Environment

Prepared for:
Town of Mashpee
Mashpee, Massachusetts

Prepared by:
AECOM
Westford, MA
60140124
July 19, 2010

Santuit Pond Diagnostic Study
Mashpee, Massachusetts

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Prepared By Sarah MacDougall

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Executive Summary

Santuit Pond is a shallow kettlehole pond in Mashpee, Massachusetts. Listed on the “Massachusetts List of Impaired Waterbodies” for nutrients and noxious aquatic plants, Santuit Pond suffers from poor water quality due to eutrophication (i.e., overabundant nutrient levels) and the pond does not fully support the desired water uses including contact recreation and aquatic life support. Symptoms include low water transparency, frequent and dense cyanobacteria blooms, and periodic loss of oxygen in bottom waters.

In 2009, the Town of Mashpee commissioned a diagnostic/feasibility study of Santuit Pond to document current conditions and to characterize and quantify the phosphorus sources. This report provides the results of the AECOM diagnostic study and presents available results from complementary studies in 2009. This report also estimates phosphorus loading from the quantifiable sources and suggests an in-lake phosphorus target to address Total Maximum Daily Load requirements. Finally, this report recommends feasible techniques to reduce external and internal phosphorus loading in order to improve water quality and support primary contact and aquatic habitat uses

Diagnostic Assessment

Santuit Pond is a 170 acre Great Pond with a maximum depth of approximately 9 ft and a volume of 870,974 m3. Precipitation and groundwater are the dominant sources of water to Santuit Pond, with only a small fraction originating from overland runoff in the 1,250-acre sandy watershed. The average flushing rate is approximately 3 times per year resulting in a residence time of 0.33 years (120 days). The pond has substantial development around the perimeter, but most of the shoreline has a native vegetation buffer due to steep slopes requiring residences to be built further from the water. The pond has a popular warmwater fishery with a public access ramp at the Mashpee Town Landing.

Historically, Santuit Pond was a moderately enriched, clear water pond with abundant aquatic vegetation. Extensive summer and winter algal blooms became more prevalent in the late 1990s and 2000s. The Mashpee Board of Health posted health advisories in 2006 and 2008 due to low clarity and the presence of toxic producing cyanobacteria. The Massachusetts Department of Public Health posted a health advisory in 2009 due to presence of potentially toxic cyanobacteria.

The 2009 AECOM investigations, along with complementary studies by the Mashpee Environmental Coalition, the Mashpee Wampanoag Tribe/Town of Mashpee Collaboration, the Massachusetts Department of Environmental Protection, and the Massachusetts Department of Public Health, indicate that Santuit Pond is a highly nutrient rich (eutrophic) pond. As is characteristic of eutrophic waterbodies, Santuit Pond has high phosphorus concentrations, low Secchi disk transparency, and high chlorophyll a concentrations. Phosphorus is the nutrient of concern in Santuit Pond as it is the limiting nutrient in most freshwater systems. The shallow pond can weakly stratify in the summer, but mixes frequently. Although the frequent water column mixing replenishes dissolved oxygen in the bottom waters of Santuit Pond, oxygen depletion is observed in the bottom waters. This oxygen depletion in the bottom waters is likely due to the high oxygen demand of the sediments rich in organic matter and settled algal cells. These periods of oxygen depletion allow the phosphorus-rich soft sediments to release available phosphorus in a process termed “internal loading.”

Internal loading accounts for the largest single source of phosphorus in Santuit Pond at an estimated 297 kg/yr or 78% of the total phosphorus load. Other sources of phosphorus include direct precipitation, surface runoff, groundwater, active cranberry bogs, septic systems, and waterfowl. Direct precipitation provides approximately 5% of the annual phosphorus load or 17 kg/yr. Surface runoff and groundwater contribute 18 kg/yr (5%) and 12 kg/yr (3%), respectively. The active cranberry bogs contribute an estimated 13 kg/yr or 3% of the total load. Septic systems contribute 19 kg/yr or 5% of the annual phosphorus budget. Waterfowl account for only 1% of the annual phosphorus load (3 kg/yr). The total phosphorus loading to Santuit Pond is estimated with a water quality model to be 380 kg/yr, which translates to an average annual in-lake phosphorus concentration of 80 µg/L. The predicted in-lake phosphorus concentration closely matches the 2009 average observed in-lake concentration.

Restoration Options

The management of Santuit Pond to attain restoration goals should target both internal and external load reductions through in-lake and watershed actions. The primary goal of a restoration management plan is to improve water quality to minimize the frequency of algal blooms. An in-lake total phosphorus target of 15 µg/L is recommended to obtain the desired primary contact and aquatic habitat uses. Given the current high phosphorus loads in Santuit Pond, it may be difficult to attain an in-lake concentration of 15 µg/L, but it is possible. AECOM recommends an aggressive phosphorus management strategy that works toward a target of an in-lake TP concentration of 15 µg/L. Improvements in water quality will occur at higher in-lake concentrations; TP concentrations below the permissible limit (Vollenweider, 1975; 1978) of 28 µg/L will certainly reduce the frequency of algal blooms and improve overall water quality.

Phosphorus source reduction will be most successful with a comprehensive approach rather than a single source approach. Although internal loading is the largest source at 78% of the total load, reducing other phosphorus inputs is vital to successfully restoring Santuit Pond. Aimed at providing long-term protection of Santuit Pond for future generations, external source reduction include 1) **watershed management** including stormwater management,fertilizer use, and retention of existing vegetated buffer zones; 2) **septic system maintenance and upgrade** including education of the residents and detailed septic surveys; 3) **cranberry bog management** including enforcement of best management practices and the use of low phosphate fertilizers; and 4) **waterfowl control** including discouraging feeding by residents, and maintaining riparian areas at the shoreline for reduced pollutant input to Santuit Pond.

Three in-lake options were evaluated for their feasibility in reducing internal phosphorus loading in Santuit Pond: 1) dredging, 2) artificial circulation, and 3) phosphorus inactivation.

Dredging

Dredging provides a very direct way of removing a significant amount of phosphorus mass from the pond. Hydraulic or wet mechanical dredging is feasible due to the shallow nature of the pond. However, this technique is not well suited for Santuit Pond due to the difficulty in locating a suitable mobilization point, the lack of readily accessible dewatering and disposal areas, and the extremely high cost of dredging and permitting. Also, the degree of reduction in internal loading is uncertain based on available information. If Santuit Pond were dredged, costs would potentially approach $12-16 million. Environmental permitting would be extensive and there may be a large set of conditions and extensive monitoring costs if dredging is permitted. Taking into account the technical difficulties and high costs, AECOM does not recommend dredging for the restoration of Santuit Pond.

Artificial Circulation

Whole lake circulation involves the introduction of more oxygen into the bottom waters of ponds to limit the amount of phosphorus recycling, thereby controlling algal blooms. Santuit Pond frequently mixes naturally due to its weak thermal stratification. Artificial circulation would be a potential option for minimizing oxygen depletion in the bottom waters during calm periods. The two types of artificial circulators considered are subsurface diffusers and solar power surface circulators. The solar power surface circulators may be the most appropriate artificial circulation technique for Santuit Pond due to low maintenance needs. However, while artificial circulation is feasible in Santuit Pond, if the circulators are insufficiently spaced, anoxic zones will persist and internal loading will continue to occur. Also, the presence of surface circulators may interfere with recreation as the physical structures pose navigational hazards. There is some uncertainty regarding the amount of predicted improvement, so the reduction in internal load is conservatively estimated at 67%. The costs associated with purchasing, installing and maintaining solar artificial circulation over a 15 year period is estimated at $215,000-315,000. Costs associated with a subsurface diffuser will likely range from $210,000-420,000 over a 15 year periods. Also, environmental permitting is not expected to be complex. AECOM recommends further consideration of artificial circulation as an in-lake restoration technique for Santuit Pond.

Nutrient Inactivation

Nutrient inactivation by alum treatment involves short-term phosphorus precipitation (flocculation) during or just after application, but mainly aims to achieve long term control of phosphorus release from lake sediments. Nutrient inactivation would be a very effective option to reduce internal phosphorus recycling in Santuit Pond. There is a potential for short-term toxicity with the alum treatment if the pH is not maintained between 6 and 8 during the application. AECOM conservatively estimates that a phosphorus inactivation treatment will reduce the internal load by 75%. Reductions in algal blooms and increases in the water clarity have been observed following alum treatment at nearby ponds, including Hamblin, Ashumet, and Long Pond. Longevity associated with this technique was conservatively estimated at 15 years but is likely longer. Longevity is inversely proportional to the amount of future loading the pond receives. The greater external loading of phosphorus, the shorter the effective lifespan of an alum treatment. The cost for nutrient inactivation at Santuit Pond was estimated at approximately $180,000-200,000. Environmental permitting is not expected to be complex. AECOM recommends further consideration of nutrient inactivation for restoration of Santuit Pond.

1.0 Introduction

Santuit Pond, a 170-acre shallow kettlehole pond, is a Great Pond located within the Town of Mashpee, in Barnstable County, Massachusetts (Figure 1-1). Santuit Pond provides important recreational and ecological features to the local residents. There is substantial residential housing along the perimeter of the pond. Most of the residential development along the eastern and western banks of Santuit Pond is buffered by vegetated steep slopes. There are two active cranberry bogs located on Santuit Pond: Baker's Bog on the north shore and Brackett's Bog on the east shore. The Town of Mashpee purchased the historic cranberry bogs on the east and south shores of Santuit Pond in a 200-acre acquisition called the "Santuit Pond Preserve." The Mashpee Town Landing public boat launch provides fishing and boating opportunities. The only pond outlet, the Santuit River is located on the southern end of pond and also serves as a herring run. The Santuit River flows into Popponesset Bay, which is impaired by excessive nutrients (MDEP, 2008).

Santuit Pond is a very nutrient rich (eutrophic) pond with characteristic high phosphorus concentrations and cyanobacteria blooms. It is a considered a Category 5 water body on the "Massachusetts Integrated List of Waters" published by the Massachusetts Department of Environmental Protection (MDEP)(MDEP, 2008). Massachusetts lists each waterbody in one of five categories ranging from 1 (unimpaired and not threatened for all designated uses), to 5 (impaired or threatened for one or more uses and requiring the development of a Total Maximum Daily Load (TMDL)). The U.S. Environmental Protection Agency (USEPA) must approve the TMDLs created for Category 5 waterbodies. For Santuit Pond, the pollutants needing TMDL calculations are nutrients and noxious aquatic plants (MDEP, 2008). MDEP considers toxin-producing cyanobacteria blooms to be a "noxious aquatic plant" impairment. The pond has a low Secchi disk transparency (SDT) level that falls well below the State Sanitary Code guidance criterion of 1.2m (4 ft) for swimming. Santuit Pond Estates on the eastern shore maintains a private beach. The surface total phosphorus (TP) concentrations measured in 2009 at the deep spot off Bryants Neck ranged from 40-140 ug/L, which is very elevated compared to the Cape Cod Commission regional phosphorus criterion of 10 ug/L.

Historically, Santuit Pond was a moderately enriched, clear water pond with abundant aquatic vegetation. Extensive summer and winter algal blooms became more prevalent in the late 1990s and 2000s. The Mashpee Board of Health posted health advisories in 2006 and 2008 due to low clarity and the presence of potentially toxic cyanobacteria. The Massachusetts Department of Public Health (MDPH) posted a health advisory in 2009 due to presence of toxic producing cyanobacteria. One private beach closed due to the poor water quality conditions.

In response to apparent declining pond water quality, residents formed the Friends of Santuit Pond. In 2009, the Town of Mashpee contracted AECOM to conduct a diagnostic study of the pond to identify current phosphorus sources causing the extreme algal blooms and to recommend management strategies that would effectively rehabilitate Santuit Pond to meet desired uses. Several other organizations also conducted studies on Santuit Pond in 2009, including the Mashpee Environmental Coalition (MEC), Mashpee Wampanoag Tribe and the Town of Mashpee Collaborative Water Quality Monitoring Program (MWT-M-WQMP), MDEP, and MDPH.

AECOM used historical data as well as the results of the 2009 studies to provide the basis for the evaluation and recommendation. This report summarizes the results of the evaluation and outlines the plan of action to restore Santuit Pond to improve water quality and increase ecological, recreational, and aesthetic functions of this waterbody.

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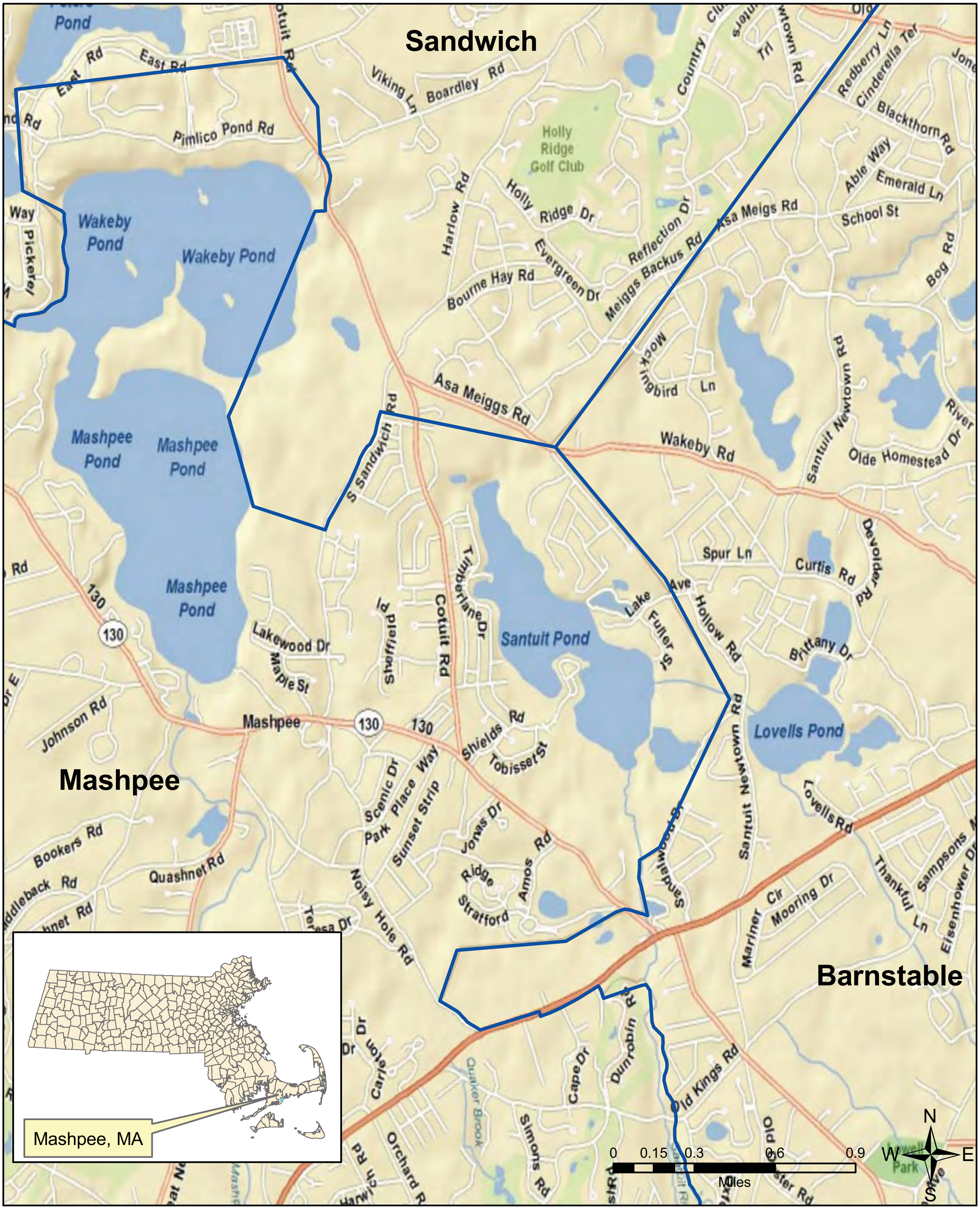

Figure 1-1. Santuit Pond locus map

2.0 Review of Existing Data and Historical Information

2.1 Introduction

AECOM reviewed existing data and information for Santuit Pond in order to integrate the historical information with the field study results for a comprehensive picture for pond assessment and restoration effort. The existing data research focused on water quality, fisheries, and lake/watershed characteristics.

2.2 Historic Water Quality

The Water Resources Office of the Cape Cod Commission (CCC) collected the earliest water quality records in 1948 (CCC, 2003), which indicated no thermal stratification and a well-oxygenated water column. The decline in water quality in Santuit Pond became first noticeable in the 1980s. Spurred by resident concern, numerous studies in the 1980s indicated signs of increasing nutrient enrichment. In the Massachusetts Division of Water Pollution Control's 1980 water quality sampling effort, phosphorus concentration measurements were 350 µg/L at the surface and 700 µg/L one-foot off the bottom (DWPC, 1984). These values are not consistent with results from the Aquatic Control Technology (ACT) 1989 study, which observed surface water phosphorus concentrations of 30 µg/L (ACT, 1989). It is AECOM's opinion that the 1980 values were 35 and 70 µg/L rather than the reported 350 and 700 µg/L. The August 12, 1980 sampling event also indicated anoxic conditions at 2 m (6.6 ft). This decline in dissolved oxygen near the pond bottom is likely due to oxygen demand from decomposers in the water column and the sediments and is indicative of a productive waterbody. Santuit Pond appeared to be relatively clear in the 1980s. In 1980, the SDT was measured at 3.5 ft and in 1987 the result was >7ft. The Division of Water Pollution Control's report classified Santuit Pond as "mesotrophic" or moderately enriched (DWPC, 1984).

UMass Dartmouth Cape Cod Pond and Lake Stewardship program (PALS) volunteer monitoring program began in 2001, and the volunteer data, as shown in Table 2-1, indicate very high phosphorus concentrations during the 2000s (PALS, 2009). The lowest surface and bottom phosphorus concentrations were observed in 2001 (17.3 µg/L and 18.9 µg/L, respectively). The highest surface and bottom water phosphorus concentrations were observed in 2004 (both 96 µg/L). Water transparency was also low in the 2000's, especially in the mid to late 2000's. The SDT in 2001 was 7.5 ft, while fluctuating between 1 and 3.3 ft in 2008.

Table 2-1 PALS Data 2001-2008

Site Description	Stat	TN	TP	Alkalinity	Chl *a*	SDT
		mg/L	µg/L	mg/L	µg/L	ft
Bryant's Neck Deep Spot-Surface (0.5 m)	Mean	1.1	55	17.5	30.8	3.0
	Median	1.0	56	15.2	21.7	2.5
	Min	0.5	17	1.7	2.2	1.0
	Max	1.8	96	29.1	77.5	7.5
	n	9	9	9	8	38
Bryant's Neck Deep Spot-Bottom	Mean	1.0	60	17.4	33.5	
	Median	1.1	60	14.8	23.4	
	Min	0.5	19	1.7	2.7	
	Max	1.6	96	28.3	75.8	
	n	10	11	9	8	

This decrease in clarity corresponded to the shift from an aquatic macrophyte dominated pond to an algal dominated one. In fact, a 1948 Massachusetts Division of Fish and Wildlife (DFW) fish survey could not be completed due to the dense aquatic plant growth (MEC, 2009). Potamogeton robbinsii (Robbin's Pondweed) and Vallisneria sp. (Tape Grass) dominated the shoreline in 1980 (DWPC, 1984). According to an August 1989 ACT study, the plant community did not change greatly from 1980 except that Elodea canadensis (Waterweed) was the co-dominant aquatic plant species (ACT, 1989). All of those plant species are common in nutrient rich waters. The early studies noted a low density phytoplankton community composed of green algae and cyanobacteria. In contrast, algae dominated the water column in the mid to late 2000's as PALS volunteers observed high chlorophyll a (chl a) concentrations (an indicator of algal growth). Chl a concentrations in 2001-2004 ranged from 2.2 to 6.4 µg/L while in 2005-2008 the concentrations ranged from 32 to 77.5 µg/L (PALS, 2009).

2.3 Historic Fisheries

Santuit Pond is one of the most productive Cape Cod ponds and has historically provided an excellent warmwater fishery. Historical records from the DFW date back to August 17, 1911 when a fish survey indicated the presence of *Perca flavescens* (yellow perch), *Morone Americana* (white perch), *Lepomis auritus* (sunfish), *Esox niger* (chain pickerel), *Ameiurus nebulosus* (brown bullhead catfish), and *Clupea harengus* (herring) (DFW, 2007; MEC, 2009). The DFW stocked *Micropterus dolomieu* (smallmouth bass) and white perch from 1831 to 1947. In addition to yellow and white perch, an August 1958 fish survey found *Lepomis gibbosus* (pumpkinseeds),*Lepomis macrochirus* (bluegills), brown bullheads, *Notemigonus crysoleucas* (golden shiners), *Alosa pseudoharengus* (alewives), *Fundulus diaphanous* (banded killifish), chain pickerel, *Notopris bifrenatus* (bridle shiners), and *Catostomus commersoni (*white suckers). In 1982, DFW stocked Santuit Pond with *Esox masquinongy* (hybrid tiger muskies). The pond was last surveyed by the DFW in July 1998, at which time the following species were observed: *Micropterus salmoides* (largemouth bass), chain pickerel, golden shiner, pumpkinseed, alewife, yellow perch, brown bullhead, white sucker, white perch and *Anguilla rostrata* (American eel). Santuit Pond continues to serve as a herring run for alewife and *Alosa aestivalis* (blueback herring). Several other fish studies have been conducted on Santuit Pond. Yako et al. (2000) assessed the contribution of anadromous herring on largemouth bass growth. Yako et al. (2002) also studied the mechanisms that trigger anadromous herring migration. A United

States Geological Survey (USGS) study used Santuit Pond as a reference lake to determine the prevalence of raised lesions and liver neoplasms in brown bullheads in ponds contaminated by the Massachusetts Military Reservation (Baumann et al., 2002). The brown bullheads in Santuit Pond had higher presences of lesions and liver neoplasms compared to other reference ponds, but significantly lower presences than the contaminated pond, Ashumet Pond.

2.4 Sensitive Species

The 2008 Massachusetts Natural Heritage Endangered Species Project indicates that there is no priority or estimated habitat in Santuit Pond (MA NHESP, 2008). The north and south shoreline, however, is identified as having Massachusetts NHESP priority and estimated habitats (Figure 2-1). Priority habitat indicates the presence of a Massachusetts listed rare species. Estimated habitat is a subset of priority habitat and indicates the presence of rare wetland wildlife. The Eastern Box Turtle (*Terrapene carolina*) is a wetland species of special concern found in Mashpee and the priority and estimated habitat delineations are likely indicating its habitat in the wetlands found on the north shore and south shore of Santuit Pond.

2.5 Historic Watershed and Lake Characteristics

Santuit Pond served as a traditional Mashpee Wampanoag fishing and hunting ground (MEC, undated). The native tribes used the shoreline as a meeting spot and marketplace. English settlers homesteaded in the area in the late 1700s. Seasonal cottage settlement began in Mashpee in the 1920s and resulted in increased development along Santuit Pond in the 1970s to 2000s (MHC, 1984). Cranberry bog operations began after the 1830s and provided the primary economy of Mashpee in the 1930s. The cranberry bogs on Santuit Pond have been active since the early to mid 1900s. Prior to 2007, the bogs on the southern and eastern shores were also active cranberry operations. The towns of Mashpee and Barnstable along with the Commonwealth of Massachusetts purchased 200 acres on the eastern and southern shores of Santuit Pond, which includes the cranberry bogs, with funds from the Division of Fisheries Wildlife and Environmental Law Enforcement (MEC, 2009). The outlet to Lovells Pond on the southeast shore of Santuit Pond was also blocked in 2007.

