32.00 cm²

Test data[b]							*Test data used*				
Test no.	h_1, cm	h_2, cm	t, s	Q_{in}, cm³	Q_{out}, cm³	T, °C	Test no.	h_1, cm	h_2, cm	t, s	T, °C
1	119	107	53					107	87	158	
2	119	107	52					107	87	157	
3											
4											
							Average				

$\alpha = \eta_T/\eta_{20}$ = 1.135

$k_T = \frac{aL}{At}\ln\frac{h_1}{h_2} = \frac{10.2}{363} \times \frac{16.5}{53} \times \ln\frac{119}{107}$ = 0.0927 cm/s

$k_{20} = \alpha k_T$ = 1.135 × 0.0927 = 0.105 cm/s

90.72 m/day

[a] Use averaged values only if there is a small difference in test temperature, say, 1–2°C.
[b] Simplify by using the same h_1 and h_2 each time, so you can average k.

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APPENDIX C

LAB ANALYSIS DATA SHEETS

IDENTIFICATION OF ABBREVIATIONS USED IN SAMPLE ANALYSIS

Pages 96-99: Results of NO_3-N + NO_2-N Analysis

Cal – Calibration, for calibrating the instrument.

GC – Greenwich Cove Site (not used in this document).

OAK B – Oakland Site, B indicates the date (September 4, 1998) of sample collection.

ST – Standards, run for calibration check.

OAK A – Oakland Site, A indicates the date (May 21, 1998) in of sample collection.

SMALLBROOK – A small brook located in upper Brushneck Cove.

WP – Sample collected from a monitor well.

Pages 100-101: Results of NO_3-N + NO_2-N Analysis

Samples 51-68 – Samples collected from Arnold Site (May 21, 1998).

Sample 1b-21b – Samples collected from Potowomut Site (May 21, 1998) (computer printout of results for samples 21b-36b were misplaced).

Page 102: Results of NO_3-N + NO_2-N Analysis (Potowomut Site) (May 21, 1998).

Pages 103-107: Results of NH_3-N Analysis

1a-31a – Samples collected from Oakland Site (May 21, 1998).

50-68 – Samples collected from Arnold Site (May 21, 1998).

1b-36b – Samples collected from Potowomut Site (May 21, 1998).

