

# A Management-Oriented Water Quality Investigation of Trustom Pond National Wildlife Refuge

By

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## **EXECUTIVE SUMMARY**

Managed by the U.S. Fish and Wildlife Service (FWS) since 1974, Trustom Pond National Wildlife Refuge (Trustom) provides habitat and nesting grounds for more than 300 resident and migratory bird species, some rare and endangered. The 160-acre freshwater pond on 800 acres of protected land is the only lagoon in the coastal pond region of southern Rhode Island with an undeveloped shoreline, making the refuge a critical sanctuary for a range of wildlife species. Despite its relative protection from human disturbance, Trustom periodically exhibits characteristics linked to impaired water quality including low water clarity, dense algal biomass, elevated nutrient concentrations and high bacteria counts. Because managers are concerned with impacts of impaired water quality on wildlife, this study was undertaken to document water quality parameters and characterize the extent and composition of the algal community.

### **Water Chemistry, Nutrients and Pathogens**

During the study period of June 15 through October 29, 2010, Trustom was monitored weekly for Secchi depth (water clarity), chlorophyll-*a*, dissolved oxygen, temperature and total dissolved solids (TDS). Low water clarity consistent with nutrient-rich or *eutrophic* conditions (Secchi depth < 1 meter) was observed on 41% and 29% of monitoring dates at the Osprey and Otter Point sampling stations, respectively. Periods of low clarity coincided with elevated chlorophyll-*a* concentrations, suggesting algae in the water column contributed to increased turbidity. These observations, along with monthly evaluations of phosphorous, nitrogen and pathogens, indicate Trustom is a highly productive, eutrophic water body.

Trustom has historically been investigated along with other “salt ponds” in the region. Although Trustom was historically maintained as an estuarine system through the use of forced breaching, in 2006 FWS ceased mechanical breaching and now the pond is a freshwater system with TDS of 0.2 parts per thousand (PPT). Primary productivity in estuarine and fresh systems is controlled by different nutrients: freshwater systems are generally limited by phosphorus (P) and exhibit a nitrogen (N) to phosphorus ratio (N:P) greater than 16:1, while estuarine systems are N-limited and exhibit N:P < 16:1. Total N and P data collected from Trustom in 2008, 2009 and 2010 exhibit N:P ratios in the range of 19:1 to 26:1, indicating Trustom is P-limited. Neighboring coastal ponds with permanent breachways are estuarine (salinity 10–25 PPT) so caution should be exercised in applying management strategies designed for R.I. salt ponds.

An analysis of phosphorus inputs was undertaken to determine the relative importance of different P sources. Cropland is the largest potential source of land-based P loading in the Trustom watershed. Phosphorus loading from waterfowl was estimated based on a range of potential bird-days; although bird inputs are difficult to quantify, it is likely waterfowl P contributions may equal land-based sources. Elevated fecal coliform counts in the basin in October coincided with the first influx of migratory waterfowl, suggesting fecal loads may vary significantly throughout the year. Finally a “shake test” in which bottom sediment was allowed to equilibrate with solutions of various P concentrations was performed to determine if internal nutrient recycling is occurring in Trustom; results suggest the pond sediment acts alternatively as a source and a sink for phosphorus in the water column.

### **Algae in Trustom Pond**

Algae are an important component of freshwater food webs; however in eutrophic ponds algae can grow profusely and degrade water quality. Rapid proliferation or “blooms” of toxic blue-green algae (*cyanobacteria*) commonly referred to as Harmful Algal Blooms (HABs), can threaten wildlife and plants. Cyanobacteria evolved over billions of years and have successfully adapted to the low-light, elevated-nutrient conditions of eutrophic water bodies and therefore are well-suited to dominate impaired waters. At the most basic ecosystem level highly-inedible HABs change the food web by displacing more palatable phytoplankton such as diatoms and green algae. Dense algae can further degrade ecosystem values by limiting light penetration, thereby shading out rooted aquatic plants that provide food to

wildlife and stabilize pond sediments. During hot and windless days HABS can accumulate as thick surface scums and float to shore, where they smother valuable emergent plants. The dead algae and detrital plant matter is then decomposed by aerobic bacteria, and the increased microbial activity may contribute to partially depleted (hypoxic) or completely depleted (anoxic) oxygen in the water column and sediment pore water. Soil anoxia can also trigger the sudden re-release of particulate phosphorus, thereby contributing a burst of nutrients to the water column and further enhancing algal blooms.

In this study we identified numerous cyanobacteria including *Anabaena*, *Lyngbya*, *Microcystis*, and *Oscillatoria* in water sampled from Trustom in early July. A weekly sampling protocol was then implemented to determine cyanobacteria cell counts and cyanotoxin concentration in the water column. Two HABS were observed in Trustom in September and October; elevated chlorophyll-*a* levels at multiple sampling stations reflect the bloom conditions. Water samples collected in October contained elevated counts of *Anabaena*, a filamentous blue-green algae that may produce toxins harmful to liver, brain and/or skin cells. It is unknown if the *Anabaena* detected in Trustom are expressing toxicity and we recommend more extensive analysis for future HABS. Water samples were also evaluated for microcystin, the most common cyanotoxin detected worldwide. Concentrations of microcystin ranged from undetectable (< 0.003 µg/L) to 0.63 µg/L in September; although the EPA does not regulate microcystin, the World Health Organization recommends drinking water supplies contain less than 1.0 µg/L. State wildlife agencies suggest that concentrations lower than 1.0 µg/L may impact fish and bioaccumulate in piscivorous waterfowl. We therefore recommend monitoring Trustom for microcystin, and possibly for additional cyanotoxins, especially during HABS.

### **Management Considerations and Breaching Effects**

Although Trustom is more protected from human impacts than other coastal lagoons in the region, its watershed extends beyond the refuge property and thus FWS cannot control all activities that may impact water quality. Human-controlled factors within the watershed including (1) extent and nature of crop production in adjacent farmlands (i.e., high-phosphorus manured row crops vs. haylands), (2) residential lawn maintenance (fertilization, disposal of clippings, etc.), and (3) quality of onsite wastewater treatment systems, can influence nutrient loading to Trustom. In addition the length and intensity of waterfowl activity will affect nutrient inputs. If shoreline and aquatic habitats become compromised by increasingly dense or frequent algal blooms, or if birds show signs of cyanotoxin poisoning, managers may need to develop strategies to reduce phosphorus inputs.

Managers are considering breaching Trustom as a means to improve water quality. Although breaching is used in some coastal lagoons to dilute and/or export nutrients to coastal waters, the potential for breach success depends on a complex interaction of local hydrodynamic factors, sedimentation patterns, water chemistry, legacy nutrients and algal propagules in the benthos. Based on available data it is not clear if breaching Trustom will result in lower P levels and/or decreased HABS. Furthermore, forced breaching may increase salinity of the pond and change dominance and distribution of submerged vegetations, thereby shifting the food web. Therefore breaching should not be implemented at Trustom without first undertaking (1) a careful study of hydrodynamics and (2) a comprehensive review of potential effects on the aquatic macrophytes important to waterfowl using the pond.

Management recommendations for preventing eutrophication include: minimizing watershed nutrient inputs by maintaining vegetative buffers, implementing low-impact development to prevent storm water runoff, and expanding nutrient monitoring and bird surveys. Managers should also be aware of proposed land use changes in the watershed and work with landowners to minimize alterations to the natural hydrology and nutrient loads. Finally, if HABS occur, managers should monitor waterfowl closely for poisoning and collect water and algae for analysis. A multi-year assessment of water quality parameters, local weather conditions, nutrient loading and HAB composition is necessary to design a comprehensive management plan to control algal blooms and protect habitat values within the Trustom Pond ecosystem.

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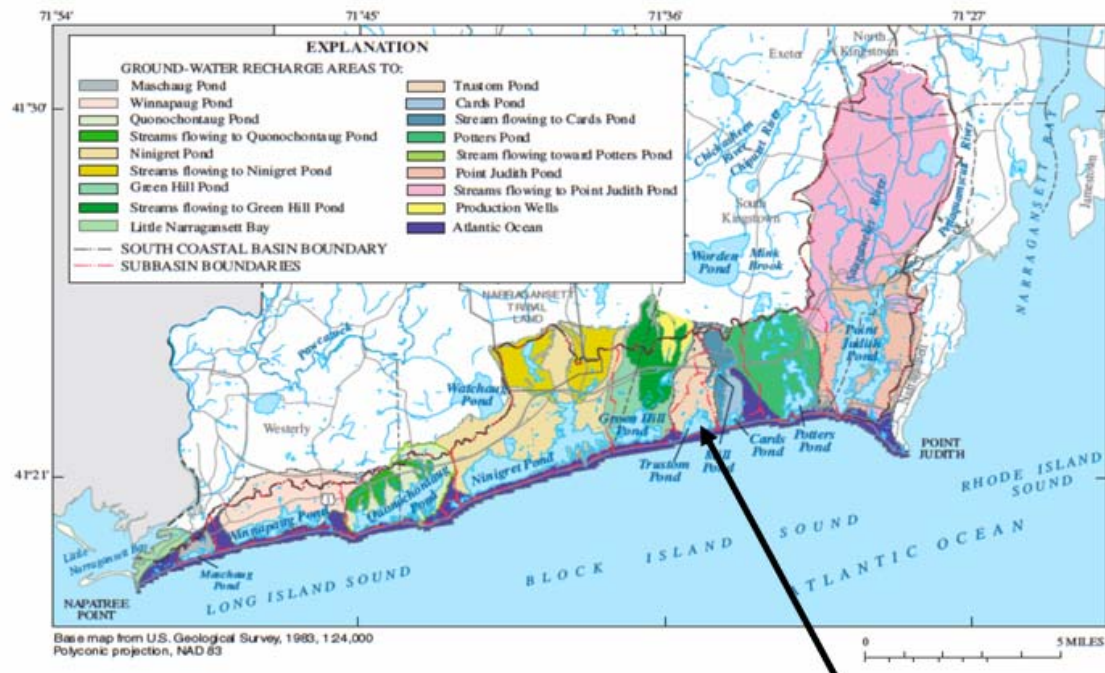
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## 1.0 OVERVIEW OF TRUSTOM POND AND ITS WATERSHED

Trustom Pond is a fresh water coastal pond located in South Kingstown, Rhode Island, in the area known locally as the *Coastal Pond Region* (Figure 1). The shallow lagoons for which the region is named formed at the end of the last glacial maximum when rising ocean levels eroded glacial till and deposited sediments as barrier spits parallel to the coast, thereby isolating pools of water from the open ocean system (CRMC, 1999). The dynamic high-energy marine environment influences the biological, chemical, and ecological characteristics of the coastal ponds and for centuries humans have used management practices that alternately served to enhance and reduce the estuarine characteristics of the ponds depending on the ecosystem values and functions being exploited.



**Figure 1: Coastal pond region of southern Rhode Island**  
 Source: U.S. Geological Survey

**Trustom**

Because of its association with salt water coastal embayments along the southern Rhode Island coast, Trustom has historically been referred to as a “Salt Pond” and consequently its chemistry and physical characteristics have often been compared to estuarine systems. Most of the coastal ponds are “salty” due to regular exchange with tidal marine waters through permanent breachways. Trustom differs from the other coastal lagoons in that it lacks a permanent breachway and has limited contact with the ocean. Before its acquisition by FWS, Trustom was managed by private owners who periodically breached the pond to decrease water levels, expose more land for farming (Lee, 1980) and possibly to stimulate the growth of oysters, which require pulsing salinity for maximum productivity (La Peyre et al., 2009).

Regardless of their motivation, once or twice a year the owners breached the pond by digging a trench in the barrier beach. If the breach was successful, Trustom would be temporarily transformed into a tidal system: marine water would have flowed into the pond at high tide, increasing salinity and allowing salt water fish to enter the lagoon, while at low tide the basin would partially drain into Block Island Sound. Unfortunately historical chemical data for Trustom Pond is scarce, so it is unknown how these breachings affected nutrient concentration or bacteria counts. Most importantly for the purposes of this study, it is unclear if the pond experienced improved water clarity or decreased algae as a result of breaching.

**Historical water chemistry:** Trustom Pond’s water chemistry has changed dramatically over the past six decades. Data from 1948 indicate much higher salinity levels (~ 10 to 25 g/L or parts per thousand [ppt]) than current levels of 0.2 ppt (*Table 1*). Unfortunately the sample location was not indicated for the 1948 samples so it is unknown if the higher salinity is evidence of tidal exchange caused by a forced breaching. Elevated salinity throughout the pond basin would suggest a significant exchange between the pond and ocean, while high salinity restricted to the seaward border may have been caused by localized washover or submarine saltwater intrusion along the barrier beach. Salinity in 1976 was low, which could indicate breaching had not been implemented recently. Again we do not the sample location, and water in the landward coves may remain fresh regardless of breaching frequency and duration.

Dates observed	Seawater access	Salinity	pH Range	Alkalinity ppm CaCO <sub>3</sub>	Sample Site
* Apr - Oct, 1948	temporary breach & storms	9.8 - 22.6 ppt	7.4 - 8.7	53 - 62	unknown
** Aug, 1976	unknown	0.0 - 0.7 ppt	~	~	unknown
*** Jun - Oct, 2008	temporary breach & storms	0.7 - 1.8 ppt	7.2 - 8.9	~	unknown
*** Jul - Oct, 2010	none	0.2 ppt	7.4 - 9.2	30	throughout pond

**Table 1: Snapshot of historical salinity, pH and alkalinity values for Trustom Pond**

\*Wright et al., 1949. \*\*Untitled FWS file document \*\*\*WW data & conditions observed during study

### 1.1 Rhode Island population trends

Until the 1940s southern Rhode Island was dominated by rural tracts of undisturbed forest and wetlands. The densely-vegetated land protected coastal waters from activity inland and with these buffers intact, the coastal ponds supported commercially-important estuarine and freshwater finfish and shellfish (Lee, 1980). Additionally, the location along the Atlantic flyway made the ponds attractive to migratory waterfowl and songbirds including federally-listed and protected species (FWS, 2010), and communities throughout New England valued the ponds for wildlife observation and recreation. Unfortunately the ponds’ popularity may have affected their capacity to support these historic functions and values.

During the past 50 years the coastal pond region has changed dramatically. In the 1940s, population centers began shifting out of dense city units and into single-family homes in suburban and rural areas (RI DA, 2006). The construction of Route One in the 1950s effectively opened up the southern Rhode Island coastal area for development, and soon after the highway’s completion the water quality, habitats and organisms of the ponds began to change under the pressures associated with residential and commercial activity (NAPA, 2000). The shift in employment location was especially striking: between 1970 and 1995, the number of Rhode Island jobs located in coastal zones increased by almost 80% (*Table 2*).

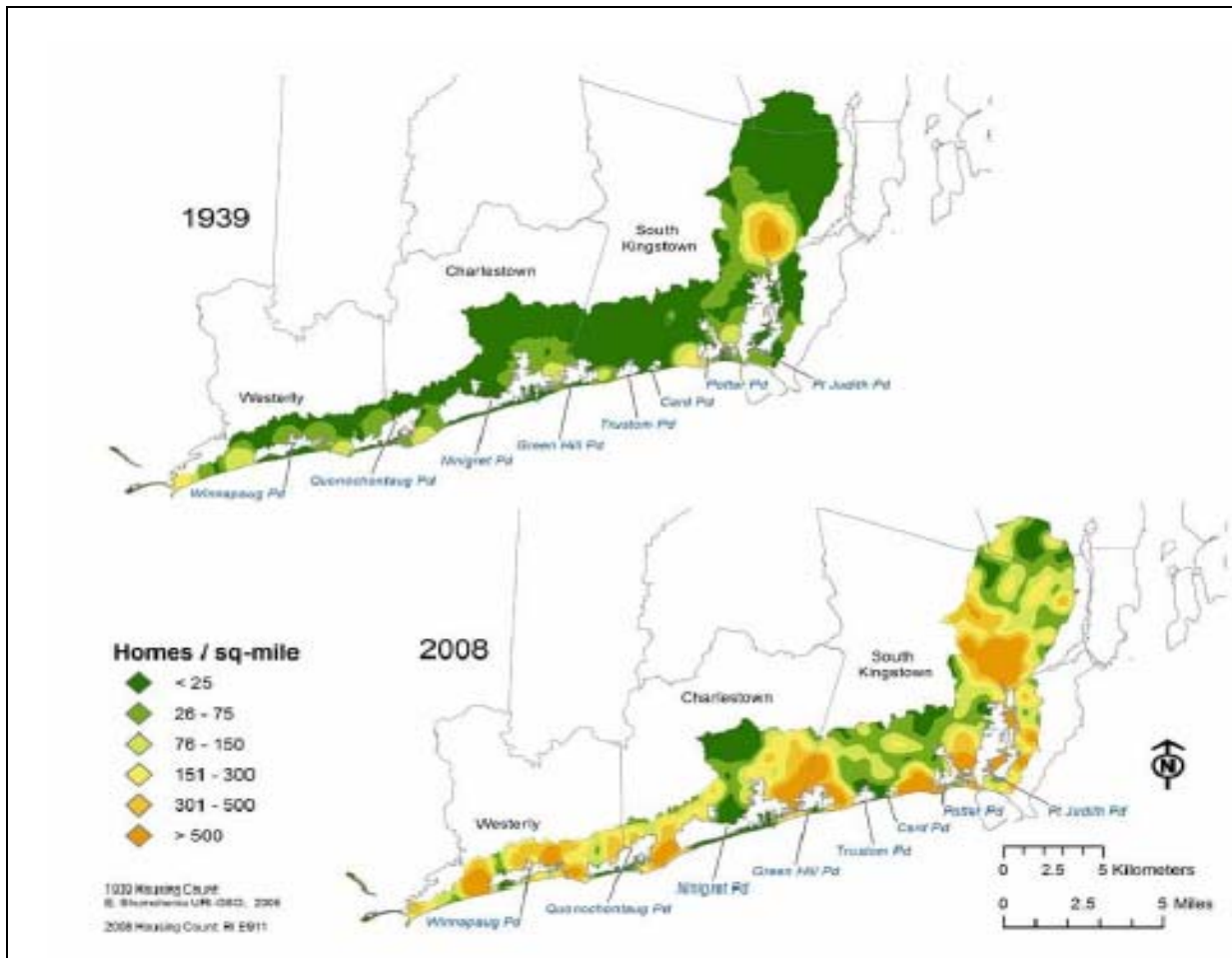
Spatial Zone	1970	1980	1990	1995	1970-1995 % change
Older Central Cities	168,438	162,210	164,331	158,047	-2.4
Inner Ring	75,284	91,377	110,463	119,694	46.7
Outer Ring	43,207	51,250	51,234	54,279	18.8
Western	10,068	9,132	11,616	13,076	15.4
Coastal	9,991	13,259	17,939	21,816	79.6
State Total	306,988	340,555	386,137	373,962	21.8

**Table 2: Rhode Island Employment by Spatial Zone, 1970-1995**

Source: Rhode Island Land Use Trends and Analysis, Technical Paper 149, July 2000

Residential development continued to increase steadily through the following decades. In 1939 there were 2,821 houses in the Salt Pond watershed; by 2003 there were 14,691. Between 1995 and 2005 more than 30% of Rhode Island’s undeveloped land was transformed to residential and commercial properties, with some of the most rapidly-growing towns losing up to 75% of their vacant land in the development frenzy (RI CRMC, 2010). The majority of construction has occurred in coastal communities and several coastal ponds are now bordered by housing tracts containing more than 500 homes per square mile (*Figure 2*).

Although figures from the 2010 censuses indicate only a 0.5% increase in Rhode Island population between 2000 and 2009 (U.S. Census Bureau, 2010), residential and commercial centers may continue to shift toward coastal communities, thereby contributing to even more development in the Salt Pond watershed.

