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Characterization of Ground Water Discharge to Hampton Harbor

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CHARACTERIZATION OF GROUNDWATER DISCHARGE TO HAMPTON HARBOR

A Final Report to

The New Hampshire Estuaries Project

Submitted by

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New Hampshire Estuaries Project

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Introduction

Coastal Managers across the nation recognize nutrient enrichment as one of the most serious problems in coastal areas[1]. In estuarine environments such as these, nitrogen is the main contaminant of concern. This problem is apparent within the Great Bay Estuarine System, where recent research[2] indicates that groundwater discharge to the bay is extensive and in many cases carries a significant nutrient load. This is consistent with other researchers that have identified groundwater inflow to coastal areas as a very significant fraction of the total fresh water flow to coastal waters[3], and in some cases even exceeding contamination from surface waters[4]. Perhaps more importantly, this nitrate-rich groundwater may be the dominant freshwater source to an estuary during the low flow summer months when oxygen-depletion is most critical. Oxygen-depleted waters have been observed in some of the tributaries of the Great Bay Estuary.[5] Oxygen-depleting substances and nutrients are the leading stressors upon estuarine ecosystems, as reported by the USEPA.[6]

Contaminant loading estimates are an integral part of effective resource management and typically include the major sources: atmospheric deposition, point-source contamination (industry, waste water treatment facilities, surface waters), and finally an assessment of non-point sources (stormwater, and groundwater). Unregulated non-point sources, such as groundwater, are difficult to estimate, as they are typically not monitored. However contributions from major sources are the foundation of current regulatory approaches including the determination of Total Maximum Annual Loads. In order for coastal managers to protect and preserve coastal areas, an accurate assessment of contaminant sources is needed including knowledge of the magnitude and water quality characteristics of ground water flowing into the coastal system. Thus, effective management, mitigation strategies, and development of Best Management Plans requires a basic understanding of the issues and processes that affect an ecosystem.

Project Goals and Objectives

The project goals were to assess inter-tidal groundwater discharge and concurrent nutrient loading to Hampton Harbor. This will include maps of suspected groundwater discharge zones and measurements of nutrient loading. The principal means of assessment was an aerial survey of the study area during low tide using thermal infrared (TIR) imagery. The TIR imagery was used to detect and locate upwelling groundwater discharge zones within the harbor. The location of groundwater discharge zones as it relates to upgradient land use can be instructive for water quality.

Methods

Recent research in thermal infrared imagery coupled with field verification has been shown to be an effective and affordable means to assess inter-tidal groundwater discharge[2]. Therefore in tidal environments, a direct assessment of groundwater discharge to coastal waters has some advantages over conventional methods in that it evaluates the groundwater at the point of discharge into surface waters. Many researchers have found that in brackish waters, the bulk of groundwater discharge appears limited to a narrow horizon at the perimeter of the water body. This has been explained by the occurrence of a zone of diffusion at the interface between a seaward saltwater wedge and upgradient freshwater discharge. This phenomenon forces the exit of groundwater below the high tide line and at the contact with the saltwater wedge, called submarine groundwater discharge (at depth), or inter-tidal groundwater discharge (between the low tide and high tide limits). This can be further controlled by the occurrence of seaward-thickening marine clays. Because of this phenomenon, TIR is ideal for evaluating inter-tidal groundwater discharge.

Methodology: Characterization of groundwater was performed by use of thermal infrared imagery coupled with field verification. The technology of thermal infrared imaging is useful in any location where there is a measurable contrast in the temperature of groundwater, receiving waters, and surrounding landforms. A thermal infrared aerial survey performed at altitude can effectively resolve up to 0.08 °C temperature differences, thereby delineating the thermal signature of groundwater discharge. TIR only measures surface temperatures so its application is limited to the intertidal zone and above, with some exceptions. Figure 1 illustrates multiple suspected groundwater discharge zones that combined are likely greater than 100,000 gallons per day. Field-verification of this site revealed a large saltwater discharge zone, and thus is not included in loading calculations. Salinity is always verified when examining groundwater discharge zones to distinguish between saltwater intrusion and freshwater discharge. This is needed for calculating loading to distinguish between ocean-derived nutrients and land-derived nutrients.