Peak	Cup	Name	Type	Dil.	[illegible]	[illegible]	[illegible]
130	143	OAK B3 -	U	1	1	4000742	9.694917
131	144	OAK B4 5	U	1	1	3758115	9.106692
132	144	OAK B4 -	U	1	1	3810299	9.233207
133	145	OAK B5 5	U	1	1	3375192	8.178333
134	145	OAK B5 -	U	1	1	3335366	8.081779
135	146	OAK B6 5	U	1	1	3787239	9.177301
136	146	OAK B6 -	U	1	1	3794633	9.195226
137	147	OAK B7 5	U	1	1	4760516	11.536918
138	147	OAK B7 -	U	1	1	4775390	11.572977
139	148	OAK B8 [illegible]	U	1	1	3181413	7.708534
140	148	OAK B8 -	U	1	1	3172386	7.686650
141	149	OAK B9 6	U	1	1	2179160	5.278668
142	149	OAK B9 -	U	1	1	2164284	5.242501
143	150	OAK B10 6	U	1	1	2123017	5.142555
144	150	OAK B10 -	U	1	1	2135950	5.173910
145	151	OAK B11 [illegible]	U	1	1	3027264	7.334814
146	151	OAK B11 -	U	1	1	2888946	6.999477
147	152	OAK B12 6	U	1	1	2101310	5.089928
148	152	OAK B12 -	U	1	1	2129174	5.157481
149	153	OAK B13 5	U	1	1	1115536	2.700014
150	153	OAK B13 -	U	1	1	1100068	2.662514
151	154	OAK B14 4	U	1	1	1518742	3.677548
152	154	OAK B14 -	U	1	1	1521517	3.684277
153	155	OAK B15 4	U	1	1	2256811	5.466925
154	155	OAK B15 -	U	1	1	2258104	5.470061
155	156	OAK B16 4	U	1	1	1274242	3.084780
156	156	OAK B16 -	U	1	1	1290266	3.123631
157	157	OAK B17 [illegible]	U	1	1	1590900	3.852489
158	157	OAK B17 -	U	1	1	1597065	3.867435
159	158	OAK B18 8	U	1	1	3203041	7.760968
160	158	OAK B18 -	U	1	1	3219754	7.801488
161	159	OAK B19 10	U	1	1	3283128	7.955132
162	159	OAK B19 -	U	1	1	3270771	7.925174
163	160	OAK B20 9/4 8	U	1	1	5151194	12.484078
164	160	OAK B20 9/4 -	U	1	1	5162638	12.511823
165	0	BLANK	BLNK	1	1	8503	0.016119
166	0	BLANK	BLNK	1	1	1653	-0.000488
167	4	CCV	CCV	1	1	244328	0.587854
B	0	Baseline	RB	1	1	-13	-0.004527
B	0	Baseline	RB	1	1	0	-0.004496
170	161	ST.5	U	1	1	421201	1.016667
171	161	ST.5	U	1	1	420220	1.014288
172	162	ST1	U	1	1	33647	0.077078
173	162	ST1	U	1	1	32718	0.074825
174	163	ST5	U	1	1	3056204	7.404977
175	163	ST5	U	1	1	3041650	7.369692
176	164	ST20	U	1	1	6515046	15.790606
177	164	ST20	U	1	1	6450882	15.635046
178	165	OAK A1 5/21/98	U	1	1	324763	0.782862
179	165	OAK A1 5/21/98	U	1	1	308140	0.742559
180	166	OAK A2	U	1	1	1516968	3.673249
181	166	OAK A2	U	1	1	1510751	3.658176
182	167	OAK A4	U	1	1	890201	2.153711
183	167	OAK A4	U	1	1	904436	2.188224
184	168	OAK A5	U	1	1	2657366	6.438034
185	168	OAK A5	U	1	1	2562337	6.207643
186	169	OAK A6	U	1	1	3018027	7.312420
187	169	OAK A6	U	1	1	2973637	7.204802
188	170	OAK A7	U	1	1	1845346	4.469368
189	170	OAK A7	U	1	1	1880390	4.554328
190	171	OAK A8	U	1	1	3770915	9.137725
191	171	OAK A8	U	1	1	4033746	9.774935
192	172	OAK A9	U	1	1	3889872	9.426126
193	172	OAK A9	U	1	1	4030988	9.768247
194	173	OAK A10	U	1	1	4514804	10.941212
195	173	OAK A10	U	1	1	4462070	10.813363
196	174	OAK A11	U	1	1	5170430	12.530714

197	174	OAK A11	U	1	1	5264856	12.759641	
198	175	OAK A12	U	1	1	4797792	11.627289	
199	175	OAK A12	U	1	1	4580662	11.100878	
200	176	OAK A13	U	1	1	4741114	11.489879	
201	176	OAK A13	U	1	1	4743370	11.495347	
202	177	OAK A14	U	1	1	5841980	14.158821	HI
203	177	OAK A14	U	1	1	5963896	14.454394	HI
204	178	OAK A15	U	1	1	3928142	9.518906	FL
205	178	OAK A15	U	1	1	3710087	8.990253	FL
206	179	OAK A16	U	1	1	3976653	9.636519	
207	179	OAK A16	U	1	1	4024999	9.753727	
208	180	OAK A17	U	1	1	2887835	6.996782	
209	180	OAK A17	U	1	1	2924911	7.086669	
210	0	BLANK	BLNK	1	1	10435	0.020803	
211	0	BLANK	BLNK	1	1	2748	0.002167	
212	4	CCV	CCV	1	1	378248	0.912530	F
B	0	Baseline	RB	1	1	-20	-0.004544	BL
B	0	Baseline	RB	1	1	0	-0.004496	BL
215	181	OAK A18	U	1	1	2176160	5.271393	I
216	181	OAK A18	U	1	1	2328038	5.639609	I
217	182	OAK A19	U	1	1	1826319	4.423240	I
218	182	OAK A19	U	1	1	1791390	4.338558	I
219	183	OAK A20	U	1	1	4108384	9.955885	I
220	183	OAK A20	U	1	1	4256900	10.315947	I
221	184	OAK A21	U	1	1	2509558	6.079687	I
222	184	OAK A21	U	1	1	2383844	5.774906	I
223	185	OAK A22	U	1	1	3249318	7.873162	I
224	185	OAK A22	U	1	1	3352564	8.123473	I
225	186	OAK A23	U	1	1	2693462	6.525545	I
226	186	OAK A23	U	1	1	2655796	6.434226	I
227	187	OAK A24	U	1	1	3165832	7.670759	I
228	187	OAK A24	U	1	1	3108916	7.532771	I
229	188	OAK A25	U	1	1	5261114	12.750568	I
230	188	OAK A25	U	1	1	5389740	13.062409	I
231	189	OAK A26	U	1	1	4127796	10.002949	I
232	189	OAK A26	U	1	1	3991302	9.672032	I
233	190	OAK A27	U	1	1	3678348	8.913305	I
234	190	OAK A27	U	1	1	3678894	8.914630	I
235	201	OAK A28	U	1	1	5885080	14.263315	HI
236	201	OAK A28	U	1	1	5918446	14.344208	HI
237	202	OAK A29	U	1	1	3751030	9.089516	I
238	202	OAK A29	U	1	1	3538016	8.573084	I
239	203	OAK A31	U	1	1	431820	1.042411	I
240	203	OAK A31	U	1	1	119837	0.286037	I
241	204	OAK WP 9/18	U 8	1	1	4827774	11.699978	I
242	204	OAK WP 9/18	U	1	1	5106070	12.374680	I
243	205	SMALLBROOK 9/24	U	1	1	2716676	6.581824	I
244	205	SMALLBROOK 9/24	U	1	1	2590912	6.276922	I
245	206	SMALLBROOK WP 9/24	U	1	1	1804836	4.371156	
246	206	SMALLBROOK WP 9/24	U	1	1	1722008	4.170344	
247	207	ARMOLD WP 8/15	U	1	1	-169640	-0.415772	LO
248	207	ARMOLD WP 8/15	U	1	1	-85398	-0.211535	LO
249	208	GC WP 8/15	U	1	1	384905	0.929669	I
250	208	GC WP 8/15	U	1	1	415785	1.003535	I
251	209	OAK WP 8/15	U	1	1	-51071	-0.128312	LO
252	209	OAK WP 8/15	U	1	1	-83217	-0.206248	LO
253	210	OAK WP 9/4	U	1	1	5907564	14.317824	HI
254	210	OAK WP 9/4	U	1	1	5763148	13.967700	HI