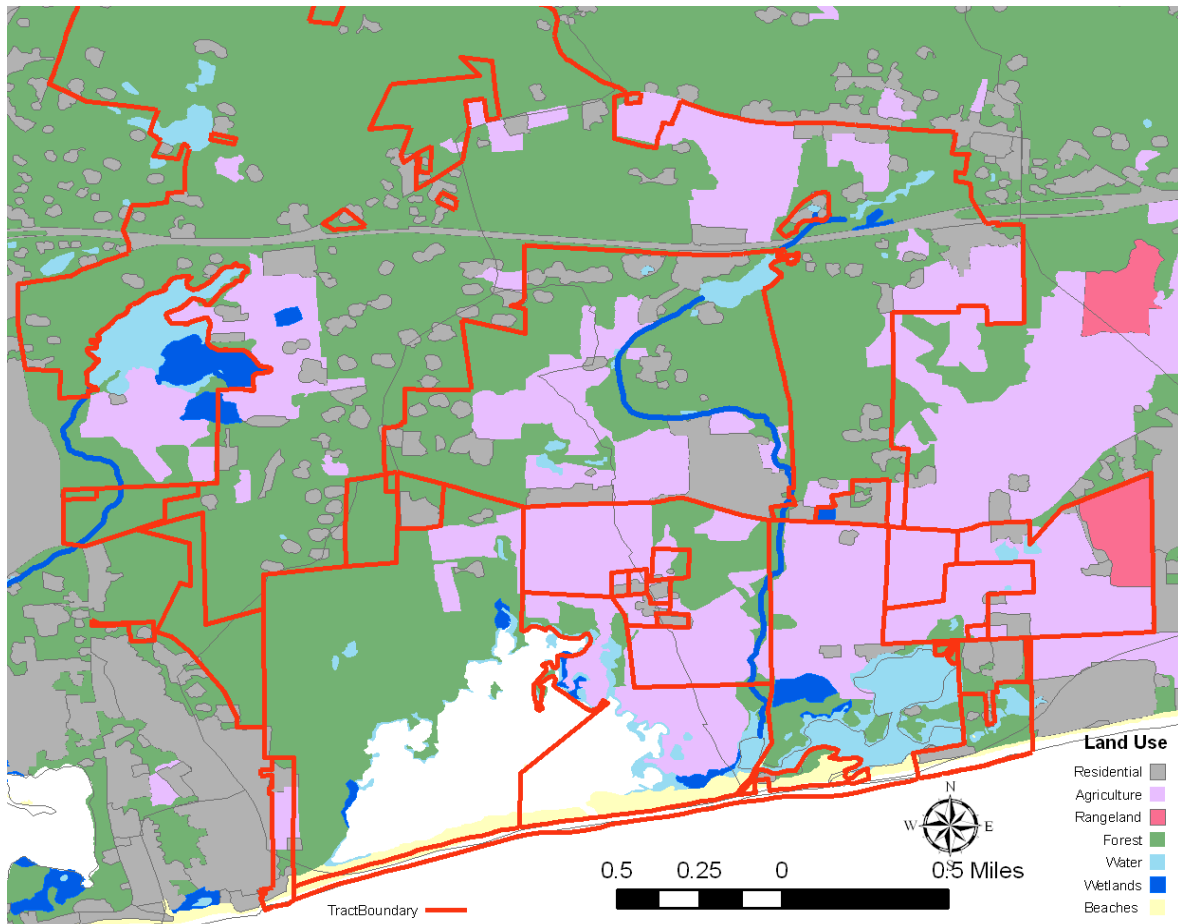


**Figure 2: Population density in RI Coastal Pond Region, 1939 and 2008**  
 Source: Narragansett Bay Estuary Program <http://www.nbep.org/statusand trends/CoC-finaltech-3auq09.pdf>

### 1.2 Land use in Trustom Pond watershed within refuge boundaries

Trustom Pond was established as a National Wildlife Refuge in 1974 with 365 acres donated by Ann Kenyon Morse. In keeping with the Migratory Bird Conservation Act of 1929 and the Refuge Recreation Act of 1962, the refuge purposes include use “as an inviolate sanctuary, or for any other management purpose, for migratory birds” (FWS, 2002). To achieve this mission, FWS has worked to minimize human impacts by expanding the refuge through the acquisition of new land conservation easements on adjacent properties. *Please refer to Appendix A to see the official land status map delineated by FWS.*

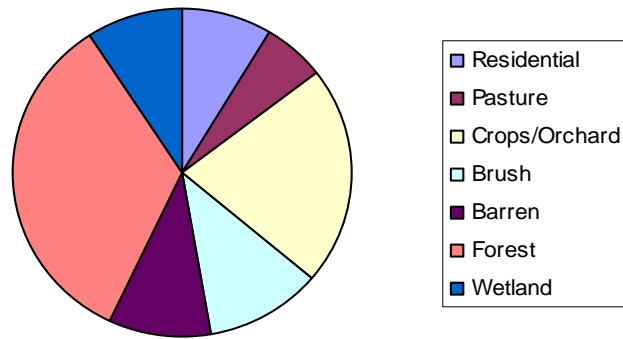
Even though Trustom Pond has been largely protected from development, the nature of the property has changed along with refuge expansion. In 2002 the refuge covered 643 acres: forest occupied 33%, grass and shrubs covered 20% and agriculture claimed less than 3% of the total refuge area (FWS, 2002). Today the refuge encompasses 787 acres with plans to expand to 1,536 acres by purchasing land from owners within the acquisition boundary. Although forest and other natural vegetation are still the largest land use, agricultural land now occupies a larger portion of the refuge than it did in 2002 (*Figure 3*).



**Figure 3: Land use within southern segment of Trustom National Wildlife Refuge**  
 Red lines delineate land tracts managed by FWS or approved for acquisition or conservation easement. Forest cover includes other native vegetation types (shrubs, grassland). *Data source: RIGIS and FWS.*

### 1.3 Land use in Trustom Pond watershed beyond refuge boundaries

The largest land use type within the entire surface watershed is forest, covering approximately 27% of the land surface (*Figure 4*). Agricultural uses including cropland, orchard and pasture account for the next-largest land use at 22%. Brush, barren (beach) and residential uses claim 8% each. Normally residential development is associated with high impermeable surface and degraded water quality, but only 2% of the entire watershed is impervious so changes to natural hydrology patterns, including the undesirable rapid storm water runoff that occurs in paved areas, should be minimal. *For a detailed description of impervious cover distribution within the Trustom watershed refer to Appendix B.*



**Figure 4: Distribution of land use in Trustom watershed**

**Watershed delineation:** The United States Geological Survey (USGS) has delineated the surface watershed and the groundwater recharge areas for Trustom Pond (*Figure 5*). Although the refuge boundaries are not depicted on this map, the watershed boundaries extend beyond the refuge perimeter. Therefore some of the water draining to Trustom Pond will be influenced by land management practices and activities that FWS does not control.



**Figure 5: Groundwater recharge area and surface sub-watersheds, Trustom Pond**  
 Yellow pins indicate tributary sites regularly monitored by FWS for nutrient load and pathogens.  
 Source: U.S. Geological Survey

## 2.0 HYDROLOGY OF TRUSTOM POND

Trustom Pond is a small, shallow coastal pond with average depth of less than 0.5 meter and area of approximately 0.65 square kilometers (RI Salt Ponds SAMP, 2000). Although Trustom may receive limited input as overland flow, the pond is best described as a groundwater depression wetland because groundwater provides the primary input and the pond lacks distinct connections with a stream channel. As is common for small ponds in flat landscapes, Trustom has a small watershed/surface area ratio.

### 2.1 Groundwater hydrology of Trustom Pond

Because the glaciated landscape of the southern Rhode Island coast encompasses a complex range of till, stratified material and organic deposits, the hydrology of the coastal ponds is difficult to quantify. It is known that groundwater is an important feature of the coastal pond hydrologic cycle, and insights into freshwater inputs and retention time have been developed based on basin characteristics and precipitation.

Several studies have estimated the flow of ground and surface water into the coastal embayments of southern Rhode Island (Grace & Kelley, 1981; Scott & Moran, 2001; USGS, 2007; Hourham et al., 2008). In general, groundwater flow in the area is poorly understood. A report from 1981 estimated groundwater discharge to Trustom Pond at 1.2 cubic feet per second (cfs) or approximately  $1.1 \times 10^6$  cubic meters ( $m^3$ ) per year (Grace & Kelley, 1981). A more recent investigation by the United States Geological Survey (USGS) projected groundwater discharge of 3.3 cfs ( $2.9 \times 10^6 m^3/yr$ ) using a model designed to simulate changes in recharge rates and hydraulic conductivity in the watershed (USGS Report 2006-5271). Based on these values, the flushing rate or hydraulic residence time in Trustom Pond due to groundwater flux could range from approximately one to three months (*Table 3*).

	Projected GW Discharge (yr)	Pond Volume	Calculated Flushing Rate
<b>Grace &amp; Kelley</b>	$1.1 \times 10^6 m^3/yr$ ( $\sim 2.9 \times 10^8 gal/yr$ )	$2.96 \times 10^5 m^3$ ( $7.8 \times 10^7 gal$ )	0.3 yr (3.2 months)
<b>USGS</b>	$2.9 \times 10^6 m^3/yr$ ( $\sim 7.8 \times 10^8 gal/yr$ )	$2.96 \times 10^5 m^3$ ( $7.8 \times 10^7 gal$ )	0.1 yr (1.2 months)

**Table 3: Estimated flushing rate for Trustom based on two groundwater fluxes**

It is difficult to determine which values truly represent conditions at Trustom. Some hydrologists have suggested the groundwater recharge zones for the coastal ponds may extend underneath the morainal hills at the northern boundary of the surface watershed. If this assumption is correct, the larger catchment area delineated in these scenarios explains the elevated recharge estimates predicted by some hydrologic models. If the USGS groundwater discharge estimate from *Table 3* is used to calculate recharge depth based on a surface watershed of 3.2  $km^2$  we obtain a value of 36 inches per year (*Table 4*), which far exceeds the average net precipitation (annual precipitation minus annual evaporation and transpiration) of 24 inches, which is the typical annual value for the Trustom watershed. Clearly more research is necessary to accurately quantify groundwater flux in the area.

* Precipitation on Pond (yr)	Watershed Area (Surface)	Watershed Runoff	Groundwater Flow Volume	Recharge Depth	GW Flux Estimate Source
$3.95 \times 10^5 m^3$ ( $\sim 1.0 \times 10^8 gal/yr$ )	794 acres ( $3.2 km^2$ )	$2.54 \times 10^6 m^3$ ( $\sim 6.7 \times 10^8 gal/yr$ )	$1.1 \times 10^6 m^3/yr$	13.5 in (0.34 m)	Grace & Kelley
			$2.9 \times 10^6 m^3/yr$	35.7 in (0.9 m)	USGS

**Table 4: Precipitation, watershed area and potential groundwater recharge values for Trustom Pond**

\*Annual net precipitation (total precipitation less annual evapotranspiration) in the Trustom watershed estimated to be 24 inches (0.6096 m)

## 2.2 Surface water features of Trustom Pond watershed

Hydrologic features that occur naturally in the landscape adjacent to Trustom Pond influence the movement of water throughout the watershed.

**2.2.1 Wetlands:** Depending on their location within the watershed, wetlands can act as either source areas or storage areas for excess water. Basin-type wetlands are most likely to intercept and store peak runoff flows generated by intense rain events, while slope-type wetlands may have less storage capacity. Wetlands up-gradient of Trustom Pond may be functioning as a sediment trap, slowing overland flows so that pollutants can settle out before water discharges to the basin. Wetlands may also allow for recharge to groundwater during dry periods when the water table is low. The recharge function is extremely valuable for protecting water; during infiltration, water can be further “cleaned” of contaminants including nutrients, road salts and heavy metals, albeit by different mechanisms. Overall, wetlands tend to enhance water quality in the associated water body and reduce flooding in the surrounding area.

**2.2.2 Rapid recharge areas:** Most of the Trustom watershed is undeveloped. Of the 34% land cover that is forested, 92% is located on soil of hydric classes A and B, which are well-drained soils that allow rapid infiltration of precipitation. Rain falling on wooded areas near Trustom is expected to recharge to groundwater almost immediately provided the soil is not saturated from previous rainfall. Development of well-drained forest areas usually causes the most severe changes in peak runoff rates and volumes, so best land management practices should include maintaining natural hydrology in these parcels.

**2.2.3 Tributaries:** The two tributaries to the north of Trustom Pond are monitored monthly by FWS for nutrients, pathogens and pH. Although water chemistry in the tributaries may be a useful indicator of activity within the watershed, the tributaries are intermittent and thus are unlikely to directly export significant contaminant loads to the pond basin. During the study period from May through October 2010, flow in both tributaries was gentle and diffused in the wetlands north of the pond before eventually drying up by the end of the growing season (*Figures 6 and 7*).



Figure 6: East Tributary, flowing (6/10/2010)



Figure 7: East Tributary, dry (10/20/2010)

Although tributary flow was minimal for a significant portion of the 2010 study, tributaries may deliver larger flows at higher velocities during times of intense precipitation. Therefore the impacts of the tributaries on Trustom Pond water quality may be highly variable and data should continue to be collected at both sites as part of the FWS standard monitoring protocol.

### 3.0 METHODS – WATER QUALITY MONITORING

During the study period of June 15, 2010 through October 29, 2010, Secchi depth (water clarity), chlorophyll-*a* (an indicator of algal biomass), dissolved oxygen, temperature, and total dissolved solids (TDS) were measured weekly at five sampling sites within the pond basin (*Figure 8*). The Otter and Osprey Point sites were monitored along with three new sites, which were established closer to the pond banks in order to observe potential effects of nutrient export from land sources. As the growing season progressed Site 2 became overgrown with submerged aquatic vegetation and had to be abandoned, and a new point was established near the pond center to examine spatial variability of chlorophyll-*a* in deeper water. Analysis of total and dissolved phosphorus and nitrogen, pH, and bacteria was conducted monthly at the Otter Point, Osprey Point, East Tributary and West Tributary stations.



**Figure 8: Trustom Pond basin sampling stations monitored during the study period**

#### 3.1 Physical characteristics – Secchi depth

The Secchi disk method is the most widely-used measure of clarity or water column transparency. This simple test is performed by lowering a black and white hatched disk (*Figure 9*) into the water body until it disappears and recording the value (the “descending depth”). The disk is lowered a few inches more, then raised until it becomes visible again; the value is recorded as the “ascending depth.”

Secchi depths were obtained weekly for each sampling site in the pond by taking two sets of descending and ascending readings and averaging the values. Monitors also recorded light conditions (distinct shadows, no shadows, or overcast), wind intensity, and rainfall at the site during the previous 48 hours.

#### 3.2 Chemical characteristics

Chemical parameters measured at Trustom Pond during the study include nutrients (phosphorus and nitrogen), alkalinity, pH, dissolved oxygen, temperature and total dissolved solids.

### 3.2.1 Nutrients (Phosphorus and Nitrogen)

Water samples for total phosphorus and nitrogen analysis were collected monthly at the Otter and Osprey Point stations from one meter depth using the same bulb-type sampler and pumping method described in the chlorophyll-*a* procedure (Section 3.3.1). Water was pumped into a sample bottle, swirled around to rinse all interior surfaces, and discarded. A fresh sample was pumped into the rinsed bottle, filling it to 1 inch from the top. The bottle was capped, labeled with collection time and date, and stored on ice in a cooler until delivery to URI Watershed Watch.



Figure 9: Secchi Disk

Total and dissolved nutrient analysis was also conducted monthly at the East and West Tributary sites. To collect water from a tributary, the nutrient sample bottle was uncapped, submerged as deeply as possible in the water without touching the sediment, and scooped forward. The bottle was swirled to rinse, the water discarded, and the process repeated to fill the bottle to one inch from the top. The bottle was capped, labeled with collection time and date, and stored on ice in a cooler until delivery to URI WW.

### 3.2.2 Alkalinity and pH

Total alkalinity and hardness were measured in the lab on samples collected on July 15 and August 4, 2010. Phenolphthalein alkalinity was 15 mg/L, BG-MR alkalinity was 30 mg/L and hardness was 68.4 mg/L. Results were identical for both sample dates. According to U.S. EPA classification standards, lakes with calcium carbonate alkalinity greater than 20 mg/L are considered well-buffered and should be able to withstand the effects of moderate acid inputs of acid rain or basic wastewater effluent (Godfrey et al., 1996). Trustom Pond's alkalinity is higher than is typical for freshwater Rhode Island ponds and reflects the influence of atmospheric deposition of salts that originate in the marine environment.

### 3.2.3 Dissolved oxygen, temperature and total dissolved solids

Dissolved oxygen (DO), temperature and total dissolved solids (TDS) were measured simultaneously *in-situ* using the YSI Model 85 probe. At each data collection site, the probe was lowered to one meter depth and allowed to equilibrate with the water column. When the values stabilized, the values for DO (mg/L), temperature and TDS (ppt) were recorded for one meter depth. The probe was then pulled up so that it was approximately two inches beneath the water surface and measurements were taken at surface depth. The process was repeated and a second set of measurements at one meter and surface depth recorded.

## 3.3 Algal biomass and phytoplankton community

Algal biomass in the water column (chlorophyll-*a*) was monitored weekly throughout the study. A skilled taxonomist provided an informal assessment of green and blue-green algal relative abundance by examining samples under microscope on two dates in July, and an extensive metagenomic analysis of phytoplankton composition and concentration of the cyanotoxin *Microcystin* was conducted on samples collected on 12 dates between August 1 and October 20, 2010.

### 3.3.1 Chlorophyll-*a*

Chlorophyll-*a* concentration was monitored weekly at five sampling sites in the pond. Two samples were collected at each site from one meter depth. Sampling was accomplished using a bulb-type tube sampler (Figure 10). The sampler was placed in the water with the metal pipe hanging down and the float resting on the water surface. The bulb was squeezed ten times to rinse the tubing; the water drawn up was used to rinse two gray Nalgene sample bottles. Water was then pumped into the first bottle, which was immediately capped and placed on ice in a cooler out of direct sunlight. A second sample was collected at the site using the same protocol.

Water samples were filtered to prepare for chlorophyll-*a* analysis back on shore out of direct sunlight in the order collected, according to the protocols outlined in the *URI Watershed Watch Revised Lake and Pond Monitoring Manual* (2006). Four plastic filter holders were fitted with glass fiber filters. A 60 mL syringe was disassembled and attached to a prepared filter holder. The first sample was removed from the cooler, inverted three times to allow flocculates to re-suspend, then set on a flat surface and uncapped. Then 50 mL of water from the sample was poured into the syringe and four drops of magnesium carbonate preservative were added. The syringe plunger was then inserted into the barrel and depressed slowly and evenly. On days where dissolved nutrient samples were being collected, the effluent was captured in a bottle prepared for that purpose; otherwise effluent was discarded. The filter holder was then detached, the plunger was removed, a fresh filter holder attached, and a second 50 mL volume was poured from the same sample bottle. This process was repeated for the 2<sup>nd</sup> bottle collected from the site.

Each glass fiber filter was removed from its casing using tweezers and folded in half with the chlorophyll sample surface (*Figure 11*) facing in, wrapped in a paper towel square, wrapped in an aluminum foil square to protect from light, and labeled with sample date, sample location, and sample volume filtered. Wrapped filters were then placed in a plastic zipper bag filled with dessicant chips and stored on ice, then transferred to a freezer until analysis. Filters were analyzed within six weeks in duplicate replication using a Turner Designs Model TD-700 fluorometer.

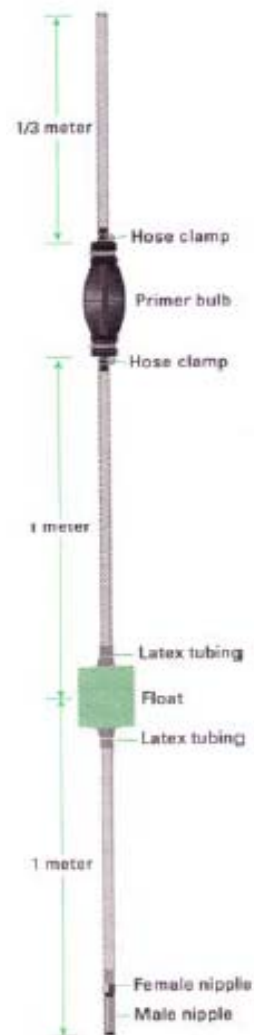
### 3.32 Algal composition

Water samples from July 10 & 15 were examined under microscope by a phytoplankton taxonomist. Detailed cell counts were not conducted; rather the taxonomist gave an opinion on algal dominance based on her perceptions of relative abundance of green and blue-green phytoplankton visible on the slides. Samples were collected according to the chlorophyll-*a* protocol.

