II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT

Nutrient additions to aquatic systems cause shifts in a series of biological processes that can result in impaired nutrient related habitat quality. Effects include: 1) excessive plankton and macrophyte growth (which leads to reduced water clarity), 2) organic matter enrichment of waters and sediments, with the concomitant resulting increased rates of oxygen consumption and periodic depletion of dissolved oxygen, (especially in bottom waters), and 3) the limitation of the growth of desirable species such as eelgrass. Even without changes to water clarity and bottom water dissolved oxygen, the increased organic matter deposition to the sediments generally results in a decline in habitat quality for benthic infaunal communities (animals living in the sediments). This habitat change causes a shift in infaunal communities from high diversity deep burrowing forms (which include economically important species), to low diversity shallow dwelling organisms. This shift alone causes significant degradation of the resource and a loss of productivity to both the local shellfisherman and to the sport-fishery and offshore fin fishery, all of which are dependent upon these highly productive estuarine systems as a habitat and food resource during migration or during different life cycle phases. This process is generally termed “eutrophication” and in embayment systems, unlike in shallow lakes and pond, it is not a necessarily a part of the natural evolution of a system.

In most marine and estuarine systems, such as the Sesachacha Pond System, the limiting nutrient, and thus the nutrient of primary concern, is nitrogen. In large part, if nitrogen addition is controlled, then eutrophication is controlled. This approach has been formalized through the development of tools for predicting nitrogen loads from watersheds and the concentrations of water column nitrogen that may result. Additional development of the approach generated specific guidelines as to what is to be considered acceptable water column nitrogen concentrations to achieve desired water quality goals (e.g., see Cape Cod Commission 1991, 1998; Howes et al. 2003).

These tools for predicting loads and concentrations tend to be generic in nature, and overlook some of the specifics for any given water body. The present Massachusetts Estuaries Project (MEP) study focuses on linking water quality model predictions, based upon watershed nitrogen loading and embayment recycling and system hydrodynamics, to actual measured values for specific nutrient species. The linked watershed-embayment model is built using embayment specific measurements, thus enabling calibration of the prediction process for specific conditions in each of the coastal embayments of southeastern Massachusetts, including the Sesachacha Pond, a great salt pond. As the MEP approach requires substantial amounts of site specific data collection, part of the program is to review previous data collection and modeling efforts. These reviews are both for purposes of “data mining” and to gather additional information on an estuary’s habitat quality or unique features.

Concern over the health of the Nantucket Island embayments have resulted in a number of studies relating to the nutrient related health of the Sesachacha Pond System over the past 2 decades. These investigations include both habitat assessments and studies relating to nitrogen loading, hydrology/hydrodynamics and habitat health. While the majority of the previous studies did not provide a holistic view of the Sesachacha Pond System, they provide useful information to the present MEP effort. One report in particular, the *Final Report on Nutrient Conditions in Sesachacha Pond,* was an initial attempt to evaluate this generally closed estuarine system and its watershed within the larger regional system and to evaluate the nutrient conditions/fluxes for watershed nitrogen inputs producing habitat declines within the receiving waters of the pond.

The initial nutrient study of Sesachacha Pond was undertaken by members of the MEP Technical Team while in residence at the Woods Hole Oceanographic Institution (Howes and Goehringer 1989). The study was conducted in 1988 and 1989 and was prepared for Aubrey Consulting Inc to provide the ecological management assessment related to the 1989 EIR. The goals of the 1988-1989 Sesachacha Pond nutrient study was to ascertain the current environmental health of the Sesechacha Pond ecosystem and to determine if the nutrient balance of the pond under various management options would allow for the establishment of a healthy and stable freshwater, or conversely, marine system. Healthy in this case was defined as an aquatic system absent of deleterious eutrophication or episodic anoxia, allowing the development of diverse and productive pelagic and benthic populations.