Figure 1: Thermal Imagery of a Multiple Groundwater Discharge Zones From 4,000 Feet

Prior to surveying, an initial site characterization was performed. The study area was reviewed for existing hydrogeologic, land use, and land cover data. Site characterization also included locating sites for deployment of temperature data loggers. Data loggers were used to provide calibration data to correlate temperatures with imagery gray scale. Subsequent image calibration enables image analysis to determine the discharge zone area. Based on site characterization, survey requirements will be determined. Conditions include tides and ambient temperatures of surface landforms (surface waters, mud flats, surface water impoundments, deeper channel waters).

The thermal imagery used staring array digital thermal cameras, which require little image post-processing, a distinct advantage over other types of imaging devices. The vendor provided the researchers with the imagery data and maps of the flight paths. The imagery was reviewed for suspected groundwater discharge zones, such as illustrated in Figure 1. Suspected discharge zones were identified and catalogued as to their characteristics (size, intensity, shape, confidence) and locations. The zones were plotted in a GIS format for later usage in field verification efforts and for future work by the New Hampshire Estuaries Project. GIS-based analysis was used to select suspected discharge zones, run a query for a thermal signature of a desired temperature range, and derive a delineated discharge area. From the resulting discharge area, field generated flow measurements, and water quality results, contaminant loading estimates could be made.

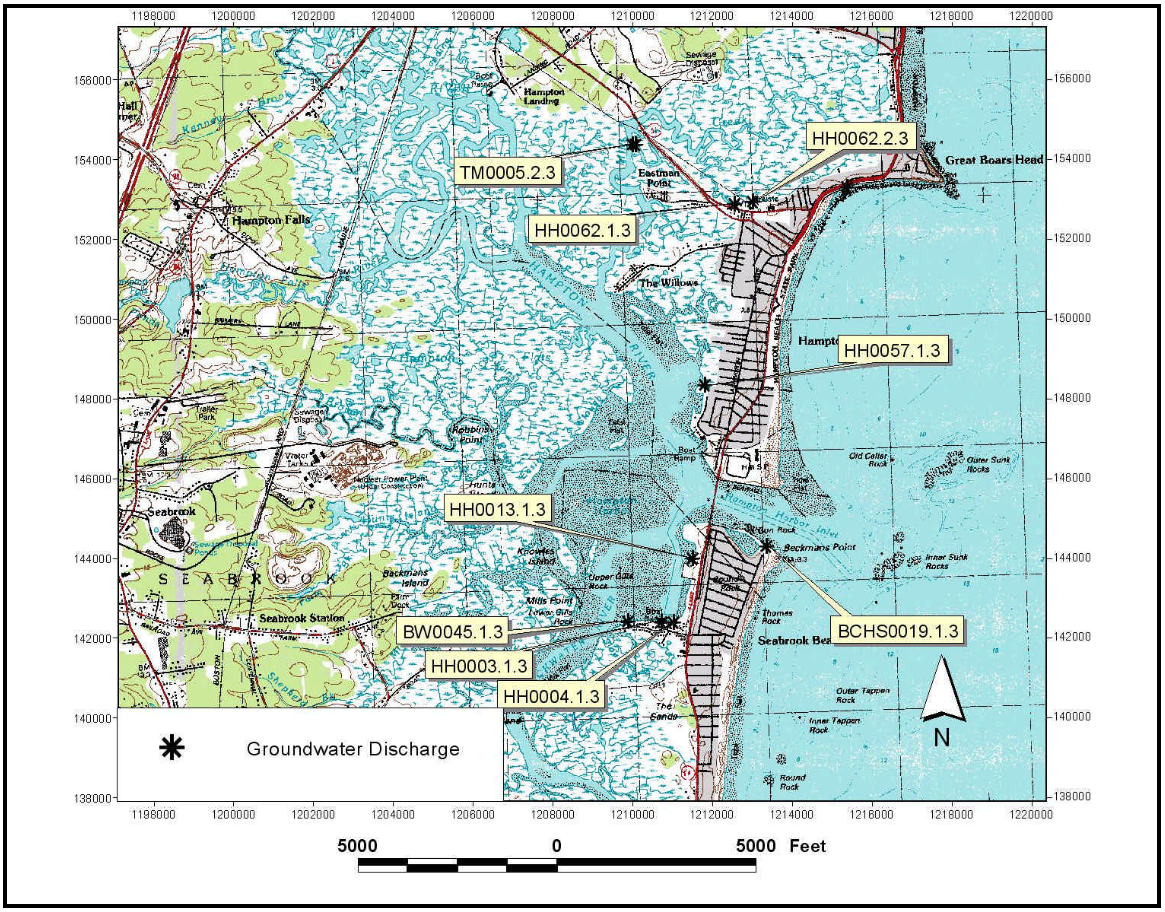
The field verification phase of the research entailed characterizing a representative number of the suspected discharge zones. Representative sites were investigated for hydrogeology, piezometric gradient, discharge zone area, and water quality. The salinity of discharging water was monitored to verify presence of groundwater rather than saltwater storage. Water quality samples were taken in duplicate, and preserved and stored immediately prior to analysis. Analyses include nitrate, ammonium, and phosphorous.