Beginning August 4, samples were collected weekly and shipped to the DNA Analysis Facility at the University of Vermont (UVM) for metagenomic analysis of phytoplankton and microcystin (a common toxin produced by blue-green algae). This analysis was conducted as part of a collaborative research project, the Northeast Cyberinfrastructure Consortium. All samples were handled and shipped according to the protocol prescribed by UVM:

- a) Nitrile gloves were to be worn during sampling to prevent contamination with human DNA.
- b) Specially-prepared sterile, Pyrogen-free bottles provided by UVM were used.
- c) Sample bottles remained sealed and were uncapped only when immersed in pond.
- d) To collect sample: Submerged bottle in water to 1 foot depth with the mouth down, removed cap, turned bottle to allow water to fill. Re-capped bottle while it was beneath water surface to prevent contamination with airborne genetic material.
- e) Placed filled bottle in cooler on ice packs.
- f) Filled two more bottles at the sampling location in the same manner.
- g) Transferred bottles to 4° Celsius walk-in refrigerator on return to campus.
- h) Labeled bottles, packed in ice and sent to UVM via overnight express delivery.

Laboratory techniques and standards for metagenomic analysis of samples can be obtained from the Vermont Genomics Network by contacting VGN@UVM.EDU.



**Figure 10: 1 meter sampler**

### 3.33 Cyanotoxins

The water collected for metagenomic analysis of phytoplankton composition was also evaluated for concentration of microcystin, the most widely-occurring cyanotoxin in natural waters. *Please see section 3.32 for sample collection protocol.* All laboratory analysis was conducted by the DNA Analysis Facility at UVM and more information can be obtained by contacting VGN@UVM.EDU.

### 3.4 Bacterial Indicators (Fecal coliform and Enterococci)

Water samples for fecal coliform and enterococci analysis were collected monthly at the Otter and Osprey Point stations and at both tributaries. A sterile sample bottle was used at each site. The “sterile” label was removed from the bottle cap and placed on the side of the bottle. The bottle cap was removed and the monitor used care to avoid touching the inside of the cap. The bottle was then plunged down into the pond and swept away from the boat to avoid contamination. Excess water was poured out to leave one inch headspace in the bottle. The bottle was capped, labeled with collection time and date, and stored on ice until delivery to URI WW.

For tributary sites, the same procedure was followed except that water was too shallow to “plunge” into. The bottle was instead drawn quickly across the surface to scoop up water, taking care not to disturb streambed sediment. The bottle was capped, labeled with collection time and date, and stored on ice in a cooler until delivery to URI WW.



**Figure 11: Chlorophyll-a sample from algal bloom at Trustom Pond, Oct 2010**

## 4.0 METHODS – PHOSPHORUS BUDGET

### 4.1 Watershed loading

The simplest methods for modeling external phosphorus inputs use a mass-balance approach in which loading factors are assigned to land parcels according to land use type. More complicated models account for variables including turbulence and biogeochemical transformations in the water column and sediment, but the additional factors may not significantly increase the accuracy of estimated values.

In this study we used the MANAGE model to estimate phosphorus loading from the surface watershed. The model designers factored in local precipitation patterns and net rainfall depths to create runoff coefficients based on land use types and underlying soil characteristics. Please see *Appendix C* for more information regarding the MANAGE approach and interpretation of results.

### 4.2 Waterfowl inputs

Because comprehensive year-long bird counts are not available for Trustom Pond, a range of values was selected to predict approximate values for phosphorus loading based on low, moderate, and intense waterfowl use. A spreadsheet provided by FWS was consulted to identify bird counts for species of interest. Assuming moderate numbers of geese, swans and ducks are contributing droppings to the pond, the phosphorus contribution by waterfowl may range from 200-600 lbs per year and could equal the P loading due to land use. Managers with a good grasp of bird populations may wish to review the estimates to identify the best values to use in these calculations. Please see *Appendix D* for the range of scenarios used to approximate waterfowl contributions to the P budget.

### 4.3 Internal loading from pond sediment

To gain insight into the potential for nutrient recycling in the pond, a “shake test” was conducted to determine if the bottom sediment at Trustom is contributing phosphorus to or removing phosphorus from the water column. Sediment samples were allowed to equilibrate with a range of phosphate/pond water

solutions and the resulting phosphate concentration was measured. This is a common test for assessing the degree of phosphorus saturation and equilibrium concentration of phosphorus in natural waters.

Subaqueous soil samples were collected from three locations within the Trustom Pond basin. To evaluate differences in sorption capacity among soil types, we chose soils that appeared to differ in their mineral and organic material content. A square-edged spade was used to loosen and remove a block of sediment from the pond bottom. The sediment was placed into a clean plastic tub and large pieces of plant roots and leaves were removed from the soil surface. A clean, acid-washed Mason jar was then used to scoop sediment. Pond water was poured on top of the sediment to minimize exposure to the atmosphere and a piece of Duofilm was stretched over the jar opening and secured with brass canning ring. The jar was then stored on ice in a cooler. Two additional jars for the sample site were then filled using the same procedures. The jars were transferred to a 4° C refrigerator and samples were prepared the following day.

Samples were prepared in triplicate. Moist soil grabs weighing approximately 5 g each were placed in individual 25mL plastic centrifuge tubes. A glass pipette was used to add 10 mL of pond water/orthophosphate solution (added P concentrations were 0, 30, 60, 120, 250 and 50 ppb). Each sample was then capped and placed on a mechanical shaker. Samples were shaken for one hour at room temperature (~25° C), then stored undisturbed for 20 hours at room temperature. Samples were centrifuged at 1207g for 10 minutes on a Sorvall RT6000B at 20° C to clarify the solution and remove particulate matter from the sample, then filtered twice through a glass fiber filter into a plastic storage bottle. The samples were then frozen until analysis.

Prepared samples were analyzed for orthophosphate (dissolved phosphorus) in duplicate runs using an Alpkem Model 300 automated spectrometer (autoanalyzer); the average of the two values was used to determine the overall change in dissolved P concentration in each vial.

## 5.0 RESULTS AND DISCUSSION

### 5.1 Water quality status at Trustom Pond

Trustom Pond was first monitored as part of the URI Watershed Watch (WW) in 2008. At that point only one sample location was used. In 2009 FWS managers established the Otter Point and Osprey Point sites according to WW protocols: these sites are located in two sub-basins at points of greatest depth to bottom (~ 2.0 m at Osprey and 1.7 m at Otter). In addition, two tributaries north of the pond (East and West Tributary) were designated as water quality sampling points to evaluate potential nutrient and bacteria sources in the watershed.

Numerous factors influence the quality of ground and surface waters. Natural processes such as weathering of bedrock, formation of soils, and filling of lake basins with peat and transported sediment occur over centuries and millennia, and the resulting interactions between earth and water alter lake chemistry over geologic time. Meanwhile humans make changes to the earth over much shorter time periods and can cause the basin-filling process to accelerate rapidly, achieving high-nutrient status in just decades (Figure 12). The resulting changes to water quality can occur in years, months, and even days.

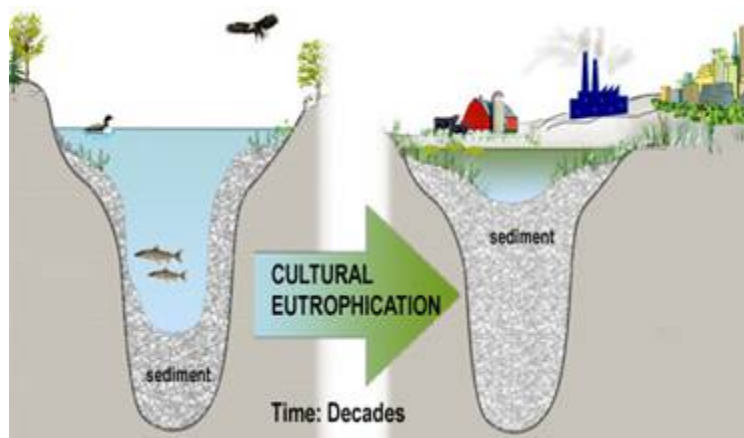


Figure 12: Representation of accelerated nutrient loading  
Source: Lakes Monitoring Program, RMB

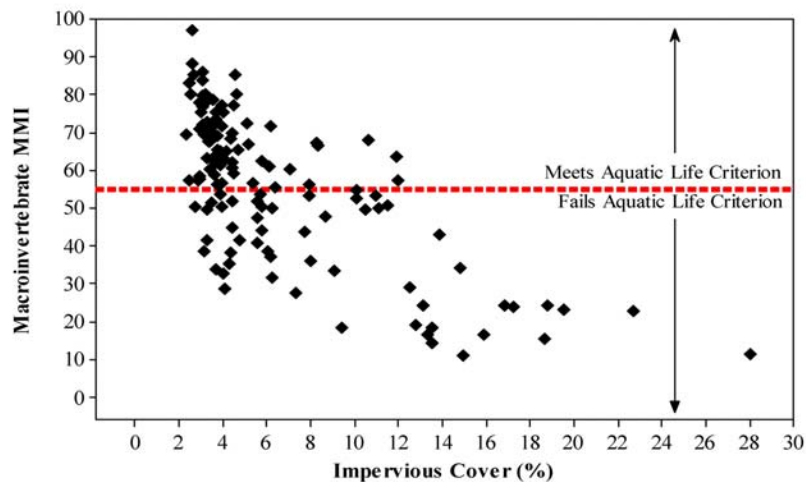
Unfortunately when managers discuss human-induced changes to water resources, they are often referring to processes that impair rather than improve conditions. Changes in the nutrient character or *trophic status* of water bodies have become widespread across the globe in tandem with increases in fertilizer use, livestock production and human wastewater discharge; therefore studies of degraded surface waters often focus on quantifying nutrient sources in the watershed.

### 5.1.1 Trophic status and eutrophication

“Trophic status” describes the level of biological productivity and is linked to the amount of nutrients present in a water body. In the most general terms lakes can be described as *oligotrophic* (nutrient-poor), *mesotrophic* (nutrients present) or *eutrophic* (nutrient-rich). If the nutrient supply to a system suddenly changes, the food web will shift to accommodate new baseline productivity. When plant and algae growth spike in response to elevated nutrient inputs we say the environment is undergoing *eutrophication*, which is, at essence, an accelerated aging of the water. “Eutrophication” can refer to both an increase in organic carbon (usually from elevated rates of primary production) and from the addition of excess nutrients. Characteristics of eutrophication include (1) increased algal density, (2) increased plant biomass, (3) lowered water clarity, and (4) decreased dissolved oxygen in the water column and sediment pore water. These degraded conditions create a stressful living environment that sensitive species may not be able to tolerate. Thus the long-term effects of eutrophication may include decreasing species diversity and shifting dominance patterns, thereby lowering ecosystem and habitat values of the water body.

Surface waters are especially vulnerable to nutrient pollution in culturally-impacted areas due to the coupling of elevated nutrient loads with offsite sediment erosion. In developed areas pollutants tend to be captured by storm runoff and deposited in lakes and reservoirs via streams and overland flow, instead of infiltrating the soil and remaining attached to the land. The nutrients of greatest interest to us (phosphorus and nitrogen), behave quite differently from each other: phosphate in groundwater tends to attach to soil particles and become immobilized in the subsurface, while nitrates will flow along with groundwater unless they undergo a denitrifying process in the anaerobic zones commonly found in wetland soils. Phosphates are often exported to surface waters when the soils to which they are attached erode.

The percentage of impervious cover in a watershed often correlates positively with degrading habitat quality in aquatic systems (*Figure 13*). Fortunately the Trustom Pond watershed is lightly developed with less than 2% impervious cover and thus we would not expect storm water runoff to affect water quality significantly. Phosphorus inputs from this watershed are most likely the result of highly-eroding tilled croplands, onsite residential septic systems and animal waste. *For a detailed breakdown of impervious land cover in the Trustom watershed refer to Appendix B.*



**Figure 13: Habitat quality versus watershed imperviousness**  
Source: UCONN NEMO

### 5.1.2 Secchi depth

During the seventeen-week observation period, Secchi depths at Otter Point (Figure 14) and Osprey Point (Figure 15) indicated a trend of *decreasing* water clarity through July and *increasing* clarity from August through early September. Secchi depths of one meter or less in Trustom Pond are associated with *eutrophic* (nutrient-rich) conditions; depths of less than one meter were observed on 29% of monitoring dates at Otter Point and 41% of monitoring dates at Osprey Point. Maximum Secchi depth at Otter Point (1.68 meters) was observed on 6/16/10; the second greatest depth (1.6 m) occurred on 9/1/10. Osprey Point showed greatest clarity on 6/23/10 (1.65 m) and on 9/1/10 (1.63 m).

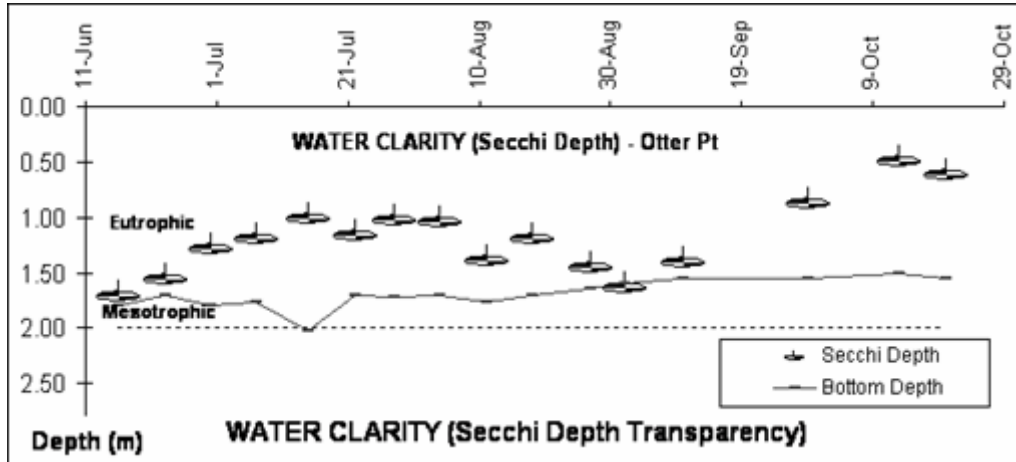


Figure 14: Secchi depth transparency at Otter Point, 2010

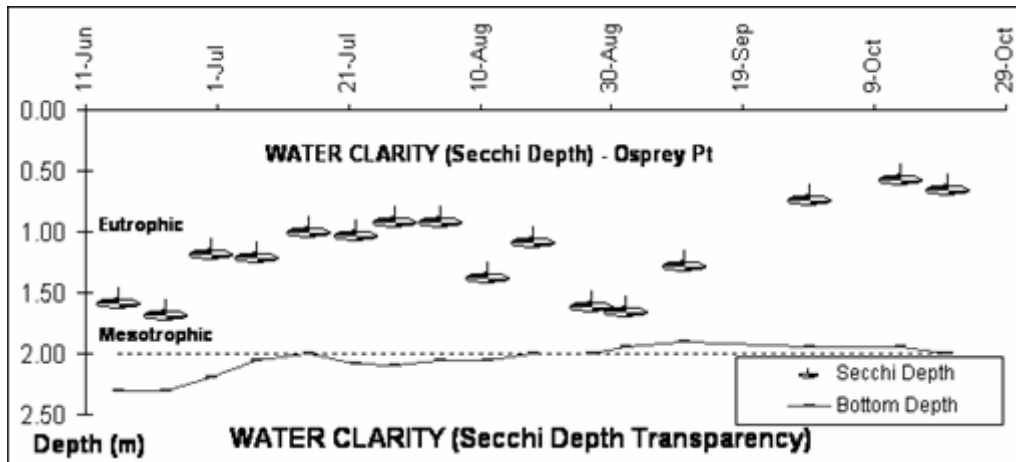


Figure 15: Secchi depth transparency at Osprey Point, 2010

Because water clarity in some ponds is largely determined by algal biomass in the water column, Secchi data often relates to chlorophyll concentrations. In this study we evaluated chlorophyll-*a* directly, so the Secchi data can be compared to those measurements to evaluate the importance of algal biomass to the water clarity at Trustom Pond. Secchi depth readings which deviate markedly from chlorophyll-*a* values may provide evidence that other factors including suspended sediment in the water column and tannic acid runoff may be contributing to turbidity. In this study the dates of lowest water clarity corresponded with the highest chlorophyll-*a* values, indicating that Secchi depth is a good proxy for algae at Trustom.

### 5.1.3 Nutrient limitation in Trustom Pond

Total phosphorus ranged from 26 – 66 ug/L (ppb) at Otter Point (mean 44) and 11 – 54 ppb at Osprey (mean 54); maximum values occurred in August (*Table 5*). Values ranged from 9–149 ppb and 18–242 ppb at the East and West Tributary sites. Dissolved phosphorus represented the same trend. In general ***total P of more than 30 ppb in freshwater lakes indicates eutrophic conditions***, so these data suggest Trustom Pond is enriched in nutrients capable of stimulating considerable plant and algal growth. Total nitrogen ranged from 660 – 860 ppb at Otter Point and 770 – 1440 at Osprey Point with maximum values in July and June (*Table 6*).

SAMPLING SITE	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN
Otter Point	31	26	54	66	45	-	<b>44</b>
Osprey Point	-	11	52	54	49	-	<b>39</b>
Tributary - East	9	19	27	149	145	-	<b>51</b>
Tributary - West	18	69	105	242	Dry	Dry	<b>109</b>

**Table 5: Total Phosphorus (ppb) detected at Trustom in 2010 (detection limit 4 ppb)**

SAMPLING SITE	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN
Otter Point	970	660	970	760	860	-	<b>844</b>
Osprey Point	-	1440	910	770	880	-	<b>1000</b>
Tributary - East	1330	1010	1040	1960	1900	-	<b>1448</b>
Tributary - West	710	1170	1540	2710	Dry	Dry	<b>1533</b>

**Table 6: Total Nitrogen (ppb) detected at Trustom in 2010 (detection limit 30 ppb)**

Although mean total N and P values for Tributary East and West exceeded mean values for Otter and Osprey Points, ***there was no consistent relationship between the basin and tributary nutrient concentrations***. Otter Point exhibited the highest total P in May, with West Tributary containing the highest level relative to the other sampling points from June until it dried up in August. Highest relative N concentrations occurred in Tributary East, Osprey, Tributary West, Tri West, and Trib East in May, Jun, Jul, Aug and Sept respectively. Channel flow was sluggish throughout July and stagnant in August, likely contributing to elevated nutrient concentrations in the tributaries during the study.

The soils of the watershed are relatively permeable and excess rainfall is likely to infiltrate the ground and recharge to the water table. Nitrogen introduced into the watershed that is not assimilated into plant or microbial biomass usually converts to nitrate and moves to the ponds through the permeable soils and groundwater of the watershed. Nitrates may de-gas to the atmosphere as di-nitrogen gas molecules (N<sub>2</sub>) when they encounter anaerobic zones characteristic of hydric wetland soils, but considerable research in the coastal pond area suggests nitrate inputs to the coast are substantial. Conversely when phosphate ions infiltrate into the surface, they tend to be adsorbed by manganese and iron in the granitic soils of the watershed. This adsorption process effectively prevents phosphate ions from entering surface waters; unfortunately phosphorus can still be exported to surface water when the sediment to which phosphates are attached is picked up by overland flow and storm water runoff. The paved surfaces that accompany residential and commercial development prevent water from infiltrating the soil and tend to increase the delivery of dissolved and suspended nutrients to streams and lakes, thus speeding eutrophication.

In freshwater systems elevated concentrations of phosphorus and nitrogen have been linked with the occurrence of *harmful algal blooms (HABs)* of cyanobacteria (Cook et al, 1989; Duy et al., 2000; Downing et al., 2001). Thus nutrient character of a pond can be a critical determinant of overall ecosystem health. Any water body perceived to be at risk for increased nutrient loads should be monitored regularly for total and dissolved phosphorus, nitrogen, and the occurrence of HABs.

### 5.1.4 Phosphorus, chlorophyll-*a* and Secchi depth values

Chlorophyll-*a* is a widely-used indicator for algal biomass in the water column. Although numerous chlorophyll types are found in plant cells, chlorophyll-*a* dominates in prokaryotic (blue-green algae) and eukaryotic green algae (Carlson & Simpson, 1996). For wildlife management purposes we are most interested in blue-green algae (*cyanobacteria*) due to the toxicity associated with some genera.

Mean chlorophyll-*a* concentrations ranged from 7.44 - 55.6 at Otter Point (*overall mean 21.5*) and 5.5 - 47.5 at Osprey (*overall mean 18.9*); maximum values occurred on Sept 29 at Otter and Jun 30 at Osprey. Mean chlorophyll concentration was higher at Sites 1 and 2, both of which were at depths near 1 m and closer to land (*Table 7*).