To ascertain the environmental conditions that existed in the pond at the time of the study measurements were made of water column, sediment and groundwater nutrient concentrations, sediment-water column nutrient flux and associated physical parameters under summer (maximum) and winter (minimum) levels of biological productivity. All of this data collection enabled the assessment of the environmental health of the pond to allow the prediction of the potential impacts of two specific management strategies; 1) the effects of reinstating an exchange with the ocean versus 2) continuation of diminishing surface exchange (generally only during storm related breaching) possibly to the point of preventing surface water flow under all conditions. Data collected under this initial Sesachacha Pond nutrient study was envisioned as serving in the development of a water quality baseline for any potential future monitoring effort undertaken to observe the response of the pond to any chosen course of management

Based on the work undertaken during this initial in depth investigation into the ecological function and nutrient cycling of Sesachacha Pond, specific conclusions were reached as follows:

Water Budget

1) Pondwater loss to the ocean through the barrier beach dune system (as groundwater) is large relative to the pond volume resulting in a relatively high transport rate. It was found that this could represent a major potential pathway for nutrient loss from the pond, when the pond level had reached equilibrium with the groundwater system (after 4-5 years of closure).

2) Between 1981 when the pond was last opened in the 1980's and 1984 when the first hydrologic measurements were made under the Perkins Jordan, Inc. investigation of the pond, water levels increased significantly due to groundwater inflow. During the period 1984 to 1988 water levels were determined to not be increasing in any significant manner thus enabling a hydrologic budget of the pond.

3) The freshwater inflow to the pond (1.42×10^9 L/yr) is large relative to the pond volume (65%) and is approximately equal to the increase in pond volume (1.4×10^9 L) from 1981 to the 1988-89 time frame when the nutrient study was conducted. This suggested that the time required to increase the water level within the pond once surface loss to the ocean ceases is short.

4) Inputs of freshwater through direct rainfall are on the same order as groundwater inputs, 1.1 versus 1.4×10^9 L/yr thereby suggesting that groundwater is less important to the water balance of the pond than was generally found at the time of the study.

Note that the total freshwater inflow estimated from this early study (2.5 x 10^6 m^3 y^{-1}) is consistent with the long-term freshwater inflow rates determined from the MEP watershed model (Chapter IV) and the short term rates based upon salinity dilution (Chapter VI).

Nitrogen Balance

5) Nitrogen was determined to be the nutrient limiting plant production in Sesachacha Pond as evidenced by water column data collected during the 1988-89 study. The major indication of nitrogen limitation came from both February and September water column data that showed that a DIN to PO_4^{3-} ratio of less than 1 existed in the pond. Values for the ratio of N to P less than 16 are generally indicative of nitrogen limitation.

6) The water column total nitrogen levels in the pond were very high (1.04-1.77 mg N/L) and were higher than values obtained in 1984 (0.46 mg N/L). Furthermore, the high TN values, low dissolved oxygen concentrations, low light penetration (Secchi depth = 1.1 meters), and high phytoplankton biomass in the water column supported the conclusion that Sesachacha Pond was a highly eutrophic system.

7) The input of nitrogen in rainfall and groundwater was of the same order of magnitude in 1988-89 as the loss in sediment accretion and groundwater effluent, but best estimates at the time indicated that inputs exceed outputs given the eutrophic state of the pond.

8) Loss of nutrients through groundwater flow to the ocean under the barrier beach accounted for approximately half of the outputs. Ultimately that meant that the pond did flush in a very limited way under a closed configuration and as such if the exchange is impeded in any way without providing for alternative transport of nutrients, then conditions in the pond would tend to worsen. However, the estimated rate of outflow depended upon the elevated pond levels that resulted after prolonged closure.

9) The removal of nutrients from the pond via groundwater outflow while a significant pathway for nutrient export is limited not just by flow rate, but by the fact that particulate N is retained in the pond. Subsequently, sediment remineralization of nitrogen provides 75 percent of the nitrogen to the water column therefore only a relatively small annual input of nitrogen to the pond is required to keep nutrient conditions high.