Estimates of total groundwater flow to the receiving waterbody were made following calculations from field derived flow estimates and imagery derived flow area. Finally, upon water quality analyses, contaminant loading estimates were made per representative site and estuary-wide. Flow and contaminant loading estimates will be compared with published research including local data from the upper Great Bay.

Results and Discussion

The results of the thermal imagery survey indicated there were essentially no groundwater discharge zones within Hampton Harbor but were instead located upon the perimeter. Figure 2 illustrates groundwater discharge zones within the study area. Field conditions for the survey were ideal and the resolution of thermal signatures from upwelling groundwater was clear. This is exemplified by the identification of a few very clear groundwater discharge zones (Figure 1). The temperature dataloggers recorded field temperatures in the range of 34-36 degrees Fahrenheit, with background groundwater temperatures expected to be in the vicinity of 47 degrees Fahrenheit (Figure 4). Surprisingly, the thermal imagery indicated a distinct lack of groundwater discharge zones within the salt marsh.

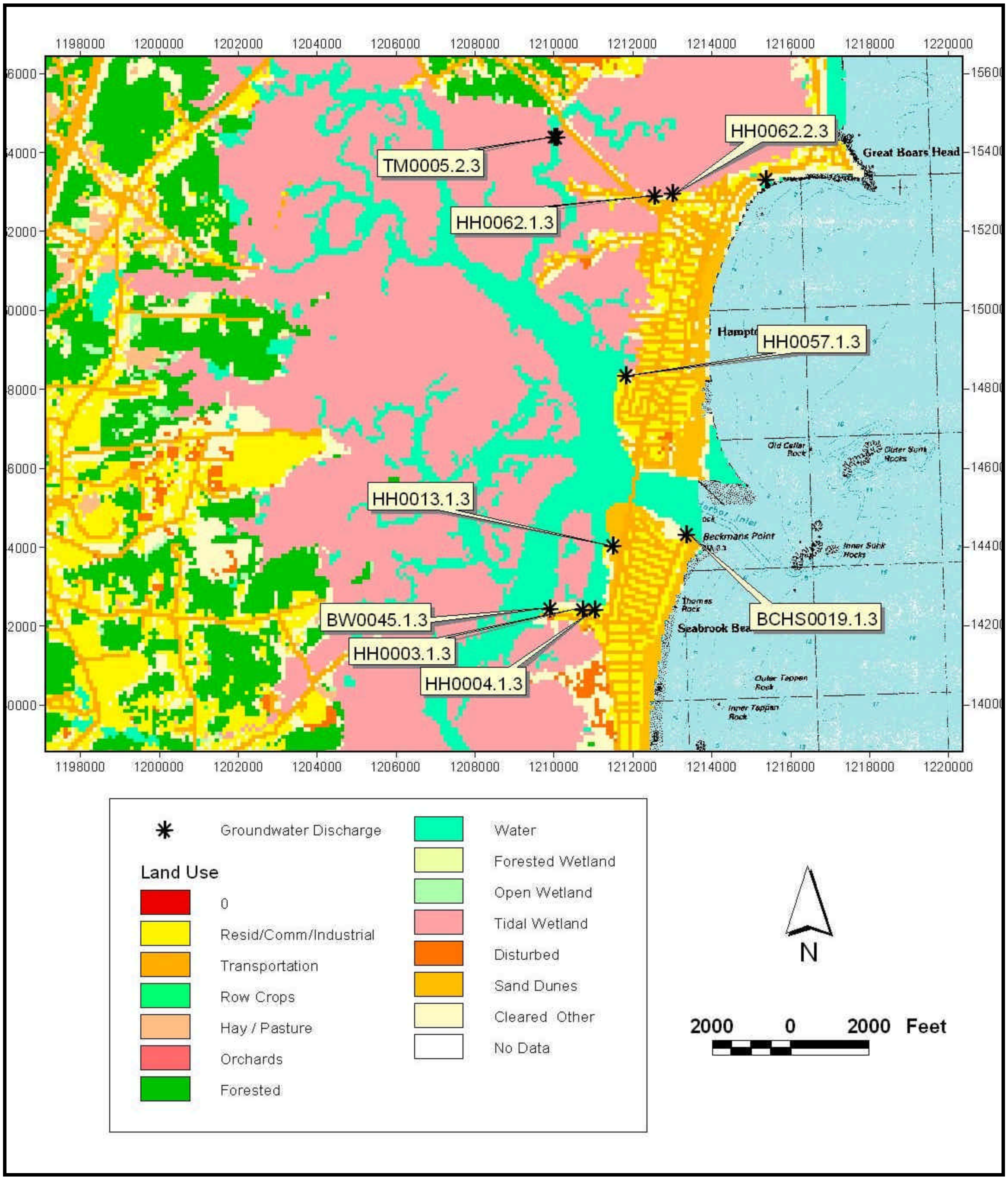
Figure 2: Locations of Thermal Imagery Detected Groundwater Discharge Zones



(NAD 83, NH State Plane Feet)

Figure 3 illustrates the strong correlation of groundwater discharge zones and the land use and land cover. There is a distinct lack of discharge zones within the marsh. Discharge zones were limited to the areas in which salt marsh is absent, such as the barrier dunes, or where development is present. Because this finding was somewhat surprising, field investigations were performed which verified the lack of discharge zones within the marsh and presence elsewhere. This was determined primarily by the presence of high salinity discharge at the suspected discharge locations (Table 1). Field investigations revealed that false positives occurred at the interface between the overlying peat layer (varying in thickness from 0-6 ft thick inland) and the underlying sands. This interface appeared to be a good location for saltwater storage and thus flows similar to groundwater discharge, albeit very minor. The few excellent discharge zones had extremely high salinities (HH62.1.3 and HH0062.2.3) and thus are deemed to be the result of saltwater pumping rather than freshwater discharge. The single site with a low salinity (HH3.1.3) was bordered by rip rap and coarse sands and gravels, and thus was likely the result of disturbance. This site had low flow and was thus insignificant in overall loading.