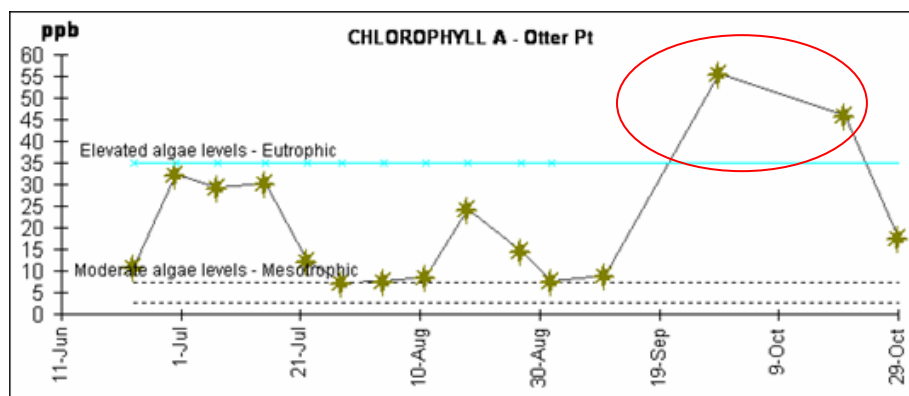
The higher average algae density at Sites 1 and 2 could be attributed both to increased algal growth in the warmer, shallower water and a tendency to capture benthic algal particles

Sampling Station	Highest conc	Occurred on	Lowest conc	Occurred on	Overall Mean
Otter Point	55.60	9/29	7.44	7/28	21.50
Osprey Point	47.54	6/30	6.47	9/10	19.21
Site 1	46.34	8/27	5.14	9/10	33.38
Site 2	77.22	6/30	5.14	9/10	31.22
Site 3	43.85	6/30	6.63	9/1	15.56

**Table 7: Ranges of chlorophyll-*a* concentrations for Trustom sites, 2010**

with the 1 m depth sampler. The outlying value of 77.22 at Site 2 was likely due to the influence of epiphytic algae attached to beds of *Ceratophyllum sp.*; the site became so thickly vegetated that monitoring was impeded, and Site 2 was abandoned in mid-August.

The Otter and Osprey points are located at areas with greater depth to bottom, and may more accurately reflect phytoplanktonic algae concentrations in the water column. Trends were similar at both sample points, with spikes occurring in early July, mid-August and early October (*Figures 16 and 17*).



**Figure 16: Chlorophyll-*a* concentrations at Otter Point, 2010**

Elevated chlorophyll-*a* levels coincided with periods of decreased water clarity as shown previously in *Figures 11 and 12*. Although detailed algal counts were not performed in this study, water collected from Trustom Pond on July 8 and 15 was examined under microscope and appeared to be dominated by green

algae. Therefore it is likely the first chlorophyll-*a* spike in July reflected a rapid increase in abundance green algae, while the spike in late September coincided with climbing cyanobacteria populations.

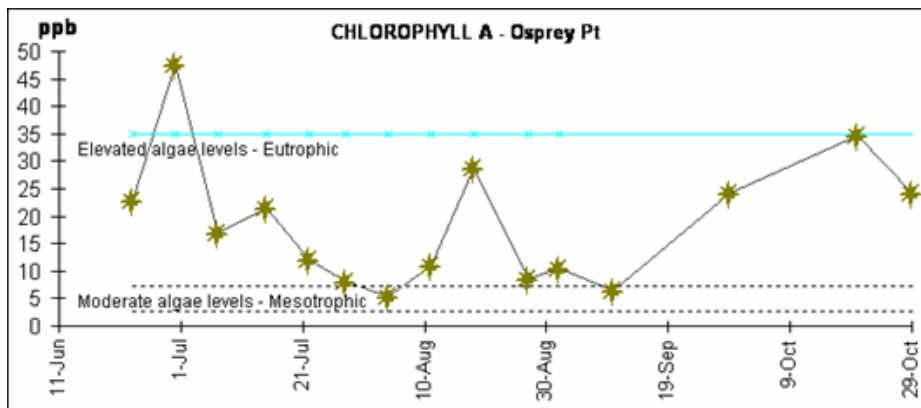


Figure17: Chlorophyll-a concentrations at Osprey Point, 2010

### 5.1.5 Determining trophic status from Secchi depth, chlorophyll-*a* and total P

The Carlson trophic status index (TSI) is a numerical value used to classify a lake according to its nutrient characteristics. Water quality parameters including total phosphorus, Secchi depth and chlorophyll-*a* can be used to calculate the TSI; the value is then evaluated and a nutrient category of *oligotrophic* (TSI < 40), *mesotrophic* (40 < TSI < 50), *eutrophic* (50 < TSI < 65 ) or *hypereutrophic* (65 < TSI < 80) is assigned to the water body. According to calculations based on 2010 data, Trustom Pond would be categorized as a *eutrophic* water body based on all three parameters (Table 8)

Total Phosphorus (ppb) Summary - Sampled once per month							TSI Value
SAMPLE SITE	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN	$14.42 * (\ln P) + 4.15$
Otter Pt	26	54	66	45	-	<b>44</b>	59
Osprey Pt	11	52	54	49	-	<b>39</b>	57

TSI > 50 = eutrophic

Average Monthly Secchi Depth (M) Summary - sampled once per week							TSI Value
SAMPLE SITE	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN	$60 - [14.41 * \ln (Z)]$
Otter Pt	1.48	1.06	1.23	1.27	0.74	<b>1.16</b>	58
Osprey Pt	1.45	1.01	1.22	1.19	0.72	<b>1.12</b>	58

TSI > 50 = eutrophic

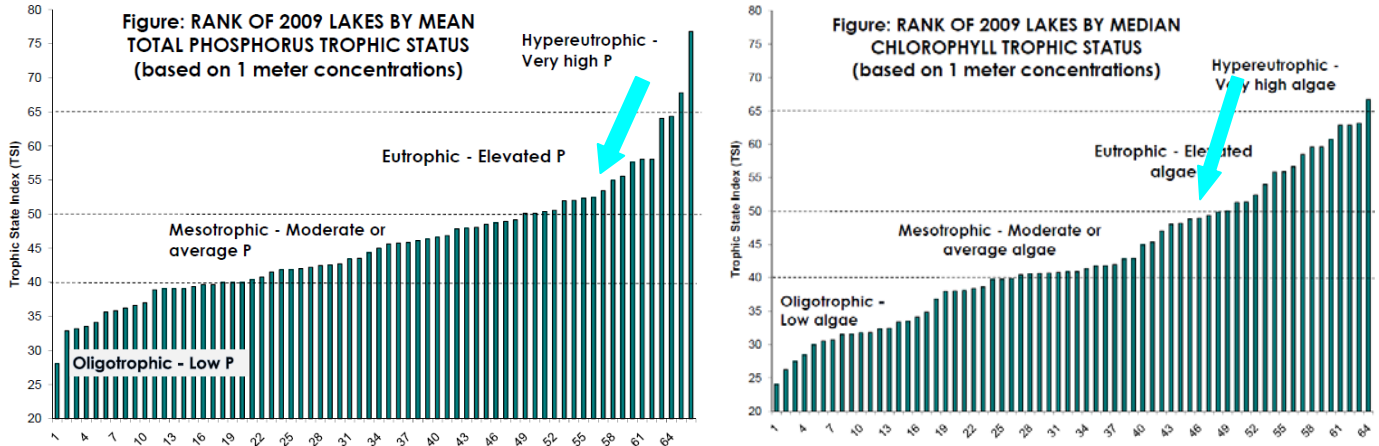
Average Monthly Chlorophyll (ppb) Summary - sampled once per week							TSI Value
SAMPLE SITE	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN	$[9.8 * \ln c] + 30.6$
Otter Pt	21.6	19.9	13.8			<b>18.43</b>	59
Osprey Pt	35.2	14.7	13.5			<b>21.13</b>	60

TSI > 50 = eutrophic

Table 8: 2010 Trophic Status Index Values Based on Total P, Secchi Depth and Chlorophyll-*a*

Compared to URI WW data for freshwater ponds throughout Rhode Island, Trustom Pond falls in the top third with respect to highest total phosphorus and chlorophyll-*a* concentration. Out of 66 fresh water lakes and ponds monitored by URI WW in 2009, Trustom ranked 56 overall in water quality according to

the phosphorus-based TSI ratings and 42nd in the chlorophyll-*a* TSI ratings (*Figure 18*). The URI WW did not rank ponds according to Secchi depth TSI, but Trustom's Secchi TSI values for 2010 and 2009 were identical and the values were very close to the TSI index calculated from phosphorus and chlorophyll-*a*; it is quite likely that Trustom's statewide rank by Secchi depth TSI would be quite similar.

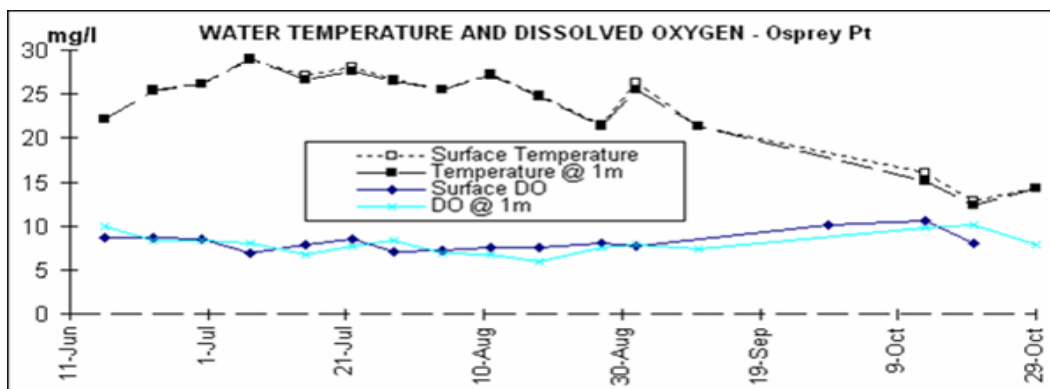


**Figure 18: Trustom Pond (indicated by blue arrow) TSI rank among RI ponds monitored by URI WW.**  
 Source: URI Watershed Watch

### 5.1.6 Dissolved oxygen and mixing characteristics

Average DO values were above the threshold of 5.0 mg/L recommended for fish and wildlife habitat. The seasonal average at Otter Point (1 m depth) was 7.13 mg/L and extreme values ranged from a low of 3.91 (7/22/10) to 9.86 (10/13/10). The 7/22/10 reading was the only DO value less than 5.0 mg/L. Observations at Osprey Point (1 m depth) yielded an average seasonal DO of 7.97 mg/L with extreme values ranging from a low of 5.88 (8/18/2010) to a high of 10.05 (10/20/2010).

During the monitoring period water temperature was nearly identical at surface and 1m depth at Otter Point (*Figure 19*), with average difference of 0.18° C. The largest temperature difference of 1.2° C was observed on 07/07/10; for 44% of monitoring dates there was no difference between surface and 1m temperature. Observations at Osprey Point showed a similar pattern (*Figure 20*) with average surface/1m depth temperature difference of 0.21° C. The largest difference of 1.2° C was observed 10/13/10 and on 25% of monitoring dates there was no difference in temperature values.



**Figure 19: Water temperature and dissolved oxygen profile of Trustom Pond at Osprey Point, 2010**

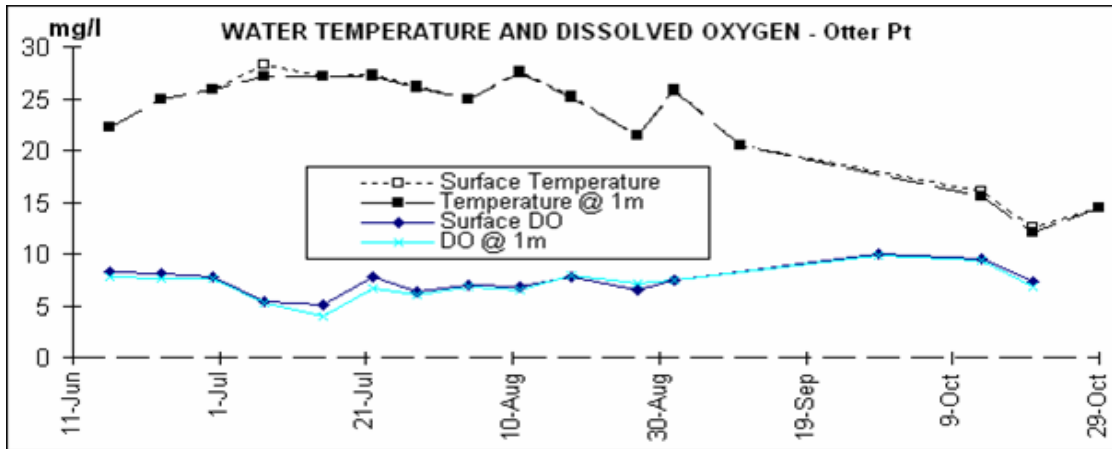


Figure 20: Water temperature and dissolved oxygen profile of Trustom Pond at Otter Point, 2010

Dissolved oxygen (DO) in a pond is determined by water temperature, mixing characteristics, salinity, nutrient loads and the timing and extent of primary production and respiration of the aquatic ecosystem. Water’s capacity to hold dissolved gas decreases as temperature increases, so DO concentrations usually reach minimum values in summer. In temperate climates, lakes deeper than 5 meters generally undergo “thermal stratification” in the summer: colder, denser water separates into a distinct layer beneath warmer, more buoyant water. Thermal stratification is an important control mechanism and can contribute to depleted DO levels in the bottom water and sediment. This may seem counterintuitive because cold water can hold more gas than warm water; however the bottom water is isolated from atmospheric oxygen, and photosynthetic production of oxygen is often restricted to the upper waters due to light attenuation in deeper waters. In highly-productive lakes the high oxygen demands associated with decomposition of lake-bottom detritus may consume most or all DO in the bottom layer, resulting in anoxic or hypoxic conditions in the water column and sediment (Addy & Green, 1997). Prolonged DO depletion can lead to mortality of sensitive species including fish, shellfish and benthic invertebrates and can stress aquatic and emergent plants, sometimes causing far-reaching changes in food webs. Anoxia in the bottom sediment can also prompt the release of soil-bound inorganic phosphate molecules, forming a positive feedback loop that exacerbates eutrophic conditions and contributes to additional HABs.

The data indicate that *Trustom Pond does not undergo thermal stratification*; therefore the bottom water of Trustom is at relatively low risk of developing anoxic or hypoxic conditions. It is important to acknowledge that water temperature was recorded in the morning. Stratification effects are often more pronounced in late afternoon after the pond had been subjected to hours of warming sun exposure; however the lack of stratification during the morning temperature readings indicates any layering that may have occurred the previous day did not persist overnight. Therefore the bottom water at Trustom Pond is likely to receive regular oxygen renewal through frequent mixing with surface water.

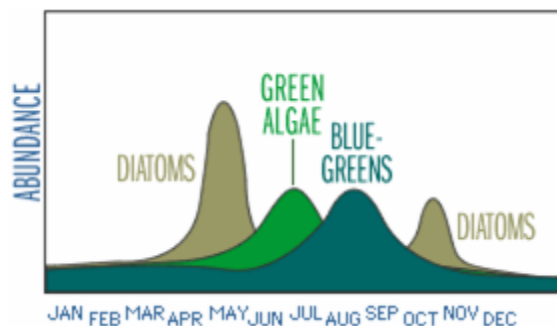
### 5.1.7 Alkalinity and pH

As of this writing, 2010 URI WW pH data are not yet available. The pH values for Trustom in 2009 ranged from 7.3 - 9.4 (mean 9.0) at Otter Point and 7.4 - 9.3 (mean 8.9) at Osprey. As with the alkalinity values observed at Trustom, these values are higher than typical for freshwater Rhode Island ponds, and are consistent with conditions associated with the coastal environment. In 2009 the pH of East Tributary ranged from 6.4 – 6.7, consistent with average RI stream pH values; however West Tributary was acidic with pH ranging from 4.1 – 4.3. During the 2010 sampling West Tributary was tea-brown, possibly indicating tannic acid leachate from leaf and pine needle litter and/or organic soils in the stream bed. The West Tributary flowed very slowly throughout summer and ceased flowing by September, so it is unlikely acidic water from this tributary reached the basin. At any rate, moderate acidic overland flow and

acidic rain deposition into the basin would have a negligible effect on water chemistry due to the high alkalinity in the pond, so the low stream pH is unlikely to influence conditions within Trustom Pond.

### 5.1.8 Algae observed in Trustom Pond

Phytoplankton in Trustom Pond appeared to be dominated by green algae in the early summer, while blue-green algae populations increased throughout the growing season and peaked in late summer and early autumn. This pattern is consistent with seasonal succession of phytoplankton typical of temperate climates (Figure 21).



**Figure 21: Seasonal succession of phytoplankton.**  
Source: Water on the Web 2004

**Green algae:** Mat-forming green macroalgae were visible throughout the study as epiphytic *Cladophora* clinging to the submerged plants growing in the shallows along the pond border (Figure 22). Although excessive green algae can indicate eutrophication and may contribute to degraded habitat, mat-forming green algae also exist in healthy ecosystems and may provide a valuable food source for Black Ducks (Lynch, 1939). Green algal mats were not widespread and did not appear to be compromising water quality in 2010.



**Figure 22: Green algae, likely *Cladophora*.**  
Trustom Pond, 10/13/2010

Phytoplanktonic green algae observed in water samples collected on July 10 and July 15 included the genera *Chlorococcum*, *Chlorella*, *Oedogonium*, *Scenedesmus*, *Spirogyra* and *Treubaria*. Although detailed cell counts were not obtained, the green algae appeared to dominate in all samples evaluated under microscope.

**Blue-green algae:** Unlike green algae, blue-green algae or *cyanobacteria* have little food value and may be harmful to animals including invertebrates and waterfowl. Thus dense cyanobacteria growth is often referred to as a “Harmful Algal Bloom” or HAB. The occurrence HABs is a growing problem in the United States: during the National Lakes Assessment conducted in 2007, the EPA found approximately 27% of the lakes nationwide contain cyanobacteria levels considered to pose a “high” or “moderate” risk of toxic exposure (EPA, 2007), with cell counts exceeding 20,000 per liter.

The water samples mentioned in the “Green Algae” section above were also examined under microscope for cyanobacteria. In addition to the dominant green algae mentioned above, five genera of cyanobacteria were identified, all of which are toxin-producing types (Table 9). Detailed cell counts were not conducted but the taxonomist believed green algae was dominant in the water column in all the July samples.

Genera	Potential Toxin Group(s)	Target organs(s)
Anabaena	Anatoxin, Microcystin, Saxitoxins	Liver, nerve synapse, skin
Lyngbya	Lyngbyatoxin-a	Skin, gastro-intestinal
Microcystis	Microcystin	Liver
Nostoc	Microcystin	Liver
Oscillatoria	Microcystin, Anatoxin-a, Aplysiatoxins	Liver, nerve synapse, skin

**Table 9: Potentially toxic cyanobacteria observed Trustom water samples in July 2010.**

Source of cyanobacteria toxicity information: World Health Organization

In addition, two HABs were observed at Trustom with unaided eye in late summer and early fall. The classic “spilled paint” appearance of cyanobacteria blooms (Figure 23) makes them distinguishable from most green algal types.



**Figure 23: Blue-green algal bloom at Trustom Pond on 10/20/2010**

Cyanobacteria are difficult to control because their superior ability to tolerate severely degraded water conditions including low light, fluctuating oxygen and pH, high nutrient loads and bacteria counts allow them to flourish in the most polluted waters. Unfortunately widespread disturbance of landscapes has caused rapid eutrophication of some surface waters and led to the increased turbidity and nutrient levels that allow HABs to dominate an ecosystem (Figure 24).