Based on the 1988-89 nutrient study of Sesachacha Pond the system was deemed eutrophic with episodic anoxia. Those conditions resulted in an unstable environment with low light penetration, high plant production and depauperate bottom communities. At the time of the study Sesachacha Pond required a mechanism to increase nutrient losses without which the pond conditions would worsen. Maintaining the pond as a saltwater system with continuous exchange with the ocean was seen as the best ecological solution as it would certainly lower nutrient levels in the pond and most likely result in the establishment of a productive marine ecosystem, however, the increased improvement over alternatives based on limited exchange was not deemed cost effective. A scenario based on maintaining the pond as a saltwater system with semi-annual exchange with ocean water was determined to be a sound management approach whereby nutrient export could be achieved via the increased exchange and salinity in the pond could be maintained above the 5 ppt threshold for shellfish growth and reproduction.

As a result of the 1988-89 nutrient study for Sesachacha Pond, an Environmental Notification Form (ENF) was submitted to the Massachusetts Environmental Policy Act (MEPA) Unit describing several pond management alternatives as follows:

- Status Quo – the pond would be left alone in its current (1988-89) state allowing nature to govern its condition
- Dune Restoration – dunes along the barrier beach would be rebuilt to reduce storm overwash and influence of salt spray
- Pond Opening – open the pond by dredging for a brief period of time as was done in the past (pre 1981)
- Connector Regulation – regulate a connector (one-way or two-way) between the pond and the ocean to maintain a specified range of salinity, water temperature and water level.

A Draft Environmental Impact Report (EIR) was developed by Aubrey Consulting Inc. whereby an analysis of Sesachacha Pond management alternatives (as described above) was presented in July 1989 under EOEA File Number 7452. The Draft EIR was prepared for the Massachusetts Audubon Society and was necessary prior to any pond opening or connector regulation. The technical work conducted in the development of the EIR resulted in a consensus being reached amongst representatives of a number of stakeholder groups (Massachusetts Audubon Society, Nantucket Land Council, Board of Selectman, Nantucket Conservation Commission, Quident-Squam Association, Shellfish Advisory Board and local residents) that would have the pond system managed as a brackish to marine aquatic environment. The EIR reflected the consensus reached amongst the various stakeholders and as such presented two specific management alternatives (periodic pond opening and two-way connector regulation) for maintaining Sesachacha Pond as a brackish environment.

Based on the results of the scientific study (discussed above) and associated data collection for the development of the EIR, an analysis of likely impacts for each management alternative was submitted to the MEPA Unit. Key points of the analysis of likely impacts include but are not limited to the fact that if the pond was left alone and no management of the pond was undertaken (status quo) the brackish pond would gradually revert to essentially a freshwater system as salt is diluted by groundwater inflow and precipitation. The pond would be slightly brackish due to over-washing events during storms and occasionally experience major perturbation as the barrier beach is naturally breached during extreme events such as a hurricane. As a result of the general freshening of the system the wetlands associated with the Sesachacha Pond system will transition from brackish to freshwater wetlands with consequent die-off of brackish wetland causing high carbon/nutrient loading to the pond. Additional die-off of freshwater wetlands could occur during natural breaches of the barrier beach during extreme events thus further increasing the carbon and nutrient load to the pond. As a result of increasing nutrient loads to the pond and limited flushing of the system it was concluded in the Draft EIR that plankton would proliferate during periods of the year when blooms tend to occur thereby driving oxygen levels in the pond even lower with resultant effects on existing flora and fauna. Freshening of the pond system would preclude the establishment or maintenance of any saltwater shellfish populations and more frequent periods of anoxia would preclude the existence of a healthy benthic infaunal community (be it freshwater or saltwater organisms). As regards the nutrient conditions of the pond under a status quo scenario, it was determined that nutrient levels in the pond would continue to increase as inputs remained the same or increased over time with potential development and no sinks or avenues for increased export of nutrient load would exist. The pond system would remain eutrophic as much of the annual load of

nutrients to the pond remains in the pond in a particulate form while some of the nutrient pool (dissolved nutrients) is exported with groundwater flow to the ocean.