Run Results Report
Results: C:\FLOW_3\GRDH20A.RST
Results completed: 17:08 July 29, 1998.
Operator: sv

Cup	Name	NO2+N03 Height	Calc.
---	Carryover	1588	0.020298
---	Carryover	87	0.006055
---	Baseline	0	0.00523
1	cal 0	71	0.0059
2	cal 1	1033	0.015025
3	cal 2	10321	0.103135
4	cal 3	52921	0.507231
5	cal 4	105001	1.001257
6	cal 5	520802	4.945493
7	cal 6	1056465	10.02673
---	Blank	-266	0.002708
---	Blank	-1055	-0.00478
8	ICV	544159	5.167052
---	Read Bas	0	0.00523
---	Read Bas	0	0.00523
---	Baseline	0	0.00523
---	Baseline	0	0.00523
101	51	1219468	11.57296
102	52	1028478	9.761251
103	53	898664	8.529843
104	54	907086	8.609734
105	55	671675	6.376658
106	56	714466	6.782564
107	57	752983	7.147934
108	58	866488	8.224628
109	59	679263	6.448632
110	60	955665	9.070555
111	61	848188	8.051035
112	62	911546	8.652047
113	63	676042	6.418079
114	64	595414	5.65326
115	65	619843	5.884983
116	67	424145	4.028621
117	68	848436	8.053389
118	1b	71095	0.67963
119	2b	89502	0.854239
120	3b	74290	0.709931
---	Blank	-1349	-0.00757
---	Blank	-1576	-0.00972
8	ICV	543620	5.161941
---	Read Bas	0	0.00523
---	Read Bas	0	0.00523
121	4b	65543	0.626966

122	5b	68612	0.656079
123	6b	80896	0.772601
124	7b	84349	0.805352
125	8b	65521	0.626756
126	9b	75735	0.723646
127	10b	85204	0.813468
128	11b	99870	0.952582
129	12b	112563	1.072984
130	13b	75551	0.721893
131	14b	59893	0.57337
132	15b	102957	0.981864
133	16b	83763	0.799798
134	17b	78157	0.746614
135	18b	86748	0.82811
136	19b	60323	0.577446
137	20b	57764	0.553172
138	21b		