**Figure 24: Turbid conditions observed at Trustom Pond, 10/13/2010**

Toxin production by cyanobacteria is difficult to predict and wildlife are at highest risk of exposure during bloom die-off when cells break open and leak toxins into the water column. It is unknown which genus or genera dominated Trustom during July 2010, but water samples collected between 8/4/2010 and

10/20/2010 showed a striking increase of the cyanobacteria genus *Anaebena* (count of 0 cells on 8/4/2010 to a count 2166 cells on 10/20/2010). The elevated cell count suggests *Anaebena* was present during the observed blooms and may have been the dominant genus of blue-green algae in Trustom. Although the *Anaebena* cells were not directly analyzed for toxin expression, the same water samples were analyzed for microcystin and researchers reported varying toxin levels (0.26 – 0.40 µg/L) throughout the study period. *For a complete report of all cyanobacteria cell counts and Microcystin levels in Trustom water samples, please refer to Appendix H.*

## **5.2 Phosphorus sources for Trustom Pond**

Three sources of phosphorus loading to the pond were considered in this study: (1) external load from the surface watershed, (2) direct load from waterfowl droppings and (3) internal load recycled from pond sediment. Additional phosphorus could enter the pond via atmospheric deposition but the relative contribution would be small compared to the aforementioned factors. No one model was available to quantify all three sources so estimates were generated for watershed and waterfowl loading based on available data, and an experiment was conducted to determine if pond sediment is a P source or sink.

Groundwater is not generally a significant source of phosphorus contamination because phosphate molecules tend to sorb to iron and manganese particles as groundwater flows through the soil pore space. Nonetheless, groundwater flow volumes could be significant to water chemistry in Trustom Pond because decreased groundwater recharge can lead to longer residence times and may contribute to increased eutrophication in the pond basin. Additionally, if development in the area increases the area of impermeable surface, recharge to groundwater may decrease and surface runoff will increase, thereby contributing to increased sediment and phosphorus loads in overland flow.

### **5.2.1 Phosphorus loading from watershed runoff**

The simplest methods for modeling external phosphorus inputs use a mass-balance approach in which loading factors are assigned to land parcels according to land use type. More complicated models account

for variables including turbulence and biogeochemical transformations in the water column and sediment, but the additional factors may not significantly increase the accuracy of estimated values.

The MANAGE loading model used in this study, which has been applied to local decision making in Rhode Island since 1996, approximates phosphorus loading factors based on land use and NRCS hydrologic soil category. Land use categories are defined by the Anderson III coding schema (see metadata for Land Use 2003/2004 on RIGIS web site <http://www.edc.uri.edu/rigis/data/all.aspx> for full details). Because phosphorus tends to sorb to mineral soil in the subsurface, groundwater is not a significant vector for phosphorus transport.

Using MANAGE, phosphorus export to Trustom Pond was calculated based on 12 discrete land use types identified in the watershed (Table 10). The phosphorus loading factors (labeled “P Load Factor”) are estimates of low/high values for phosphorus runoff per acre of given land use category. For more information on the Manage model please refer to Appendix C.

Land Use Type	Area (acres)	% Total Land	P Load Factor Low (lb/ac/yr)	P Load Factor High (lb/ac/yr)	Low Total (lbs/year)	High Total (lbs/year)	Avg Total (lbs/year)
MHD							
Residential	9.5	1.4	2.1	3.4	19.7	32.3	26.0
MD Residential	30.0	4.4	1.2	2.1	36.7	62.2	49.4
MLD Residential	9.4	1.4	0.8	1.2	8.0	11.5	9.7
LD Residential	9.6	1.4	0.5	0.8	5.1	8.2	6.6
Pasture	39.7	5.9	0.3	1.0	11.9	39.7	25.8
Cropland	127.5	18.8	0.5	4.5	63.8	573.8	318.8
Orchard	19.7	2.9	0.4	2.0	7.9	39.4	23.6
Brush	75.2	11.1	0.1	0.2	7.5	15.0	11.3
Forest	228.4	33.7	0.1	0.2	22.8	45.7	34.3
Barren	66.1	9.8	0.1	0.2	6.6	13.2	9.9
Wetland	62.8	9.3	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.3	0.3	0.0	0.0	0.0
<b>TOTAL</b>	<b>678</b>	<b>100</b>	<b>n/a</b>	<b>n/a</b>	<b>190</b>	<b>841</b>	<b>515</b>

**Table 10: Estimated Trustom Pond watershed P loading based on land use and hydric soil group**  
Source: MANAGE model by Lorraine Joubert, URI NEMO

Based on the “Avg Total” values, *Cropland* has the largest contribution (~ 320 lbs/yr or ~ 60% of watershed P load), followed by combined residential land uses (~ 18%). Because cropland, pasture and orchard cover almost 30% of the Trustom watershed, activity in those areas may contribute a disproportionately large portion of the phosphorus load. Therefore agricultural activity on these land use types has the potential to significantly influence water quality.

### 5.2.2 Phosphorus deposition by waterfowl

Because Trustom Pond and its surroundings are managed to support many resident and migratory waterfowl, the water may be affected by nutrient loads contained in the bird droppings deposited *in-situ*.

Large birds including Canada geese and Mute swans (Figures 25 and 26) were observed at Trustom Pond throughout the study period. Although bird counts were not part of this study, FWS data from previous seasons indicate large numbers of Canada geese use Trustom Pond during migration and a steady number of swans inhabit the pond year-round. According to a spreadsheet provided by Trustom Pond managers, 3800 Canada geese were on site during a single day in January 2009. From 1992 through December 2008

the next highest day counts range from 1000-1050. Due to lack of continuity in the data it is unclear if Canada goose populations are increasing, but there is no apparent trend of decreasing population either. The mute swan (*Cygnus olor*) is an invasive species in Rhode Island. Between 1955 and 1985 the statewide population increased from zero to over 700 birds (Olsen & Ely). Daily counts of the mute swan at Trustom are much lower than for Canada geese, but swans may contribute disproportionately large nutrient loads during their August molt when they are confined to the pond (Suzanne Paton, FWS, *personal communication*) and 100% of their droppings are deposited directly in the water. The highest mute swan count at Trustom Pond since 1992 was 225 in August 1993; the next highest count was 155 in October 2007. Unfortunately August counts are not available for each year.



**Figure 25: Resident or migratory Canada geese on Trustom Pond, October 2010**



**Figure 26: Resident mute swans on Trustom Pond, September 2010**

**Waterfowl effects on water quality:** Dense populations of geese and swans have the potential to contribute phosphorus loads equaling or exceeding inputs from the watershed, especially when birds import nutrients to the ecosystem by feeding outside of the pond and defecating upon return to the water. Other waterfowl activity may have an indirect effect on nutrient loading and FWS has already identified intense grazing by Canada geese as a significant problem in maintaining water quality standards. Several state agencies reported erosion as the primary waterfowl-related quality concern along with the elevated fecal concentrations, and managers in Missouri attributed algal blooms specifically to high concentrations of geese in affected areas (FWS, 2010). Some managers implement non-lethal controls to prevent large populations of geese and swans from congregating, but unfortunately these controls may impact desirable species as well. Trustom managers have used egg addling to manage mute swan reproduction in past years (Erin King, FWS, *personal communication*).

Studies in chemical limnology suggest that although an influx of bird droppings may not initially increase phosphorus in the water column, prolonged loading will impact nutrient recycling and nutrient levels in the pond. Researchers focusing on Canada geese concluded that phosphorus and nitrogen were not immediately biologically available in fresh feces but instead leached into the water column slowly from feces loads that accumulated on the sediment (Unckless & Makarewicz, 2007). Therefore it is possible the full effects of one season of intense feces loading may not be realized until months or years later.

**Wildlife impacts on water quality:** Development of a watershed often results in net loss of habitat and causes displaced animals to concentrate in smaller parcels of remaining wilderness. These dense wildlife populations are often associated with additional degradation of habitat; waterfowl in particular are known to impair water quality in lakes (Manny et al., 1994; Unckless & Makarewicz, 2007). Canada geese and mute swans contribute significant nutrient loads to an ecosystem, producing ~82 grams of feces per day, 1.8% of which is phosphorus by weight (~1.5 g P per day). These large waterfowl contribute nearly four times the phosphorus load of ducks (~0.37 g P/bird/day). Although numerous variables including daily feeding migration patterns, N:P ratio of diet and roosting behavior influence nutrient loading by birds,

population density appears to be the most critical factor on water quality (Post et al., 1998). Therefore water bodies with concentrated waterfowl populations should be monitored carefully for impairments.

### 5.2.3 Internal loading from pond sediment

In addition to external loads originating in the watershed or deposited by waterfowl, some ponds may contain an internal nutrient source within the bottom sediment. Phosphorus tends to bind to iron and manganese particles in the soil and thus phosphates in the water column may be effectively removed from solution when they contact the bottom sediment. Unfortunately the removal is by no means permanent and phosphorus can be quickly released back into the water column if anoxic conditions develop at the bottom of the pond. Ponds with a long history of nutrient loading are at risk for accumulating “legacies” of excess phosphorus, and these legacy stores can often be traced to a specific high-impact activity such as crop fertilization, dairy farming, shellfish processing or municipal wastewater treatment. Legacy stores may build up to such an extent that even if phosphorus loads from external sources (i.e., overland flow and streamflow) is eliminated, the phosphorus contained in the pond sediment can continue to re-dissolve in the water column and contribute to eutrophication for many years.

To determine if the sediment at Trustom is loading phosphorus to the water column, we performed a simple soil shake test. Samples in which pond sediment was shaken with solutions containing added phosphorus demonstrated a decrease in dissolved phosphorus. These results indicate sediments at Trustom have phosphorus storage capacity and therefore the pond floor may be acting as a “sink” for phosphorus. Samples in which sediment was shaken with pure Trustom water (i.e., no phosphate was added to the solution) showed an increase in dissolved phosphorus concentration.

These results demonstrate *the sediment of Trustom has the potential to act both as a “sink” for excess phosphorus in the water column and as an internal nutrient “source” of phosphorus to the water column*; however it is unclear which conditions would need to develop for the sediment to begin functioning as a source of dissolved P. In this experiment, the amount of dissolved P in the test solutions increased from the background level in the collected water (6.3 ppb) up to 35.5 ppb. Because the background level of 6.3 ppb reflects the ambient background P in Trustom during the July sample date, it appears the water column at Trustom was not reaching the elevated P concentrations observed in the laboratory. The low background level of dissolved P is likely a result of rapid uptake of dissolved P by submerged and emergent plants and phytoplankton, and background levels could climb in the absence of photosynthesis. *Please see Appendix I for P shake test data results.*

Water samples collected from Trustom later in the season contained slightly higher dissolved P concentrations of 14 and 13 ppb at Otter Point and 10 and 9 ppb at Osprey Point in August and September, respectively (*Table 11*). Plant and algae growth was still robust in August and September, so dissolved P would have still been removed rapidly from the water column. It is unknown if the higher dissolved P values were a result of nutrient recycling or fresh P inputs from the watershed. *See Appendix E for a complete summary of the 2010 Watershed Watch nutrient data for Trustom Pond.*

LOCATION	Depth (m)	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN
Trustom Pond - Otter Pt	0.5	8	11	6	14	13	-	<b>10</b>
Trustom Pond - Osprey Pt	0.5	-	8	5	10	9	-	<b>8</b>
Trustom Tributary - East	0.2	5	3	7	19	33	-	<b>13</b>
Trustom Tributary - West	0.2	11	51	63	149	Dry	Dry	<b>69</b>

**Table 11: 2010 dissolved P summary for Trustom Pond** Reported as ug/L or ppb, Limit of detection = 5 ug/L  
Source: URI Watershed Watch

Sediment near Trustom’s barrier beach is generally sandy with high mineral content, while the bottom sediments located closer to land are silty and organic. Mineral soils, which tend to contain the highest concentrations of iron and/or aluminum, are generally able to sorb more phosphorus than organic soils (Reddy et al., 1999), so we would expect P adsorption to be higher near the beach. We observed much denser submerged and emergent plant growth in the organic-rich soils than in sandy areas. Because Trustom Pond is so shallow, bottom sediment can be readily influenced by wind and wave action at the pond surface. Soil experts have indicated that the fine silt particles in the landward sediments could easily become re-suspended in the water column, thereby contributing to increased turbidity and dissolved nutrient concentrations (*Brian Oakley, URI Dept of Geoscience, personal communication*).

Subaqueous soil salinity was determined to be 0.2 ppt at various points in the pond (*Jillian Phillips, RI USDA-NRCS, personal communication*) which was consistent with total dissolved solids (TDS) measured in the water column throughout the pond. Although analyses were conducted to determine if sediment was contributing to internal recycling of phosphorus, an in-depth analysis of soil types was outside the scope of this study. The subaqueous soil of Trustom Pond is being evaluated as part of the national Soil Survey, and maps of soil polygons and pond bathymetry are available from USDA/NRCS.

### 5.3 Pathogens in Trustom Pond and tributaries

Recreational waters, shellfishing waters and drinking water reservoirs are routinely monitored for fecal bacteria to assess the risk of pathogen contamination. Coliforms and enterococci are important indicators of other pathogens, such as viruses, which may also be present in contaminant sources including human or animal feces. At Trustom, bacteria can be important indicators of bird droppings in the pond and/or animal manure application in the bordering agricultural fields.

Fecal coliform was highly variable at both Otter and Osprey points, with barely detectable values throughout summer that increased to 3400 – 4600 range beginning in October (*Table 12*). Although origin of the bacteria cannot be determined without further testing, the spike coincides with the first wave of migratory waterfowl arriving at the pond and thus may indicate increased loads of waterfowl droppings, which can contribute significant fecal coliform bacteria to surface waters (Alderisio & DeLuca, 1999).

<b>Fecal Coliform</b>	JUN.	JUL.	AUG.	SEPT.	OCT.	MEAN
Otter Point	< 4	4	20	10	3440	16
Osprey Point	< 4	<2	110	12	4600	8
Trib - East	140	1240	900	750	6	371
Trib - West	296	960	1900	Dry	Dry	814
<b>Enterococci</b>	JUN.	JUL.	AUG.	SEPT.	OCT.	MEAN
Otter Point	48	11	<2	6	20.8	11
Osprey Point	8	22	<2	13	21.2	6
Trib - East	78	585	722	775	144	172
Trib - West	3466	1633	34	Dry	Dry	178

**Table 12: Fecal coliform (colonies per 100 mL) and enterococci (probable count per 100 mL)**

Fecal coliform counts in the East and West Tributaries peaked at 1240 (Jul) and 1900 (Aug) respectively, while enterococci peaked in June at 3466 in the West and dropped off steeply until streamflow ceased in September. The East exhibited climbing levels up to 775 through September before dropping to 144 in October. Flow in the tributaries is sluggish and elevated values may reflect highly localized conditions.

### **5.3.1 Bacteria parameters for human uses**

The RIDEM allows a maximum of 14 fecal coliform units for shellfish waters and several Rhode Island salt ponds are no longer suitable for shellfishing due to long-term elevated fecal levels. Oysters may have been harvested from Trustom by previous landowners and it is unknown if shellfish that previously grew in Trustom were safe for human consumption, but clearly the fecal concentrations observed in October 2010 are well beyond accepted parameters. Although maintaining human health is not a priority of FWS, shellfish safety is still a concern because some waterfowl eat shellfish and may be susceptible to some forms of shellfish toxicity.

Enterococci counts are used by the Rhode Island Department of Health (RI DOH) as a standard for recreational water contact such as swimming. The RI DOH threshold for enterococci in freshwater is 61 per 100 mL or geometric mean density of 33 per 10 mL at designated beaches (Watershed Watch, 2006). Therefore although human recreation in Trustom Pond is prohibited, enterococci levels are within contact limits for humans. The elevated counts in both the East and West Tributaries reflect watershed conditions and could indicate high concentrations of bacteria in the soil. Soil tests would need to be conducted to determine relative bacteria loads from fecal sources, but at this point the elevated levels in the tributaries do not appear to have an impact on the pond basin.

Elevated bacteria counts were common in the other Rhode Island salt ponds in 2010, with the highest value of 9300 reported at the Wesquage Outlet (Oceanside) in Narragansett in May. *Please see Appendix F for 2010 bacteria counts recorded at other Rhode Island sites monitored by Watershed Watch.*

## **6.0 POTENTIAL EFFECTS OF BREACHING ON TRUSTOM POND**

The absence of a permanent breachway is a distinguishing characteristic of Trustom relative to nearby coastal ponds. While the breached ponds maintain brackish or estuarine conditions with salinity ranging from 0.5–30 ppt, Trustom is a freshwater system with total dissolved solids of 0.2 ppt. The pond is separated from the ocean by a narrow barrier beach but is not completely isolated from marine water, as spontaneous natural breaching may occur occasionally. Marine water may overwash the barrier beach during storm or extreme high-tide events, or elevated water levels inside Trustom may cause spillover of freshwater to Block Island sound (*Figure 27*). Regardless of the breaching mechanism, these occasional natural occurrences do not appear to impact the salinity profile of Trustom. Freshwater vegetation is found throughout the pond and the submerged aquatic distribution is dominated by the native species *Najas Flexilis*, which prefers circumneutral conditions and very low salinity.

Breaching has been suggested as a management strategy for improving water quality in Trustom Pond. An evaluation of breaching dynamics requires expertise in environmental engineering and sediment hydrodynamics and hence is beyond the scope of this project, but relevant information mined from FWS file reports is summarized here for future study.

### **6.1 History of breaching by private landowners**

Historically the Rhode Island coastal ponds were artificially breached to maintain estuarine conditions suitable for oyster and perch fisheries (Lee, 1980). File documents indicate Trustom was breached twice annually in April and October by the previous landowners to lower water levels and expose more land for farming. Because the pond is at a higher elevation than the ocean, water can drain spontaneously from the basin when a channel is opened to the sea. The water level in the pond generally reaches a maximum in early spring, so April is a strategic choice for a breach intended to partially drain the pond basin. File documents do not indicate the reasons for the October breach but it was likely done to encourage oyster growth, which requires pulsing salinity for maximum production (La Peyre et al., 2009). By the end of the growing season the water level in the pond should have dropped due to evapotranspiration occurring throughout the summer, so it is unlikely that water levels needed to be lowered in autumn.



**Figure 27: Site of occasional natural breaching events at Trustom Pond**

## **6.2 FWS use of breaching at Trustom Pond**

When FWS took over management of the pond, the artificial breaching were continued and as a result Trustom maintained its estuarine characteristics. In 2006 FWS ceased forced breaching to minimize anthropogenic disturbances to wildlife and as a result the pond's salinity has decreased dramatically. Saltwater does occasionally wash over the barrier beach that separates Trustom Pond from Block Island Sound, but the majority of water inflow to the pond is via groundwater discharge and precipitation.

## **6.3 Techniques and purpose of forced breaching**

In coastal landscapes breaching techniques may be used to temporarily connect coastal ponds or lagoons with the ocean. A breach is usually accomplished by digging a narrow trench in the barrier beach or spit separating the two water bodies. Reasons for breaching a coastal lagoon include to:

- a) Lower water levels in the lagoon to protect nearby property
- b) Increase or decrease salinity in the lagoon
- c) Flush nutrients and/or contaminants from the lagoon
- d) Facilitate migration or spawning of marine wildlife
- e) Allow navigation of watercraft between lagoon and marine system (US ACE, 2003).

In the case of the Trustom refuge, managers are most concerned with elevated nutrient levels that may lead to algal blooms in the pond and thus flushing nutrients out of the pond would be a primary goal of breaching. Although breaching techniques have been used successfully to achieve some water management objectives, it must be noted that allowing salt water into a freshwater pond may upset the composition and diversity of submerged aquatic vegetation as well as the nutrient characteristics of the water column. Because the mission of Trustom Pond is to maximize wildlife values, it is important to carefully evaluate the potential impacts of breaching before acting.

#### 6.4 Breaching and harmful algal blooms

Because Trustom Pond is experiencing elevated nutrient levels and periodic HABs, managers seek noninvasive ways to improve water quality. Based on information we have regarding past breaches, we are unable to tell if breaching will help or hurt wildlife management goals. Although cyanobacteria tend to inhabit fresh waters, dense and persistent blooms of freshwater genera including *Aphanizomenon* and *Anabaena* have been detected in brackish and estuarine systems including the Baltic Sea and (Laamanen et al., 2002; Raganiemi et al., 2005) and researchers working in the Adriatic found that picoplanktonic cyanobacteria adapted well to varying salinity levels (Del Negro et al., 2007). Therefore it is unknown if increasing the salinity of Trustom Pond would reduce the threat of blue green algal blooms.

According to an untitled FWS document, refuge managers induced artificial breaching at Trustom once or twice annually through the early 2000s to expose foraging habitat for piping plovers. Because water quality parameters were not measured during this period, effects of breaching on water quality are unknown. And although the Nature Conservancy undertook a study to assess the value of mudflat area for piping plover reproduction, investigators were unable to determine if manipulating water levels through breaching had any impact on plover fledgling success (Goldin & Regosin, 1997). Therefore it is difficult to determine if breaching will help managers achieve piping plover management goals at Trustom.