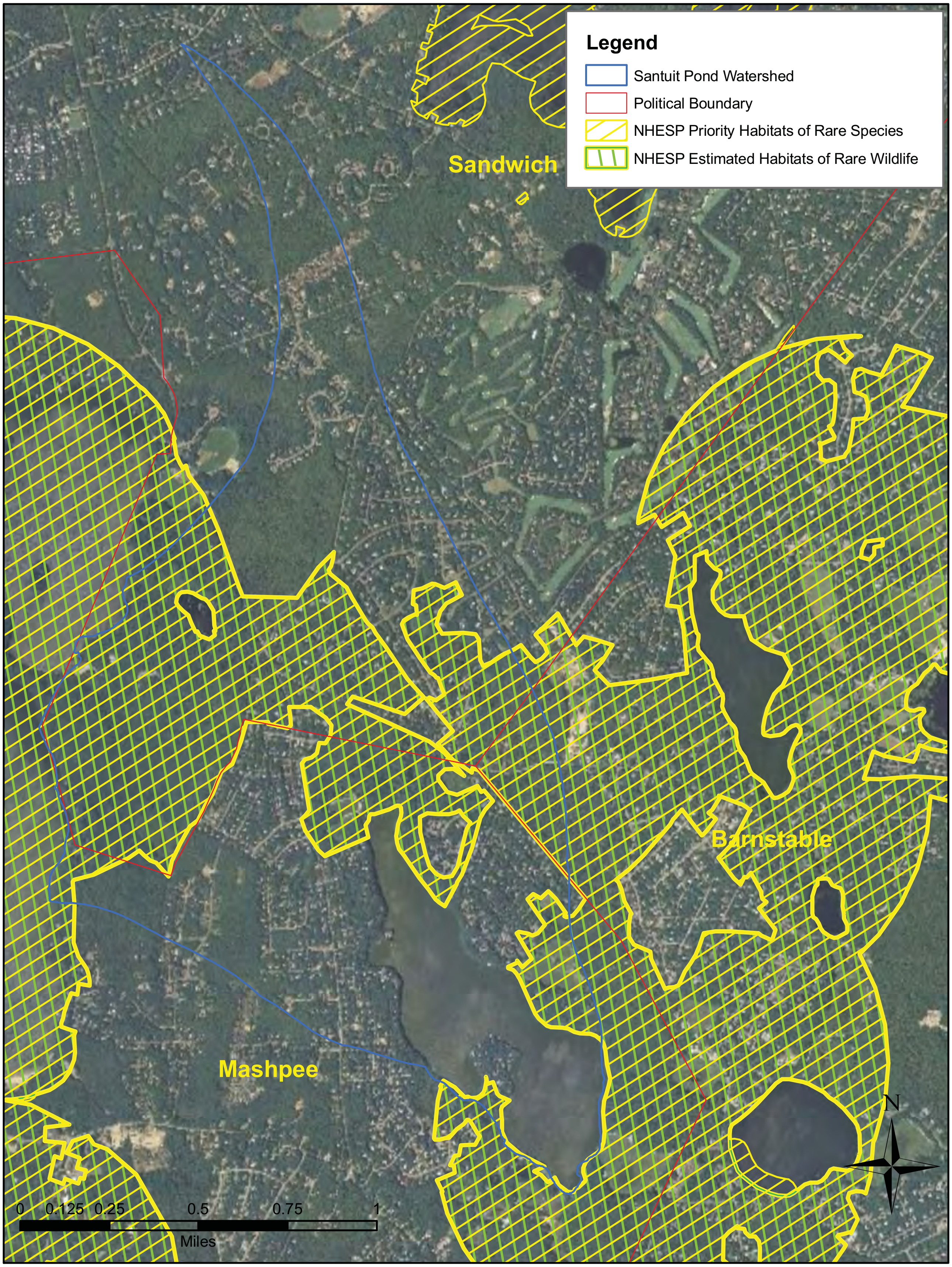

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Figure 2-1. NHESP priority and estimated habitats in Santuit Pond watershed.

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3.0 AECOM Field Investigations Methodology

In 2009, AECOM conducted extensive field investigations and sent water quality and sediment samples for laboratory analyses. The field surveys conducted include: 1) in-lake water quality, 2) interstitial littoral porewater (groundwater), 3) sediment quality, 4) aquatic macrophyte, 5) stormwater quality, and 6) cranberry bog flood water quality.

3.1 In-lake Water Quality Surveys

AECOM collected grab samples of pond water at the deepest location (~9 ft) off Bryants Neck and at the Town Landing (Figure 3-1) on four dates: July 29, 2009, August 26, 2009, October 1, 2009, and November 3, 2009. Surface water samples at the deep spot (SW-1S) and the Town Landing (SW-2S) were collected approximately 0.5 ft below the air-water interface thereby avoiding particles floating on the water surface. At the deepest location, AECOM collected grab samples in an alpha bottle at a depth of 8.5 ft (0.5 ft from the bottom) (SW-1B). SDT was taken at both locations (SW-1 and SW-2) on all four sampling dates. AECOM also collected two samples for laboratory chl a analysis at the deepest location (SW-1) on each of the four 2009 sampling dates: 1) an integrated sample of the photic zone, which is defined for this study as 2.5 times the SDT and 2) a grab sample at 8.5 ft, which is approximately the depth of the probe deployed by the MWT-M-WQMP. On August 26, 2009, a zooplankton sample was collected using a vertical zooplankton tow from 0-8.5 ft and preserved in isopropyl alcohol for later identification.

AECOM performed water column profiles on three of the four in-lake surveys by lowering an YSI® 600XL probe with a graduated cable throughout the water column. Due to an equipment malfunction, AECOM did not collect a water column profile for the August sampling round. In-situ measurements of temperature, dissolved oxygen, specific conductance, and pH were recorded at one-foot intervals at the deep location (SW-1) and at one-half foot below the surface at the Town Landing (SW-2).

AECOM prepared the chl a samples for shipment to the University of New Hampshire Cooperative Extension limnology laboratory by field filtering the water samples with 0.45 µm filters. A recorded volume of water was filtered and the filters were placed in aluminum foil and placed on ice. AECOM shipped the chilled filters overnight to the University of New Hampshire where they were frozen until analyzed. Water quality samples were placed on ice and shipped overnight to the state certified laboratory, Berkshire Enviro-Labs in Lee, Massachusetts to be analyzed for total phosphorus, dissolved phosphorus, nitrate-N, ammonium-N, total Kjeldahl nitrogen (TKN), dissolved iron, alkalinity, and total suspended solids. The water samples were field filtered with a 0.45 um filter for dissolved phosphorus and iron analyses for the October and November sampling rounds and filtered in the laboratory for the July and August sampling rounds. One duplicate sample and one field blank was collected for quality control purposes during each of the four survey rounds. Also, the MDEP provided two QC samples for total nitrogen and total phosphorus to test the accuracy and precision of the Berkshire Enviro-Labs - nutrient sample analyses. The laboratory methods and quality assurance/quality control procedures are discussed in the study Quality Assurance Work Plan (AECOM, 2009).

The results of the in-lake surveys are discussed in Section 5.1.

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Figure 3-1. Santuit Pond in-lake sampling locations and bathymetry

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3.2 Littoral Interstitial Porewater (Groundwater) Surveys

Groundwater monitoring was conducted on July 28, 2009 and October 1, 2009 in eight segments along the shoreline of Santuit Pond (Figure 3-2, Figure 3-3), and included measurement of both quality and quantity of seepage. In each of the eight segments up to three discrete samples were taken over the length of the segment along the shore using a littoral interstitial porewater (LIP) sampler following the methods of Mitchell et al. (1988, 1989). The LIP sampler was inserted into the sediment in the littoral zone approximately three feet from shore - to a depth of at least 1 ft. Porewater was then extracted with the aid of a hand-operated vacuum pump and an intermediate fluid-trapping vessel. Samples from each segment were composited into a single sample. Berkshire Enviro-Labs analyzed the composited samples for dissolved phosphorus, nitrate-N, ammonium-N, and dissolved iron. AECOM field filtered the October 1st samples for dissolved analyses while Berkshire laboratory filtered the July 28th samples immediately upon arrival. A duplicate sample was included in the July sampling round.

Seepage meters provided a means to quantify the amount of groundwater movement into or out of the pond during the July and October 2009 surveys by applying the methods of Mitchell et al. (1988). Seepage meters consisted of an inverted 55-gallon drum section with an attachment for a plastic bag containing a known volume of water (100 mL). Change in the initial volume of the water after a measured period of time was used to determine seepage per unit area. Extrapolation to the portion of the lake bottom covered with sand allowed estimation of total seepage.

The results of the groundwater surveys are described in Section 5.3.1.

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Figure 3-2. Santuit Pond littoral interstitial porewater (LIP) sampling and seepage meter locations July 29, 2009

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Figure 3-3. Santuit Pond littoral interstitial porewater (LIP) sampling and seepage meter locations October 1, 2009

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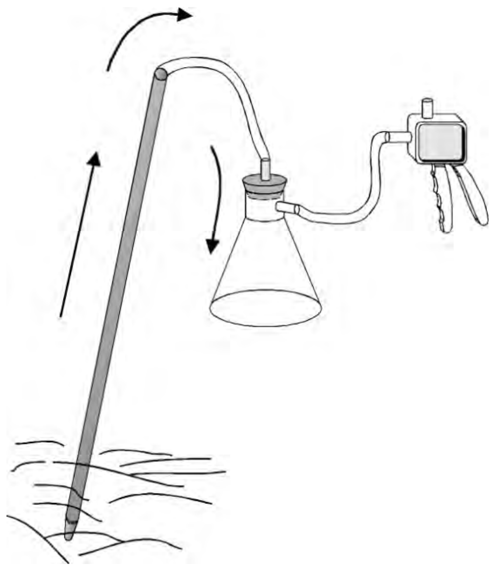
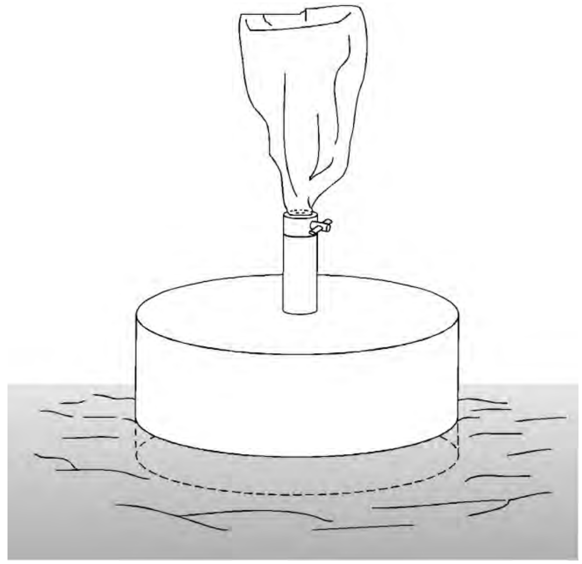


Littoral Interstitial Porewater Sampler



Seepage Meter

Figure 3-4 Pictures of Equipment Used to Collect Groundwater Quality and Quantity Data in Santuit Pond.

3.3 Sediment Survey

AECOM conducted a survey of the Santuit Pond sediments to determine the areal extent of the soft "muck" sediments covering the pond bottom. AECOM determined the sediment consistency (sand vs. muck) using a 10-ft tall metal pole and an underwater camera.

AECOM collected sediment samples with an Ekman dredge at four locations in order to represent a range of bottom substrate (Figure 3-5), from organic muck at the deepest location to sand in the shallower parts of the pond. The sediment samples were sent to Spectrum Analytical of Agawam, MA for analysis of grain-size, total phosphorus, loosely bound (or labile) phosphorus, iron bound phosphorus, total aluminum, total iron, and percent solids. Sediment phosphorus quantification was determined using a modification of the method of Rydin and Welch (1998, 1999). The laboratory methods and quality assurance/quality control procedures are discussed in the study Quality Assurance Work Plan (AECOM, 2009).

The results of the sediment survey are described in Section 5.2.

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Figure 3-5. Santuit Pond sediment sampling locations and soft sediment coverage

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3.4 Aquatic Macrophyte Survey

AECOM mapped the aquatic macrophyte (plant) community in Santuit Pond on August 26, 2009, which is during the period of peak plant biomass. The survey focused on macroscopic fully submerged, floating-leaved, and/or floating plants. Observations were made from a boat, viewing an area covering ~3 ft (~1 m) around each transect point with an AquaView submersible camera. AECOM collected data on plant cover, biovolume, and taxonomic composition at 66 points along the shoreline. Plant taxa were identified in situ, upon visual inspection, and was supplemented by sampling with a plant rake and subsequent identification as needed. For each plant species, AECOM recorded whether the species was present at trace (one or two sprigs), sparse (a handful of the plant), moderate (a few handfuls of the plant), or dense (many handfuls of the plant) levels at each site. Plant cover represents the total surface area covered in plants (2 dimensions). For cover, areas with no plants were assigned a “0,” areas with approximately 1-25% cover were assigned a “1,” a “2” for 26-50%, a “3” for 51-75%, a “4” for 76-99%, and a “5” for 100% cover. Like plant cover, a quartile scale was used to express plant biovolume, defined as the estimated volume of living plant material filling the water column (3 dimensions). For biovolume, 0=no plants, 1= 1-25%, 2=26-50%, 3=51-75%, 4=76-99%, and 5=100% of plants filling the water column.

The results of the aquatic macrophyte survey can be found in Section 5.4.1.

3.5 Stormwater Quality Survey

AECOM collected stormwater at five locations during the wet weather events on August 29, 2009 and November 20, 2009 (Figure 3-6). Both storm events were preceded by a 72-hr+ dry period without measurable precipitation. The August 29th stormwater sampling captured the remnants of Hurricane Bill, which produced 4.7 inches of heavy rain throughout the day. The November 20th storm event was smaller and amounted to 0.15 inches of rain over a four hour period. Since there are no active stormwater drainage outfalls discharging stormwater into the pond, AECOM collected samples from locations where sheetflow discharged into the pond or nearby wetlands during the storm events. Samples were sent to Berkshire Enviro-Labs where they were analyzed for total phosphorus, dissolved phosphorus, nitrate-N, ammonium-N, total Kjeldahl nitrogen, TSS, and alkalinity. One QC field blank was included for laboratory analysis during each sampling round. AECOM also collected field measurements of water temperature and pH.

The results of the wet weather sampling events are described in Section 5.3.2.

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Figure 3-6. Santuit Pond wet weather sampling locations
August 29, 2009 and November 20, 2009

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3.6 Cranberry Bog Flood Water Quality Surveys

AECOM sampled flood water quality from the two cranberry bogs on Santuit Pond to better quantify these potential surface water inputs to the pond. Berkshire Enviro-Labs analyzed the water samples for nutrients, TSS, bacteria, alkalinity, and specific conductivity. Field staff measured field water temperature and pH while collecting each sample. One QC field blank was included for laboratory analysis during each of the two sampling rounds. One QC field replicate was taken during the February bog sampling round.

On October 21, 2009, AECOM sampled the Baker bogs on the northern end of Santuit Pond when the bogs were flooded for weed control. The bog water was not being released at the time of sampling. Surface grab samples were collected at the following locations: 1) the upper bog, 2) the lower bog, and 3) the northern end of Santuit Pond away from the cranberry bog discharge. Figure 3-7 displays the Baker cranberry bog sampling locations.

On February 8th and 9th, 2010 AECOM collected a round of water quality samples from Brackett bog, located on the eastern shore of Santuit Pond. Surface grab samples were collected in the flood waters near the outlet and on the lakeside of the culvert. One surface grab was collected at the Town Landing for a reference sample. AECOM attempted to follow the UMass Cranberry Station protocol (DeMoranville, 2009) as closely as possible. However, AECOM collected only 2 grab samples (one during the middle of the release and one during the end of the release) instead of the recommended 3 grab samples (beginning, middle and end). The slow release of the winter frost flood began on approximately February 5th and ended on February 9th. The maximum flood water depth was observed at approximately 1.5 ft. Figure 3-8 displays the Brackett cranberry bog sampling locations.

The results of the cranberry bog sampling events are presented in Section 5.3.3.

\\uswesf001\jobs\Water\ProjectFiles\P130\13547001_Santuit Pond\GIS\Santuit_BakerCranberryBog_Sampling_Map.mxd

Figure 3-7. Sampling locations at Baker cranberry bogs, October 21, 2009

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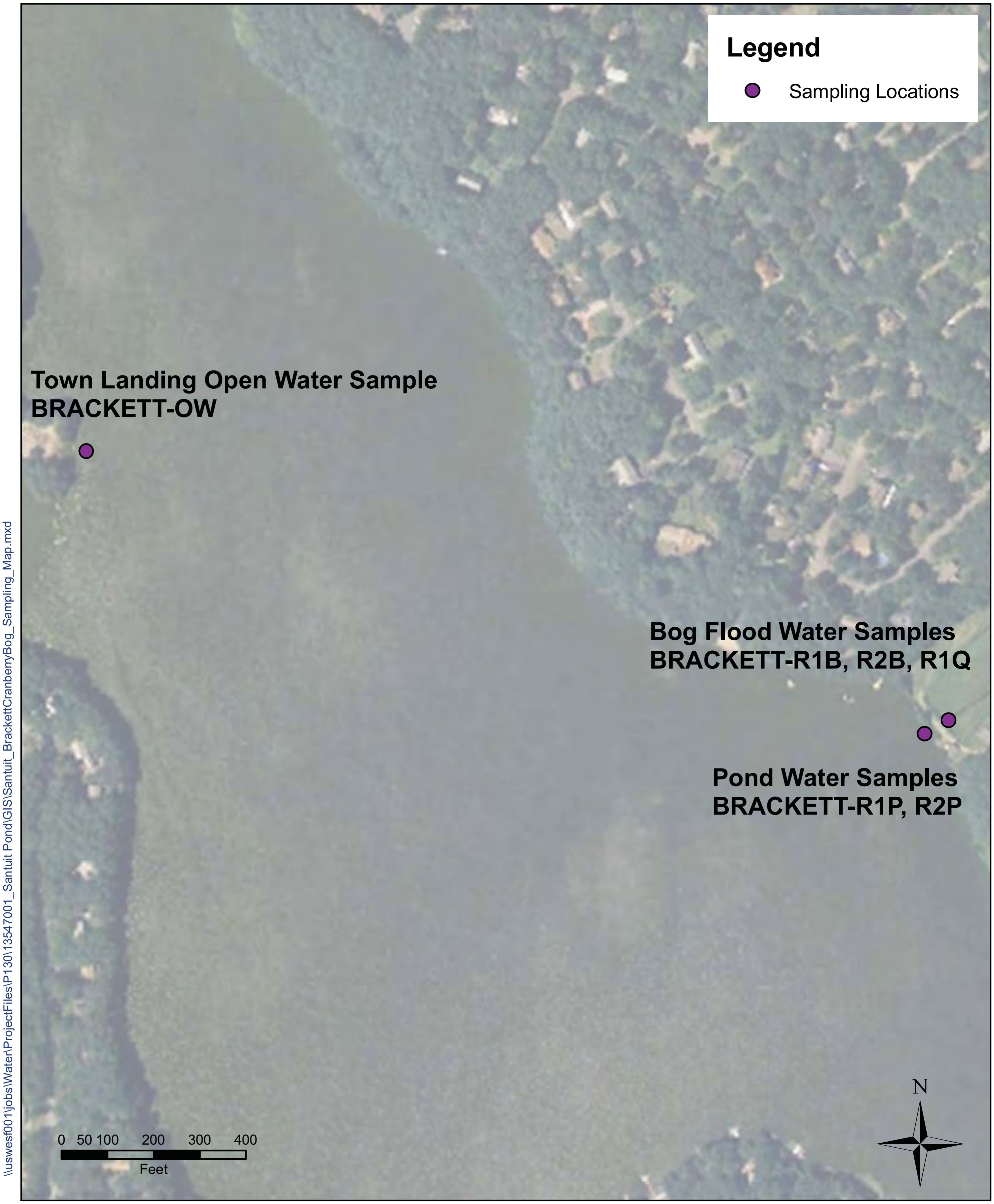


Figure 3-8 Sampling locations at Brackett cranberry bog, February 8 & 9, 2010

AECOM

3.7 Waterfowl Survey

Local Santuit Pond residents, Richard and Rita Gollin, recorded periodic Santuit Pond waterfowl counts by bird type from July through September 2009. The Gollins cumulatively made 18 observations.

The results of the waterfowl survey are included in Appendix A and used in the phosphorus modeling in Section 6.4.

4.0 Complementary Studies and Data Collection

The extensive cyanobacteria blooms in Santuit Pond attracted the attention of numerous local and state agencies/organizations. As a result, the AECOM diagnostic study is only one of many conducted on Santuit Pond in 2009. The publically available complementary study data can be found in Appendix B.

The Mashpee Environmental Coalition (MEC) continued volunteer monitoring through the UMass Dartmouth Cape Cod Pond and Lake Stewardship program (PALS) in 2009. Volunteers collected monthly water column profiles and SDT from May through October.

The Mashpee Wampanoag Tribe/Town of Mashpee Collaborative Water Quality Monitoring Program (MWT-M-WQMP) started monitoring Santuit Pond in October 2008. The Tribe purchased a YSI 6600 V2 sonde for unattended deployment in the pond (Figure 4-1). The sonde was deployed about one foot or less from the bottom in the deep area east of Bryants Neck. Parameters including temperature, specific conductivity, depth, pH, chl a, and dissolved oxygen (concentration and percent saturation) were recorded at fifteen minute intervals. The sonde chl a data is in-situ fluorescence. At each 15 minute interval, the sonde was set to take 24 chl readings and average them for the recorded number. Data reported is from October 16, 2008 to November 23, 2008; April 1, 2009-May 10, 2009; May 20, 2009-July 7, 2009; August 5, 2009-August 20, 2009; October 22, 2009-November 25, 2009. Water column profiles including depth, temperature, and dissolved oxygen (DO) were measured, and samples were collected for analysis near the probe and at other areas periodically from December 2008-June 2009. Samples were analyzed microscopically for phytoplankton identification and concentration in the Town's Water Quality Lab, and others were sent Barnstable County Health Laboratory for analysis of nitrate-nitrogen, total Kjeldahl nitrogen, ortho-phosphorus, and total phosphorus.

Massachusetts Department of Environmental Protection (MDEP) collected surface water samples at the deep spot off Bryants Neck on July 29, 2009, September 9, 2009, and September 30, 2009. The MDEP also conducted water column profiles and collected water samples for nutrient analysis in 2009. The MDEP laboratory analyzed the samples for TP and total nitrogen (TN).

Massachusetts Department of Public Health (MDPH) collected weekly surface water samples from June 18, 2009 to October 14, 2009 at the Town Landing for species identification, cell counts and microcystin toxin testing. The MDPH also collected the following parameters: temperature, dissolved oxygen (percent saturation and concentration), specific conductivity, salinity, chl a, urea, pH, turbidity, SDT, nitrate/nitrite-nitrogen, TKN, TP, and TSS.

Figure 4-1 Mashpee Wampanoag Tribe Natural Resources Department Director Quan Tobey with YSI 6600 V2 Sonde Deployed at Santuit Pond Bottom.