Figure 3: Groundwater Discharge Zones Correlated with Land Use and Land Cover Classification for Hampton Harbor



(NAD 83, NH State Plane Feet)

Table 1: Salinity Readings for Saltwater/Groundwater Discharge Sites

Groundwater Discharge Site	Salinity (ppt)
TM0005.1.3	28.5
HH0005.3.3	25.8
HH0003.1.3	5.3
HH0004.1.3	28.7
HH00013.1.3	27.6
HH00057.1.3	29.4
TM0010.1.3	29.6
HH0062.1.3	23.8
HH0062.2.3	21.9

An examination of surface infiltration rates was performed at 4 locations within the marsh to evaluate the potential for localized recharge (

Figure 5). Surface infiltration rates were evaluated using a double-ring infiltrometer[7], the results of which showed that, with the exception of very large rain events, very little localized groundwater recharge is occurring. Infiltration rates were extremely slow and ranged form 0.06-0.006 cm/hour. This suggests the absence of localized recharge and shallow path groundwater discharge within the salt marsh. This would mean that precipitation within the marsh all runs off in the form of surface water, and little or no is recharged as groundwater. This suggests that in areas with large fringing salt marsh, that intertidal groundwater discharge may be extremely limited and rather discharging elsewhere, presumably at depth as submarine groundwater discharge, and as such not detectable by thermal infrared imagery.

Conclusions

The study of intertidal groundwater discharge zones suggests that intertidal groundwater discharge is extremely limited in Hampton Harbor due to the presence of a large impermeable salt marsh. Numerous sites were located, and all but one had salinities greater than 21 ppt. With salinities that high, these sites were deemed locations of saltwater pumping rather groundwater discharge. A single site was located which had a salinity of 5 ppt which had insignificant flow and likely caused by installation of upgradient rip rap. The strict hydrogeologic control limited all potential sites to coarse sands, likely the location of historic deposition of coastal barrier features. No potential sites were located within the salt marsh. Hampton Harbor is characterized by shallow glacial deposits akin to a barrier system coastal feature and has over 5,000 acres of contiguous salt marsh. A review of land use and land cover, for both of these settings showed a nearly complete correlation between the salt marsh and absence of groundwater discharge zones and a positive correlation with the residential/commercial land cover classification.

This addresses locally derived intertidal groundwater discharge (w/in the marsh), but the issue of groundwater discharge derived from the exterior of the marsh is affected for another reason. Because of the large fringing saltmarsh, the presence of a saltwater wedge is presumably limited to the perimeter of the marsh, rather than the interface between the marsh and upland habitat (the typical location). The saltwater wedge seems to be one of the dominant forces causing groundwater discharge to occur within the intertidal zone, its absence would allow the groundwater flowpath to continue downwards. And because of the lack of infiltration to contribute recharge, and the potentially long flow paths for upgradient source waters to travel under the marsh, no daylighting groundwater discharge is observed within the intertidal zone. It is possible that groundwater discharge occurs at depth off shore. While the majority of the harbor was intertidal, the absence of intertidal groundwater discharge potentially rules out the majority of it. The vast majority of Hampton Harbor is less than 3 feet deep at mean high water, such that an thermal infrared survey timed at low tide should expose nearly all of the harbor as an intertidal zone. Field surveys support this finding such that with the exception of very shallow channels (0-5 feet), nearly the entire harbor is drained at low tide. Many studies support the contention that the majority of groundwater discharge occurs within the top 1 meter of the MLLW.

Recommendations for Future Work

Clearly the upgradient source waters that are the typical cause for SGD are still present, as the surrounding watershed is a large source for recharge, the question is then where does it go? Deeper offshore SGD is likely, however beyond the scope of the project. Investigations of deeper offshore SGD could be performed using resistivity at depth.

Additionally the issue of groundwater discharge derived from the exterior of the marsh could be investigated by installation of small diameter wells or piezometers at the upgradient perimeter of the marsh to determine water table depth and direction of flow. This information would enable the assessment of location and influence of a saltwater wedge.

Project Products

The project results were presented in February 2002 at the *Technology Transfer Conference*, Emerging Technologies, Tools, and Techniques, To Manage Our Coasts in the 21st Century, sponsored by the U.S. EPA Office of Water, Office of Wetlands, Oceans, and Watersheds, Oceans and Coastal Protection Division. The title of the presentation was *Limitations of the Use of Thermal Infrared Imagery for the Assessment of Inter-Tidal Groundwater Discharge based on Land Use, Land Cover, and Hydrogeology*, by Robert M. Roseen, Thomas P. Ballestero, Gabriel Bacca-Cortez, and William G. McDowell.