A water management plan for Trustom Pond submitted to FWS in July of 1987 recommended increasing the frequency and duration of forced breaches as a means of improving water quality. For nutrient export to occur, the nutrient-rich pond water must flow into Block Island Sound with the falling tide and relatively nutrient-poor marine water must flow up into the pond with the rising tide, thereby reducing the amount of nutrients in the basin and consequently controlling algal growth; ***however there is no evidence this hydrodynamic pattern can be accomplished at Trustom Pond with a breach.*** It is notable that the majority of technical documents related to breaching focus on sediment transport issues rather than water quality concerns, so an assessment that focuses on phosphorus transport during the breach may be necessary to determine if breaching can be used effectively for nutrient export at Trustom.

#### 6.5 Effect of breaching on submerged aquatic vegetation (SAV)

The SAV and algal distribution at Trustom has changed significantly over the past sixty years. In a 1954 report on a macroalgae survey of the coastal ponds, Wood and Palmatier observed estuarine species including *Cladophora* and *Ulva*, both suited to the salinity range 9.81 – 22.6 reported during the study period (Apr - Oct, 1948). Several genera of cyanobacteria including *Lyngbya* and *Oscillatoria* were reported in several area salt ponds, but not in Trustom; however the detection of *Oscillatoria* attached to *Cladophora* mats in adjacent Cards Pond suggests cyanobacteria could have been undetected in Trustom.

It is difficult to assess impacts of marine inputs on species distribution due to lack of longitudinal data from Trustom. However there is evidence the pond has responded to changes in breach implementation. In a report by Wright et al. (1949), researches suggested variable productivity in Trustom and Cards ponds was caused by irregular and unpredictable changes in water level and chemistry from uncontrolled breaching; however no data on breach frequency and duration were presented in their discussion. Moreover, the species composition and distribution of SAV in the coastal ponds is greatly influenced by salinity levels. In a survey conducted in 1995, researchers found that SAV species dominance had changed dramatically since the previous study in 1978 (Harlin et al., 1995). The 1995 investigation showed lower SAV biomass, and researchers suggested excess nitrogen provided by waterfowl fecal matter had enhanced algal production, thereby increasing turbidity, decreasing water clarity and limiting light penetration in the water column. Twice-yearly breaching was recommended to dilute nutrients in the pond and decrease turbidity. However Rhode Island environmental managers have observed that species richness for SAV is much lower in the coastal ponds with permanent breachways than in unbreached ponds (*Jay Osenkowi, RI DEM, personal communication*), so it is difficult to know if reinstating the biannual breach as recommended by the 1995 study will increase desirable SAV biomass.

In conclusion, we cannot predict how the Trustom ecosystem will respond to artificial breaching without further study. Managers at Trustom should carefully consider the potential impacts on food web composition when considering re-introducing breaching as a water quality management technique.

## 7.0 MANAGEMENT RECOMMENDATIONS

### 7.1 Impacts of watershed modification on coastal ponds

Increased development in the coastal pond region has spurred a complex combination of environmental changes, which in turn have affected the ponds' water chemistry, wildlife populations, nutrient loads, primary productivity, turbidity, and retention or flushing time. All these factors contribute to the relative health and ecosystem values of the individual ponds.

In a natural, vegetated landscape, pollutants such as fertilizers, road salts and petrochemicals are largely absent. As development occurs vegetated buffers have the capacity to remove many water-borne contaminants by filtering and or/geochemical transformations that occur in the soil layer before water reaches the water table. When an area is paved, the newly-impermeable surfaces prevent infiltration and instead funnel water across land surfaces where it collects soil, salts, and petrochemicals. These pollutants are then deposited in surface waters where they become part of the ecosystem's chemical budget, accumulating both in the water column and bottom sediments. Nutrients are a particularly important component of runoff because they promote rapid growth of the most plant responsive species, thereby creating changes in the food web and altering aquatic habitats. In the Salt Pond region, the cumulative effect of land development has been *cultural eutrophication*, or accelerated aging of the pond ecosystems caused by increased nutrient levels that, in turn, enhance primary productivity.

One of the most pronounced effects of the evolution of the natural land cover to a developed landscape was increased non-point source pollution (NPS), which is caused by storm water runoff from impermeable surfaces such as roadways, parking lots, and roofs. In rural or mixed-used watersheds, dense nutrient sources such as high intensity croplands, animal waste and individual septic disposal systems also contribute to NPS and degrade water quality. According to the Environmental Protection Agency, NPS is the leading cause of cultural eutrophication and surface water quality impairment in the United States (EPA, 1993). The undeveloped lands in the coastal ponds region possess significant conservation, ecological, historical and recreational values and resource values (RI CRMC, 2010); many ecosystem values in the Salt Pond Region have been lost as a result of NPS, but perhaps the most widely discussed impact of coastal pollution in Rhode Island has been long-term prohibitions on collecting shellfish, an important sector of the state's economy, in many of the salt ponds (RIDEM, 2008).

#### MANAGEMENT RECOMMENDATION

**Maintain adequate vegetated buffer strips** at the pond perimeter, especially near agricultural fields. Croplands, both active and fallow, are a significant source of nutrients and sediment, with tilled and/or easily-eroded soils most likely to impair water quality. Buffers help prevent nutrients and sediment from washing into the pond with storm or irrigation runoff; maintaining native trees, shrubs, and stiff grasses can create an effective trap and help stabilize soils. Net nutrient runoff from cropland will depend on numerous variables including (1) extent of edge of field sediment (2) hydrologic flux (3) soil characteristics (4) fertilizer application rate (5) plant growth (6) nutrient uptake rates and (7) precipitation patterns, among other considerations. Because additional farmland is likely to be acquired through conservation easements, FWS should consider implementing, refining or expanding efforts to mitigate agricultural runoff by minimizing the area of tilled croplands and assuring that buffer strips border those practices.

### MANAGEMENT RECOMMENDATION

Use **low-impact development (LID)** principles for all new construction projects to maintain natural hydrology; install storm water controls (rain gardens, bioretention areas) near existing impermeable areas to control surface runoff and export of sediment and other pollutants.

### MANAGEMENT RECOMMENDATION

**Track development projects and land use changes within the Trustom Pond watershed that may alter natural hydrology.** Increased impermeable areas and new storm water control structures such as drains can contribute to changes in water chemistry.

In 1999 the Coastal Resources Management Council (CRMC) revised the Rhode Island Salt Pond Region Special Area Management Plan (SAMP) to include more aggressive measures for reducing nutrient inputs and managing storm water runoff to the ponds. In 2010 RI DEM adopted new stormwater management standards requiring developers to use low impact development (LID) to maintain pre-development site hydrology in order to reduce nonpoint source pollution. These standards should be implemented in the Trustom watershed wherever possible, paying special attention to areas adjacent to the pond basin and to well-drained, rapid recharge areas where pollutants can easily contaminate groundwater.

### MANAGEMENT RECOMMENDATION

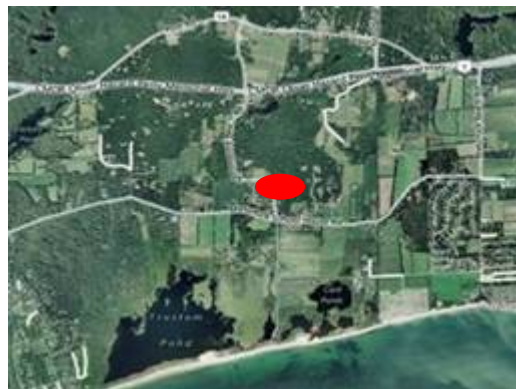
**Track development projects and land use changes within the Trustom Pond watershed that may alter nutrient loads.** To control negative impacts it is advisable to monitor farm management practices within the watershed, especially use of manure fertilizers and activity of large livestock.

Although manure provides a valuable pathway for recycling animal waste and can be used to build up organic matter in the soil, the N:P ratio of manure is higher than most crops require. Thus long term use of animal manure has been found to enrich croplands with excessively high levels of phosphorus, which can then pose a risk to some water bodies and especially P-limited aquatic systems such as Trustom Pond. When fields are tilled or vegetation is burned, crop soils erode more easily and can be washed into the pond with storm runoff. In addition to maintaining buffers, managers should consult with farmers on adjacent land parcels about best management practices for soil conservation and fertilization.

Large livestock are prolific producers of manure, and thus are an important source of nutrients and bacteria. During summer 2010 approximately 30 dairy cows were pastured near the intersection of Matunuck Schoolhouse Road and Oliver Street (*Figures 28 and 29*). Although the animals were grazing outside the watershed boundary, they could relocate in the future. Therefore managers may wish to meet with livestock owners to discuss water quality goals and concerns at Trustom Pond.



**Figure 28: Cows grazing near Matunuck Schoolhouse Rd, August 2010**



**Figure 29: Location of cows pastured near Trustom Pond watershed during August 2010**

### MANAGEMENT RECOMMENDATION

**Monitor manure use** by farmers on cropland, pasture and orchard parcels adjacent to Trustom Pond when possible. Encourage farmers to use BMPs when applying manure or synthetic fertilizers, especially in riparian zones and other ecologically-sensitive areas. Avoid applying fertilizer before rain events to reduce runoff.

### 7.2 Breaching and potential effects on Trustom Pond

FWS has not breached Trustom Pond since 2006 or 2007 and as a result salinity has dropped to less than 0.5 ppt. This evolution to a freshwater environment has caused a significant change in plant distribution: the estuarine species *Ruppia maritima* (widgeon grass) and *Potamogeton perfoliatus* (sago pondweed), which were identified as the co-dominant submerged aquatics in a 1978 vegetation survey (Harlin & Thorne-Miller, 1978), have been replaced by the Northern naiad, *Najas flexilis*, which now dominates the pond (K. Stillwell, R.I. Natural History Survey, personal communication, 9/23/2010). *N.flexilis* is a valuable duck food and stabilizes the subaqueous soil, thereby reducing turbidity by limiting re-suspension of sediment in the water column. This species is intolerant to salinization and acidification and requires circumneutral (pH 6.5 – 7.5) conditions to thrive (EPA Report 600/3-90/073), and so its distribution and growth density may be influenced by any water management practices that alter pH and salinity. Therefore managers should consider the potential impacts of breaching on macrophyte dominance and food web dynamics before reinstating this practice at Trustom.

A change from estuarine to fresh water is also significant in terms of watershed management. Most studies on the Rhode Island coastal ponds have focused on nutrient dynamics in the estuarine or marine environment, in which primary productivity is limited by nitrogen (Ryther & Dunstan, 1971; Oviatt & Gold, 2005; Nixon & Buckley, 2007). Fresh water systems tend to be limited by phosphorus (Vollenweider, 1968; Wetzel, 2001) and so studies and management decisions for Trustom Pond need to consider phosphorus dynamics in the ecosystem. Therefore managers should use caution when interpreting management recommendations written for the neighboring nitrogen-limited salt ponds.

### MANAGEMENT RECOMMENDATION

**Do not implement forced breachings at Trustom Pond** without first conducting a thorough study of the site's sediment hydrodynamics and the potential effects of increased salinity on the distribution of submerged and emergent vegetation.

### 7.3 Wildlife influence on Trustom Pond water quality

Waterfowl pressure on Trustom Pond may continue to increase as the salt pond region becomes more developed. Because the overarching mission of FWS is to protect wildlife, it is important to consider how wildlife activity affects ecosystem values at the refuge.

### MANAGEMENT RECOMMENDATION

**Continue to monitor bacteria and track relationship** among values of coliforms, nutrient concentrations and bird counts. A strong positive correlation among these parameters may indicate that waterfowl droppings are influencing water quality.

### MANAGEMENT RECOMMENDATION

**Expand survey schedule** for Canada geese, Mute swans, and Cormorants, as these large birds contribute much higher nutrient loads than ducks and smaller waterfowl. High numbers of large waterfowl can significantly impact water quality.

## 7.4 Cyanobacteria or Harmful Algal Bloom (HAB) monitoring

As stressed throughout this report, HABs can potentially sicken or kill waterfowl. Although HABs are becoming increasingly prevalent in impaired waters, the science of tracking and predicting HABs is still in its infancy. Regional and national programs are being created to help managers identify data collection priorities and as a national wildlife refuge Trustom Pond may be able to direct resources toward creating a comprehensive longitudinal database of HAB events.

### MANAGEMENT RECOMMENDATION

**Implement on-site monitoring for cyanobacteria.** Probes are available to measure the ratio of blue-green algae to green algae in the water column, allowing managers to predict the onset of HABs and plan mitigation strategies to protect wildlife.

### MANAGEMENT RECOMMENDATION

**Monitor waterfowl in and around Trustom Pond for signs of cyanotoxin poisoning.**

Symptoms exhibited by poisoned birds include: seizures, confusion, labored respiration, paralysis and death. Conduct cyanotoxin screenings on dead birds. Collect pond water samples for detailed cell counts and cyanotoxin analysis when dead or sick birds are discovered.

### MANAGEMENT RECOMMENDATION

**Extend monitoring of dissolved and total P through the dormant season** to determine the relative contribution of legacy P to the water column. If elevated dissolved P levels are observed in the winter, this may be an indication that Trustom sediment is a nutrient source. These legacy stores may contribute to internal P recycling in Trustom for years even if external loads are eliminated. Ponds with legacy stores of P are sometimes treated with aluminum, hydrogen peroxide or other chemical compounds in order to remove excess P from the water column; however chemical treatments are not usually recommended for water bodies managed as wildlife refuges. Managers should continue to participate in the tri-season Watershed Watch evaluations during the growing season and consider expanding the monitoring schedule through the dormant season in order to create a more complete data set of Trustom nutrient levels.

## 8.0 CONCLUSIONS

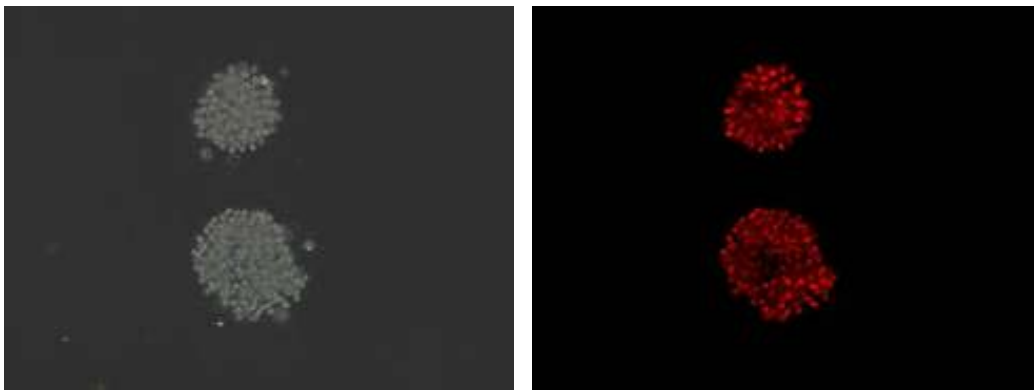
Trustom Pond is a highly-enriched, eutrophic water body that provides essential habitat values for numerous species of resident and migratory birds, some rare and endangered. Because the pond is a national wildlife refuge, it has been protected from the effects of residential and commercial development, while other ponds in the area are now bordered by dense housing tracks containing up to 500 homes per square mile. As a result, Trustom is one of the few undisturbed habitats in southern Rhode Island and waterfowl tend to concentrate there on their migration stopover. Large seasonal populations of Canada geese as well as an increasing number of resident Mute swans may be contributing to high nutrient loads and elevated fecal coliform counts in the pond. Historical data on bird counts is not continuous and we recommend expanding the bird survey when possible to create a more accurate record of bird days. The bird data can then be used to create a better estimate of nutrient inputs due to bird droppings.

Water quality at Trustom appears sufficient to support major ecosystem functions. Secchi depth measurements (water clarity) were low throughout the summer but within the range expected for a productive water body, and chlorophyll-*a* concentrations fluctuated according to expected seasonal succession patterns for phytoplankton. Trustom experienced blue-green algal blooms in September and October 2010, and although no adverse effects on wildlife were observed, the concentration of the hepatotoxin *microcystin* detected in the pond water from August through October was sufficient to impact fish; furthermore *microcystin* is known to bioaccumulate in fish and crustaceans. In addition, the

dominant blue-green algae appeared to be *Anabaena*, a genus known to produce the neurotoxin *anatoxin-a* in addition to *microcystin* and other toxins.

To evaluate risks for waterfowl, managers may wish to implement long-term monitoring protocols to track toxin levels in the pond and identify potential relationships between HABs, cyanotoxin levels and waterfowl health. It is advisable for managers to be alert for HABs in the late summer and early fall months and when blooms are observed, managers should watch for signs of poisoned waterfowl and collect sick and/or dead birds and water and algae samples for toxin analysis.

Managers have considered re-implementing forced breaches at Trustom with the goal of decreasing nutrient concentrations and improving water quality. Although lower total and dissolved phosphorus in Trustom could result in fewer algal blooms, it is unclear if a breach will serve to decrease dissolved phosphorus concentration in the water column and/or legacy stores of particulate-bound phosphorus in the pond sediment. Therefore we recommend managers refrain from breaching the pond until they have conducted a thorough study of hydrodynamics in the pond basin. It is recommended that water quality monitoring be continued during the growing season (May – October) according to the Watershed Watch protocols. In addition, managers should consider monitoring P levels throughout the winter to determine the extent of internal recycling of P from the pond sediments.



**Figure 30: *Microcystis* spp. cells detected in Trustom Pond on 7/15/210.**  
Photos by Lucie Maranda, URI Graduate School of Oceanography.

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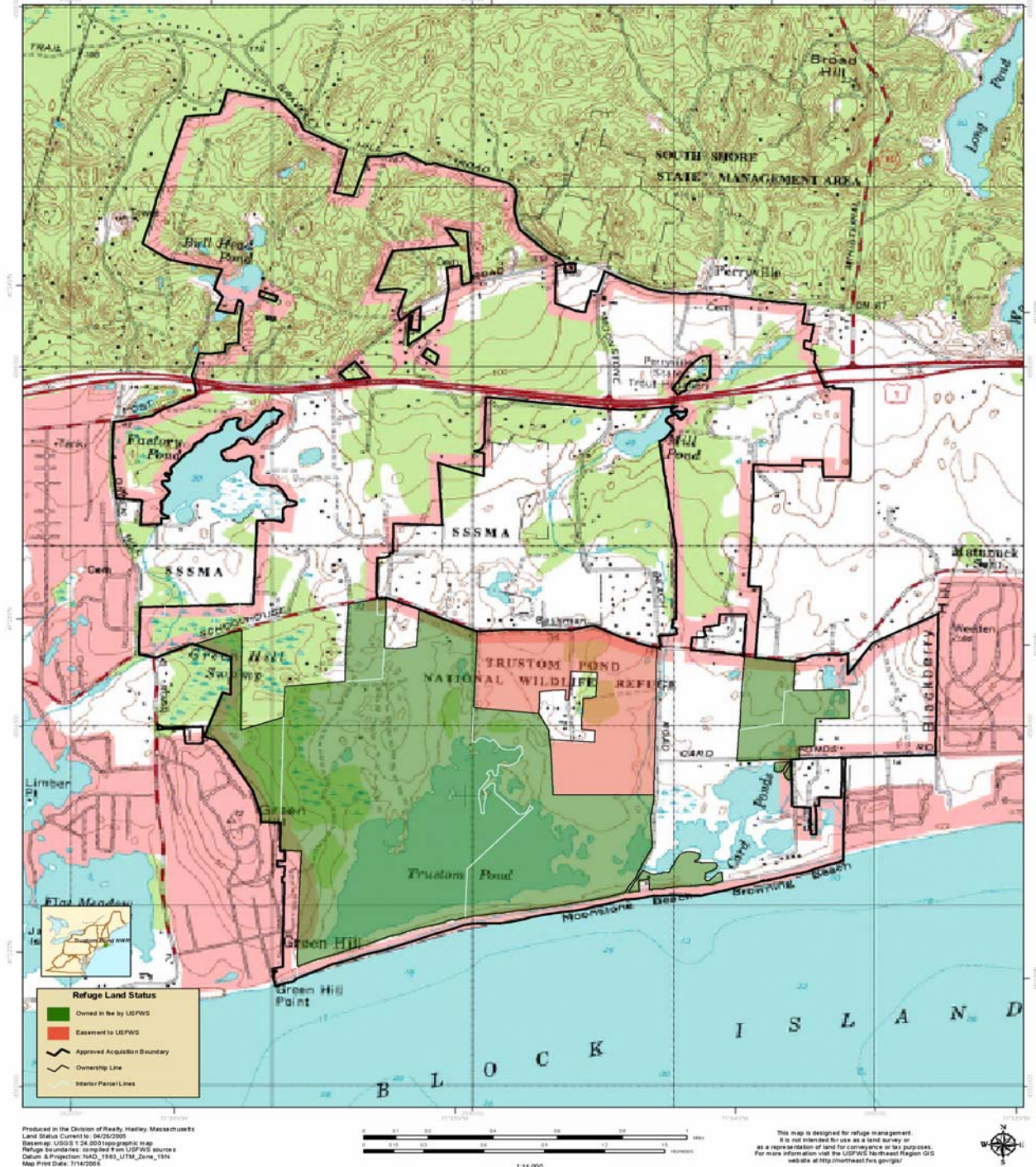
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## APPENDIX A: Land Status, Trustom Pond National Wildlife Refuge



**Figure A-1: Land status at Trustom Pond National Wildlife Refuge**

Green areas are owned by FWS, pink areas are conservation easements to FWS, and heavy black borders indicate the limits of the approved acquisition boundary. Source: U.S. Fish & Wildlife Service

Original map and geospatial data: <http://www.fws.gov/northeast/gis/metadata.html#Rhode%20Island>

## APPENDIX B: Impervious cover in Trustom Pond watershed

Currently only 2% of the Trustom Pond watershed is impervious cover. Note that high residential development and most infrastructure (roads, railroads, etc.) translate to 72% impervious cover. Any development is likely to increase the impermeable area, so it is advisable to keep track of proposals for new construction projects within the watershed.