Of specific interest to the MEP were the findings in the draft EIR which related to the management alternative (periodic pond opening) that was essentially adopted through the 1990's to present. Up until 1981 the barrier beach was artificially breached once to twice per year using a bulldozer and the inlet remained open naturally for a temporary amount of time as a result of natural daily tidal flow in and out of the pond. Long shore transport would then fill the breach in over 1-14 days and the pond would remain closed until the next time it was determined the pond should be opened to the ocean. From a biological point of view, periodic opening of the pond system would result in a more saltwater dominated marsh system with the distribution of species such as cattails, *Panicum* and *Phragmites* being limited to higher elevation areas of low salinity in the vicinity of groundwater seepage into the pond. With regards to phytoplankton the influx of saltwater and the exchange of nutrient rich pond water with nutrient poor ocean water would drive nutrient concentrations in the pond to a lower level and as such produce an aquatic environment less supportive of major plankton blooms. That is not to say that blooms would not occur, but rather, that bloom events may be less frequent and less intense. The flushing of nutrients out of the pond and exchange with "clean" ocean water would allow the salinity to be sustained at levels supportive of marine shellfish species while also reducing the incidence of low dissolved oxygen events.

Considering the current (2006) state of Sesachacha Pond in light of the analysis of likely impacts presented in the Draft EIR (1989) for the pond opening management scenario, certain 1989 findings were shown to be reasonable while others did not manifest themselves. Despite the periodic opening of Sesachacha Pond, the aquatic system remains extremely eutrophic with very high chlorophyll levels, extremely poor water clarity and very low dissolved oxygen. The ecological state of Sesachacha Pond remains impaired as evidenced by data collected by the MEP (Section VII) and as a result the MEP analytical approach has been invoked to refine the management of the Sesachacha Pond system to drive further restoration of this aquatic resource.

As part of the Town of Nantucket's management of Sesachacha Pond, the Marine and Coastal Resource Department and Health Department established a water quality monitoring program to track salinity, nutrient related parameters and bacterial indicators. In the development of the MEP Nutrient Threshold Report for the Sesachacha Pond system, the MEP Technical Team incorporated into its analysis of nutrient conditions in Sesachacha Pond all water quality results generated by this program. This data also supported the MEP Technical Report that served as the basis for the MassDEP's TMDL development related to bacterial contamination of Sesachacha Pond.

In addition to its focus on nutrient related habitat quality and developing a nitrogen management approach for Sesachacha Pond, the MEP was tasked with the development of a Bacteria Technical Report to serve as the basis for the MassDEP development of a bacteria TMDL for Sesachacha Pond (as noted above). The technical report was submitted to the MassDEP in January of 2006 and is currently under review. A well developed database of historical bacteria data was available for the development of the technical report for Sesachacha pond. The bacterial data used for the MEP bacteria analysis of the system were generated exclusively by the Massachusetts Division of Marine Fisheries as well as the Town of Nantucket Marine and Health Departments. Based on previous discussions with the MassDEP, the technical report was not meant to direct the reader to specific bacterial sources (point or non-point), nor was it intended to produce Fecal Coliform Waste Load Allocations (WLAs) or Load

Allocations by bacteria source for the Sesachacha Pond system. The reported aimed to point to likely geographic sections of the overall Sesachacha Pond system that are the most likely source of the highest bacterial concentrations recorded to date. Historical data was compiled from multiple agencies and was synthesized in the context of land use distributions as provided to the Massachusetts Estuaries Project (MEP) by the Nantucket Land Council. In order to identify likely sections of Sesachacha Pond responsible for highest bacterial contamination, geometric means and percent exceedances were developed for historical data obtained for the report. In the present effort, the MEP Technical Team is focusing on restoring the resources of Sesachacha Pond and in the bacterial report, focused on the ability to utilize the resources of the Pond (swimming and shellfishing) post-restoration.