5.0 Study Results and Discussion

The results of the 2009 AECOM field investigations and complementary studies listed above provide a comprehensive assessment of current water and sediment quality of Santuit Pond. These data were used to determine the relative contribution of phosphorus sources to Santuit Pond. This section includes the results and discussion broken down by topic: in-lake water quality, sediment quality, groundwater quality, stormwater quality, and cranberry bog flood release water quality, and aquatic biota. Appendix A provides the AECOM data while Appendix B contains the 2009 complementary study data.

5.1 In-lake Water Quality

Water column profiles, Secchi disk transparency, and water chemistry all indicate the overall in-lake health of a waterbody. The results from the 2009 studies are presented and discussed below.

5.1.1 Water Column Profiles

The summer temperature and DO profiles for Santuit Pond shown in Figure 5-1 indicate that the pond does not strongly thermally stratify. Unlike deeper lakes, there is not a distinct warm water surface layer (epilimnion) and colder bottom layer (hypolimnion) with a rapid decline in temperature between the layers (thermocline). The AECOM July 29, 2009 profile, however, does indicate a small difference between surface and bottom water temperatures (weak thermal stratification). The PALs summer profiles show little sign of stratification, but the MWT-M-WQMP data do indicate weak thermal stratification in the June 29, 2009, July 31, 2009, and August 5, 2009 profiles. Strong winds encourage circulation of the water column because there is no strong thermal resistance to this circulation in shallow Santuit Pond. Periods of calm in the summer will allow weak thermal stratification to occur; this may explain why some summer profiles do show the weak stratification while others do not.

The surface DO readings were generally around 100% saturation, with supersaturation (>100%) common in the surface of the summer profiles. This supersaturation is likely due to algal oxygen production during photosynthesis. There is also evidence of a deep water column and/or sediment oxygen demand in the summer with a drop in DO concentrations/saturation in the bottom waters. The earliest profile to indicate deep water column oxygen depletion is the PALS June 14, 2009 profile. The AECOM October 1, 2009 profile is the latest profile to show oxygen depletion in the bottom waters. In most profiles oxygen depletion occurs below 8ft. The observed DO concentrations in the bottom waters rarely drop to anoxic levels (< 1 mg/L), but the difference between surface and bottom concentrations do indicate a deep water column and/or sediment oxygen demand. Some summer profiles (PALS August 7, 2009 and September 1, 2009) do not show oxygen depletion in the bottom waters. This may be due to the introduction of oxygen to the bottom waters through water circulation during windy periods. Also, the August 7, 2009 profile did not include values below 8 ft in the water column, which is the depth where oxygen depletion begins to be observed in the summer in most of the profiles.

The MWT-M-WQMP continuous monitoring sonde deployed approximately one foot off the bottom provides a unique look into the Santuit Pond DO dynamics. During the May 20, 2009-July 7, 2009, DO saturation fluctuated from supersaturation to substantial oxygen depletion (<20%) at a depth of

7.1 ft. This indicates that algal photosynthesis may be occurring in the bottom waters and sediment oxygen demand depletes the water column above a depth of 8 ft (as observed with the profiles). The first large drop in DO occurred on May 30, 2009 2:46 EST with a saturation of 29.5%. Figure 5-2, a depiction of DO saturation dynamics from May 29-June 1, 2009, indicates that DO saturation generally decreases during the night and increases during the day (with some lag time). During daylight, photosynthesis supersaturates the water column with DO. The oxygen demand is observed at night when respiration continues after photosynthesis ceases. The increase in pH during DO supersaturation further suggests that the fluctuation is due to photosynthesis. This diurnal DO depletion is found throughout the summer (end of May-August). Records for September are not available, but it is expected that a similar trend would be observed.

Comparing the MWT-M-WQMP sonde DO record to the average wind speed at Otis Air Force Base suggests the influence of water column circulation on DO dynamics (Figure 5-3). The greatest drops in oxygen saturation from May 20-July 7, 2009 tended to occur during times with the lowest average wind speed and thus calmest periods. This trend suggests that the wind actively circulates the pond water and replenishes oxygen in the bottom waters. The greatest oxygen depletion is observed during the calmest periods because the atmospheric oxygen is not being actively mixed into the bottom waters.

The DO dynamics are tied to phosphorus dynamics because sediment phosphorus can be released during anoxic conditions and accumulations of phosphorus in the deep water column can be re-circulated into surface waters. The sediment oxygen and lower water column demand is driven by decomposition of organic matter in the mucky sediment and settling of algae just above or on the sediments. Anoxia at the sediment/water interface and oxygen depletion in the overlying water column can facilitate the recycling of phosphorus from bottom sediments.

Figure 5-1a. Temperature and Dissolved Oxygen Profiles for Santuit Pond

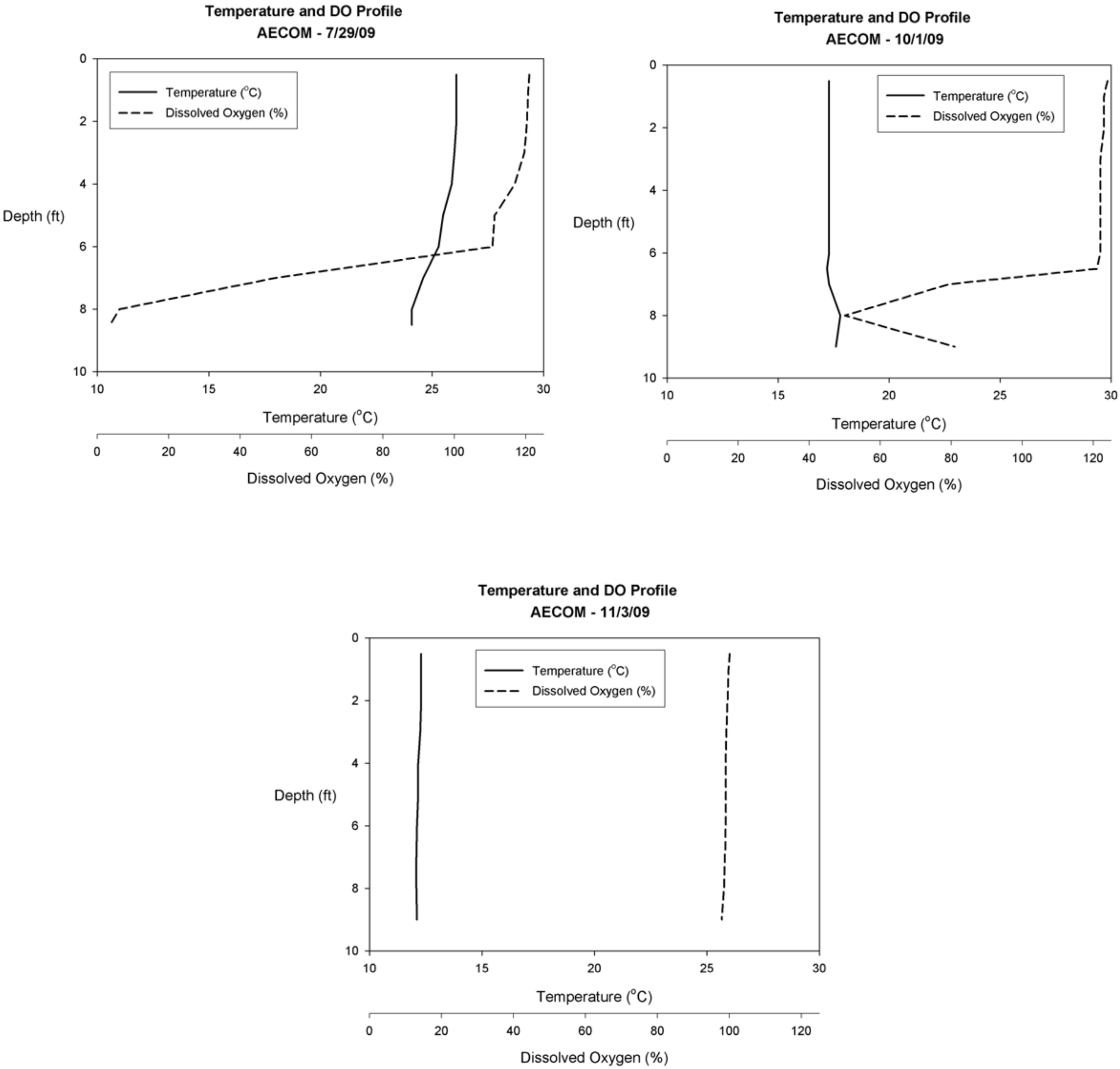


Figure 5-1b. Temperature and Dissolved Oxygen Profiles for Santuit Pond

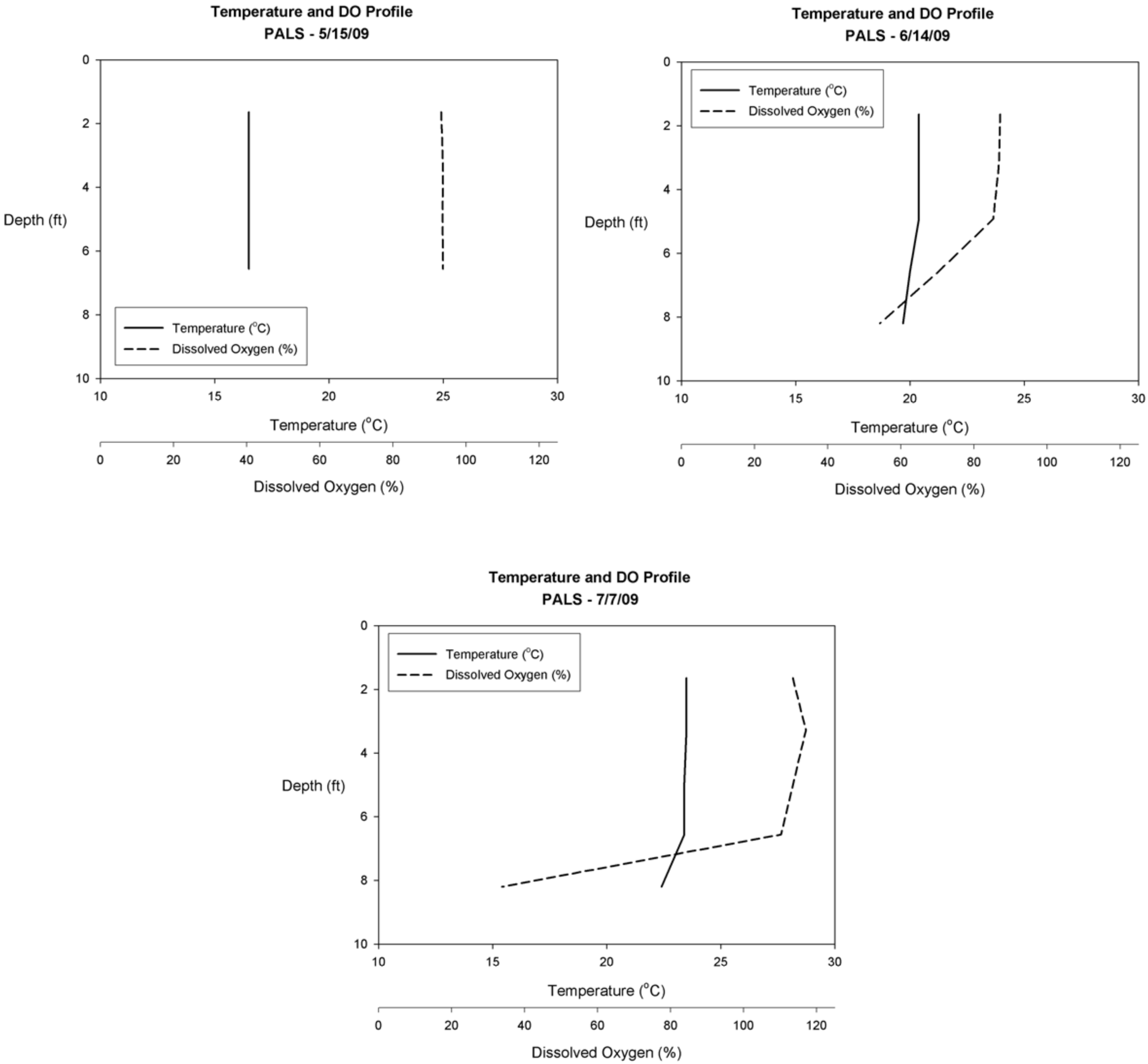
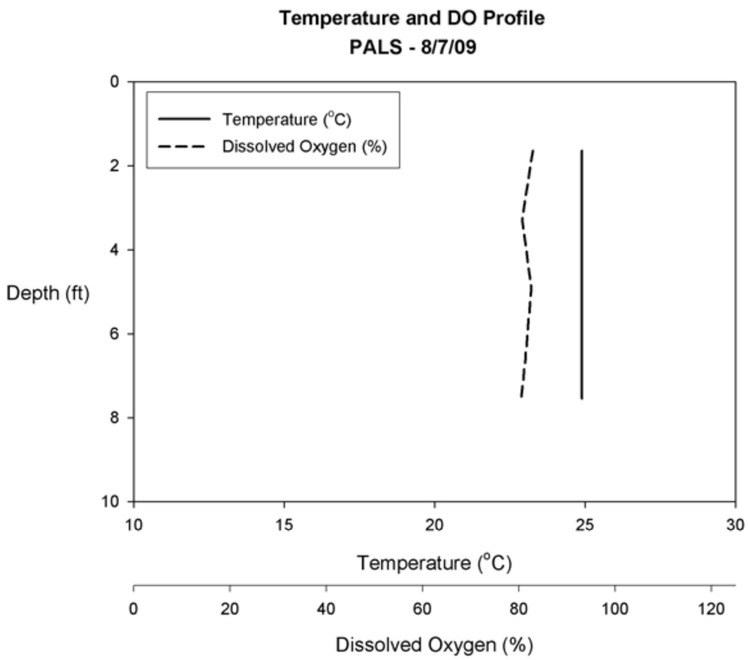
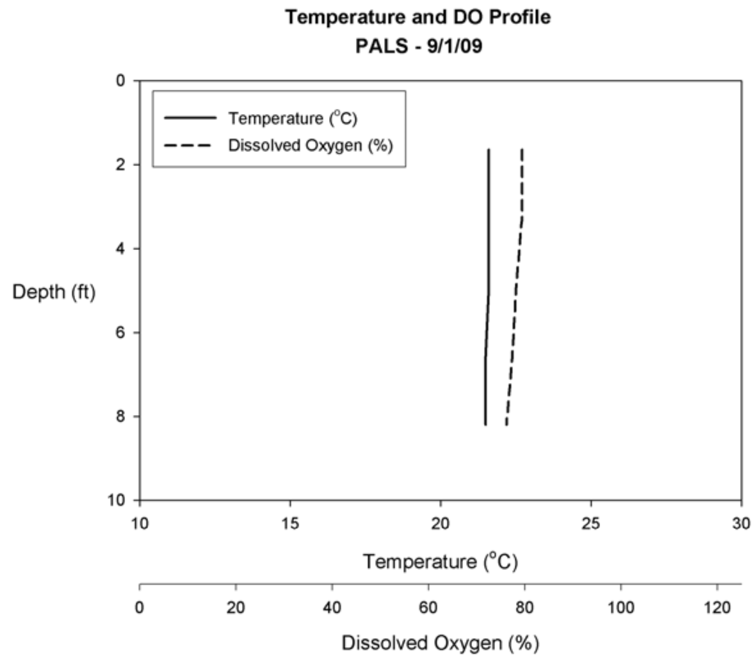


Figure 5-1c. Temperature and Dissolved Oxygen Profiles for Santuit Pond





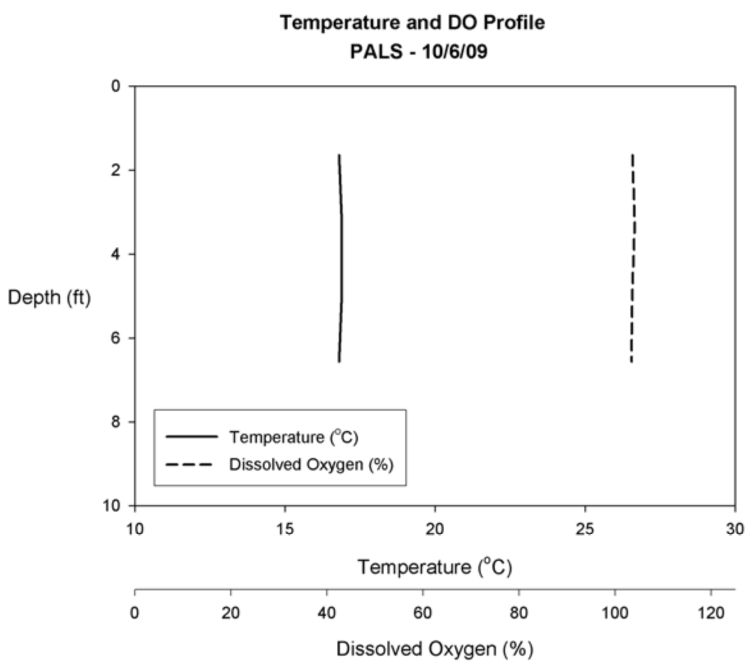
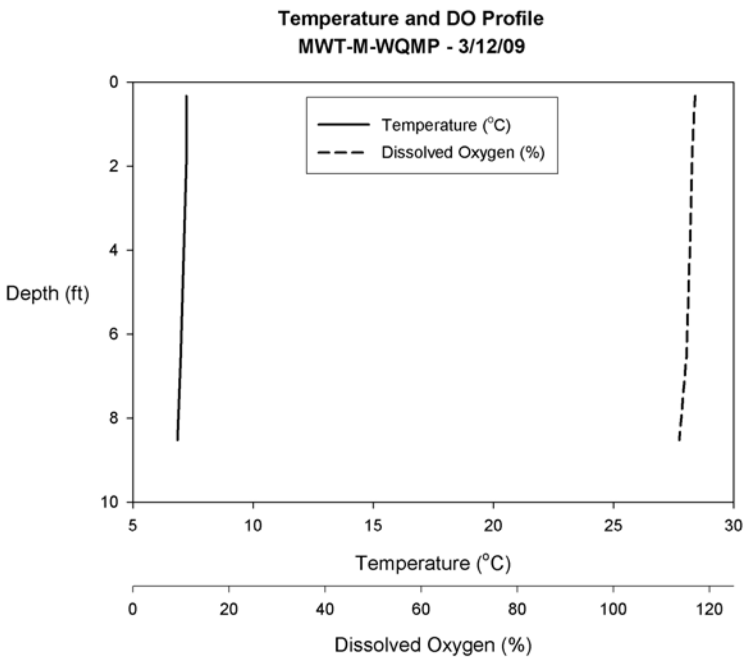
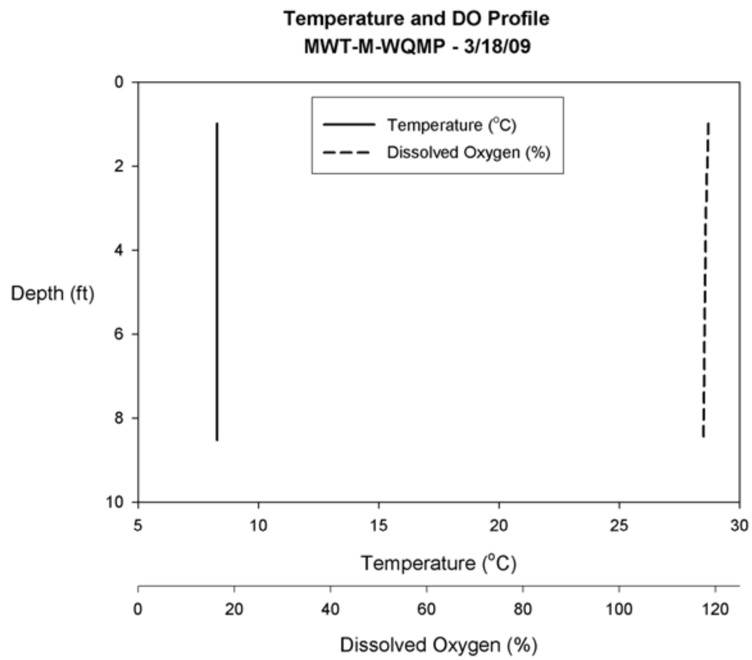


Figure 5-1d. Temperature and Dissolved Oxygen Profiles for Santuit Pond





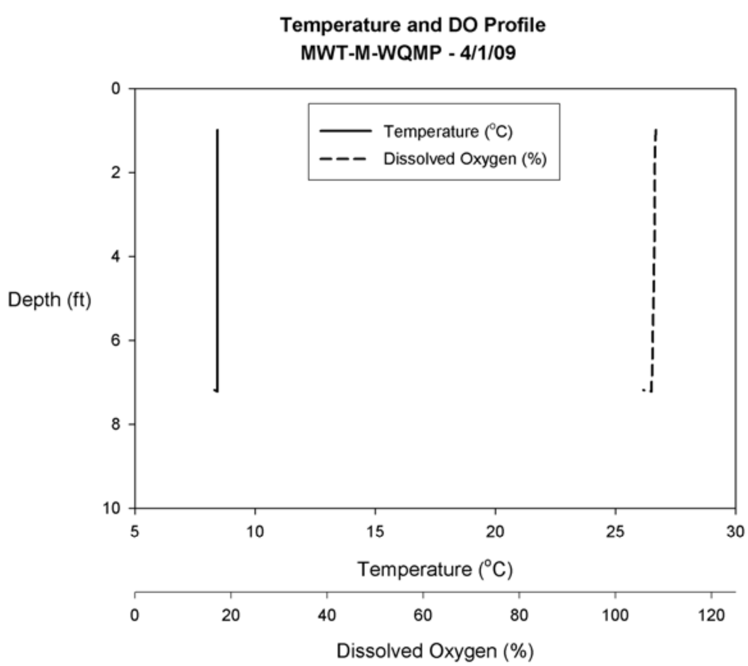
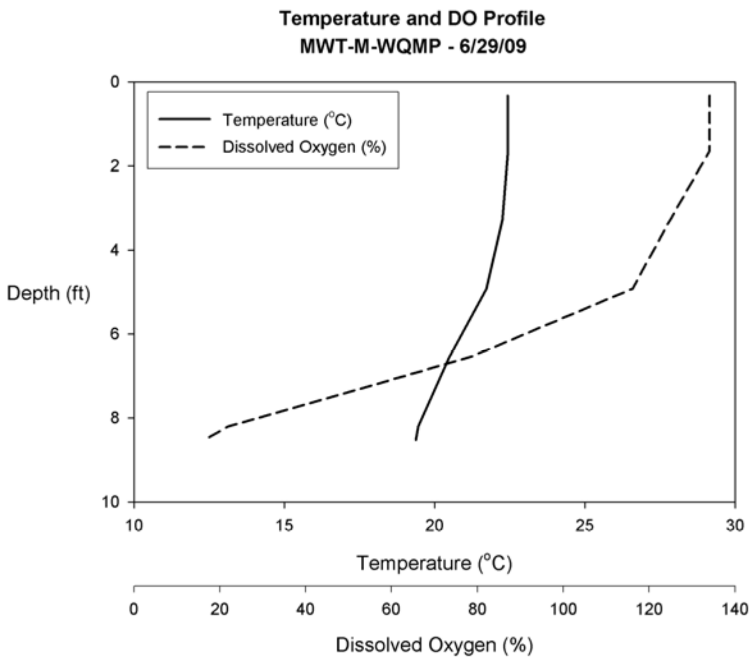
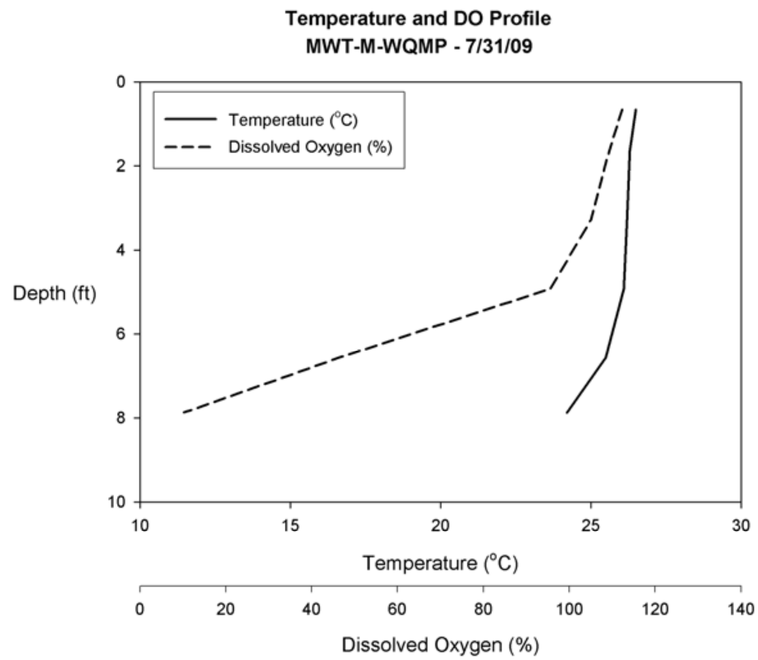
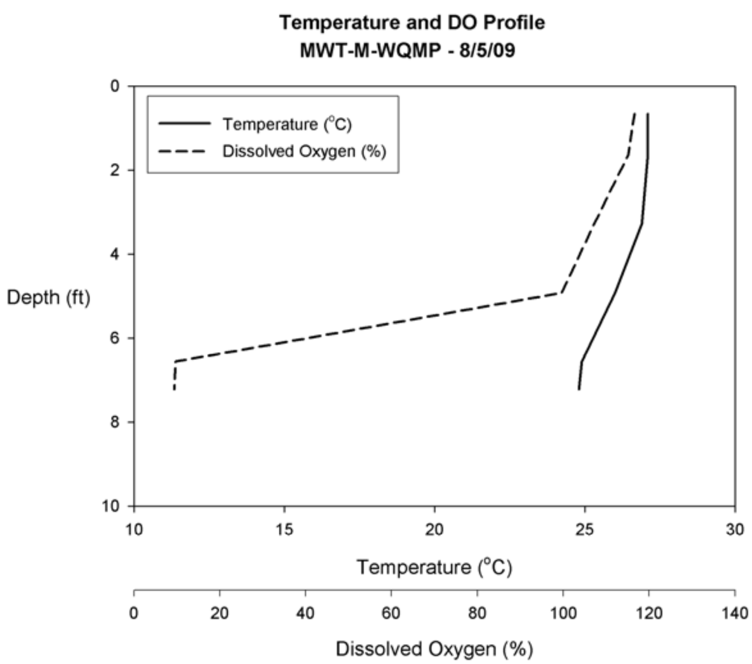