Potowomut F.W. Discharge

Sample	transect meters	transect C-C' feet	1500 Low tide .-2ft NO3-N + NO2-	salinity	NH3-N
6/25/98					
18b	0	0	0.8	17	0.08
17b	3.0	10	0.7	17	0.08
16b	6.1	20	0.8	22	0.04
15b	9.1	30	1	10	0.12
14b	12.2	40	0.6	14	0.21
13b	15.2	50	0.7	16	0.18
12b	18.3	60	1.1	17	0.21
11b	21.3	70	1	15	0.32
10b	24.4	80	0.8	20	0.1
9b	27.4	90	0.7	16	0.11
8b	30.5	100	0.6	18	0.08
7b	33.5	110	0.8	20	0.14
6b	36.6	120	0.8	12	0.12
5b	39.6	130	0.7	13	0.09
4b	42.7	140	0.6	14	0.15
3b	45.7	150	0.7	15	0.11
2b	48.8	160	0.9	15	0
1b	51.8	170	0.7	18	0
19b	53.3	175	0.6	20	0.2
20b	54.9	180	0.6	15	0.2
21b	56.4	185	0.4	20	0.25
22b	57.9	190	0.4	15	0.15
23b	59.4	195	0.6	13	0.1
24b	61.0	200	0.9	12	0.05
25b	62.5	205	1.1	10	0.09
26b	64.0	210	0.5	10	0.08
27b	65.5	215	1.3	7	0.02
28b	67.1	220	1.5	8	0.3
29b	68.6	225	0.8	6	0.2
30b	70.1	230	0.7	6	0.35
31b	71.6	235	0.7	5	0.34
32b	73.2	240	0.9	7	0.38
33b	74.7	245	0.4	6	0.58
34b	76.2	250	0.4	7	0
35b	77.7	255	0.5	12	1.2
36b	79.2	260	0.6	15	1.5

Run Results Report
Results: C:\FLOW_3\GNDNH3B.RST
Results completed: 15:37 July 31, 1998.
Operator: SV

Cup	Name	ammonia Height	Calc.
---	Carryover	40	-0.054104
---	Carryover	-924	-0.123527
---	Baseline	0	-0.056986
1	Cal 0.00 ppm	-416	-0.086957
2	Cal 0.02 ppm	-42	-0.059976
3	Cal 0.20 ppm	3520	0.196497
4	Cal 1.00 ppm	15270	1.042589
5	Cal 4.00 ppm	61127	4.344577
6	Cal 7.00 ppm	97176	6.940391
7	Cal 10.00 ppm	138276	9.899866
---	Blank	-877	-0.120105
---	Blank	714	-0.005562
8	ICV	27328	1.910808
---	Read Baseline	0	-0.056986
---	Read Baseline	0	-0.056986
---	Baseline	0	-0.056986
101	1a	8447	0.551291
101	1a	8028	0.521095
102	2a	33381	2.346653
102	2a	32393	2.275555
103	4a	13413	0.908848
103	4a	15181	1.036131
104	5a	4312	0.25348
104	5a	4727	0.283411
105	6a	50631	3.588775
105	6a	53129	3.768682
106	7a	-307	-0.079058
106	7a	-3	-0.057176
107	8a	14462	0.984393
107	8a	14037	0.953741
108	9a	32132	2.25671
108	9a	31993	2.246707
109	10a	42900	3.03214
109	10a	43577	3.080888
110	11a	22442	1.558983
110	11a	24187	1.684669
---	Blank	330	-0.033198
---	Blank	605	-0.01345
8	CCV	27907	1.952495
---	Read Baseline	0	-0.056986
---	Read Baseline	0	-0.056986
---	Baseline	0	-0.056986
111	12a	544	-0.017849