Sesachacha Pond is currently classified as Prohibited. It is currently used only as a seed grow out area from which mature seed are transplanted to clean areas. Based upon the MEP Bacterial Technical Report, most of the bacteria data for Sesachacha Pond were collected from 1985 through 1995 with Town data available for 2000-2003. Summer exceedances of the geometric mean of the water quality standard of 14 cfu/100ml range from approximately 26% to approximately 64% at the stations sampled. Exceedances of the water quality standard of 43 cfu/100ml range from approximately 20% to approximately 43%. Winter exceedances of the water quality standard of 14 CFU/100 mls by the geometric mean are 0% at all stations sampled except for Station 2 which has an exceedance of 17%. More than 10% of the samples exceeded the water quality standard of 43 cfu/100ml only at Station 2. Summer wet/dry data from the Town of Nantucket showed a wet geometric mean approximately 3 times the dry mean, although neither mean exceeded the water quality standard of 14. More than 10% of the wet samples only exceeded the water quality standard of 43 cfu/100ml.

Sesachacha Pond clearly exhibited bacterial contamination from 1985 to 1991 and based on recent data of the Nantucket Health Department, there is potential contamination currently. Waterfowl is a potential source of bacteria inputs but buildup of bacteria in the pond may be significant because of a lack of flushing of the pond which is limited to the few times during the year when the barrier beach is dredged to create a temporary inlet to allow exchange with oceanic water.

Overall, the DMF and Town of Nantucket datasets suggest waterfowl and/or wildlife as the most likely sources to Sesachacha Pond, although potential runoff along the southwestern shore may also be a contributory factor. This conclusion is based upon:

- observation of higher bacterial levels in summer than winter (biological activity)
- association with rain events (wetland and possible runoff)
- spatial distribution of contamination, highest in southwestern station adjacent undeveloped watershed area and wetlands (to northwest)

Although the bacterial levels are highest in the southwestern station, it is possible that the contamination is also associated with the wetlands entering along the northwestern shore where there is not sampling data. Given the low levels of bacterial contamination within the Pond and the above factors, it appears that sampling associated with summer rain events, with refined spatial coverage would help to address the source issue.

The land-uses along the southwestern shore of Sesachacha Pond indicate “natural” sources of bacteria, as the land is currently undeveloped and protected. However, the open space and wetlands almost certainly support populations of waterfowl and wildlife that would be more prevalent during the summer months when higher bacterial contamination is evident. In

addition, rain events tend to help transfer bacterial loads from emergent wetlands to adjacent Pond waters.

- The limited number of potential bacterial sources and the availability of existing data allows for generation of a bacterial TMDL using existing water quality data. At present, the data suggests wildlife and/or waterfowl as major bacterial sources to pond waters. Additional sources include runoff, with septic systems being less likely. A sanitary survey approach which provides a refined spatial sampling of summer time wet/dry weather fecal bacteria and includes assessments of the wetland area (culvert under Polpis Rd) and the waters off Quidnet should be considered. In addition, targeted assessment of (a) bacterial levels at the culvert under Polpis Road and the southwestern wetlands under wet and dry weather conditions and (b)potentially "failed" septic systems within Quidnet (BOH).

Sesachacha Pond is a eutrophic pond exhibiting very high nutrient levels, low dissolved oxygen and intermittently bacterial levels exceeding the standards for shellfishing. The Town of Nantucket, from whom most of the bacteria data was acquired, has demonstrated through water quality testing pre and post breaching that the pond must remain open for sufficient duration during regular breechings in order to flush the stagnant biological matter from the system and allow for a return to a salt water based ecological system.