Figure 5-1e. Temperature and Dissolved Oxygen Profiles for Santuit Pond







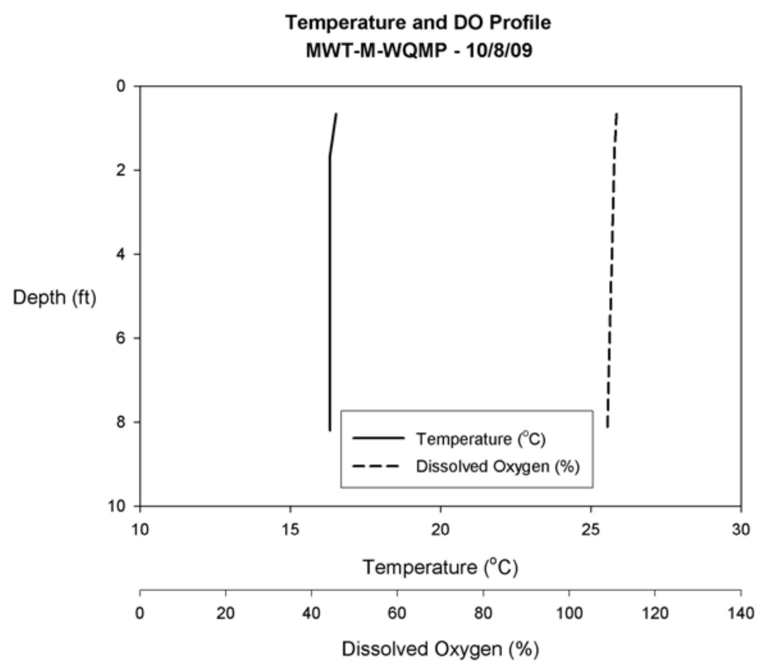


Figure 5-2. Dissolved oxygen saturation measurements from YSI 6600V2 sonde deployed at 7.1 ft at Santuit Pond deep spot

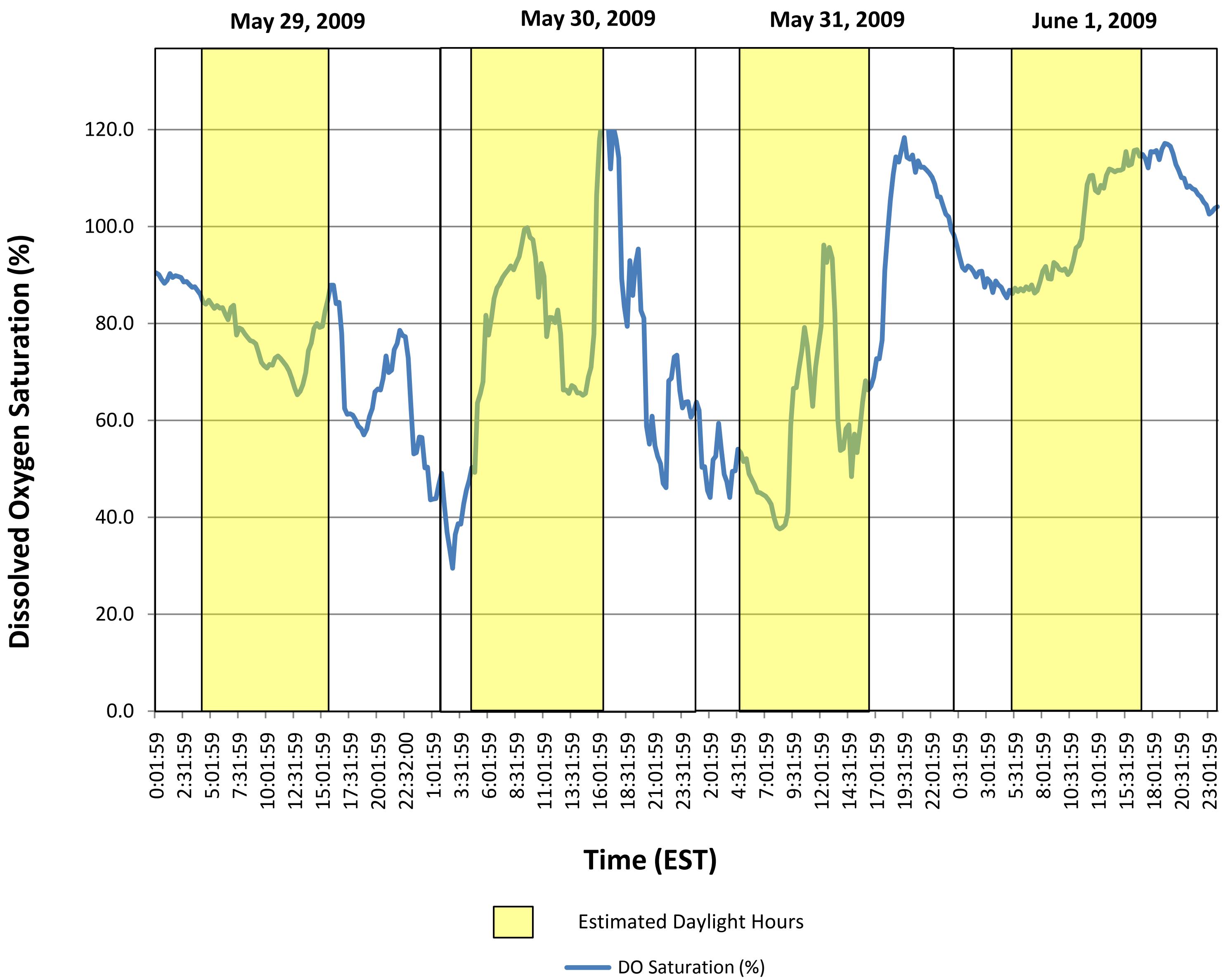
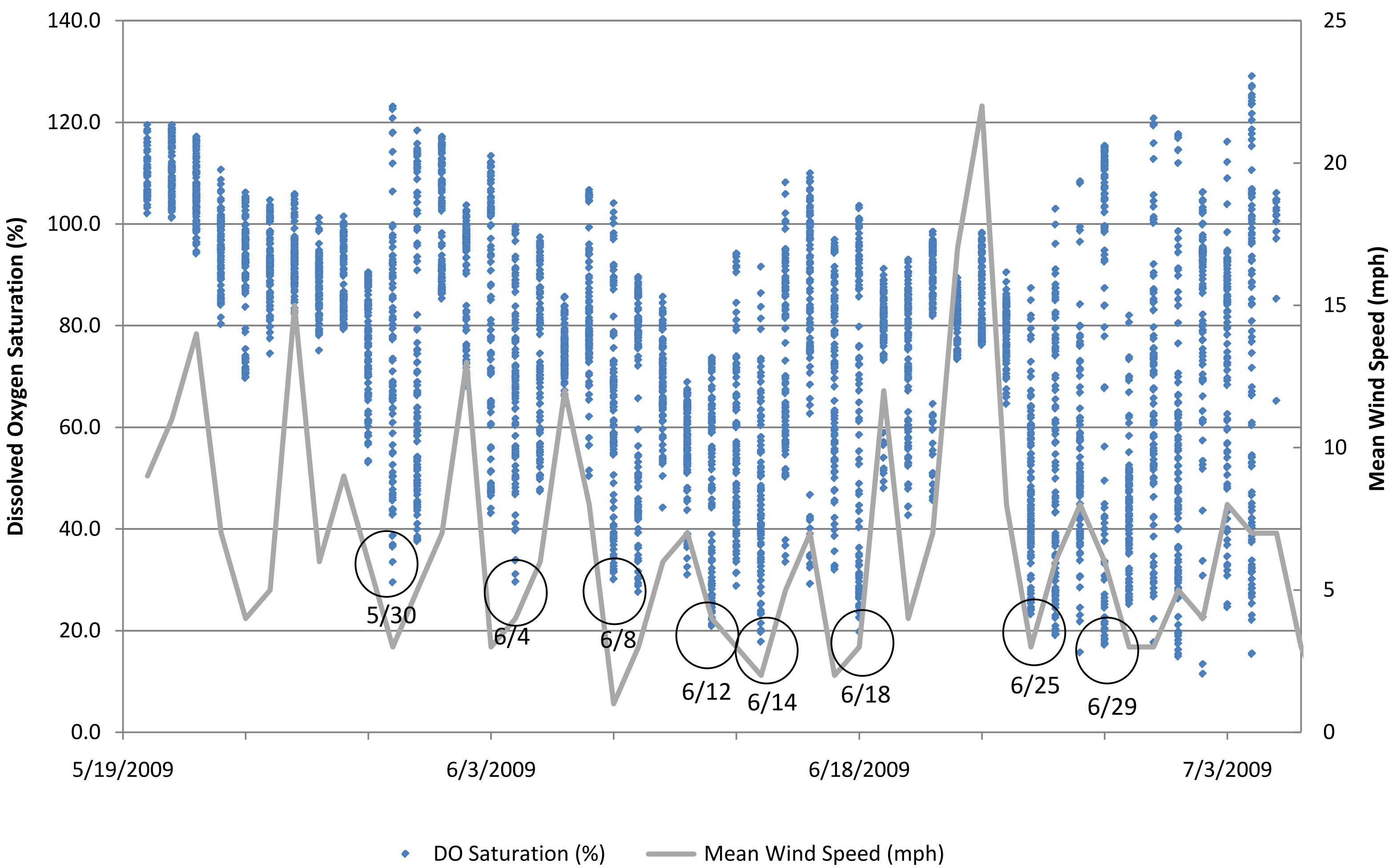


Figure 5-3. Dissolved oxygen saturation measurements from YSI 6600V2 sonde deployed at 7.1 ft at Santuit Pond deep spot and mean wind speed recorded at Otis Airforce Base



5.1.1.1 **Secchi Disk Transparency (SDT)**

SDT depths taken at the deep spot off of Bryants Neck and at the Town Landing indicate very low water clarity most of the year. Combining all of the 2009 SDT data from AECOM, MWT-M-WQMP, MDPH, and PALS (March-November), the average SDT from at the deep spot off Bryants Neck is 2.6 ft (range of 1.2-5.6 ft). The average summer SDT readings at the Town Landing were lower (1.8 ft with a range of 0.4-3.0 ft). The Santuit Pond SDT generally did not meet the MA visibility criterion of 4 ft.

5.1.1.2 **Water Chemistry**

The 2009 AECOM water chemistry results are combined in a summary table with the MDPH, MWT-M-WQMP and PALS data (Table 5-1). The water chemistry parameters analyzed include phosphorus, nitrogen, pH, alkalinity, dissolved iron, and TSS.

Table 5-1 Santuit Pond In-Lake Water Quality Summary, December 2008-November 2009

Site Description	Statistic	NH_3-N mg/L	$N0_3$-N[1] mg/L	TKN mg/L	DP µg/L	TP µg/L	Alkalinity mg/L	D Fe mg/L	TSS mg/L	SDT ft	Chl *a*[2] µg/L	pH s.u
Bryant's Neck Deep Spot-Surface	Mean	0.031	0.014	1.4	16	81	8	0.25	15	2.6	39	8.6
AECOM, MWT-M-WQMP, PALS	Median	0.025	0.005	1.3	16	80	6	0.20	13	2.2	26	9.0
	Min	0.025	0.005	0.7	4	40	2	0.04	11	1.2	14	7.4
	Max	0.050	0.050	2.2	29	140	16	0.55	21	5.6	90	9.2
	n	4	5	10	5	10	4	4	4	18	4	4
Bryant's Neck Deep Spot-Bottom	Mean	0.034	0.014	0.9	15	87	8	0.18	18	-	36	7.4
AECOM & MWT-M-WQMP	Median	0.025	0.005	0.8	16	82	6	0.21	18	-	32	7.3
	Min	0.025	0.005	0.5	6	68	4	0.03	12	-	24	6.5
	Max	0.060	0.050	1.7	20	113	16	0.27	24	-	54	7.6
	n	4	5	5	5	5	4	4	4	-	4	5
Town Landing-Surface	Mean	0.143	0.019	1.8	13	140	6.5	0.24	30	1.8	708	8.2
AECOM & MDPH	Median	0.105	0.005	1.6	12	114	5	0.12	20	1.8	430	8.2
	Min	0.025	0.005	0.3	5	36	2	0.04	6	0.4	9	6.2
	Max	0.805	0.129	5.2	23	402	14	0.68	120	3.0	1950	9.4
	n	17	17	17	5	17	4	4	17	12	13	15

[1] All deep location nitrate samples were below detection limits. The maximum reflects a higher detection limit rather than a higher nitrate concentration.
[2] Surface Chl a= Integrated Sample (2.5xSDT)

Phosphorus

Phosphorus is a nutrient necessary for plant and algal growth, and it is typically the nutrient in limited supply in fresh waters. As a result, water quality as defined by water clarity or degree of presence of algal blooms is typically directly proportional to phosphorus concentration in most lakes. Total phosphorus (TP), which includes the phosphorus bound to particulate matter, has been used historically to determine lake trophic state. Dissolved phosphorus is the proportion of the phosphorus in a sample that passes through a standard-size filtering membrane. Dissolved phosphorus represents the amount of phosphorus immediately available for plant or algal growth.

The 2009 phosphorus values indicate that Santuit Pond is a very nutrient rich (eutrophic) lake with surface TP concentrations observed at the deep spot ranging from 40 µg/L to 140 µg/L (average of 81 µg/L, median of 80 µg/L). TP concentrations greater than approximately 25 µg/L can promote algal blooms and generally, lakes with phosphorus concentrations greater than 30 µg/L are considered eutrophic (Vollenweider, 1968). The very small concentrations of readily biologically available DP observed in the summer (average of 16 µg/L) suggests that the algae are incorporating most of the readily available phosphorus into organic matter and leaving little in the water column. The dearth of dissolved phosphorus in the water column may disrupt the adsorption/desorption kinetics and lead to phosphorus release from the pond sediments (Scheffer, 2004).

There is not a large difference between phosphorus concentrations in the surface and bottom waters. TP concentrations at the surface averaged 81 µg/L while bottom values average 87 µg/L and a large accumulation of TP is not observed in the bottom waters. In eutrophic, stratified lakes with low oxygen concentrations at depth, there can be an accumulation of TP in the bottom waters over the course of the summer due to sediment release of phosphorus during anoxic conditions. Quantification of this phosphorus accumulation provides a measure of phosphorus release rate from the sediments (internal loading). In Santuit Pond, the internal loading cannot be quantified in this manner because it is a shallow, weakly stratified pond. The water column in Santuit Pond regularly mixes and likely frequently incorporates any phosphorus accumulation in the bottom waters into the surface making it available for algal growth. The internal loading calculation for Santuit Pond is discussed in Section 6.4.

Nitrogen

Nitrogen is another nutrient essential for plant and algal growth. This element is rarely limiting, but in combination with phosphorus may determine the taxonomic composition of the algal community. The inorganic forms of nitrogen (Ammonium-Nitrogen, Nitrate -Nitrogen) are readily available to algae and plants. The Total Kjeldahl Nitrogen (TKN) fraction, when corrected for the ammonia fraction, represents the organic nitrogen fraction. Some portion of the TKN represents nitrogen bound in organic material that is resistant to degradation and is less available for uptake to support algal and plant growth.

The surface and bottom nitrate-nitrogen concentrations (NO3-N) at the deep spot of Santuit Pond were below detection limits. Most of the nitrate-nitrogen summer samples at the Town Landing were also below detection; only one detectable value was elevated (0.129 mg/L). Ammonia-nitrogen (NH3-N) in the surface water of the deep spot averaged 0.031 mg/L and was similar to the bottom concentrations. The Town Landing samples yielded higher concentrations of ammonia-nitrogen with an average of 0.143 mg/L. The elevated concentrations at the Town Landing may be due to the influence of groundwater seepage through the sandy bottom near the shoreline. Even the elevated concentrations were typical concentrations found in unpolluted surface waters.

TKN was the largest nitrogen fraction analyzed, and since the ammonia concentrations are below detection is the organic nitrogen fraction and is not available for algal or plant growth. TKN concentrations in the surface water of Santuit Pond deep location averaged 1.4 mg/L with a range of 0.7- 2.2 mg/L. The TKN concentrations at the Town Landing range from 0.3-5.2 mg/L. The elevated TKN concentrations measured at the Town Landing may be due to the accumulation of nitrogen-fixing cyanobacteria along the shore.

pH & Alkalinity

The pH measurements indicate the acidity or alkalinity of water. The average surface pH at the deep spot and Town Landing is greater than 7 (circumneutral), which is higher than the natural pH of surface waters in the region of 6 to 7. These slightly elevated pH levels are likely due to the influence of algal photosynthesis. As primary producers, algae photosynthesize and uptake CO_2 as a carbon source. In productive systems, such as Santuit Pond, photosynthesis is greater than respiration in the photic zone (lighted zone) during the day due to excessive algal growth. When photosynthesis is high in a waterbody, the pH of the waterbody will often rise because CO_2 is removed from the water.

Alkalinity is a measure of the buffering capacity of water. In Santuit Pond, alkalinity values ranged from 2-16 mg/L calcium carbonate ($CaCO_3$) in the surface waters and 4- 16 in the bottom waters. These values are very low and mean that Santuit Pond is sensitive to any acidity inputs, such as from acid deposition or acidic chemicals. Low alkalinity is common in Cape Cod lakes.

Iron

Iron acts as a binding agent for phosphorus during well oxygenated conditions. As with phosphorus, dissolved iron can be released from the sediments during anoxic periods. Surface and bottom water dissolved iron concentrations are similar. In deep, productive lakes, an accumulation of dissolved iron is usually observed. Since Santuit Pond is shallow and regularly mixes, the accumulation of dissolved iron in the bottom waters is not expected.

Total Suspended Solids

TSS is a measure of the suspended particles in a water body. Suspended particles may include algal cells, silt, or resuspended sediments and are usually associated with poor water quality. Suspended sediments can also carry nutrients that can enrich a water body. The surface TSS measurements in the Santuit Pond deep spot range from 11 to 21 mg/L while the measurements taken at the Town Landing range from 6 to 120 mg/L. The elevated concentrations at the Town Landing may be due to concentrated algal cells.

5.2 Sediment Quality

Table 5 2 summarizes the sediment chemistry of Santuit Pond at the locations displayed in Figure 3 5.

Table 5-2 Results of Santuit Pond Sediment Sampling July 29, 2009

			SED-1 Deep Spot	SED-2 North Central	SED-3 Town Landing	SED-4 South
Physical Characteristics						
Water Content (%)			88	95	17	92
Solids (%)			12	5	83	8
Grain Size Analysis (ASTM D422)		**Sediment Type**	**% Retained**			
Sieve # 4	4.75 mm	Fine pebbles	4.4	2.9	23.7	3.2
Sieve # 10	2.00 mm	Very fine granules	20.0	20.6	11.6	25.4
Sieve # 20	0.850 mm	Coarse to very coarse sand	30.0	29.4	22.4	31.7
Sieve # 40	0.425 mm	Medium sand	17.8	17.6	31.7	12.7
Sieve # 60	0.250 mm	Medium/Fine sand	8.9	11.8	8.8	4.8
Sieve # 100	0.150 mm	Fine sand	5.6	5.9	1.6	6.4
Sieve # 200	0.075 mm	Very fine sand	7.8	5.9	0.3	6.4
Sieve # 230	>0.075 mm	Silt/Clay	5.6	5.9	0.1	9.5
Physical Characteristics		**Method**				
Iron bound Phosphorus as P (mg/kg dry)		ASTM D515-88(A)	316	650	9.9	490
Loosely-sorbed Phosphorus as P (mg/kg dry)		ASTM D515-88(A)	<2.01	<5.12	<0.3	<3.04
Aluminum (mg/kg dry)		SW846 6010B	6440	5020	678	7320
Iron (mg/kg dry)		SW846 6010B	16600	22500	1350	17300
Phosphorus as P (mg/kg dry)		SW846 6010B	920	2550	66.4	1270

The sediment sample taken near the Town Landing (SED-3) was sandy gravel with approximately 90% of the sample having a grain size of >425 um (fine pebbles to medium sand). The remaining sediment samples (SED-1, 2, and 4) were brown-black muck in appearance, finer grained with approximately 30% of the samples having a grain size smaller than 425 um (medium/fine sand to silt/clay). The sandy/gravel sample (SED-3) had a much higher percent solids measure (83%) than the other three soft muck samples (5-12%). These soft muck sediment samples are the remains of organic material derived largely from within-lake processes, as would be expected in a productive kettlehole pond without large surface water inputs.