	111	12a		641	-0.0108
	112	13a		859	0.004838
	112	13a		995	0.01467
	113	14a		1718	0.06672
	113	14a		2007	0.087544
	114	15a		1032	0.01733
	114	15a		10942	0.730897
	115	16a		13350	0.904317
	115	16a		14151	0.961964
	116	17a		11217	0.750684
	116	17a		11820	0.794116
	117	18a		26667	1.863195
	117	18a		26014	1.816171
	118	19a		10249	0.681022
	118	19a		10368	0.689547
	119	21a		6600	0.418241
	119	21a		7586	0.489274
	120	22a		12514	0.844108
	120	22a		13459	0.912136
---		Blank		-196	-0.07112
---		Blank		727	-0.004643
	8	CCV		27745	1.94088
---		Read Baseline		0	-0.056986
---		Read Baseline		0	-0.056986
---		Baseline		0	-0.056986
	121	23a		-402	-0.085968
	121	23a		10	-0.056243
	122	24a		51	-0.053331
	122	24a		201	-0.042547
	123	25a		750	-0.002952
	123	25a		441	-0.02526
	124	26a		785	-0.000435
	124	26a		8446	0.5512
	125	27a		7678	0.495916
	125	27a		7681	0.496102
	126	28a		30379	2.130544
	126	28a		30708	2.154193
	127	29a		63432	4.510584
	127	29a		64864	4.613661
	128	30a		166069	11.9011
	128	30a		166290	11.917037
	129	31a		110516	7.900946
	129	31a		108829	7.779452
	130		50	10193	0.676964
	130		50	10819	0.722025
---		Blank		-199	-0.071343
---		Blank		1123	0.023847
	8	CCV		26947	1.883359
---		Read Baseline		0	-0.056986
---		Read Baseline		0	-0.056986
---		Baseline		0	-0.056986

	131		51	-121	-0.065709
	131		51	33	-0.054594
	132		52	73	-0.051714
	132		52	712	-0.005709
	133		53	504	-0.020701
	133		53	919	0.009176
	134		54	1890	0.079109
	134		54	1977	0.085347
	135		55	3376	0.18612
	135		55	5794	0.360254
	136		56	1064	0.019661
	136		56	1643	0.061346
	137		57	2147	0.097617
	137		57	1973	0.085094
	138		58	2904	0.1521
	138		58	2738	0.140187
	139		59	8384	0.546685
	139		59	8729	0.571583
	140		60	2845	0.147878
	140		60	2364	0.113245
—		Blank		-102	-0.064307
—		Blank		1061	0.019425
	8	CCV		27331	1.911066
—		Read Baseline		0	-0.056986
—		Read Baseline		0	-0.056986
—		Baseline		0	-0.056986
	141		61	949	0.011369
	141		61	1677	0.063802
	142		62	1646	0.061558
	142		62	2335	0.111174
	143		63	3719	0.210782
	143		63	3924	0.22555
	144		64	3929	0.225898
	144		64	4448	0.263335
	145		65	2101	0.094311
	145		65	1818	0.0739
	146		67	2271	0.106563
	146		67	2177	0.099801
	147		68	2945	0.155095
	147		68	2788	0.143775
	148	1b		289	-0.036191
	148	1b		139	-0.046998
	149	2b		971	0.012959
	149	2b		928	0.009829
	150	3b		2336	0.111202
	150	3b		2492	0.12247
—		Blank		-734	-0.109863
—		Blank		722	-0.004991
	8	CCV		26619	1.859748
—		Read Baseline		0	-0.056986
—		Read Baseline		0	-0.056986

---	Baseline	0	-0.056986
	151 4b	2882	0.150516
	151 4b	2760	0.141734
	152 5b	1940	0.0827
	152 5b	2313	0.109584
	153 6b	2660	0.134533
	153 6b	2339	0.111472
	154 7b	2727	0.139395
	154 7b	2933	0.154206
	155 8b	1676	0.063701
	155 8b	2060	0.091314
	156 9b	2379	0.114334
	156 9b	2425	0.117619
	157 10b	2262	0.105863
	157 10b	2224	0.103148
	158 11b	5619	0.347649
	158 11b	5051	0.306703
	159 12b	3821	0.218176
	159 12b	3726	0.211337
	160 13b	3558	0.199186
	160 13b	3270	0.178473
---	Blank	-66	-0.061725
---	Blank	1176	0.027683
	8 CCV	26792	1.872191
---	Read Baseline	0	-0.056986
---	Read Baseline	0	-0.056986
---	Baseline	0	-0.056986
	161 14b	3924	0.225561
	161 14b	3572	0.200196
	162 15b	2420	0.117252
	162 15b	2632	0.132509
	163 16b	1378	0.042263
	163 16b	1467	0.048659
	164 17b	1980	0.085588
	164 17b	1977	0.085402
	165 18b	1852	0.076335
	165 18b	2088	0.09335
	166 19b	3910	0.224548
	166 19b	3295	0.180269
	167 20b	3812	0.217517
	167 20b	3515	0.196126
	168 21b	4402	0.259973
	168 21b	4364	0.257242
	169 22b	2826	0.146498
	169 22b	3254	0.177323
	170 23b	-30	-0.059163
	170 23b	4359	0.256868
---	Blank	4688	0.280561
---	Blank	6545	0.414271
	8 CCV	27338	1.911532
---	Read Baseline	0	-0.056986