<b>MANAGE Estimated Level of Imperviousness</b>		
Study Area:	<b>Trustom Pond Watershed</b>	
Scenario:	Current Land Use	
<b><u>ESTIMATED IMPERVIOUSNESS</u></b>		
Average over Study Area		2%
Average over Riparian Area		0%
<b>Trustom Pond Watershed</b>		
Current Land Use		
<u>LAND USE CATEGORY</u>	<u>Total Acres</u>	<u>% Impervious</u>
[1] HD Res.(>8 /ac)	0.0	72
[2] MHD Res.(4-7.9/ac)	9.5	50
[3] MD Res.(1-3.9/ac)	30.1	30
[4] MLD Res.(0.5-0.9/ac)	9.4	16
[5] LD Res.(<0.5/ac)	9.6	8
[6] Commercial	0.0	72
[7] Industrial	0.0	72
[8] Roads	0.0	72
[9] Airports	0.0	72
[10] Railroads	0.0	72
[11] Junkyards	0.0	72
[12] Recreation	0.0	10
[13] Institution	0.0	50
Total Developed Areas	58.5	
All Other Pervious Areas	778.4	
Total Watershed Area	837.0	2%

Source: Lorraine Joubert, URI Nonpoint Education for Municipal Officials (NEMO)

## APPENDIX C: Interpreting the MANAGE model results

As is common with many models, there is inherent uncertainty in the values projected by MANAGE. The landscape being modeled is not homogeneous and loading rates can vary extensively within a given land use type. Significant confounding factors include:

- (1) differences in management practices within and between land use classes,
- (2) spatial variability of soil characteristics,
- (3) nutrient “hot spots” such as confined livestock, manure storage or unmarked waste dumping areas,
- (4) “legacy” stores of phosphorus that may have accumulated after decades of agricultural production and
- (5) placement and retention capacity of riparian buffer zones.

For example (*Table C1*), Cropland has the potential to contribute the most phosphorus at a rate of at 4.5 pounds per acre per year; however the low estimate for cropland predicts only 1/8 that amount, or 0.5 lbs/ac/year. The low estimate may describe land managed using best practices including low or no-tillage methods and minimal fertilizer, while the high estimate could represent sites with a long history of manure inputs or highly-enriched or easily eroded soils. The “average” value is the mean of the high and low loading estimates.

The projections generated by MANAGE therefore should not be considered a “true” quantitative assessment of P loading but should instead serve as a tool to identify which areas should be targeted for nutrient-reduction efforts.

Land Use Type	Area (acres)	% Total Land	P Load Factor Low (lb/ac/yr)	P Load Factor High (lb/ac/yr)	Low Total (lbs/year)	High Total (lbs/year)	Avg Total (lbs/year)
MHD Residential	9.5	1.4	2.1	3.4	19.7	32.3	26.0
MD Residential	30.0	4.4	1.2	2.1	36.7	62.2	49.4
MLD Residential	9.4	1.4	0.8	1.2	8.0	11.5	9.7
LD Residential	9.6	1.4	0.5	0.8	5.1	8.2	6.6
Pasture	39.7	5.9	0.3	1.0	11.9	39.7	25.8
Cropland	127.5	18.8	0.5	4.5	63.8	573.8	318.8
Orchard	19.7	2.9	0.4	2.0	7.9	39.4	23.6
Brush	75.2	11.1	0.1	0.2	7.5	15.0	11.3
Forest	228.4	33.7	0.1	0.2	22.8	45.7	34.3
Barren	66.1	9.8	0.1	0.2	6.6	13.2	9.9
Wetland	62.8	9.3	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.3	0.3	0.0	0.0	0.0
<b>TOTAL</b>	<b>678</b>	<b>100</b>	<b>n/a</b>	<b>n/a</b>	<b>190</b>	<b>841</b>	<b>515</b>

**Table C1: Estimated Trustom Pond watershed P loading based on land use and hydric soil group**

Source: MANAGE model by Lorraine Joubert, URI NEMO

## APPENDIX D: Estimated waterfowl phosphorus contribution

<b>SCENARIO 1</b>	Highest #	# bird	Droppings per	*g P per	g P per	g P per
SPECIES	one sighting	days/m	bird/day (g)	bird/day	bird/month	species/year
Canada goose	3800	114000	82	1.5	46.0	2097691.2
Mute swan	40	1200	82	1.5	46.0	22080.96
Ducks/Other	600	18000	20	0.4	11.2	80784
TOTAL	4440	133200	184	3.4	103.2	2200556.16
						<b>4401</b>
<i>(based on highest daily count sustained for 12 months - overestimate)</i>						<b>lbs P/year</b>
<b>SCENARIO 2</b>	Highest #	# bird	Droppings per	*g P per	g P per	P contributed
Species	one sighting	days/m	bird/day (g)	bird/day	bird/month	over 2 months
Canada goose	3800	114000	82	1.5334	46.002	349615.2
Mute swan	40	1200	82	1.5334	46.002	3680.16
Ducks/Other	600	18000	20	0.374	11.22	13464
TOTAL	4440	133200	184	3.4408	103.224	366759.36
						<b>734</b>
<i>(based on highest daily count sustained for two months)</i>						<b>lbs P/year</b>
<b>SCENARIO 3</b>	Resident	Bird	Droppings per	*g P per	g P per	P contributed
Species	Birds	days/year	bird/day (g)	bird/day	bird/month	over 12 months
Canada goose	400	146000	82	1.5334	46.002	220809.60
Mute swan	20	7300	82	1.5334	46.002	11040.48
Ducks/Other	600	219000	20	0.374	11.22	80784.00
TOTAL	1020	372300	184	3.4408	103.224	312634.08
						<b>625</b>
<i>(based on a smaller number of year-round residents)</i>						<b>lbs P/year</b>
<b>SCENARIO 4</b>	Resident	Bird	Droppings per	*g P per	g P per	P contributed
Species	Birds	days/year	bird/day (g)	bird/day	bird/month	over 12 months
Canada goose	200	73000	82	1.5334	46.002	110404.8
Mute swan	20	7300	82	1.5334	46.002	11040.48
Ducks/Other	200	73000	20	0.374	11.22	26928
TOTAL	420	153300	184	3.4408	103.224	148373.28
						<b>297</b>
<i>(based on a smaller number of year-round residents)</i>						<b>lbs P/year</b>
<b>SCENARIO 5</b>	Resident	Bird	Droppings per	*g P per	g P per	P contributed
Species	Birds	days/year	bird/day (g)	bird/day	bird/month	over 12 months
Canada goose	25	9125	82	1.5334	46.002	13800.6
Mute swan	25	9125	82	1.5334	46.002	13800.6
Ducks/Other	25	9125	20	0.374	11.22	3366
TOTAL	75		184	3.4408	103.224	30967.2
						<b>62</b>
<i>(based on a very small number of year-round residents - underestimate)</i>						<b>lbs P/year</b>

\*P concentration estimated assuming 1.87% dry weight of droppings

## APPENDIX E: Watershed Watch 2010 Draft Data, Trustom Pond

**2010 Nitrate-nitrogen Summary** (Reported as ug/L or ppb, Limit of detection = 10 ug/L)

LOCATION	Depth (m)	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN
Trustom Pond - Otter Pt	0.5	20	ND	10	10	10	-	<b>13</b>
Trustom Pond - Osprey Pt	0.5	-	10	10	ND	10	-	<b>10</b>
Trustom Pond Tributary - East	0.2	1030	640	630	500	440	-	<b>648</b>
Trustom Pond Tributary - West	0.2	60	50	60	50	Dry	Dry	<b>55</b>

**2010 Ammonia Summary**( Reported as ug/L or ppb, Limit of detection = 20 ug/L)

LOCATION	Depth (m)	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN
Trustom Pond - Otter Pt	0.5	30	70	30	40	-	-	<b>43</b>
Trustom Pond - Osprey Pt	0.5	-	130	20	20	-	-	<b>57</b>
Trustom Pond Tributary - East	0.2	60	110	70	140	-	-	<b>95</b>
Trustom Pond Tributary - West	0.2	60	50	140	350	Dry	Dry	<b>150</b>

**2010 Total Nitrogen Summary** (Reported as ug/L or ppb, Limit of detection = 30 ug/L)

LOCATION	Depth (m)	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN
Trustom Pond - Otter Pt	0.5	970	660	970	760	860	-	<b>844</b>
Trustom Pond - Osprey Pt	0.5	-	1440	910	770	880	-	<b>1000</b>
Trustom Pond Tributary - East	0.2	1330	1010	1040	1960	1900	-	<b>1448</b>
Trustom Pond Tributary - West	0.2	710	1170	1540	2710	Dry	Dry	<b>1533</b>

**2010 Dissolved Phosphorus Summary** (Reported as ug/L or ppb, Limit of detection = 5 ug/L)

LOCATION	Depth (m)	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN
Trustom Pond - Otter Pt	0.5	8	11	6	14	13	-	<b>10</b>
Trustom Pond - Osprey Pt	0.5	-	8	5	10	9	-	<b>8</b>
Trustom Pond Tributary - East	0.2	5	3	7	19	33	-	<b>13</b>
Trustom Pond Tributary - West	0.2	11	51	63	149	Dry	Dry	<b>69</b>

**2010 Total Phosphorus Summary** (Reported as ug/L or ppb, Limit of detection = 4 ug/L)

LOCATION	Depth (m)	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	MEAN
Trustom Pond - Otter Pt	0.5	31	26	54	66	45	-	<b>44</b>
Trustom Pond - Osprey Pt	0.5	-	11	52	54	49	-	<b>39</b>
Trustom Pond Tributary - East	0.2	9	19	27	149	145	-	<b>51</b>
Trustom Pond Tributary - West	0.2	18	69	105	242	Dry	Dry	<b>109</b>

## APPENDIX F: Bacteria data (2010) for URI Watershed Watch

### Coastal Ponds and Tributaries Fecal Coliform Data (Arranged east to west)

Watershed code	MONITORING LOCATION	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	GEOMEAN
<b>Number of Fecal coliform colony forming units per 100 mL</b>								
CE	Quicksand Pond	8	-	not run	-	-	not run	-
CE	Quicksand Tributary - East upstream	-	-	not run	-	-	not run	-
CE	Quicksand Trib - East downstream	-	-	not run	-	-	not run	-
CE	Quicksand Tributary - North	-	-	not run	-	-	not run	-
SK	Nanaquaket Pond	4	-	1	-	-	10	3
NA	Wesquage Pond	not run	-	88	-	-	76	82
NA	Wesquage Outlet - Pondsides	9200	-	1600	~1200	-	260	1464
NA	Wesquage Outlet - Oceanside	9300	-	1300	~1000	-	130	1120
CW	Trustom Pond - Otter Pt	not run	<4	4	20	10	3440	16
CW	Trustom Pond - Osprey Pt	-	<4	<2	110	12	4600	8
CW	Trustom Pond Tributary - East	not run	140	1240	900	750	60	371
CW	Trustom Pond Tributary - West	not run	296	960	1900	Dry	Dry	814

### Coastal Ponds and Tributaries Enterococci Data (Arranged east to west)

Watershed code	MONITORING LOCATION	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	GEOMEAN
---- <b>Most Probable Number of Enterococci per 100 mL</b> ----								
CE	Quicksand Pond	20	-	10	-	-	11.1	13
CE	Quicksand Trib - North (Cole Brk)	-	-	1330.6	-	-	328.2	661
CE	Quicksand Trib @ Rock Bridge	-	-	3465.8	-	-	124.6	657
CE	Quick. Trib - Downstream Rock Brdg	-	-	3465.8	-	-	103.6	599
SK	Nanaquaket Pond	<10	-	<10	-	-	<10	<10
NA	Wesquage Pond	10	-	34.8	-	-	10	15
NA	Wesquage Outlet - Pondsides	2755	-	932	52	20	63	176
NA	Wesquage Outlet - Oceanside	2481	-	637	41	10	41	122
CW	Trustom Pond - Otter Pt	159.4	48	10.6	<2	6.2	20.8	11
CW	Trustom Pond - Osprey Pt	-	8	22.2	<2	12.6	21.2	6
CW	Trustom Pond Tributary - East	7.2	77.2	584.8	721.8	774.6	144	172
CW	Trustom Pond Tributary - West	5.2	3465.6	1632.8	34.2	Dry	Dry	178

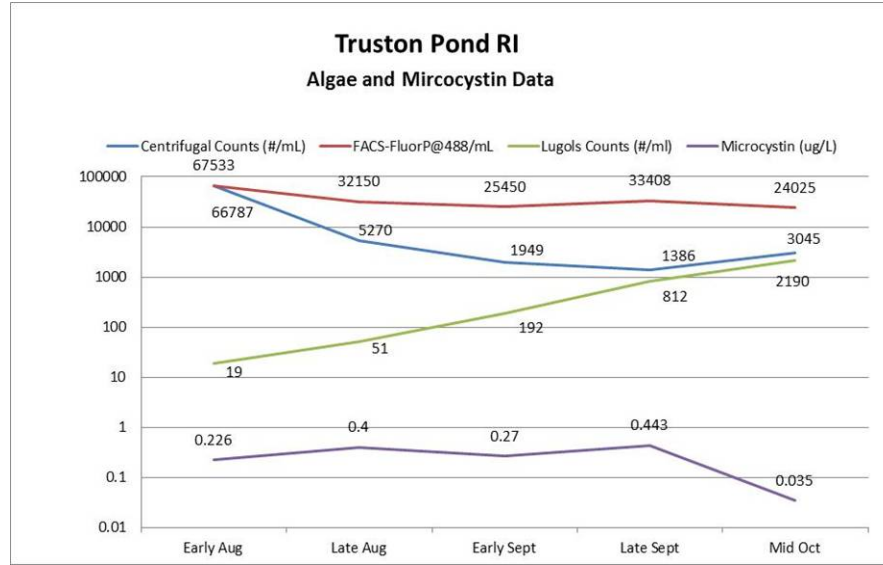
## APPENDIX G: Storm runoff projections for Trustom Pond watershed

Based on One, Two, and Ten Year Storm Events

Land use	Area (acres)	Hydrologic Condition	Hydrologic Soil Group	Curve Number	Curve No. X Area
MHD Residential (4.7-9/ac)	9.48	Good	B	72	683
MD Residential (1-3.9/ac)	30.12	Good	B	72	2169
MLD Residential (0.5-0.9/ac)	9.36	Good	B	68	636
LD Residential (<0.5 ac)	9.58	Good	B	68	651
Pasture	9.83	Good	A	39	383
Pasture	29.30	Good	B	61	1787
Pasture	0.50	Good	D	80	40
Cropland (Straight Row)	2.05	Good	A	67	137
Cropland (Straight Row)	120.00	Good	B	78	9360
Cropland (Straight Row)	1.85	Good	C	85	157
Cropland (Straight Row)	3.72	Good	D	89	331
Orchards	19.72	Good	B	78	1538
Brush	5.00	Good	A	30	150
Brush	70.00	Good	B	58	4060
Brush	0.18	Good	D	78	14
Forest	2.00	Good	A	25	50
Forest	209.00	Good	B	55	11495
Forest	1.10	Good	C	70	77
Forest	16.39	Good	D	77	1262
Barren (Fallow)	18.66	Good	A	77	1437
Barren (Fallow)	34.45	Good	B	86	2963
Barren (Fallow)	13.03	Good	D	94	1225
Wetland	62.77	Good	C	92	5775
TOTAL WATERSHED	678.09				46381
	<b>Weighted Curve Number</b>	<b>(Sum curve</b>	<b>numbers/ area)</b>	<b>=</b>	<b>68.4</b>

	1 yr storm (1.8 in)	2 yr storm (3.4 in)	10 yr storm (4.7 in)	
Predicted runoff depths:	<b>0.4</b>	<b>0.5</b>	<b>1.4</b>	<b>inches</b>
Predicted runoff volumes:	<b>7,365,210</b>	<b>9,206,513</b>	<b>25,778,236</b>	<b>gallons</b>

## APPENDIX H: Molecular Analysis of Algae and Microcystin in Trustom



Trustom Pond RI	RI-84-2TP		RI-819-2TP		RI-92-3TP		RI-930-3TP		RI-1021-1TP	
	Lugols	centri	Lugols	centri	Lugols	centri	Lugols	centri	Lugols	centri
Staurastrum	2	43	6	21	1	20	19	60	20	22
Synedra	3	0	12	0	165	47	0	0	0	62
Ceratium	3	0	21	37	10	18	0	0	0	0
Eudorina	0	0	1	0	1	0	0	0	0	0
Microcystis	9	18	5	21	7	9	3	5	0	9
Oscillatoria	2	60	1	0	0	0	0	0	0	0
Pandorina	0	46	4	8	0	2	0	0	0	0
Anabaena	0	11	1	4	6	7	786	552	2166	1969
Pediastrum	0	4	0	0	1	0	2	0	4	0
Oocystis	0	0	0	29	1	20	0	12	0	18
Sphaerocystis	0	0	0	0	0	0	1	17	0	0
Coelastrum	0	0	0	0	0	0	1	15	0	0
Scenedesmus	0	548	0	25	0	24	0	36	0	44
Centric diatom	0	4	0	0	0	4	0	0	0	36
Pennate diatoms	0	210	0	45	0	16	0	17	0	80
Gloeocystis	0	7	0	0	0	0	0	0	0	0
Ankistrodesmus	0	146	0	0	0	0	0	0	0	0
Trachelomonas	0	4	0	21	0	36	0	0	0	4
UCBG (colonies broken)	0	65016	0	775	0	315	0	244	0	350
UCG	0	672	0	4071	0	1313	0	366	0	420
Chroococcus-like	0	0	0	213	0	82	0	12	0	0
Gloeocapsa	0	0	0	0	0	18	0	17	0	0
Dictyosphaerium	0	0	0	0	0	11	0	7	0	0
Snowella	0	0	0	0	0	7	0	0	0	0
Tetraedron	0	0	0	0	0	0	0	14	0	9
Pediastrum	0	0	0	0	0	0	0	3	0	4
Selenastrum	0	0	0	0	0	0	0	7	0	0
Cosmarium	0	0	0	0	0	0	0	2	0	0
Lyngbya	0	0	0	0	0	0	0	0	0	9
Merismopedia	0	0	0	0	0	0	0	0	0	4
Fragilaria	0	0	0	0	0	0	0	0	0	4
<b>Total</b>	<b>19</b>	<b>66787</b>	<b>51</b>	<b>5270</b>	<b>192</b>	<b>1949</b>	<b>812</b>	<b>1386</b>	<b>2190</b>	<b>3045</b>

Source: Tim Hunter, Manager, University of Vermont VCC DNA and Microarray Facilities. Analysis funded by Northeast Cyberinfrastructure Consortium metagenomic study on harmful algal blooms.