Table 5-3 Estimation of Available Phosphorus in Santuit Pond Sediment Samples

Sample	Solids (%)	Loosely sorbed P (mg/kg)	Fe-bound P (mg/kg)	Available P (mg/kg)	Min Available P (g/m2)	Max Available P (g/m2)
SED-1: Deep Spot	12.4	1.0	316.0	317	0.9	1.7
SED-2: North Central	4.9	2.6	650.0	653	0.7	1.4
SED-3: Town Landing	83	0.2	9.9	10	0.2	0.4
SED-4: South	8.2	1.5	490.0	492	0.9	1.8

An estimate of available phosphorus in each of the sediment samples is provided in Table 5-3. Loosely-sorbed phosphorus is considered the most available fraction. The iron-bound phosphorus, determined after extraction for loosely-sorbed phosphorus, is that fraction bound to iron and often mobilized from anoxic sediment as a consequence of redox reactions. The sum of the loosely-sorbed and iron-bound phosphorus fractions are used to estimate an "available phosphorus" fraction that is considered representative of the phosphorus that may be potentially released in anoxic conditions.

There is a difference in the available phosphorus in the sandy vs. mucky sediment samples. The sandy sample (SED-3) had only 10 mg/kg of available phosphorus while the soft, mucky sediments had concentrations ranging from 317 to 653 mg/kg; the soft, mucky sediment has a higher potential for phosphorus release than the sandy sediment. As a rule of thumb, sediments with available phosphorus concentrations greater than 300 mg/kg are considered high. A visual inspection of the pond bottom verified by sediment probes indicates that approximately 49 ha (121 ac) of the pond bottom is covered with soft sediment, which encompasses 71% of the pond area (Figure 3-5). These results indicate that most sediment in the pond is highly enriched with phosphorus in a form which will be readily released into the water column under anoxic conditions.

These sediment phosphorus concentrations were further refined by considering just the volume and phosphorus contained in the top sediment layers that would be most actively involved in phosphorus release. Rydin and Welch (1998, 1999) suggest that the upper 2 to 4 cm of sediment are involved, indicating that the active volume is therefore 0.02 to 0.04 m3. Multiplying the percent solids, the specific gravity, and the available phosphorus concentration yields the mass of phosphorus available for recycling per m2 (Table 5-3). It was assumed that the specific gravity for the muck sediments is approximately 1.1. The mass of phosphorus contained in the 0-2 cm layer is termed the "minimum available phosphorus" and that contained in the 0 to 4 cm layer is termed the "maximum available phosphorus."

By this process, it is estimated that the muck sediments can provide 0.70-0.90 g available P/m2 at 0-2 cm and 1.4-1.8 g available P/m2 at 0-4 cm. In contrast, the sandier sediments would provide a rather modest 0.20 to 0.40 g available P/m2 at 0-2 cm and 0-4 cm, respectively.

In summary, the mucky sediments that make up approximately 71% of the pond bottom are very phosphorus rich and have the potential to release large quantities of phosphorus into the water column during anoxic conditions. These sediment phosphorus data are used to estimate the internal phosphorus loading in Section 6.4.

5.3 Measured Nutrient Inputs

AECOM collected nutrient data from groundwater sources, stormwater, and cranberry bog flood release in order to assist with quantifying the pond's nutrient inputs. These data provide groundtruthing for the phosphorus modeling in Section 6.4.

5.3.1 Groundwater

Groundwater is an important contributor to the hydrologic budget of Santuit Pond as there are no major surface tributaries. Nutrients carried with the groundwater can be an important component of the nutrient budget. Seepage meters deployed in Santuit Pond indicated that groundwater is entering the pond at an average rate of 0.005 cubic feet per second in July and 0.031 cubic feet per second in October. This is an extremely low seepage rate and knowledge of regional flow rates suggests that the annual average seepage rate into Santuit Pond is much greater. Groundwater calculations are presented in Section 6.4. One reason for the low seepage meter flow rates may be due to the high groundwater in July and October 2009. According to groundwater level measurements from a site north of Santuit Pond, the July and October 2009 water levels were in the 76-90 percentile for the months, meaning above normal (USGS, 2010). Mitchell et al. (1988) found that periods with high water tables, such as those typically found in spring, have lower groundwater seepage rates.

The water chemistry results from the LIP sampling locations identified in Figure 3-2 and Figure 3-3 are summarized in Table 5-4. The data for the individual sampling rounds are provided in Appendix A.

Table 5-4 Summary of Results from Santuit Pond Littoral Interstitial Porewater (LIP) Sampling, July 29, 2009 & October 1, 20091.

	Average					
Site	**NH_3-N**	**$N0_3$-N**	**Total Inorganic Nitrogen**	**DP**	**Dissolved Fe**	**Fe:P**
	mg/L	mg/L	mg/L	µg/L	mg/L	
ST-GW-1	0.06	0.34	0.40	16	1.27	57
ST-GW-2	0.05	0.96	1.01	29	0.01	0.5
ST-GW-3	1.18	0.01	1.19	93	5.50	61
ST-GW-4	1.50	0.01	1.50	83	3.70	126
ST-GW-5	0.05	0.01	0.06	39	0.86	22
ST-GW-6	0.78	0.01	0.78	42	3.85	135
ST-GW-7	0.90	0.01	0.90	101	2.80	29
ST-GW-8	0.31	8.08	8.39	19.5	0.88	35
ST-GW-10	0.54	0.01	0.55	73	3.60	49

* AECOM sampled GW-5 only in July and GW-10 only in October.

DP measurements indicate potentially available phosphorus entering the pond. Average DP values of 39 to 101 µg/L from sites around the lake perimeter suggest that high concentrations of phosphorus are entering Santuit Pond through groundwater. However, groundwater inputs will be diluted and will become unavailable when the groundwater oxidizes and is bound by iron. Futhermore, these concentrations are not substantially different than observed lake water. When iron levels are at least 5 times the levels of phosphorus, most phosphorus is likely to be bound into insoluble precipitates and become part of the sediment reserve. In Santuit Pond, the average iron to phosphorus (Fe:P) ratios range from 0.5 to 135, suggesting variable binding effectiveness. However, all of the sites except one (the northern GW-2) have average Fe:P ratios greater than 5. In general, higher levels of phosphorus in the groundwater correlate to higher levels of iron; the conditions that allow phosphorus transport in groundwater (mainly anoxia) also allow greater iron transport and protect the pond from major inputs of available phosphorus. Those inputs can become part of the internal load, however, so they are not insignificant in the long-term.

The soluble inorganic nitrogen level, or sum of ammonium nitrogen and nitrate nitrogen, is the best indication of contamination from septic systems. Although exceptionally high fertilizer applications or manure piles can provide similar values, it is septic system effluent that accounts for the vast majority of elevated nitrogen levels in groundwater on Cape Cod. Values in excess of 1 mg/L are not usually natural, while values in excess of 5 mg/L are often a sign of human-derived contamination. Ammonium-nitrate nitrogen levels (total inorganic nitrogen) in the groundwater samples range from 0.06 to 8.4 mg/L. The only sample with inorganic nitrogen concentrations greater than 5 mg/L was GW-8, located off the Timberlane Drive/Fir Ct residential development. Further sampling and a survey of the age and setback of septic systems in this neighborhood will help to determine whether there are failing septic systems in this neighborhood.

5.3.2 Stormwater Quality

Although overland flow is a not a large source of water to Santuit Pond due to the sandy/gravel watershed soils, AECOM did observe stormwater flowing into the pond as sheetflow in several locations during wet weather events. These locations are shown on Figure 3-6 and the water chemistry results from AECOM wet weather sampling are presented in Table 5-5.

Table 5-5 Results of Stormwater Runoff Wet Weather Sampling, August 29, 2009 and November 20, 2009.

Site Description	Site	Date	TSS	NH_3-N	$N0_3$-N	TKN	DP	TP	DP:TP
			mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	
Town Landing Parking lot	ST-WW-1	8/29/09	85	<0.05	0.15	1.2	78	391	0.2
Hemlock Dr Dead end	ST-WW-2a		20	<0.05	0.3	0.52	80	174	0.5
Bryant's Neck	ST-WW-3a		446	0.08	0.23	1.25	216	885	0.2
Beechwood Pt Dr	ST-WW-4		5	<0.05	0.03	0.32	40	85	0.5
Cranberry Lane	ST-WW-5		28	<0.05	0.08	0.48	90	145	0.6
Town Landing Parking lot	ST-WW-1	11/20/09	114	<0.05	0.005	0.8	570	902	0.6
Timberlane-near Lantern Lane Berm	ST-WW-2b		162	0.15	0.2	0.54	680	785	0.9
Bryant's Neck	ST-WW-3b		1108	<0.05	0.005	0.65	895	1728	0.5
Beechwood Pt Dr	ST-WW-4		22	<0.05	0.06	0.9	149	199	0.8
Cranberry Lane	ST-WW-5		462	<0.05	0.005	0.58	257	798	0.3

Table 5-5 (cont).

Site Description	Site	Date	Specific Conductance umhos/cm	Alkalinity mg/L	Field pH s.u.	Field Temp ^oC
Town Landing Parking lot	ST-WW-1	8/29/09	57	10	7.63	21.7
Hemlock Dr Dead end	ST-WW-2a		33	6	7.34	21.5
Bryant's Neck	ST-WW-3a		89	20	7.63	N/a
Beechwood Pt Dr	ST-WW-4		10	6	7.98	N/a
Cranberry Lane	ST-WW-5		22	6	7.5	N/a
Town Landing Parking lot	ST-WW-1	11/20/09	83	<2	5.65	15.1
Timberlane-near Lantern Lane Berm	ST-WW-2b		27	<2	5.66	15.4
Bryant's Neck	ST-WW-3b		82	<2	5.43	14.1
Beechwood Pt Dr	ST-WW-4		51	<2	5.73	15.1
Cranberry Lane	ST-WW-5		55	<2	5.45	14.4

The wet weather sampling water chemistry results show high phosphorus concentrations. Overall, the phosphorus concentrations were higher in November (non-growing season) than July (growing season). Total phosphorus concentrations were extremely high, ranging from 85 to 885 µg/L in July and 199 to 1,728 µg/L in November. The DP component was relatively low (less than half of TP in 6 out of 10 samples); most of the phosphorus was particulate and not readily biologically available. The TSS concentrations were also high in some samples (5-1,108 mg/L), further suggesting that phosphorus may be bound to suspended solids collected during stormwater sampling. In many locations, the sheet flow sampled likely is an overestimate of what is reaching the pond as there is some groundwater infiltration between the point at which the sample was collected and the point to which the sheetflow enters the pond. AECOM scientists sampled as close to the lake as possible without trespassing on private property and as a result not all samples were collected at the pond edge. For example, all of the sheetflow originating from Beechwood Point Drive likely does not all reach Santuit Pond. And the sheetflow sampled taken off Cranberry Lane likely drains in the Brackett cranberry bog before entering the pond. Similarly, the sheetflow sample collected off Hemlock Lane likely drains into the southern cranberry bog and may not reach Santuit Pond as the cranberry bogs are downgradient from the pond.

The ammonia-nitrogen concentrations were mostly below detection limits both in August and November. The August nitrate-nitrogen values were on average higher (0.158 mg/L) than the November samples (0.055 mg/L). The largest nitrogen consistent, TKN values were similar between sampling dates (0.754 mg/L in August and 0.694 mg/L in November).

5.3.3 Cranberry Bog Flood Water Quality

The October 21, 2009 sampling results from the Baker cranberry flood water are included in Table 5-6. The TP values are similar to in-lake and groundwater concentrations observed by AECOM in 2009. No fertilizer has been applied since 2004 in the Baker cranberry bog (Ralph Baker, Bog Owner, personal communication).

The results of the AECOM February 8 & 9, 2010 sampling of the Brackett cranberry bog flood release are included in Table 5-7. The TP concentrations of the floodwaters (BRACKETT- R1B and R-2B) during release range from 75-106 µg/L with an average of 91 µg/L. These concentrations are higher than those in the open water surface sample collected at the Town Landing during the release (BRACKETT-OW). The TP concentration in BRACKETT-OW is 40 µg/L. Also, dissolved phosphorus constitutes a high percentage of total phosphorus (70-90%) in the floodwater samples and therefore much of the phosphorus discharged is readily biologically available. The pond water dilutes the phosphorus concentrations in the flood water samples as the DP and TP concentrations in the samples collected in the pond near the outlet (BRACKETT-R1P and R-2P) are lower than the floodwater samples.

Volunteers collected water quality samples during the harvest release on September 25, 2009 and sent them to the MDEP laboratory for analysis. The one sample collected in a sterile water quality bottle broke in transit and the other two samples were collected in unsterile bottles without quality control measures. These sample results cannot be validated for use in this study. The total phosphorus concentrations in the September 25th samples were higher than those measured in the AECOM Baker cranberry bog sampling on October 21, 2009 and Brackett bog sampling on February 8 & 9, 2010. The TP concentrations of the non-lab qualified samples are within the range of samples collected by MDEP in cranberry bog flood releases to other Massachusetts ponds.

Table 5-6 Results of Cranberry Bog Flood Waters Sampling, Baker Bog, October 21, 2009.

Sample ID	Time	TSS	NH_3-N	$N0_3$-N	TKN	DP	TP	Alk	Dissolved Fe	Field pH	Water Temp
	EDT	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L	mg/L	s.u.	^oC
ST-CB-2HB	16:43	<1	<0.05	<0.01	0.92	55	86	75	6	6.4	17.3
ST-CB-2LB	16:52	<1	<0.05	0.93	0.9	24	29	107	4	6.2	12.8
ST-CB-2OW	17:03	2	<0.05	0.51	0.84	22	46	108	4	5.2	13

Table 5-7 Results of Cranberry Bog Flood Waters Sampling, Brackett Bog, February 8-9, 2010.

Sample ID	Date	TSS	NH_3-N	$N0_3$-N	TKN	DP	TP	Alk	Cond	Field pH	Water Temp
		mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L	umhos/cm	s.u.	^oC
ST-BRACKETT-R1B	2/8/2010	18	0.06	0.02	0.53	66	75	4	72.7	6.2	4.4
ST-BRACKETT-R1P		6	0.06	0.54	0.5	38	48	6	84.4	6.0	3.8
ST-BRACKETT-OW		5	0.10	0.54	0.46	21	40	8	93.5	6.0	4.7
ST-BRACKETT-R2B	2/9/2010	1	0.06	0.02	0.37	77	106	4	49.8	5.5	1
ST-BRACKETT-R2P		1	0.07	0.12	0.41	72	93	4	61.8	5.2	0.9

5.4 Aquatic Biota

5.4.1 Aquatic Macrophytes

The submerged macrophyte (plant) species AECOM observed in Santuit Pond during the August 26, 2009 survey are included in Table 5-8. Cyanobacteria covered the entire pond giving the water a green tint. AECOM observed aquatic macrophyte growth primarily only 50-75 ft from the shoreline with a few exceptions (the cove south of the Town Landing and the northern end of the pond). Plant cover represents the total surface area covered in plants (two-dimensional measurement). Most of the shoreline (21 acres) has moderate to high plant coverage (>50%) (Figure 5-4). Conversely, a majority of the plant growth along the shoreline has a low plant biovolume ranking (~30 acres have a biovolume of <50%) (Figure 5-5). Plant biovolume is a three-dimensional measurement of how much of the water column plant growth occupies. Having a low biovolume means that the plants observed do not take much space in the water column. The common plant species present explain the high coverage, but low biovolume observations. Elodea Canadensis (water weed), Nitella sp. (stonewart), and pond lilies (Nymphaea odorata and Nuphar variegatum) are common in Santuit Pond. E. Canadensis and Nitella sp. are low growing ground cover while pond lilies cover the surface. These plant species would have low biovolume ranking because they would only take up the surface or bottom of the water column and a high cover because they cover a large amount of the surface or bottom of the pond. Other common species observed include Vallisneria americana (Tape grass). Overall, the aquatic plant growth was low to moderate in density. Low water clarity caused by the excessive algal growth often limits macrophyte growth.

When conducting the aquatic macrophyte survey, AECOM noted any observations of mussels. The common Eastern Floater (Pyganodonta cataracta) was found in low abundance in Santuit Pond in the shallow waters on sandy substrate.

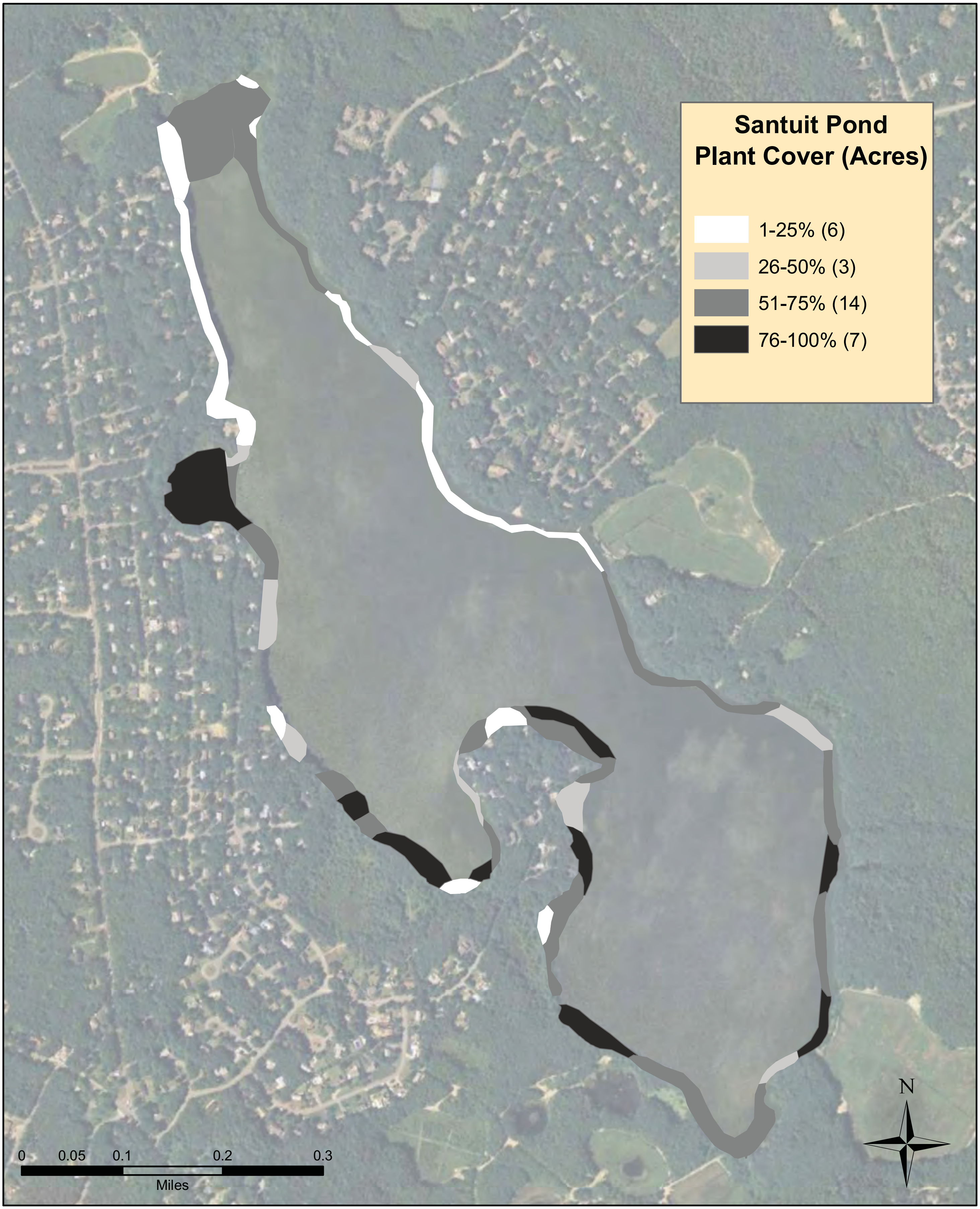


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Figure 5-4. Santuit Pond aquatic plant cover, August 26, 2009

AECOM

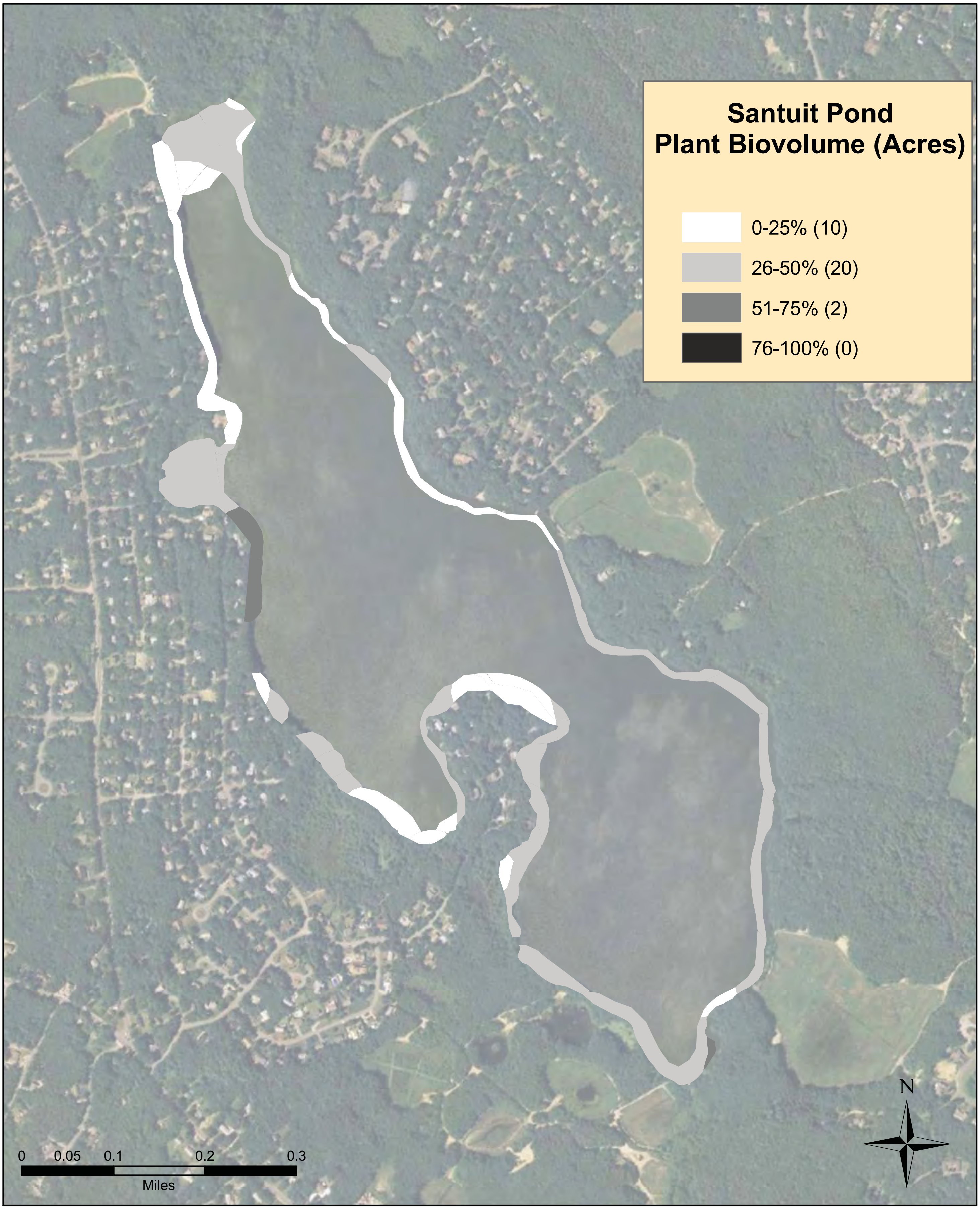

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Figure 5-5. Santuit Pond aquatic plant biovolume, August 26, 2009

AECOM

Table 5-8 Aquatic macrophyte species observed during August 26, 2009 survey.