Sustained low level bacterial levels within Sesachacha Pond indicate a relatively small but continuous source of contamination to surface waters. Among the sources of contamination which have been frequently identified as contributing to embayments within southeastern Massachusetts, waterfowl and wildlife (and possibly road runoff) are the most likely. The sustained low level bacteria concentrations are probably the result of a combination of factors:

Likely contributors

1. waterfowl (likely)
2. drainage from the wetland southwest of the pond (likely)

Possible contributors

3. wildlife throughout the protected open space portions of the watershed (possible)
4. road runoff primarily from Polpis Rd. (possible)

Unlikely contributors

5. septic systems close to the pond (unlikely – due to distribution))
6. swimmers in the summer months (unlikely)
7. point-source discharge (none identified)

The lack of flushing allows bacteria to flourish in the nutrient enriched environment created from many of the same sources. It appears that solving the problem of nutrient enrichment will also address the bacterial issue to some degree since sources of the two contaminants are in many cases the same. We recommend that the work listed above in "Recommendations for a Bacterial TMDL Program" be incorporated as recommendations into a future TMDL report being ever mindful that the pending nutrient TMDL will also include more detailed suggestions for the improvement of overall water quality.

As regards bacterial contamination in Sesachacha Pond, the Massachusetts Estuaries Project recommended that Sesachacha Pond be designated for further study to collect more recent data with which to evaluate the pond's status regarding the nature and sources of

bacterial inputs. It was not recommended that it be added to the 303d list at this time due to limited development in the watershed and the preponderance of Protected Open Space potentially supportive of large waterfowl and wildlife populations.

The common focus of the Town of Nantucket Water Quality Monitoring Program effort has been to gather site-specific data on the current nitrogen related water quality throughout all the embayments of the Island (including Sesachacha Pond) to support evaluations of observed water quality and habitat health. This multi-year effort was initiated in 1992, with significant support from the Nantucket Marine and Health Departments and the Nantucket Land Council. It has been continued by the Town of Nantucket through 2005. The Nantucket Water Quality Monitoring Program in Sesachacha Pond developed a data set at four sampling stations (Figure II-1) that elucidated the long-term water quality of the pond system.

Results of water quality sampling conducted by the Town of Nantucket are presented by the Town Biologist in a series of annual reports. Annual reports from 1992-2005 were provided to the MEP Technical Team. In general, all the annual reports reviewed did present valuable data on physical parameters at each station within Sesachacha Pond including: temperature, salinity, secchi depth and total depth. Additionally, data are presented on dissolved oxygen, pH, nutrients (nitrate, phosphorous and ammonia) and in some instances bacteria (fecal coliform). Annual report also provided a record of pond openings and duration of opening with earlier reports (1992, 1993 and 1994) also providing a summary of plankton tows and benthic surveys conducted at the established sampling stations. While these plankton and benthic surveys do not continue on in later years to the same level of detail as was found in the earlier reports, the later reports do provide data intermittently on the state of shellfish resources at specific locations in the pond system. Moreover, the later reports provided the morphometry of Sesachacha Pond as it relates specifically to surface areas of the pond as a function of changing depth as well as associated pond volumes. Collectively, all the annual reports represent an extremely valuable record of conditions in Sesachacha Pond as a function of time and the periodic openings of the pond system to the ocean and essential information on the number and duration of pond openings over the past decade.

The MEP effort builds upon the Town's Water Quality Monitoring Program, previous hydrodynamic/hydrologic evaluations conducted during the development of the Draft EIR and water quality analyses conducted by SMAST. The Town of Nantucket Water Quality Monitoring Program provided the quantitative water column nitrogen data (2000-2005) required for the implementation of the MEP's Linked Watershed-Embayment Approach. The MEP effort also builds upon previous watershed delineation and land-use analyses and the embayment water quality and eelgrass/macrophyte surveys. This information is integrated with MEP higher order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for the Sesachacha Pond embayment system. The MEP has incorporated all appropriate data from all previous studies to enhance the determination of nitrogen thresholds for the Sesachacha Pond system and to reduce costs to the Town of Nantucket. Additionally, as remediation plans for this and other various systems are implemented, the continued monitoring important to provide quantitative information to the Town relative to the efficacy of remediation efforts.