---	Read Baseline	0	-0.056986
---	Baseline	0	-0.056986
	171 24b	724	-0.004818
	171 24b	2080	0.092765
	172 25b	1969	0.084826
	172 25b	2068	0.091909
	173 26b	1819	0.074015
	173 26b	2155	0.098209
	174 27b	1033	0.017373
	174 27b	1127	0.024181
	175 28b	5392	0.331307
	175 28b	4973	0.301108
	176 29b	3579	0.200731
	176 29b	3413	0.188805
	177 30b	5635	0.348744
	177 30b	5831	0.362913
	178 31b	5383	0.330643
	178 31b	5740	0.356327
	179 32b	7015	0.448154
	179 32b	5130	0.312399
	180 33b	8401	0.547922
	180 33b	9366	0.617454
---	Blank	4293	0.252148
---	Blank	-446	-0.089075
	8 CCV	26544	1.854397
---	Read Baseline	0	-0.056986
---	Read Baseline	0	-0.056986
---	Baseline	0	-0.056986
	181 34b	-2135	-0.210698
	181 34b	-4670	-0.393273
	182 35b	15260	1.041823
	182 35b	21062	1.459658
	183 36b	27525	1.924999
	183 36b	19877	1.374296
	184 HB06 DW5 7/3/98	25949	1.811554
	184 HB06 DW5 7/3/98	27881	1.950621
	185 HB06D DW5 7/3/98	21581	1.496973
	185 HB06D DW5 7/3/98	28504	1.995494
	186 HB06E DW5 7/3/98	17403	1.196185
	186 HB06E DW5 7/3/98	16620	1.139785
	187 HB07 DW5 7/3/98	19261	1.329944
	187 HB07 DW5 7/3/98	14953	1.019744
	188 GP02 DW5 7/3/98	16009	1.095802
	188 GP02 DW5 7/3/98	4063	0.235545
	189 GP03 DW5 7/3/98	15753	1.077326
	189 GP03 DW5 7/3/98	12505	0.843446

APPENDIX D

SALINTY TRANSECTS DATA

Salinity measurements from the Oakland Site(A)

21-May-98

Conditions: Sunny, partly cloudy, temp, 80

Sample #	Distance (ft)	Salinity (ppt)	Site A
1	0	3	
2	12	18	
3	25	no sample	
4	40	5	
5	45	3	
6	50	2	
7	55	4	
8	60	2	
9	65	0	
10	70	0	
11	75	0	
12	80	3	
13	85	0	
14	90	2	
15	95	1	
16	100	0	
17	105	1	
18	110	2	
19	115	0	
20	120	no sample	
21	125	0	
22	130	1	
23	135	0	
24	140	4	
25	145	0	
26	150	0	
27	155	0	
28	160	0	
29	165	1	
30	170	0	
31	180	0	

Amold Site salinity data Site(B)

21-May-98

Conditions: Partly cloudly, mostly sunny, temp 80

Sample #	Distance (ft)	Salinity (ppt)	Site B
50	0	0	
51	10	0	
52	20	1	
53	30	0	
54	40	1	
55	50	0	
56	60	1	
57	70	2	
58	80	1	
59	90	1	
60	100	0	
	110	0	
61	120	2	
	130	0	
62	140	1	
	150	2	
63	160	0	
	170	0	
64	180	3	
	190	0	
65	200	0	
	210	0	
66	220	no sample	
	230	0	
67	240	1	
	250	0	
	260	1	
	270	1	
68	280	1	
	290	0	
	300	0	
	310	0	
	320	0	
	330	0	
	340	0	
	350	4	
	360	3	
	370	3	
	380	2	

Potowomut Site Salinity Data Site (C)

21-May-98

Conditions: Partly Cloudy, temp 80

Sample #	Distance (ft)	Salinity (ppt)	Site C
77	-40	23	
	-30	15	
	-20	4	
76	-10	5	
75	0	12	
78	10	4	
	20	20	
	30	20	
	40	17	
	50	21	
	60	20	
	70	17	
	80	20	
	100	17	
	110	20	
	120	22	
	130	22	
	140	24	
	150	24	
80	160	14	
	170	9	
	180	20	
	190	14	
	200	20	
	210	23	
79	220	20	
	230	5	
	240	16	
	250	24	
	260	25	