Scientific Name	Common Name	Distribution in Santuit Pond
Cyanophyta	Cyanobacteria	Covers entire pond, scums at shoreline
Brasenia schreberi	Watershield	Rare; Cove south of Town Landing
Ceratophyllum demersum	Coontail	Patchy; Cove south of Town Landing and North Shore
Decodon verticillatus	Swamp Loosestrife	Patchy; North Shore, Bryants Neck, Near Outlet
Elodea canadensis	Waterweed	Very common throughout littoral zone
Myriophyllum sp.	Watermilfoil	Non-invasive species; Rare; North Shore
Najas flexilis	Common naiad	Patchy; Town Landing and Central & West Shore Littoral Zone
Nitella sp.	Stonewart	Common; South and Western Shores
Nymphaea odorata	White water lily	Common; Northern and Northeastern shore, Cove South of Town Landing, Bryants Neck, Near Outlet
Nuphar variegatum	Yellow water lily	Common; Northern and Northeastern shore, Cove South of Town Landing, Bryants Neck, Near Outlet
Potamogeton robbinsii	Robbins' pondweed	Rare; Eastern shore near Brackett Bog
Utricularia sp.	Bladderwort	Rare; Cove south of Town Landing
Vallisneria americana	Tape grass	Very common throughout littoral zone

5.4.2 Phytoplankton and Zooplankton

Phytoplankton

Phytoplankton are floating algae in the water column. Being primary producers, they are the base of the aquatic food web. Chl a is an indicator of the quantity of phytoplankton in the water column. Chl a is the photosynthetic pigment found in plants and algae. It is often used as a surrogate for algal biomass in lakes and streams. Chl a breaks down into other pigments that can be measured, with phaeophytin usually taken as an indicator of dying algae. A healthy algae community will have some phaeophytin, but it is usually a minor component of the total chl a concentration.

The chl a concentrations in Santuit Pond are high, consequently the pond has a “pea soup green” color. In the 2009 AECOM study, the integrated surface chl a concentrations at the deep location ranged from 14 to 90 µg/L, with an average of 39 µg/L. The MDPH samples at the Town Landing ranged from 9 to 1,950 µg/L, with an average of 708 µg/L. Generally, values greater than 25 µg/L indicate an algal bloom. The wind blows algal cells to concentrated floating mats. These algal mats may explain the extremely high concentrations observed at the Town Landing.

The MDPH samples indicate that common algal genera in Santuit Pond are the cyanobacteria Microcystis, Coelosphaerium, Anabaena, and Aphanocapsa. Anabaena and Microcystis are common toxin producers. Microcystin is one common hepatotoxin that primarily is toxic to the liver and kidneys. The weekly MDPH toxicity testing did not detect microcystin at or above the detection limit of 1 ppb at the Town Landing over the entire summer. The MDPH will post an advisory or beach closure when microcystin levels are greater than 14 ug/L.

Zooplankton

A qualitative look at the zooplankton community of Santuit Pond suggests that the zooplankton community is dominated by small bodied species such as Chydorus sp., Bosmina sp, small cyclopoid copepods and rotifers. The dominance of small bodied species is typically associated with large populations of planktivorous fish which include the young life stages of perch and sunfish, minnows and adult and juvenile herring. A low population of large bodied zooplankton can result in an increase in algal populations as smaller species generally consume fewer algae than larger bodied species.

5.5 Summary

Santuit Pond is currently a eutrophic waterbody with high phosphorus concentrations, low clarity, and extensive cyanobacteria algal blooms. Some of the cyanobacteria species present are capable of producing toxin even though MDPH did not detect microcytins, a hepatotoxin (liver toxin). The shallow pond only weakly thermally stratifies and there is not a strong resistance to circulation during windy periods. Large differences in surface and bottom water chemistry are not observed because of this regular water column mixing. The phosphorus-rich mucky sediments have a high potential of releasing phosphorus during low oxygen periods. Due to the high organic content, the sediments have a high sediment oxygen demand. Oxygen depletion is seen in the bottom waters, especially during the night and during calm periods, so internal loading likely occurs regularly throughout the summer. The low to moderate density aquatic plant community is primarily found close to the shoreline.

Comparing historical data to the current state indicates a shift in the pond equilibrium sometime in the late 1990s to mid 2000s. Historically, Santuit Pond was a clear pond dominated by aquatic plants and little algal growth. The few nutrient samples indicate that phosphorus concentrations were around 30 µg/L. This shift is common in shallow ponds and there are many reasons for the possible shift including grazing pressure, water level changes, storm effects, and nutrient changes (Scheffer, 2004).

6.0 Phosphorus Modeling of Current Conditions

The Federal Clean Water Act (CWA) provides regulations for the protection of streams, lakes, and estuaries within the United States. Section 303(d) of the CWA requires individual states to identify waters not meeting current state water quality standards due to pollutant discharges and to determine Total Maximum Daily Loads (TMDLs) for these waters. A TMDL sets the maximum amount of a pollutant that a waterbody can receive and still support designated uses, such as swimming and recreation. Santuit Pond is included on the 2008 303(d) list or "List of Impaired Waters," due to impairment of designated uses by noxious aquatic plants (cyanobacteria blooms) and nutrients (MDEP 2008). While this report is not a TMDL for Santuit Pond, it contains many of the elements that go into a TMDL and follows a methodology that has been used for TMDL development at other lakes in New England. The extensive cyanobacteria blooms observed in Santuit Pond are indicative of nutrient enrichment. Phosphorus is the primary limiting nutrient in northern temperate lakes, hence eutrophication due to phosphorus enrichment is the likely cause of the presence of cyanobacteria. Nitrogen can also play a role in determining the type of algae present and the degree of eutrophication of a waterbody. However, phosphorus is typically more important and more easily controlled. This section provides total phosphorus modeling results of current conditions and conditions at a suggested in-lake target concentration necessary in order to meet designated uses.

6.1 Model of Current Conditions

Current TP loading was assessed using the LLRM methodology, which is a land use export coefficient model developed by AECOM for use in New England. LLRM stands for Lake Loading Response Model.

The major direct and indirect nonpoint sources of TP to Santuit Pond include:

- Atmospheric deposition (direct precipitation to the Pond)
- Groundwater seepage
- Surface runoff (stormwater runoff draining directly to the Pond through sheetflow)
- Internal recycling (release from sediment by chemical interaction)
- Waterfowl (direct input from resident and migrating birds)
- Flood release from active Cranberry Bog operations
- Direct groundwater seepage including septic system inputs from shorefront residences

There are no permitted point source discharges of nutrients in this watershed. However, construction activities in the watershed that disturb greater than one acre of land and convey stormwater through pipes, ditches, swales, roads or channels to surface water require a federal Construction General Permit for Stormwater Discharge. Construction discharges are not incorporated in the model due to their variability and short-term impacts.

Surface TP loads were estimated for each subwatershed based on runoff and groundwater land use export coefficients. The TP loads were then attenuated as necessary based on available stormwater and groundwater water quality data as well as the slope and soils direct drainage. Loads from the watershed as well as direct sources were then used to predict in-lake concentrations of TP, chl a, SDT, and algal bloom probability.

6.2 Lake Characteristics

The Division of Water Pollution Control established the bathymetric contours of Santuit Pond in 1980 which are shown in Figure 3-1. The deepest location is 9 ft east of Bryant's Neck. The surface area of Santuit Pond has been variously reported by different organizations as 167.4 acres (DWPC, 1980), 172 acres (MDFW, 2007) and 170 acres (MA GIS, 2005; CCC, 2003). These slight differences are probably attributable to differences in the water level at the time of observation or due to the method and/or precision of areal estimation. The pond level fluctuates seasonally due to groundwater levels and precipitation patterns. Since there is general good agreement between these three estimates, for purposes of this assessment, we used the 2003 CCC/2005 GIS value of 170 acres (69 hectares) as the base surface area for Santuit Pond.

There are also discrepancies in the reported Santuit Pond volume. The 1980 Department of Water Pollution Control reported the volume as 870,974 m3 while the Cape Cod Pond and Lake Atlas reported it as 25,215 ft3 or 2,343 m3. AECOM hypsograph calculations based on GIS surface area estimated the volume at 954,601 m3. For the purpose of phosphorus modeling, we used the 1980 report volume of 870,974 m3.

6.3 Hydrologic Inputs and Water Loading

Calculating TP loads to Santuit Pond requires estimation of the sources of water to the pond. The three primary sources of water are: 1) direct precipitation; 2) surface runoff; and 3) groundwater. The water budget is broken down into its components in Table 6-1.

The contributing groundwater recharge area used for the TMDL analysis was the groundwater recharge area for the pond as defined by the Massachusetts Estuaries Project (Howes et al., 2004). Due to the sandy soils of the groundwater recharge area, the land area generating stormwater flow is very small compared to the land area contributing to groundwater. Similar to other Cape Cod studies, it was estimated that only overland flow within 300 ft of the pond contributes water to Santuit Pond (ENSR, 2000 and 2008).

- Direct Precipitation – The atmospheric contribution of direct precipitation to the pond was calculated using the mean annual precipitation and multiplying it by the surface area of the pond. The mean annual precipitation was assumed to be representative of a typical hydrologic period for the watershed and used to calculate the surface and groundwater contributions to Santuit Pond. The annual precipitation estimate of 45 in/yr or 1.14 m/yr was derived from the USGS Groundwater Pumping Study in the Sagamore and Monomoy Flow Lenses (Walter and Whealan, 2005). Santuit Pond is located in the Sagamore Flow Lense, which is the largest flow lense on Cape Cod. A Massachusetts Department of Conservation and Recreation water supply publication based on MDCR, National Weather Service, and US Army Corps of Engineers precipitation records confirms that an average annual precipitation estimate for Cape Cod is 45 in/yr (MDCR, 2008).
- Surface Runoff - For each landuse category, annual runoff was calculated by multiplying mean annual precipitation by basin area and a land use specific runoff fraction. The runoff fraction represents the portion of rainfall converted to overland flow. Land uses, such as residential, have greater impervious surfaces than forest, and therefore have higher runoff fractions. Walter and Whealen (2005) estimated that less than 1% of annual precipitation

becomes surface runoff due to the permeable nature of Cape Cod sandy soils. Therefore, the runoff fractions average 1% in the LLRM model.

- Groundwater - The baseflow was calculated in a manner similar to runoff with a baseflow fraction used in place of a runoff fraction for each land use. The baseflow fraction represents the portion of rainfall converted to groundwater. The baseflow fractions average to 60% because Walter and Whealan (2005) estimate that 60% of annual precipitation in Cape Cod is recharged to groundwater.

Runoff and baseflow fractions were assumed to be representative for Cape Cod land uses. The average runoff and baseflow fractions add up to only 61% because approximately 39% percent of precipitation is lost to evapo-transpiration (Walter and Whealan, 2005). The hydrologic budget was compared to the seepage meter data and a representative standard water yield for New England coastal watersheds (Sopper and Lull, 1970; Higgins and Colonell, 1971). The seepage meter results (Section 3.2) indicate an extremely low groundwater seepage contribution to the 2009 water budget. More seepage meter data would be necessary to represent the annual average groundwater contribution and thus the standard water yield was instead used as a reality check for the Santuit Pond hydrologic budget. The modeled groundwater load was attenuated (reduced) 50% in order achieve better agreement with the standard water yield "reality check."

Table 6-1 Santuit Pond Water Inputs.

Water Inputs	m^3/yr	%
Direct Precipitation	786,600	43%
Surface Runoff	5,339	0.2%
Groundwater	1,830,808	70%
Total	2,622,747	

The estimated total water input is 2,622,747 m3/yr, with about 43 % originating from precipitation and most of the remainder comes from groundwater inflow. It would not be unusual for these values to fluctuate by +25% with the fluctuations in annual precipitation. The estimated flow, with expected variability, would allow the volume (870,970 m3) of Santuit Pond to be replaced every 120 days (flushing rate of 3 flushes per year). This relatively quick flushing rate is due to the shallow nature of Santuit Pond and suggests that current nutrient loading does not affect surface water quality in Santuit Pond for a long period of time. The basic conceptual model of lake behavior predicts that it will take 3 to 5 times the hydraulic residence time to dilute or remove persistent pollutants to a point below detection. In Santuit Pond, this means that any nutrient input on the pond would only last for 1 to 2 years. However, the analysis of phosphorus inputs below indicates that historic nutrient loads may still impact Santuit Pond water quality through internal loading from the phosphorus settled in bottom pond sediments.

6.4 Phosphorus Inputs

Land Use Export

The TP loads for surface runoff and groundwater were calculated using export coefficients for each land use type located within the groundwater recharge area and surface runoff 300 ft buffer, respectively. The groundwater and surface runoff load was then combined with direct loads (atmospheric, internal load, septic system, and waterfowl) to calculate TP loading. The generated load to Santuit Pond was then input into a series of empirical models that provided predictions of in-lake TP concentrations, chl a concentrations, algal bloom frequency and water clarity. Details on model input parameters and major assumptions used to estimate the existing conditions for Santuit Pond are described below.

- Areal land use estimates were generated from the MassGIS 2005 Landuse Layer and compared against the 2009 Town of Mashpee GIS parcel data (MA GIS, 2005; Mashpee, 2009). The land area of the active cranberry bogs was revised based on the Mashpee Conservation Commission area estimates (Baker Bog - 2.6 acres and Brackett Bog - 6.4 acres). Watershed land use is presented spatially in Figure 6-1 and summarized in Table 6-2.
- TP export coefficient ranges were derived from values summarized by Reckhow et al. (1980), and Dudley et al. (1997) as cited in ME DEP (2003). Baseflow export coefficients were chosen from the maximum of the range for each land use type. The TP runoff export coefficient for the two active cranberry bogs was set to zero as the TP contribution from the bogs was treated as a point source.
- The stormwater sampling and groundwater data were used to estimate the surface runoff and groundwater TP loading estimates. A TP attenuation factor of 70% was applied to the surface runoff due to the presence of sandy soils. Also, the resulting predicted average surface runoff concentration of 1,000 µg/L fell within the range of the observed 2009 stormwater sampling concentrations (85 µg/L to 1,728 µg/L). An attenuation factor was not applied to the groundwater phosphorus load because the predicted load of 12 kg/yr closely matches the load calculation based on measured groundwater concentrations. Assuming an average groundwater phosphorus concentration of 0.54 µg/L, which is between the July average of 0.60 µg/L and October average of 0.47 µg/L, the annual phosphorus load would be 99 kg/yr. The dissolved iron content of the groundwater sampled is very high with a dissolved iron to dissolved phosphorus ratio ranging from 0.20 to 0.87. Very little of the groundwater phosphorus (<10 %) is available when iron concentrations are greater than five times the phosphorus concentrations. Assuming only 10% of the groundwater phosphorus load becomes available in Santuit Pond (a liberal estimate based on the iron to phosphorus ratios), the annual groundwater load would be 10 kg/yr, which is close to the estimate predicted through the export coefficient method (12.3 kg/yr).

Annual areal loading of TP from the surface runoff is estimated to be 18 kg/yr, which represents 5% of the total load to the Santuit Pond. The groundwater TP contribution is estimated to be 12 kg/yr or 3% of the total load. Although groundwater water inputs represent a large percentage of the water budget, due to the high iron content of the groundwater, much of the phosphorus that enters the pond through groundwater is not immediately available. A portion of this phosphorus becomes available under anoxic conditions and is accounted for in the internal loading fraction of the nutrient budget.

Table 6-2 Santuit Pond Land Use

Land Use	Area (Hectares)
Urban 1 (Low Density Residential)	44.4
Urban 2 (Mid-Density Residential/Commercial)	132.7
Urban 5 (Mowed Fields)	1.8
Forest 1 (Upland)	298.5
Forest 2 (Wetland)	9.1
Open 1 (Wetland/Lake)	11.5
Cranberry Bogs	3.6
TOTAL	501.7

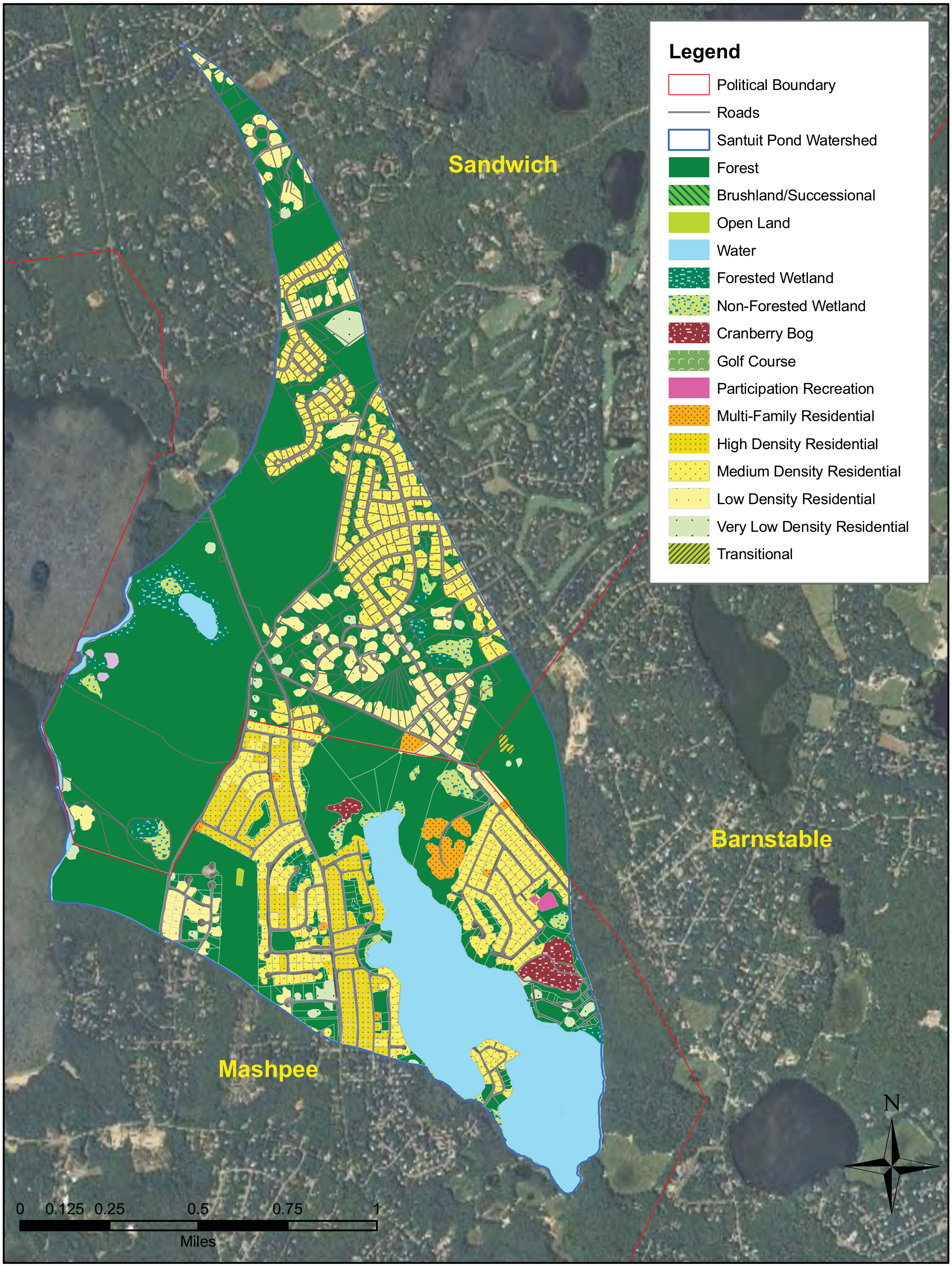

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Figure 6-1. Santuit Pond watershed land use

AECOM

Atmospheric Deposition

Nutrient inputs from atmospheric deposition were estimated based on a TP coefficient for direct precipitation. The atmospheric load of 0.25 kg/ha/yr includes both the mass of TP in rainfall and the mass in dryfall (Wetzel 2001). The sum of these masses is carried by rainfall. The coefficient was then multiplied by the pond area in order to obtain an annual atmospheric deposition TP load. The contribution of atmospheric deposition to the annual TP load to Santuit Pond was estimated to be 17 kg/yr or 5% of the total load.

Septic Systems

TP export loading from residential septic systems was estimated based on the number of homes within 300 ft upgradient of the Santuit Pond shoreline. The 300 ft buffer was selected for the septic system calculation due to rapid groundwater movement through gravel soils within 300 ft of the pond. There is general empirical consensus that phosphorus in wastewater outside this zone does not generally reach waterbodies due to soil attenuation. The number of residencies within the 300 ft zone was estimated using 2009 Mashpee GIS parcel layer data. It was assumed that if the building was within the 300 ft zone that the septic system was also within the 300 ft zone. The TP load was calculated by multiplying a TP export coefficient (based on literature values for wastewater TP concentrations and expected water use), the number of dwellings, the mean number of people per dwelling, the number of days occupied per year, and an attenuation coefficient (Table 6-3). For Santuit Pond, the TP loading from shoreline septic systems was estimated to be 19 kg/yr, which is 5% of the TP load to Santuit Pond.

Table 6-3 Septic System Calculations in Santuit Pond LLRM Model.

Category	Days of Occupancy	# of Dwellings	People/ Dwelling	Water per Person per Day (cu.m)	TP Conc. (mg/L)	TP Atten Factor	TP Load
Yearround	365	49	2.5	0.21	8	80%	15
Seasonal	90	57	2.5	0.21	8	80%	4
Total Load							19

The following assumptions were used in estimating the TP load from septic systems.

- Based on the mailing address of the dwelling owners within the 300 ft buffer, 57 residences are seasonal and 49 are used year round (Mashpee, 2009).
- It was assumed that 2.5 people reside in each dwelling (Howes et al., 2004). It was estimated that each resident uses 55 gallons per day for 365 days per year for year round residents and 90 days for seasonal residents.
- The TP coefficients were calculated based on mean TP concentration in domestic wastewater of 8 mg/L and mean household water uses (Metcalf & Eddy, 1991).
- All septic loads to Santuit Pond were attenuated 80% to account for TP uptake in the soil between the septic system and the lake. There is less attenuation assumed around Santuit Pond than is typical because of the sandy soil surrounding Santuit Pond will likely adsorb less phosphorus than silty soils (Dudley and Stephenson 1973; Brown and Associates 1980).

- There are no actively failing septic systems. Failing septic systems may produce a higher TP load.

Waterfowl

Total phosphorus load from waterfowl was estimated using a TP export coefficient and an estimate of mean annual waterfowl population. The mean annual waterfowl population was based on the summer 2009 waterfowl observation study conducted by Richard and Rita Gollin (Section 3.7). The TP export coefficient for bird species observed on Santuit Pond was multiplied by days of estimated residence and the number of waterfowl in order to obtain a TP load of 3 kg/yr. This equates to 1% of the total TP load. This estimate may be a slight underestimate as the survey was only conducted in the summer and not year-round. Table 6-4 presents calculation data and export coefficients derived from peer reviewed scientific literature.