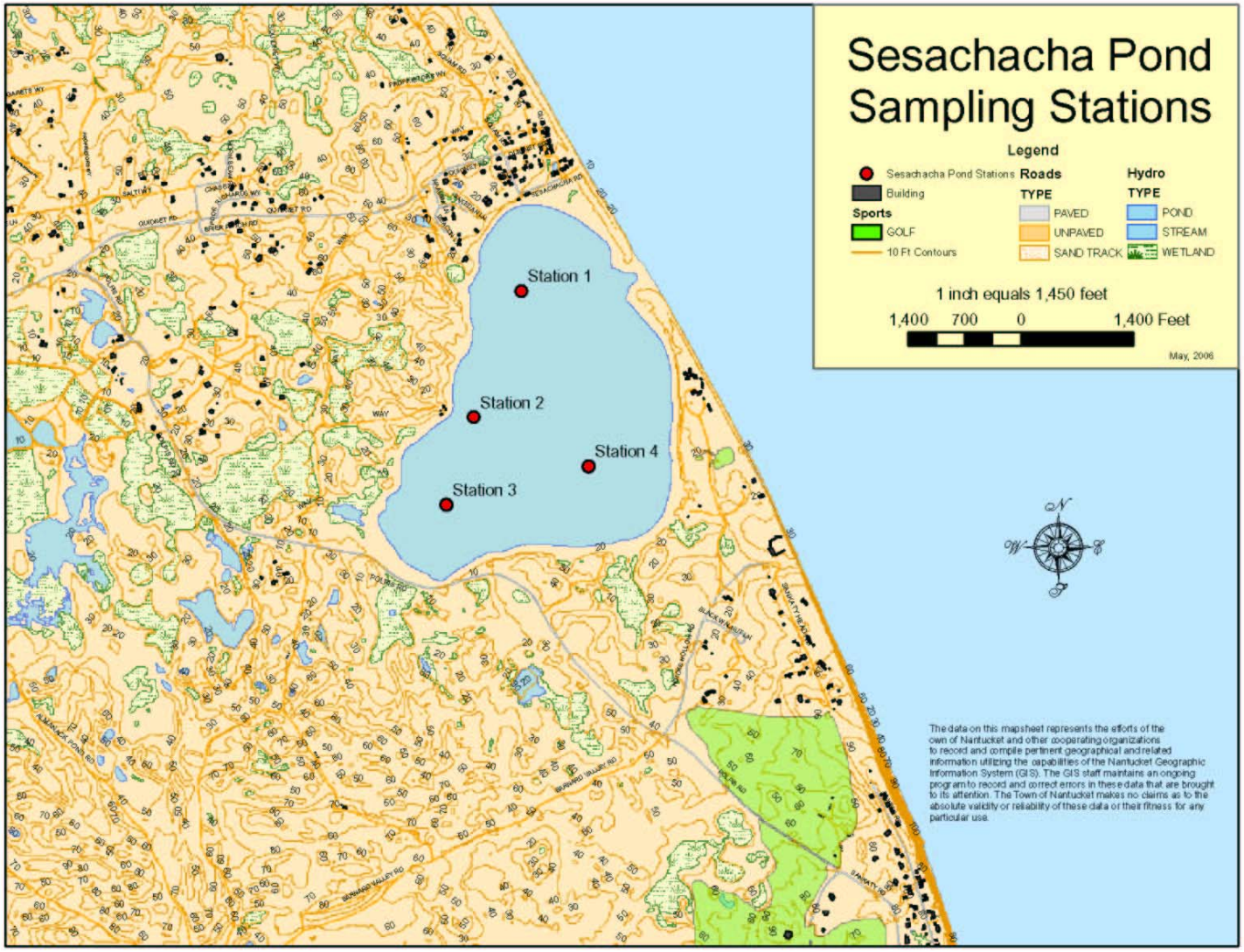

Figure II-1. Town of Nantucket Water Quality Monitoring Program sampling stations for Sesachacha Pond as provided by the Town of Nantucket Marine Department.