The project results and other related studies will be presented in December 2003 at the National Groundwater Association Convention at an invited talk entitled *A Review of Methods and Limitations on the Use of Thermal Infrared Imagery for the Assessment of Inter-Tidal Groundwater Discharge*, by Robert M. Roseen, Thomas P. Ballestero, Gabriel Bacca-Cortez, Larry K. Brannaka.

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[5] New Hampshire Estuaries Project, Management Plan—Draft, December 1999, Portsmouth, NH.

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[7] ASTM 1998, Standard Test Method For Infiltration Rate Of Soils In Field Using Double Ring Infiltrometer, D-3385-94, Vol. 4.08, Conshoken, PA.

Appendices

Figure 4: Landform Temperatures During Aerial Survey

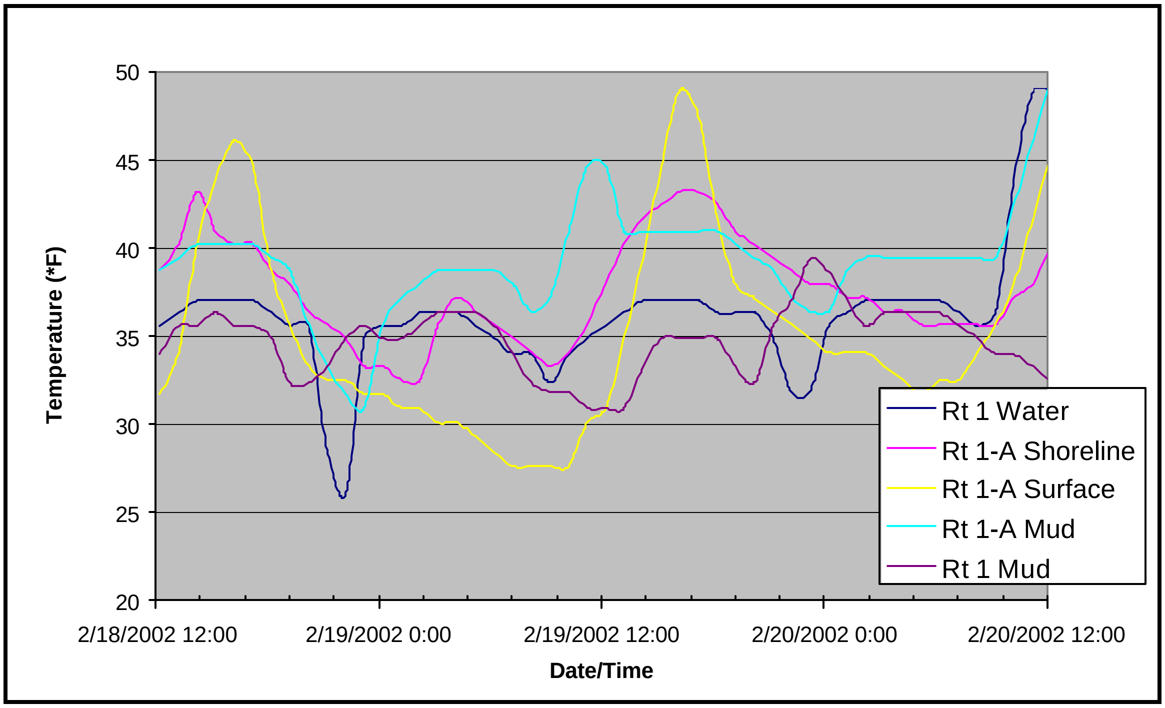

Figure 5: Locations of Infiltration Tests Within Salt Marsh

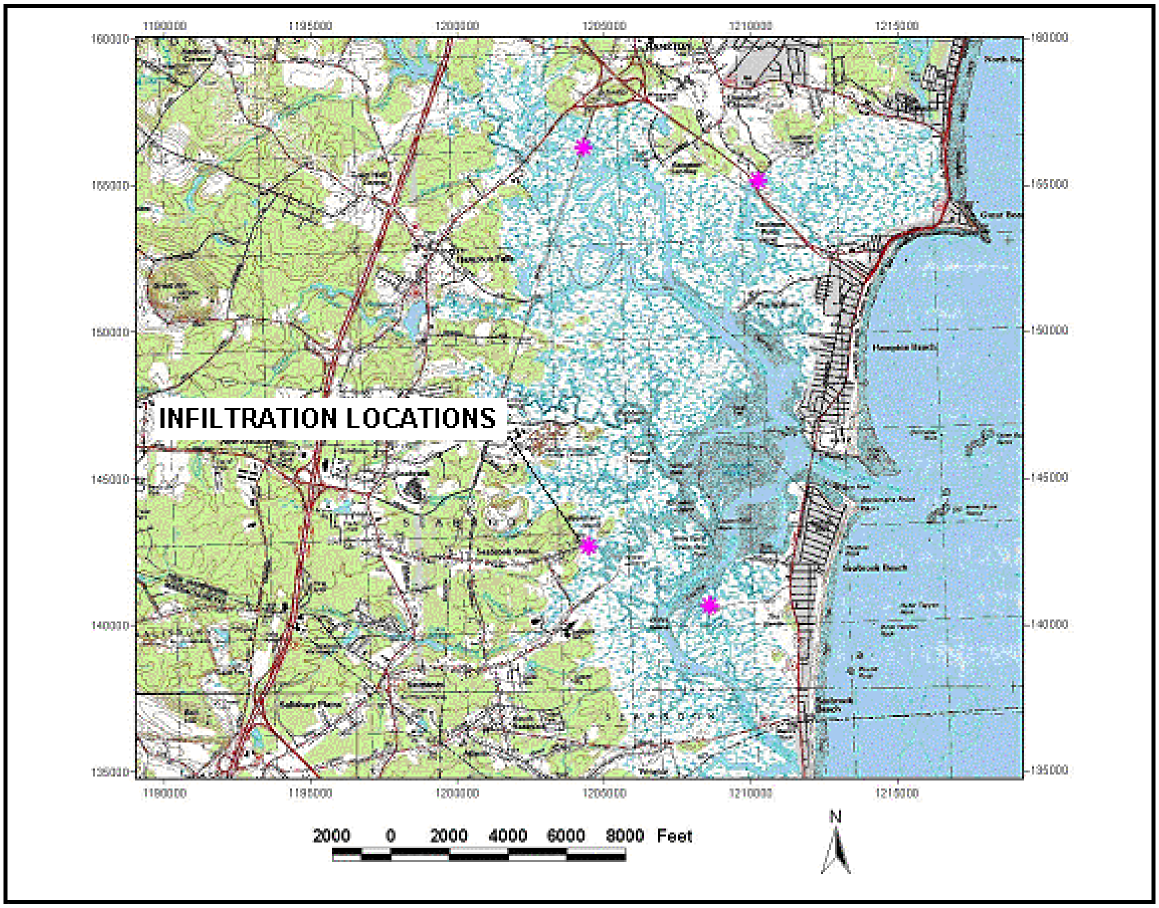

Figure 6: Groundwater Discharge Location TM0005.1.3

Figure 7:Groundwater Discharge Location TM0010.1.3

Figure 8: Groundwater Discharge Location HH0003.1.3

Figure 9:Groundwater Discharge Location HH0004.1.3

Figure 10:Groundwater Discharge Location HH0005.3.3

Figure 11:Groundwater Discharge Location HH0013.1.3

Figure 12:Groundwater Discharge Location HH0057.1.3

Figure 13:Groundwater Discharge Locations HH0062.1.3 and HH0062.3.3