Table 6-4 Santuit Pond Waterfowl TP Load Calculation in LLRM Model

Bird Type	# of Birds	TP Load (kg/bird/day)	Residence (days)	TP Load (kg/yr)	TP Coefficient Source
Commorants	2	0.000842	92	0.15	Scherer *et al.* 1995
Herring Gulls	1	0.000111	92	0.01	Portnoy 1990
Mallards	45	0.000505	92	2.09	Scherer *et al.* 1995
Canada Geese/Swans	7	0.002100	31	0.46	Manny *et al.* 1975
Swans	2	0.002100	92	0.39	Manny *et al*. 1975
Total				**3.10**	

Cranberry Bogs

The two active bogs on Santuit Pond are Baker Bog on the northern end and Brackett Bog on the central eastern shore of Santuit Pond. Due to the variability of surface water inputs of TP from cranberry bog during flood water releases, the cranberry bog TP load estimate from these two bogs was derived through multiple methods: 1) landuse export coefficients from scientific literature, 2) sampling data from flood release events, and 3) fertilizer rates.

- Landuse export coefficient method- Cranberry bog export coefficients for Cape Cod organic, closed bogs such as those found on Santuit Pond range from 1.23 to 5.57 kg TP/ha/yr (DeMoranville and Howes, 2005). Multiplying the export coefficients by the total cranberry bog area adjacent to Santuit Pond (3.7 ha) resulted in a TP load ranging from 5 to 21 kg/yr.
- Flood release concentration method- The AECOM cranberry floodwater sampling data can be used as a reality check to get a rough estimate of phosphorus loading from the cranberry bogs on Santuit Pond. Although Baker bog was not actively releasing flood water during the October 21st water quality sampling, the sample concentrations can be used to estimate flood water loading. The average TP concentration of the water samples collected in the upper and lower bogs was 58 µg/L. Assuming an average flood depth of 1 ft and a flood release occurring three times a year (Ralph Baker, personal communication), the annual phosphorus load export from Baker bog would be 0.57 kg/yr. It is noteworthy that the Baker bog operators have not applied fertilizer to the bogs in the past five years and the average bog concentrations are within the range of the in-lake concentrations and groundwater concentrations measured in the north end of the pond. The average TP concentration of the

bog flood waters during the Brackett bog flood release in early February 2010 is 91 µg/L. Assuming an average flood depth of 1.5 ft and a flood release occurring three times a year (Brian Wick, personal communication), the annual phosphorus load export from Brackett Bog would be 3.25 kg/yr. This is likely an underestimate as the fall harvest flood occurs after fertilization and the flood waters after the fall harvest would likely have a higher phosphorus concentration. In order to obtain a more accurate estimate of phosphorus inputs, an intensive study would need to be designed to collect samples during each flood release using the Cranberry Experiment Station sampling protocol methods over multiple years.

- Fertilizer Rate- Estimating the phosphorus load from the cranberry bog annual fertilizer application rates provides a maximum export for comparison and does not reflect the actual load entering Santuit Pond. Phosphorus losses result from processes such as plant uptake, soil adsorption, and harvest. The Brackett cranberry bog operation has employed the use of low phosphorus fertilizer for the past 8 years (approximately 4 lbs of P/acre/yr) (Brian Wick, personal communication). The Baker cranberry bog operation has not used fertilizer in the past five years, but typically applies fertilizer at a rate of 9 lbs/acre/yr when used (Ralph Baker, personal communication). Assuming that both cranberry bogs apply fertilizer in a given year, the resulting maximum phosphorus export would be 15 kg/yr. However, these low phosphorus fertilizer BMPs adopted by the current cranberry bog operators are not representative of historic phosphorus fertilizer rates. The southern cranberry bogs also contributed to historic nutrient loading. These historic cranberry bog flood water release discharges likely contributed to the phosphorus rich sediments found in the silt on the bottom of Santuit Pond.

The three methods provide a range of TP loads from the active cranberry bogs of 5 to 21 kg/yr. A TP load of 13 kg/yr was used for the phosphorus model as it is in the middle of the range estimated by the multiple cranberry bog loading methods. Based on the estimate of 13 kg/yr, the cranberry bog TP contribution represents approximately 3% of the TP load.

Internal Loading

Santuit Pond does not strongly thermally stratify and regularly mixes and thus an accumulation of phosphorus is not observed in the bottom waters over the summer as would be observed in a deep, thermally stratified lake. The sediment phosphorus data and oxygen profiles suggest that phosphorus release from the Pond sediments occurs throughout the summer, especially at night and during calm periods. Sediment phosphorus release rates and phosphorus modeling were used to quantify internal loading in Santuit Pond. Elevated levels of available phosphorus are found in all three muck sediment samples (SED 1, 2, and 4), so the entire muck sediment area (121 acres) of Santuit Pond has potential for sediment phosphorus release. It was assumed that the sediment release rate occurred for a period of 90 days (the summer).

Modeling all of the phosphorus inputs into Santuit Pond except for internal loading would result in a combined TP load of 82 kg/yr or an average in-lake concentration of 17 µg/L using empirical equations. In order for the model to predict the mean/median in-lake concentrations observed in 2009 (81 µg/L and 80 µg/L, respectively), the sediment release rate would need to be 6.8 mg/m2/day for 90 days over an area of 121 acres or a total of 297 kg/yr. A release rate of 6.8 mg/m2/day is 37% of the average maximum available phosphorus for the soft sediment areas sampled in Santuit Pond (1.64 g/m2 or 0.0164 mg/m2). Therefore, the release rate of 6.8 mg/m2/day is high, but realistic given the sediment phosphorus data. Also, the high density of algal growth in the summer may be, in part, fueling further algal growth. Algal cells settling on the bottom quickly decompose and mineralize and become a source of phosphorus at the sediment surface (Scheffer, 2004). This phosphorus is either recycled up in the water column during mixing events or directly incorporated into cyanobacteria algal cells at the bottom that then float to the surface.

Internal loading contribution of TP to Santuit Pond was estimated to be 297 kg/yr or 78% of the TP load to Santuit Pond.

6.5 Phosphorus Loading Assessment Summary

The current TP load to Santuit Pond was estimated to be 380 kg/yr from all sources. The TP load according to source is presented in Table 6-5.

Internal loading was overwhelmingly the largest source of TP with an annual load of 297 kg (78% of the total TP load). Surface runoff and groundwater contribute 18 kg/yr (5%) and 12 kg/yr (3%), respectively. Direct precipitation provides approximately 5% of the annual TP load or 17 kg/yr. The active cranberry bogs contribute an estimated 13 kg/yr or 3% of the total load. Septic systems contribute 19 kg/yr or 5% of the annual TP budget. Waterfowl account for only 1% of the annual TP load (3 kg/yr).

Table 6-5 Santuit Pond Phosphorus Loading Summary.

TP Inputs	Modeled TP Loading (kg/yr)	% of Total TP Load
Direct precipitation	17	5
Internal	297	78
Waterfowl	3	1
Septic Systems	19	5
Cranberry Bog	13	3
Watershed		
Surface Runoff	18	5
Groundwater	12	3
Total	**380**	**100**

6.6 Phosphorus Loading Assessment Limitations

While the analysis presented above provides a reasonable accounting of sources of TP loading to Santuit Pond, there are several limitations to the analysis:

- Precipitation varies among years and hence hydrologic loading will vary. This may greatly influence TP loads in any given year for groundwater and runoff.
- Spatial analysis has innate limitations related to the resolution and timeliness of the underlying data. In places, local knowledge was used to ensure the land use distribution in the LLRM model was reasonably accurate, but data layers were not 100% verified on the ground. In addition, land uses were aggregated into classes which were then assigned export coefficients; variability in export within classes was not evaluated or expressed.
- The TP loading estimates for all sources were limited by the assumptions associated with this calculation described in the above subsections.

6.7 Pond Response to Current Phosphorus Loads

TP load outputs from the LLRM Methodology were used to predict in-lake TP concentrations using five empirical models. The models include: Kirchner-Dillon (1975), Vollenweider (1975), Reckhow (1977), Larsen-Mercier (1976), and Jones-Bachmann (1976). These empirical models estimate TP from system features, such as depth and detention time of the waterbody. The load generated from the export portion of LLRM was used in these equations to predict in-lake TP. The mean predicted TP concentration from these models was compared to observed values. Input factors in the export portion of the model, such as export coefficients and attenuation, were adjusted to yield an acceptable agreement between measured and average predicted TP. Because these empirical models account for a degree of TP loss to the phosphorus sediments, the in-lake concentrations predicted by the empirical models are lower than those predicted by a straight mass-balance (145 □g/L) where the mass of TP entering the pond is equal to the mass exiting the pond without any retention. These empirical modeling results are presented in Table 6-6.

The TP load estimated using LLRM methodology translates to predicted mean in-lake concentrations ranging from 34 to 122 µg/L. The mean in-lake TP concentration of the five empirical models was 80 µg/L and it closely matches the mean and median observed surface P concentrations at the deep spot from 2009 data were 81 µg/L and 80 µg/L. The large variability in the empirical in-lake modeling predictions likely stems from the fact that Santuit Pond is a shallow pond whereas the empirical equations incorporate a wide variety of lakes and most are deeper and stratify. There are many mechanisms occurring in shallow lakes that may not be reflected in empirical relationships between TP loading and in-lake TP, such as algal cell phosphorus mineralization feeding algal growth, sediment resuspension inducing phosphorus release from the sediments, and phosphorus adsorption-desorption kinetics inducing sediment phosphorus release (Scheffer, 2004). Although the empirical models may not apply accurately to all lakes, they do provide an approximation of predicted in-lake TP concentrations and a reasonable estimate of the direction and magnitude of change that might be expected if loading is altered.

Table 6-6 Predicted In-Lake Total Phosphorus Concentrations using Empirical Models.

Empirical Equation	**Equation**	**Predicted TP (*µg/L*)**
Mass Balance	TP=L/(Z(F))*1000	145
Kirchner-Dillon 1975	TP=L(1-Rp)/(Z(F))*1000	51
Vollenweider 1975	TP=L/(Z(S+F))*1000	122
Larsen-Mercier 1976	TP=L(1-Rlm)/(Z(F))*1000	92
Jones-Bachmann 1976	TP=0.84(L)/(Z(0.65+F))*1000	100
Reckhow General 1977	TP=L/(11.6+1.2(Z(F)))*1000	34
Average of Above 5 Model Values		***80***
Observed Surface Mean-Deep Spot		***81***
Observed Surface Median-Deep Spot		***80***
TP = Lake Total Phosphorus Concentration **L = Phosphorus Load to Lake** **Z = Mean Depth** **F = Flushing Rate** **Rp = Retention Coefficient (settling rate)** **Rlm = Retention Coefficient (flushing rate)**		

Once TP estimates were derived, annual mean chl a and SDT can be predicted based on another set of empirical equations: Carlson (1977), Dillon and Rigler (1974), Jones and Bachman (1976), Oglesby and Schaffner (1978), Vollenweider (1982), and Jones, Rast and Lee (1979). Bloom frequency was also calculated based on equations developed by Walker (1984, 2000) using a natural log mean chl a standard deviation of 0.5. These predictions are presented in Table 6-7.

Table 6-7 Predicted In-Lake chlorophyll a and Secchi disk transparency predictions based on an annual average in-lake phosphorus concentration of 80 μg/L.

Empirical Equation	Equation	Predicted Value
Mean Chlorophyll		***μg/L***
Carlson 1977	Chl=0.087*(Pred TP)^1.45	49.9
Dillon and Rigler 1974	Chl=10^(1.449*LOG(Pred TP)-1.136)	41.8
Jones and Bachmann 1976	Chl=10^(1.46*LOG(Pred TP)-1.09)	48.7
Oglesby and Schaffner 1978	Chl=0.574*(Pred TP)-2.9	43.0
Modified Vollenweider 1982	Chl=2*0.28*(Pred TP)^0.96	37.6
Average of Model Values		**44.2**
Observed Summer Mean-Deep Spot		***39.0***
Peak Chlorophyll		***μg/L***
Modified Vollenweider (TP) 1982	Chl=2*0.64*(Pred TP)^1.05	127.3
Vollenweider (CHL) 1982	Chl=2.6*(AVERAGE(Pred Chl))^1.06	144.2
Modified Jones, Rast and Lee 1979	Chl=2*1.7*(AVERAGE(Pred Chl))+0.2	150.4
Average of Model Values		**140.7**
Observed Summer Maximum-Deep Spot		***90.0***
Bloom Probability		***% of Summer***
Probability of Chl >15 *u*g/L	See Walker 1984 & 2000	97%
Secchi Transparency		***m***
Mean: Oglesby and Schaffner 1978	SDT=10^(1.36-0.764*LOG(Pred TP))	0.8
Max: Modified Vollenweider 1982	SDT=9.77*Pred TP^-0.28	2.9
Observed Summer Mean-Deep Spot		***2.6***
Observed Summer Maximum-Deep Spot		***5.6***

Variable	Description	Units
"Pred TP"	The average TP calculated from the 5 predictive equation models	*μ*g/L
"Pred Chl"	The average of the 3 predictive equations calculating mean chlorophyll	*μ*g/L

*The observed summer maximum is based on n=4 and is not necessarily the peak chlorophyll

7.0 Diagnostic Summary

7.1 Current Conditions

Santuit is a very eutrophic pond with high levels of phosphorus, persistent summer cyanobacteria blooms, periodic low oxygen in the bottom waters (especially at night when algal photosynthesis ceases), low summer transparency (SDT), and evidence of phosphorus release from the sediments. Very high in-lake phosphorus concentrations (2009 average of 81 µg/L) contribute to the extensive cyanobacteria blooms observed in the summer and impair desired uses.

Precipitation, waterfowl, stormwater runoff, groundwater, septic systems, cranberry bog flood release, and internal recycling all contribute to the phosphorus fueling the cyanobacteria blooms. Internal recycling contributes the largest percentage of the load (78%).

7.2 In-lake Target Concentration Discussion

As a means of establishing the amount of phosphorus reduction needed in order to fully support primary contact and aquatic habitat uses of Santuit Pond, it is necessary to derive a numeric in-lake TP target value (e.g., in-lake concentration) for determining acceptable phosphorus loads. The Cape Cod Commission TP criterion for healthy ponds is 10 µg/L (CCC, 2003). An in-lake target of 10 µg/L would be unattainable as a concentration of 10 µg/L is close to background concentrations, and reverting the pond back to its pre-development state is not an option. The Vollenweider (1975, 1978) permissible and critical load approach provides guidance for a target in-lake concentration. A permissible load is generally defined as the amount of phosphorus that could enter a system without obvious or continual detrimental effects, such as nuisance algal blooms. Nuisance algal blooms would become a common problem at the critical load. For Santuit Pond, the permissible and critical phosphorus loads are 0.19 g/m2/yr and 0.39 g/m2/yr, respectively. These loads translate to an average in-lake concentration of 28 to 56 µg/L, respectively. MDEP recommended a lower target concentration of 12 to 15 µg/L (Mark Mattson, personal communication). For the purposes of this diagnostic study, a preliminary target concentration of 15 µg/L was used in order to calculate the necessary load reduction. The in-lake target concentration will be finalized and supported when the MDEP prepares a formal TMDL report for Santuit Pond.

7.3 Reduction Needed to Meet In-Lake Target

Current TP loading and in-lake concentrations are greater than required to support designated uses. In order to attain a target in-lake TP concentration of 15 µg/L, the TP load needs to be reduced to 71 kg/yr. This would require an overall reduction in phosphorus loading of 81%. As some sources are less controllable than others, the actual reduction to be applied to achieve this goal will vary by source. The evaluation of alternative loading reduction scenarios discussed below provides a means to determine the effective phosphorus management strategies for pond restoration.

7.4 Evaluation of Alternative Loading Scenarios

AECOM used the LLRM model to evaluate a number of alternative loading scenarios and the probable lake response to these loadings. These scenarios included:

- Natural Environmental Background Phosphorus Loading
- Removal of Internal Phosphorus Load
- Reduction of Phosphorus Loads to Meet Recommended 15 µg/LTarget

7.5 Natural Environmental Background Phosphorus Loading

Natural environmental background levels of TP in Santuit Pond were evaluated using the LLRM model. Natural background was defined as background TP loading from non-anthropogenic sources. Hence, land uses in the watershed were set to its assumed "natural" state of forests and wetlands. Loading was then calculated using the LLRM model. This estimate is useful as it sets a realistic lower bound of TP loading and in-lake concentrations possible for Santuit Pond. It is very unlikely that loadings and target concentrations at or below these levels will be achieved.

For the natural environmental background TP loading scenario, all developed land was converted to forests and the internal and septic loads were removed. The waterfowl load was cut in half with the assumption that half of the waterfowl were attracted to the pond because of human actions. The cranberry bogs were converted to wetland land uses.

The natural background loading for Santuit Pond was estimated at 26 kg TP /yr (Table 7-1, Table 7-2). The calculated background loading of TP to Santuit Pond would result in a mean in-lake TP concentration of 5 µg/L, a mean SDT of 6.5 m, a mean chl a of 1.1 µgL and a bloom probability of chl a > 15 µgL of 0%. The predicted mean SDT is deeper than the maximum pond depth, but indicates that the SDT would be at the lake bottom. Estimated TP loading to Santuit Pond under the natural background scenario is 93% lower than current Santuit Pond TP loading.

7.6 Internal Load Removal

Modeling the removal of the largest TP source helps to determine the influence of the other TP inputs. Under this scenario, internal loading is removed as it is the largest source of TP. Reducing total loading by 78% results in an in-lake TP concentration of 17 µg/L, which is higher than the preliminary target of 15 µg/L. Removing only internal phosphorus loading would not be sufficient to restore Santuit Pond to support its designated uses. Also, addressing the internal load without reducing external loading (stormwater runoff, groundwater, waterfowl, septic systems, and cranberry bogs) will result in the reaccumulation of phosphorus in the sediments over time and future internal loading.

7.7 Target Loading

The target loading scenario helps to determine how large of a TP load reduction is necessary in order to attain the target in-lake concentration of 15 µg/L. This modeling scenario provides only one of numerous loading reduction scenarios in order to attain the target. This scenario assumes a 100% reduction in internal loading and an 18% reduction in all external phosphorus sources other than direct precipitation (watershed, septic system, waterfowl, and cranberry bog loads). At an in-lake TP concentration of 15 µg/L, it is expected that the mean SDT would be 2.9 m, the mean chl a would be 5.1 µg/L, and the probability of a summer bloom (chl a > 15 µg/L) would be 1%. This loading reduction scenario is very ambitious. As discussed in Section 8.0, it will likely be difficult to reduce the internal loading by 100%. With in-lake management techniques, the greatest reduction in internal loading that can reasonably be expected is 75%. The maximum potential reduction is approximately 90%. However, assuming a 67% to 75% reduction in internal loading, the target in-lake TP concentration of 15 µg/L could not be attained even with a complete elimination of the controllable external loads. AECOM recommends an aggressive phosphorus management strategy that incorporates reductions in both internal (phosphorus recycling) and external loads (watershed, cranberry bogs, septic systems, and waterfowl). The target may be difficult to attain, but it is a goal to work toward. Reductions in the phosphorus loading below permissible levels (resulting in an in-lake TP concentration of 28 µg/L) will certainly reduce the frequency of algal blooms and improve overall water quality. The following section (Section 8.0) provides guidance in techniques to reduce internal and external loads.

Table 7-1 Comparison of Santuit Pond Modeled Phosphorous Loading Scenarios

Inputs	Current Load (kg/yr)	Natural Environmental Background (kg/yr)	Current Load without Internal Loading (kg/yr)	Target Load to Attain 15 µg/L In-lake Concentration (kg/yr)
Direct Precipitation	17	17	17	17
Internal	297	0	0	0
Waterfowl	3	2	3	3
Septic System	19	0	19	16
Cranberry Bogs	13	0	13	10
Watershed				
Surface Runoff	18	5	18	15
Groundwater	12	2	12	10
Total Load	380	26	82	71
Total Overall Load Reduction	0	354	297	309
Percent Overall Reduction	0%	93%	78%	81%

Table 7-2 Lake water quality response to different loading scenarios for Santuit Pond.

Parameters	Current Load	Natural Environmental Background	Current Load without Internal Loading	Target Load to Attain 15 µg/L In-lake Concentration
TP Load (kg/yr)	380	26	82	81
Mean Annual TP (ug/L)	80	5	17	15
Mean Secchi Disk Transparency (m)	0.8	6.5	2.6	2.9
Mean Chlorophyll *a* (ug/L)	44	1	6.2	5.1
Peak Chlorophyll *a* (ug/L)	141	5	21.6	17.9
Probability of Summer Algal Bloom (Chl *a* > 15 ug/L)	97%	0%	2%	1%

8.0 Potential Restoration Options

8.1 Restoration Objectives

In terms of the restoration of desirable water quality for the users of Santuit Pond, the primary goal is to eliminate nuisance algae blooms, or at least to reduce their frequency and severity. Linked objectives include reducing the internal and external loading of phosphorus. Methods for achieving phosphorus loading will be addressed in the subsequent external and in-lake phosphorus control sections.

8.2 External Phosphorus Control Techniques

The external loading phosphorus inputs (non-internal loading) represent 22% of the entire TP load. Reductions in these loads are necessary in order to attain Santuit Pond restoration goals. The atmospheric phosphorus contribution to Santuit Pond cannot be managed, but all of the other external loads can be. Best management practices (BMPs) should be applied to reduce phosphorus inputs from the watershed, groundwater, septic systems, waterfowl and cranberry bogs. Techniques for reducing pollutant loads are discussed below.

8.2.1.1 Watershed

The Santuit Pond watershed is within three towns: Mashpee, Sandwich, and Barnstable. Working with Sandwich and Barnstable, the Town of Mashpee will be able to more effectively control watershed inputs.

Developed areas are normally the primary target of watershed management. The rise in residential development in the 1970s cottage era and modern developments in the 1990s-2000 within the water likely increased watershed phosphorus loading into Santuit Pond. Residential development tends to contribute greater phosphorus loading primarily through disturbed soils and inorganic phosphate lawn fertilizer use. Phosphorus loading from residential areas does pose a threat to the pond water quality as shown through the results of stormwater sampling showing extremely high phosphorus concentrations. These inputs from residential development can also infiltrate into the shallow groundwater and seep into the pond, although phosphorus is naturally attenuated through the soil. However, water rapidly infiltrates through the sandy Cape Cod soils and may not provide as much attenuation as finer-grained soils.

Construction BMPs should be employed in order to minimize soil erosion associated with construction. US EPA requires a stormwater pollution prevent plan (SWPPP) to be created for any construction project disturbing greater than one acre. Regardless of the size of the construction project, EPA guidance documents provide useful information on sediment and erosion control (USEPA, 2010). Recommended construction BMPs include haybale/silt fence borders and slope stabilization with vegetation. Massachusetts also has guidance documents on controlling construction erosion (MDEP, 2003).

To minimize the excessive use of fertilizers, low impact yard landscaping should be encouraged. Using cold weather grass seed and planting native flora rather than phosphorus and nitrogen intensive non-native grass will minimize the need for fertilizer. Fertilizer use, especially in properties within the 300 ft buffer around the pond, should be discouraged. If homeowners feel that the appearance of their yard without fertilizer is unacceptable, there are slow release fertilizer options with low to no phosphate available on the market. The Center for Watershed Protection provides information on low phosphorus lawn care (CWP, 2000). It is recommended that educational materials be distributed to homeowners within the Santuit Pond watershed (especially within 300 ft of the pond). The educational materials should include information about the impact of nutrients on water quality and low phosphate fertilizer alternatives. Conducting lawn care surveys to gauge homeowner fertilizer usage also can create awareness and spark interest in non-nutrient intensive lawn care.