# Appendix I: Phosphorus Shake Test data

sample	ug/l	wet soil	% water	mass		P stock	P soln	from solution	µg P sorbed per g soil	ppm P soln
				soil	soil					
1	6.3	0		0.00	6.3	6.3	6.3	-29.2	-18.1	0.0355
2	35.5	4.83	300	1.61	35.5	6.3	35.5	-28.7	-17.5	0.035
3	35	4.93	300	1.64	35	6.3	35	-26.7	-15.8	0.033
4	33	5.06	300	1.69	33	6.3	33	-14.3	-6.1	0.0206
5	20.6	4.92	210	2.34	20.6	6.3	20.6	-9.2	-3.9	0.0155
6	15.5	4.94	210	2.35	15.5	6.3	15.5	-16.1	-6.8	0.0224
7	22.4	4.99	210	2.38	22.4	6.3	22.4	-15.1	-5.3	0.0214
8	21.4	5.05	176	2.87	21.4	6.3	21.4	-9.9	-3.5	0.0162
9	16.2	4.91	176	2.79	16.2	6.3	16.2	-11.9	-4.3	0.0182
10	18.2	4.83	176	2.74	18.2	6.3	18.2	5.4	3.2	0.0125
11	17.9	0			17.9	17.9	17.9	1.3	0.8	0.0166
12	12.5	5.05	300	1.68	12.5	17.9	12.5	-1.4	-0.8	0.0193
13	16.6	5.1	300	1.70	16.6	17.9	16.6	-2.3	-1.0	0.0202
14	19.3	5.03	300	1.68	19.3	17.9	19.3	6	2.5	0.0119
15	20.2	4.84	210	2.30	20.2	17.9	20.2	4.1	1.7	0.0138
16	11.9	5	210	2.38	11.9	17.9	11.9	7	2.6	0.0109
17	13.8	4.98	210	2.37	13.8	17.9	13.8	4.3	1.6	0.0136
18	10.9	4.73	176	2.69	10.9	17.9	10.9	0.6	0.2	0.0173
19	13.6	4.85	176	2.76	13.6	17.9	13.6	21.9	13.1	0.0251
20	17.3	4.86	176	2.76	17.3	17.9	17.3	29.3	17.2	0.0177
21	47	0			47	47	47	21.2	12.5	0.0258
22	25.1	5	300	1.67	25.1	47	25.1	30.7	12.8	0.0163
23	17.7	5.11	300	1.70	17.7	47	17.7	37.4	15.6	0.0096
24	25.8	5.08	300	1.69	25.8	47	25.8	34.5	14.6	0.0125
25	16.3	5.02	210	2.39	16.3	47	16.3	28.6	9.8	0.0184
26	9.6	5.05	210	2.40	9.6	47	9.6	30.9	10.8	0.0161
27	12.5	4.96	210	2.36	12.5	47	12.5	33.7	10.7	0.0133
28	18.4	5.14	176	2.92	18.4	47	18.4			
29	16.1	5.04	176	2.86	16.1	47	16.1			
30	13.3	5.53	176	3.14	13.3	47	13.3			

# Appendix I: Phosphorus Shake Test data

sample	ug/l	wet soil	% water	mass		P stock	P soln	from solution	µg P sorbed	ppm P
				soil	soil					
31	60.3	0				60.3	60.3			
32	16.7	5.29	300	1.76	60.3	60.3	16.7	43.6	24.7	0.0167
33	14.1	5.09	300	1.70	60.3	60.3	14.1	46.2	27.2	0.0141
34	16.9	5.29	300	1.76	60.3	60.3	16.9	43.4	24.6	0.0169
35	10.7	5.07	210	2.41	60.3	60.3	10.7	49.6	20.5	0.0107
36	12.1	5.15	210	2.45	60.3	60.3	12.1	48.2	19.7	0.0121
37	13	5.02	210	2.39	60.3	60.3	13	47.3	19.8	0.013
38	15.3	5.31	176	3.02	60.3	60.3	15.3	45	14.9	0.0153
39	21	5.37	176	3.05	60.3	60.3	21	39.3	12.9	0.021
40	16.1	5.27	176	2.99	60.3	60.3	16.1	44.2	14.8	0.0161
41	215.6	0			215.6	215.6	215.6			
42	31.9	5.13	300	1.71	215.6	215.6	31.9	183.7	107.4	0.0319
43	34.7	4.99	300	1.66	215.6	215.6	34.7	180.9	108.8	0.0347
44	26	5.06	300	1.69	215.6	215.6	26	189.6	112.4	0.026
45	22.4	5.29	210	2.52	215.6	215.6	22.4	193.2	76.7	0.0224
46	20.1	5.16	210	2.46	215.6	215.6	20.1	195.5	79.6	0.0201
47	13.9	5.15	210	2.45	215.6	215.6	13.9	201.7	82.2	0.0139
48	21.6	5.1	176	2.90	215.6	215.6	21.6	194	66.9	0.0216
49	25.2	5.16	176	2.93	215.6	215.6	25.2	190.4	64.9	0.0252
50	21.7	5.23	176	2.97	215.6	215.6	21.7	193.9	65.3	0.0217
51	340.2	0			340.2	340.2	340.2			
52	30.7	5.19	300	1.73	340.2	340.2	30.7	309.5	178.9	0.0307
53	27.2	5.01	300	1.67	340.2	340.2	27.2	313	187.4	0.0272
54	19.5	5.03	300	1.68	340.2	340.2	19.5	320.7	191.3	0.0195
55	25.3	5.06	210	2.41	340.2	340.2	25.3	314.9	130.7	0.0253
56	26	5.02	210	2.39	340.2	340.2	26	314.2	131.4	0.026
57	29.3	4.98	210	2.37	340.2	340.2	29.3	310.9	131.1	0.0293
58	22.1	4.98	176	2.83	340.2	340.2	22.1	318.1	112.4	0.0221
59	20.7	5.06	176	2.88	340.2	340.2	20.7	319.5	111.1	0.0207
60	18.8	5.1	176	2.90	340.2	340.2	18.8	321.4	110.9	0.0188

# Appendix J: Chlorophyll-a data

2010 CHLOROPHYLL DATA Trusdom Pond (Variable Sites)																		
Sample Date	Analysis Date	High Solid	Low Solid	#1 read 1	#1 read 2	#2 read 2	#2 read 2	#3 read 1	#3 read 2	#4 read 1	#4 read 2	100 X	REP1	REP2	REP 3	REP 4	Mean CHL CONC	TSI
<b>Trusdom #1(Otter Pt.)</b>																		
13-May	2-Jun	50.7	6.7	87.7	87.7	92.4	92.9	87.1	87.2	87.2	87.2	274	9.48	10.01	9.42	9.43	9.58	52.77
23-Jun	1-Jul	52.6	7	191.8	191.1	228.2	228.1	191.8	191.1	228.2	228.1	274	19.95	23.77	19.95	23.77	21.86	60.86
30-Jun	1-Jul	52.6	7	309.7	309.6	370.5	368.8	303.6	303.7	253.2	254.5	274	32.26	38.51	31.64	26.45	32.21	64.66
7-Jul	8-Jul	51.5	6.8	302.7	297	278.5	269.3	265.1	269	263.4	264.6	274	31.91	29.15	28.42	28.09	29.39	63.76
15-Jul	23-Jul	51.3	6.8	343.6	344.3	285.3	285.1	311.5	311.4	200.2	201.7	274	36.74	30.47	33.27	21.47	30.49	64.12
15-Jul	10-Dec	54.1	6.5	393.3	388.4	223	223.6	287.5	285.8	341.2	336.5	274	39.59	22.62	29.04	34.32	31.39	64.41
22-Jul	23-Jul	51.3	6.8	127	126.7	130.4	130	87.7	88.6	113.2	112.6	274	13.55	13.91	9.42	12.06	12.23	55.17
28-Jul	29-Jul	50.2	6.8	67.1	66.5	100.8	100.2	46.6	46.3	58.9	58.5	274	7.29	10.97	5.07	6.41	7.44	50.28
4-Aug	13-Aug	52.9	6.8	66.8	69.2	53.6	54.8	118.9	123.4	51.7	52.6	274	7.04	5.61	12.55	5.40	7.65	50.56
11-Aug	15-Aug	52.9	6.8	93.6	96.5	101.2	101.3	66.3	67.3	65.7	67.8	274	9.85	10.49	6.92	6.91	8.54	51.64
18-Aug	10-Dec	53.8	6.60	246.3	248.6	203.7	217.1	235.1	240.3	257.6	267.7	274	25.20	21.43	24.21	26.75	24.40	61.94
18-Aug	10-Dec	54.1	6.5	221.8	230.7	136.2	135	243.1	246.7	264.3	261	274	22.92	13.74	24.91	26.60	22.04	60.94
27-Aug	15-Sep	53.8	6.60	132	132.5	132.5	135.2	167.2	169.4	139.7	141.8	274	13.47	13.63	17.14	14.34	14.65	56.93
1-Sep	15-Sep	54	6.60	81.3	81.3	81.6	82.3	63	64.5	70.6	70.9	274	8.25	8.32	6.47	7.18	7.55	50.44
10-Sep	15-Sep	54	6.6	93.6	93.6	93.9	92.4	92.5	92.8	81.8	81.5	274	9.50	9.45	8.29	8.29	9.16	52.33
10-Sep	10-Dec	54.1	6.5	87.3	83.7	89.2	86.5	94.3	91.8	87	88	274	8.66	8.90	9.43	8.86	8.96	52.11
29-Sep	10-Dec	54.1	6.5	494.5	493.4	597	583.8	624.6	615	492.2	490.9	274	50.03	59.80	62.78	49.79	55.60	70.02
20-Oct	10-Dec	54.1	6.5	395.6	392.4	408	403.1	568.2	554.4	459.6	450.6	274	39.91	41.08	56.86	46.10	45.99	68.16
29-Oct	10-Dec	54.1	6.5	174.2	172.3	206.1	203.2	187.9	180.2	128.6	129.7	274	17.55	20.73	18.64	13.08	17.50	58.68
<b>Trusdom #2(Osprey Pt.)</b>																		
23-Jun	1-Jul	52.6	7	202.7	200	239.1	239.2	202.7	200	239.1	239.2	274	20.98	24.92	20.98	24.92	22.95	61.34
30-Jun	1-Jul	52.6	7	468.3	465.6	450.3	450.2	447.4	447	460.6	461.2	274	48.65	46.91	46.59	48.02	47.54	68.48
7-Jul	8-Jul	51.5	6.8	147.2	147.7	205.4	200.5	154.6	158.3	127.5	127.7	274	15.69	21.60	16.65	13.58	16.88	58.32
15-Jul	23-Jul	51.3	6.8	220	221.5	171.2	171.9	226.8	226.7	189	188.9	274	23.58	18.33	24.22	20.18	21.58	60.73
22-Jul	23-Jul	51.3	6.8	98.2	98.5	61	61.4	153.9	153.8	140.4	140.1	274	10.51	6.54	16.43	14.98	12.12	55.07
28-Jul	29-Jul	50.2	6.8	51.4	51.8	76	75.9	74.1	74.2	93.4	92.3	274	5.63	8.29	10.14	10.14	8.04	51.05
4-Aug	13-Aug	52.9	6.8	44.5	46.2	63	64.9	59.9	60.6	39.7	42.9	274	4.70	6.62	6.24	4.28	5.46	47.25
11-Aug	13-Aug	52.9	6.8	123.1	123.9	143.1	144.2	62	63.2	95.6	96.8	274	12.79	14.88	6.48	9.97	11.03	54.15
18-Aug	15-Sep	53.8	6.6	238.2	240.8	276.9	274.6	275.7	285.1	328	339.3	274	24.40	28.09	28.56	33.99	28.76	63.55
27-Aug	15-Sep	53.8	6.6	132.6	134	149.2	150.1	147.7	148.9	153.8	152.3	274	13.58	15.24	15.11	15.59	14.88	57.09
1-Sep	15-Sep	54	6.6	72.2	70.8	115.2	113.5	96.6	96.2	128.9	127.6	274	7.26	11.60	9.78	13.02	10.41	53.59
10-Sep	15-Sep	54	6.6	118.9	119.7	152.8	150.3	105.8	106.6	115.3	117.6	274	12.11	15.63	10.78	11.82	12.58	57.09
29-Sep	10-Dec	54.1	6.5	683.4	662.4	520.2	510.6	492.6	490.2	448.9	466.1	274	68.16	52.21	49.78	46.34	54.12	69.75
20-Oct	10-Dec	54.1	6.5	732.6	725.4	702	673.8	716.4	698.4	657	646.8	274	73.84	69.68	71.66	66.03	70.30	72.32
29-Oct	10-Dec	54.1	6.5	333.4	333.3	333.2	333	476.1	477.4	459	455.1	274	33.77	33.74	48.29	46.30	40.52	66.92

# Appendix J: Chlorophyll-a data

<b>Trustom #3(Site 1.)</b>																		
30-Jun	1-Jul	52.6	7	303.3	310.9	301.4	298.7	305.2	307.1	333.2	331.2	274	31.99	31.26	31.90	34.61	32.44	64.73
7-Jul	8-Jul	51.5	6.8	411.1	402.8	377.1	377.7	356.3	352.4	324.6	329.3	274	43.30	40.16	37.71	34.79	38.99	66.54
15-Jul	23-Jul	51.3	6.8	365.4	365.6	370.5	371.1	337	337.5	419.3	419.2	274	39.04	39.61	36.03	44.79	39.87	66.76
22-Jul	23-Jul	51.3	6.8	216.2	216.6	196.9	198	222.3	224.2	318.4	318.3	274	23.12	21.09	23.85	34.01	25.52	62.38
28-Jul	29-Jul	50.2	15.1	274.5	273.1	147.1	146.6	149.6	149.3	162.4	161.8	274	29.89	16.03	16.31	17.70	19.98	59.98
4-Aug	13-Aug	52.9	6.8	209.3	210.7	210.7	214.4	172.9	174.6	222.6	223.6	274	21.75	22.02	18.00	23.11	21.22	60.57
11-Aug	13-Aug	52.9	6.8	188	189.2	670.2	695.4	326.4	327.8	309.3	308.3	274	19.54	70.73	33.88	31.99	39.04	66.55
18-Aug	15-Sep	53.8	6.6	476.1	481.3	376	372.2	426.7	470.1	480.1	484.4	274	48.76	38.11	47.74	49.12	45.93	68.14
27-Aug	15-Sep	53.8	6.6	471	476.6	449.1	453.8	426.7	432.1	480.8	469.6	274	48.26	45.98	43.74	47.38	46.34	68.23
1-Sep	15-Sep	54	6.6	178.6	181	202.3	203	426.6	427.4	426.6	437.5	274	18.25	20.57	43.33	43.85	31.50	64.44
10-Sep	15-Sep	54	6.6	58.8	59.3	24.8	25	56.6	56.5	62	62.2	274	5.99	2.53	5.74	6.30	5.14	46.66
<b>Trustom #4(Site 2.)</b>																		
30-Jun	1-Jul	52.6	7	926.4	934.8	561	582.6	670.8	678	789	787.2	274	96.95	59.57	70.26	82.11	77.22	73.24
7-Jul	8-Jul	51.8	6.8	360.7	413.2	522.6	520.8	437	444.4	205.8	210.3	274	40.94	55.19	46.62	22.01	41.19	67.08
15-Jul	23-Jul	51.3	6.8	207	206.1	184.3	184.7	223.2	223.6	248.9	248.3	274	22.06	19.71	23.86	26.56	23.05	61.38
22-Jul	23-Jul	51.3	6.8	417.8	417	360.6	360.7	338.5	337.5	343	344.5	274	44.59	38.53	36.11	36.72	38.98	66.54
28-Jul	29-Jul	50.2	15.1	167.1	167	220.9	221.9	277.9	277.4	120.6	121.2	274	18.24	24.17	30.31	13.20	21.48	60.69
4-Aug	13-Aug	52.9	6.8	57.6	59.7	73	74.9	63.9	65.5	79.4	79	274	6.08	7.66	6.70	8.20	7.16	49.91
11-Aug	13-Aug	52.9	6.8	134.9	136	66.3	66.2	67	67.3	96.3	96	274	14.03	6.86	6.96	9.96	9.45	52.64
<b>Trustom #5(Site 3.)</b>																		
30-Jun	1-Jul	52.6	7	446.8	446.5	395.6	395.8	410.3	408.2	433.9	429.8	274	46.53	41.23	42.64	44.99	43.85	67.69
7-Jul	8-Jul	51.8	6.8	164	165.1	217.6	220.8	190.9	181.6	163.6	168.8	274	17.41	23.19	19.70	17.58	19.47	59.73
22-Jul	23-Jul	51.3	6.8	143.7	138.5	150.4	150	123.8	123.4	89.6	90.3	274	15.07	16.04	13.20	9.61	13.48	56.12
28-Jul	29-Jul	50.2	15.1	103.5	104	129.9	129.9	73.9	79.2	107.5	107.8	274	11.33	14.18	8.36	11.75	11.40	54.48
11-Aug	13-Aug	52.9	6.8	268.2	270.7	252.2	251.2	290.3	289.2	221.4	223.3	274	27.91	26.07	30.02	23.03	26.76	62.84
18-Aug	15-Sep	53.8	6.6	248	249.4	221.6	230.3	174.4	178.5	243.7	243	274	25.33	23.01	17.97	24.79	22.78	61.26
27-Aug	15-Sep	53.8	6.6	136.9	139.3	149.8	152.2	137.5	136.9	167	165.5	274	14.07	15.38	13.98	16.93	15.09	57.22
1-Sep	15-Sep	54	6.6	80.1	79.7	54.8	55.7	68.4	67.7	57.7	58.3	274	8.11	5.61	6.91	5.89	6.63	49.15
10-Sep	15-Sep	65	6.6	91.1	91.2	84.5	86	102.2	103.7	80	82.6	274	7.68	7.19	8.68	6.85	7.60	50.50
<b>Trustom #6(Site 4.)</b>																		
7-Jul	8-Jul	51.8	6.8	561.6	559.8	333	329.4	663.6	660.6	331.8	331.2	274	59.32	35.04	70.04	35.07	49.87	68.95
<b>Trustom #7(Site 5.)</b>																		
18-Aug	15-Sep	53.8	6.6	243.1	424.8	250	250.9	234.2	238.9	261.6	264.5	274	34.02	25.51	24.09	26.79	27.60	63.15
27-Aug	15-Sep	53.8	6.6	118.2	121.9	158.7	162.2	140.3	139.4	147.9	148.4	274	12.23	16.34	14.24	15.09	14.48	56.82
1-Sep	15-Sep	54	6.6	67.9	66.2	74.6	74.7	79.7	79.7	78.7	76.1	274	6.80	7.58	8.09	7.85	7.58	50.47
10-Sep	15-Sep	54	6.6	110.4	110.1	116.8	116.3	73.5	72.9	111.3	111	274	11.19	11.83	7.43	11.28	10.43	53.60
<b>Soil Survey Sites</b>																		
21-Jul	23-Jul	51.3	6.8	415.9	417.9	691.2	688.2	205.5	208.3	323	326.8	274	44.53	73.68	22.10	34.71	43.75	67.67
21-Jul	23-Jul	51.3	6.8	151.8	150.8	146.3	146.5	169.3	169.4	133.4	133.3	274	16.16	15.64	18.09	14.24	16.03	57.82
21-Jul	23-Jul	51.3	6.8	122.3	121.8	124.2	124.2	140	198.8	123	123.6	274	13.04	13.27	18.10	13.17	14.39	56.76
21-Jul	23-Jul	51.3	6.8	189.4	188.4	149.8	149.5	118.4	118.7	155.4	155	274	20.18	15.99	12.66	16.58	16.35	58.01
21-Jul	23-Jul	51.3	6.8	136	135.7	141	140.9	148.3	148.2	125.3	125.4	274	14.51	15.06	15.84	13.39	14.70	56.97
21-Jul	23-Jul	51.3	6.8	128	127.9	104.1	105.9	140	139.7	136.6	136.5	274	13.67	11.22	14.94	14.59	13.60	56.21
21-Jul	23-Jul	51.3	6.8	152.3	152.4	69.7	69.4	170	169.8	145.5	146.3	274	16.27	7.43	18.15	15.59	14.36	56.74
21-Jul	23-Jul	51.3	6.8	174.3	174	150.7	151.2	115.2	114.9	184.3	184.2	274	18.60	16.12	12.29	19.68	16.68	58.20