Maintaining natural vegetated buffers between lawn areas and the shoreline is also recommended. These vegetated strips allow overland flow to pass through vegetation that filters out some percentage of the particulates and decreases the velocity of the stormwater. Particulate settling and infiltration of water often occurs as the stormwater passes through the vegetation. Based on work done elsewhere and especially in Maine (Dennis et al., 1992), buffer strips need to be at least 25 ft wide before any appreciable benefit is derived, and superior removal requires a width >100 ft. Lesser widths may provide pollutant removal benefits in sandy Cape Cod soils, but evidence is scant and a minimum width of 25 ft is recommended for areas with slopes <2%. As the slope increases, the minimum should also increase; a 100 ft minimum is appropriate for slopes in excess of 20%. This will provide a minimum of 25% reduction in phosphorus transport. Most of the homes surrounding Santuit Pond have a natural buffer along the shoreline due to the steep nature of the slopes to the pond. The Bryants Neck neighborhood is an exception. Since most of the Santuit Pond shoreline has already been developed, the properties without natural shoreline buffer would need to be retrofitted. Creative planting and use of buffer strips can be low cost and can be encouraged through demonstration projects or local financial incentives. Educational programs can help raise the awareness of homeowners and inform them how they can alter drainage on their property to reduce nutrients entering the lake. Recent guidance for low impact living on the shoreline, "Landscaping at the Water's Edge: An Ecological Approach", has been developed (UNH Cooperative Extension, 2007).

Structural stormwater BMPs can also assist to minimize sheet runoff into the pond. In 2009, the Town of Mashpee took steps to improve drainage on Timberlane Drive, where sheet flow problems caused erosion in several areas. During wet weather sampling events, AECOM observed that the berms and infiltration basin off Timberlane Drive effectively prevented overland sheetflow from entering the pond. However, AECOM did locate a few areas around the pond that should be further investigated for the installation of structural BMPs that detain stormwater and encourage soil infiltration. These areas include:

1) The Town Landing access road and parking area (WW-1)
2) Non-bermed areas of Timberlane (WW-2b)
3) Locations in the Bryant's Neck neighborhood (WW-3a & 3b)
4) Beechwood Point Drive (WW-4)
5) Cranberry Lane (WW-5)

Figure 8-1 provides photos of the wet weather sampling locations where stormwater management may be improved. The Center for Watershed Protection and University of Massachusetts Amherst provide guidance documents on choosing appropriate stormwater BMPs in developed areas (CWP, 2008; UMASS, 2008).

The Beechwood Point Drive location (WW-4) has a steep woodland buffer, so the runoff may not even reach Santuit Pond as overland flow. However, repairs may prevent any runoff from flowing into the woods. Also, a few locations discharge into cranberry bogs. Stormwater runoff at the Cranberry Lane (WW-5) location discharges into the Brackett cranberry bog rather than to the pond directly. Also, runoff at the Hemlock Drive (WW-2a) location likely discharges to the sourthern abandoned cranberry bogs rather than the pond directly.

Professional experience suggests that aggressive implementation of watershed BMPs may result in a maximum practical TP loading reduction of 60-70%. Greater reductions are possible, but consideration of costs, space requirements, and legal ramifications (e.g., land acquisitions, jurisdictional issues), limit attainment of such reductions. Most techniques applied in a practical manner do not yield >60% reductions in TP loads (CWP, 2000). Better results may be possible with widespread application of low impact development techniques, as these reduce post-development volume of runoff as well as improve its quality, but there is not enough of a track record yet to generalize attainable results on a watershed basis.

Figure 8-1. Locations identified with stormwater sheetflow entering Santuit Pond.

Stormwater runoff flowing from Town landing access road and parking lot directly into Santuit Pond (WW-1) on August 29, 2009.

Stormwater runoff flowing down Hemlock Drive (WW-2a) and onto private property on August 29, 2009. Note that this runoff does not likely reach Santuit Pond.

Stormwater runoff from the Bryants' Neck neighborhood off of Santuit Lane (WW-3a) on August 29, 2009.

Stormwater runoff not all being captured by infiltration basin on Beachwood Point Drive (WW-4) and flowing toward Santuit Pond on August 29, 2009.

Stormwater runoff flowing down Cranberry Lane (WW-5) and onto dirt path toward the Brackett cranberry bog on August 29, 2009.

The asphalt berm and infiltration basin installed by Town of Mashpee capturing all stormwater runoff from Timberlane Drive and Lantern Lane on August 29, 2009.

8.2.1.2 Septic System Management

Maintenance and inspection of on-site waste disposal systems is a recommended management technique for the Santuit Pond watershed. Education is the first step in alerting residents to this need. Some effort should be made to educate septic system users of the limitations of those systems and how users can minimize strain on system capabilities. As homes are sold, homeowners are required to upgrade systems to meet current usage according to Title V regulations and reduce the phosphorus loading of any failing septic systems. A properly functioning septic system can be an effective means of reducing pollutant loading to an aquatic ecosystem, but does not trap all pollutants and requires inspection and maintenance.

With high groundwater inorganic nitrogen concentrations observed near the Timberlane Drive/Fir Court neighborhood, a detailed septic survey is recommende. Septic systems are likely not the sole source of the high inorganic nitrogen concentration, but further sampling and a survey of the age and setback of septic systems will help to determine whether there are failing septic systems in this neighborhood. A septic survey around the entire shoreline is recommended to identify any potentially failing septic systems around the shoreline.

8.2.1.3 Waterfowl Control

Waterfowl, including ducks, geese, and seabirds, are a valuable natural resource and a source of recreation to the general public, bird watchers, and hunters. In Santuit Pond, waterfowl are not considered a problem, but they are a source of nutrients.

Of all the waterfowl, Canada geese are particularly opportunistic and can easily become accustomed to urban settings. In New England, resident Canada goose populations have increased dramatically since the 1960's. In urban areas, Canada geese populations have responded explosively to landscape features that provide expanses of short grass for food with direct access to water, lack of natural predators, absence of hunting, and hand feeding by some people.

Although most people find a few geese acceptable, problems develop if local flocks grow and the droppings become excessive (a goose produces a pound of droppings per day). Problems include over-grazed lawns, accumulations of droppings and feathers on play areas and walkways, nutrient loading in ponds, public health concerns at beaches and drinking water supplies, aggressive behavior by nesting birds, and safety hazards near roads.

At this stage, waterfowl impacts on the pond are not excessive, but given that a small amount of phosphorus sponsors a significant amount of algal growth, it is recommended that waterfowl should be tolerated but not encouraged to reside at the pond. This would include discouraging feeding by residents, managing adjacent riparian shoreline areas to reduce access or attractive features (e.g., lawns right at water's edge),increasing the difference in height between the water surface and the tops of structures such as docks and walkways, and, as needed, more direct control methods.

8.2.1.4 Cranberry Bog Phosphorus Management

Cranberry bogs are a vital component of the cultural heritage of Cape Cod. They also are important to the national economy as Massachusetts produces ~23% of the United States cranberry crop (DeMoranville, 2006). Flood and associated dewatering events are the primary source of phosphorus from active cranberry bog operations (DeMoranville and Howes, 2005). Measures can be taken to reduce phosphorus export while maintaining high crop yields. Currently, the active cranberry bogs on Santuit Pond do employ many of the recommended Best Management Practices (BMPs) to protect water quality (DeMoranville, 2009), including the use of low phosphate fertilizer, avoiding applying fertilizer before flood events, and the slow release of floodwaters (1-3 days) (Brian Wick and Ralph Baker, personal communication). DeMoranville and Howes (2005) recommends phosphorus fertilizer rates of less than 20 lbs/acre. The 2005 study also recommends a slow flood release (1-3 days) to allow sediments to settle and maintaining flooding no longer than 10 days to prevent anoxia and subsequent phosphorus release.

The active cranberry bogs may wish to employ other BMPs in order to further reduce the TP contribution to Santuit Pond. Many BMPs aim to reduce water discharge into receiving waters. Computer operated irrigation systems may eliminate the need to flood bogs in the winter for frost protection (Bolton, 2001). Other BMPs target reducing phosphorus in the flood waters before discharging into the receiving water. Pumping flood water to detention basins upgradient of the cranberry bogs can improve water quality by allowing phosphorus-laden particulates to settle before entering receiving water (MDEP, 2009). Also, the flood water can be treated with phosphorus inactivation chemicals in the detention basin before being released to the receiving body to further reduce phosphorus levels.

8.3 Internal Phosphorus Control Techniques

The internal phosphorus control techniques that are most applicable to Santuit Pond are: 1) dredging, 2) circulation, and 3) phosphorus inactivation. These three techniques were deemed the most applicable after considering a long list of potential in-lake techniques for algal control. There are numerous physical, chemical, and biological controls that use the factors that limit algal growth (light and nutrients) as the basis for algal management. Algae management techniques (Table 8-1) such as dyes, artificial circulation and selective plantings seek to establish light limitation, while methods such as aeration, dilution and flushing, drawdown, dredging, phosphorus inactivation, and selective withdrawal are used to reduce nutrient availability. In Santuit Pond, light limitation is likely secondary to nutrient limitation due to its shallow nature and the presence of algae growth in the bottom waters (~7-8.5 ft) as indicated with the MWT-M-WQMP YSI 6600V2 sonde probe data. The most effective strategies in Santuit Pond will target phosphorus reduction by physical and chemical controls. However, AECOM considered all strategies and provides justification of why some are not appropriate for Santuit Pond.

Physical controls not considered appropriate for Santuit Pond include: (1) dilution and flushing; (2) drawdown; (3) light-limiting dyes; (4) mechanical removal; (5) selective withdrawal; and (6) sonication. Dilution and flushing were not appropriate since there is not excess water in the watershed to use to increase the flushing rate. Drawdown is not appropriate due to a lack of an effective outlet structure that will allow significant drawdown and is usually less feasible where groundwater is the major hydrologic input. Also, this method would increase groundwater recharge and might interfere with the operation of the private water wells. Light-limiting dyes are generally only used in small waterbodies where aesthetic considerations are the major concern (e.g., golf courses, reflecting pools). Mechanical withdrawal refers to the pumping and treatment of water generally for public water supplies, which is not applicable to Santuit Pond. Selective withdrawal of anoxic bottom water is not applicable to Santuit Pond as the pond does not thermally stratify in the summer and anoxic bottom waters regularly mix with surface waters. Sonication is generally reserved for application near the intake of drinking water supplies, but can work in ponds of up to about 10 acres; Santuit Pond is much larger.

Chemical controls not considered appropriate for Santuit Pond include: (1) hypolimnetic aeration; (2) use of algaecides; (3) sediment oxidation; (4) settling agents, and (5) selective nutrient addition. Hypolimnetic aeration was not considered as the shallow Santuit Pond does not strongly thermally stratify. Algaecides, as indicated by Table 8-1, come in many forms and most will provide short-term relief from algal blooms, but do nothing to change the fundamental reasons (excess nutrients) for the algal blooms. Further, breakdown and decay of algal biomass in the poorly flushed pond would lead to more organic oxygen demand in the water column (already a problem) and release and recycling of the nutrients to spur more growth. Sediment oxidants work to change the redox conditions in the sediments to help inactivate nutrients but would be considered as a harsh alternative to nutrient inactivation, with more impacts and potentially less benefit. The more conventional alum treatment of the sediments is simpler and more likely to work in the very low redox conditions found at the bottom, and is covered separately. Settling agents are another form of alum-based nutrient inactivation. In this case, the coagulant, which could be alum, flocculates out particles and potentially dissolved phosphorus from the water column and binds it in the sediment layer. This method is useful for treating stormwater inputs or other flow-associated nutrients. Selective nutrient addition is rarely considered for eutrophic waterbodies as excess levels of nitrogen and phosphorus are already present; changing nutrient ratios could alter the types of algae, but is not expected to lower bloom potential. Further, addition of nitrogen would not be appropriate for Santuit Pond given its potential impacts to the nitrogen-enriched coastal waters downstream.

Biological controls are not likely appropriate for Santuit Pond as a primary management technique. Common methods include: (1) enhanced grazing of algae by zooplankton through food web manipulation and (2) bottom-feeding fish removal to reduce nutrient cycling and sediment disturbance. Enhancement of grazing by biomanipulation is often unpredictable in lakes with high nutrient concentrations and may require repeated stockings. Stocking with predator fish will reduce predation on zooplankton by reducing the fish species that feed on zooplankton may have consequences for herring that use Santuit Pond as spawning and nursery grounds. Herring are considered a valuable regional resource. There is little evidence that bottom feeding fish are a large component of the fish community of Santuit pond at present. Despite the questions surrounding the application of biologic controls to Santuit Pond as a primary management technique, fisheries management that encourages a well balanced fish community with top predators, planktivores and benthic feeding species is encouraged and will result in healthier pond and a better recreational fishery. However, they are not recommended as a primary management technique.

Table 8-1 Options for control of algae.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
	WATERSHED CONTROLS		
1) Management for nutrient input reduction	♦ Includes wide range of watershed and lake edge activities intended to eliminate nutrient sources or reduce delivery to lake ♦ Essential component of algal control strategy where internal recycling is not the dominant nutrient source, and desired even where internal recycling is important	♦ Acts against the original source of algal nutrition ♦ Creates sustainable limitation on algal growth ♦ May control delivery of other unwanted pollutants to lake ♦ Facilitates ecosystem management approach which considers more than just algal control	♦ May involve considerable lag time before improvement observed ♦ May not be sufficient to achieve goals without some form of in-lake management ♦ Reduction of overall system fertility may impact fisheries ♦ May cause shift in nutrient ratios which favor less desirable algae
1a) Point source controls	♦ More stringent discharge requirements ♦ May involve diversion ♦ May involve technological or operational adjustments ♦ May involve pollution prevention plans	♦ Often provides major input reduction ♦ Highly efficient approach in most cases ♦ Success easily monitored	♦ May be very expensive in terms of capital and operational costs ♦ May transfer problems to another watershed ♦ Variability in results may be high in some cases
1b) Non-point source controls	♦ Reduction of sources of nutrients ♦ May involve elimination of land uses or activities that release nutrients ♦ May involve alternative product use, as with no phosphate fertilizer	♦ Removes source ♦ Limited or no ongoing costs	♦ May require purchase of land or activity ♦ May be viewed as limitation of "quality of life" ♦ Usually requires education and gradual implementation

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
1c) Non-point source pollutant trapping	♦ Capture of pollutants between source and lake ♦ May involve drainage system alteration ♦ Often involves wetland treatments (detention/infiltration) ♦ May involve stormwater collection and treatment as with point sources	♦ Minimizes interference with land uses and activities ♦ Allows diffuse and phased implementation throughout watershed ♦ Highly flexible approach ♦ Tends to address wide range of pollutant loads	♦ Does not address actual sources ♦ May be expensive on necessary scale ♦ May require substantial maintenance
IN-LAKE PHYSICAL CONTROLS			
2) Circulation and destratification	♦ Use of water or air to keep water in motion ♦ Intended to prevent or break stratification ♦ Generally driven by mechanical or pneumatic force	♦ Reduces surface build-up of algal scums ♦ May disrupt growth of blue-green algae ♦ Counteraction of anoxia improves habitat for fish/invertebrates ♦ Can eliminate localized problems without obvious impact on whole lake	♦ May spread localized impacts ♦ May lower oxygen levels in shallow water ♦ May promote downstream impacts
3)Dilution and flushing	♦ Addition of water of better quality can dilute nutrients ♦ Addition of water of similar or poorer quality flushes system to minimize algal build-up ♦ May have continuous or periodic additions	♦ Dilution reduces nutrient concentrations without altering load ♦ Flushing minimizes detention; response to pollutants may be reduced	♦ Diverts water from other uses ♦ Flushing may wash desirable zooplankton from lake ♦ Use of poorer quality water increases loads ♦ Possible downstream impacts

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
4) Drawdown	♦ Lowering of water over autumn period allows oxidation, desiccation and compaction of sediments ♦ Duration of exposure and degree of dewatering of exposed areas are important ♦ Algae are affected mainly by reduction in available nutrients.	♦ May reduce available nutrients or nutrient ratios, affecting algal biomass and composition ♦ Opportunity for shoreline clean-up/structure repair ♦ Flood control utility ♦ May provide rooted plant control as well	♦ Possible impacts on non-target resources ♦ Possible impairment of water supply ♦ Alteration of downstream flows and winter water level ♦ May result in greater nutrient availability if flushing inadequate
5) Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering ♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ♦ Nutrient reserves are removed and algal growth can be limited by nutrient availability	♦ Can control algae if internal recycling is main nutrient source ♦ Increases water depth ♦ Can reduce pollutant reserves ♦ Can reduce sediment oxygen demand ♦ Can improve spawning habitat for many fish species ♦ Allows complete renovation of aquatic ecosystem	♦ Temporarily removes benthic invertebrates ♦ May create turbidity ♦ May eliminate fish community (complete dry dredging only) ♦ Possible impacts from containment area discharge ♦ Possible impacts from dredged material disposal ♦ Interference with recreation or other uses during dredging
5a) "Dry" excavation	♦ Lake drained or lowered to maximum extent practical ♦ Target material dried to maximum extent possible ♦ Conventional excavation equipment used to remove sediments	♦ Tends to facilitate a very thorough effort ♦ May allow drying of sediments prior to removal ♦ Allows use of less specialized equipment	♦ Eliminates most aquatic biota unless a portion left undrained ♦ Eliminates lake use during dredging

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
5b) "Wet" excavation	♦ Lake level may be lowered, but sediments not substantially exposed ♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment	♦ Requires least preparation time or effort, tends to be least cost dredging approach ♦ May allow use of easily acquired equipment ♦ May preserve aquatic biota	♦ Usually creates extreme turbidity ♦ Normally requires intermediate containment area to dry sediments prior to hauling ♦ May disrupt ecological function ♦ Use disruption
5c) Hydraulic removal	♦ Lake level not reduced ♦ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area ♦ Slurry is dewatered; sediment retained, water discharged	♦ Creates minimal turbidity and impact on biota ♦ Can allow some lake uses during dredging ♦ Allows removal with limited access or shoreline disturbance	♦ Often leaves some sediment behind ♦ Cannot handle coarse or debris-laden materials ♦ Requires sophisticated and more expensive containment area
6) Light-limiting dyes and surface covers	♦ Creates light limitation	♦ Creates light limit on algal growth without high turbidity or great depth ♦ May achieve some control of rooted plants as well	♦ May cause thermal stratification in shallow ponds ♦ May facilitate anoxia at sediment interface with water
6.a) Dyes	♦ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting algal growth ♦ Dyes remain in solution until washed out of system.	♦ Produces appealing color ♦ Creates illusion of greater depth	♦ May not control surface bloom-forming species ♦ May not control growth of shallow water algal mats ♦ Altered thermal regime
6.b) Surface covers	♦ Opaque sheet material applied to water surface	♦ Minimizes atmospheric and wildlife pollutant inputs	♦ Minimizes atmospheric gas exchange ♦ Limits recreational use

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
7) Mechanical removal	♦ Filtering of pumped water for water supply purposes ♦ Collection of floating scums or mats with booms, nets, or other devices ♦ Continuous or multiple applications per year usually needed	♦ Algae and associated nutrients can be removed from system ♦ Surface collection can be applied as needed ♦ May remove floating debris ♦ Collected algae dry to minimal volume	♦ Filtration requires high backwash and sludge handling capability for use with high algal densities ♦ Labor and/or capital intensive ♦ Variable collection efficiency ♦ Possible impacts on non-target aquatic life
8)Selective withdrawal	♦ Discharge of bottom water which may contain (or be susceptible to) low oxygen and higher nutrient levels ♦ May be pumped or utilize passive head differential	♦ Removes targeted water from lake efficiently ♦ Complements other techniques such as drawdown or aeration ♦ May prevent anoxia and phosphorus build up in bottom water ♦ May remove initial phase of algal blooms which start in deep water ♦ May create coldwater conditions downstream	♦ Possible downstream impacts of poor water quality ♦ May eliminate colder thermal layer that supports certain fish ♦ May promote mixing of remaining poor quality bottom water with surface waters ♦ May cause unintended drawdown if inflows do not match withdrawal
9) Sonication	♦ Sound waves disrupt algal cells	♦ Supposedly affects only algae (new technique) ♦ Applicable in localized areas	♦ Unknown effects on non-target organisms ♦ May release cellular toxins or other undesirable contents into water column

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
IN-LAKE CHEMICAL CONTROLS			
10) Hypolimnetic aeration or oxygenation	♦ Addition of air or oxygen at varying depth provides oxic conditions ♦ May maintain or break stratification ♦ Can also withdraw water, oxygenate, then replace	♦ Oxic conditions promote binding/sedimentation of phosphorus ♦ Counteraction of anoxia improves habitat for fish/invertebrates ♦ Build-up of dissolved iron, manganese, ammonia and phosphorus reduced	♦ May disrupt thermal layers important to fish community ♦ Theoretically promotes supersaturation with gases harmful to fish
11) Algaecides	♦ Liquid or pelletized algaecides applied to target area ♦ Algae killed by direct toxicity or metabolic interference ♦ Typically requires application at least once/yr, often more frequently	♦ Rapid elimination of algae from water column , normally with increased water clarity ♦ May result in net movement of nutrients to bottom of lake	♦ Possible toxicity to non-target species ♦ Restrictions on water use for varying time after treatment ♦ Increased oxygen demand and possible toxicity ♦ Possible recycling of nutrients
11a) Forms of copper	♦ Cellular toxicant, suggested disruption of photosynthesis, nitrogen metabolism, and membrane transport ♦ Applied as wide variety of liquid or granular formulations, often in conjunction with chelators, polymers, surfactants or herbicides	♦ Effective and rapid control of many algae species ♦ Approved for use in most water supplies	♦ Possible toxicity to aquatic fauna ♦ Ineffective at colder temperatures ♦ Accumulation of copper in system ♦ Resistance by certain green and blue-green nuisance species ♦ Lysing of cells releases nutrients and toxins
11b) Synthetic organic herbicides	♦ Absorbed or embrane-active chemicals which disrupt metabolism ♦ Causes structural deterioration	♦ Used where copper is ineffective ♦ Limited toxicity to fish at recommended dosages ♦ Rapid action	♦ Non-selective in treated area ♦ Toxic to aquatic fauna (varying degrees by formulation) ♦ Time delays on water use
11c) Oxidants	♦ Disrupts most cellular functions, tends to attack membranes ♦ Applied most often as a liquid.	♦ Moderate control of thick algal mats, used where copper alone is ineffective ♦ Rapid action	♦ Non-selective in treated area ♦ Toxic to zooplankton/fish at possible dosage

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
12) Phosphorus inactivation	♦ Typically salts of aluminum, iron or calcium are added to the lake, as liquid or powder ♦ Phosphorus in the treated water column is complexed and settled to the bottom of the lake ♦ Phosphorus in upper sediment layer is complexed, reducing release from sediment ♦ Permanence of binding varies by binder in relation to redox potential and pH	♦ Can provide rapid, major decrease in phosphorus concentration in water column ♦ Can minimize release of phosphorus from sediment ♦ May remove other nutrients and contaminants as well as phosphorus ♦ Flexible with regard to depth of application and speed of improvement	♦ Possible toxicity to fish and invertebrates, especially by aluminum at low pH ♦ Possible release of phosphorus under anoxia or extreme pH ♦ May cause fluctuations in water chemistry, especially pH, during treatment ♦ Possible resuspension of floc in shallow areas ♦ Adds to bottom sediment, but typically an insignificant amount
13) Sediment oxidation	♦ Addition of oxidants, binders and pH adjustors to oxidize sediment ♦ Binding of phosphorus is enhanced ♦ Denitrification is stimulated	♦ Can reduce phosphorus supply to algae ♦ Can alter N:P ratios in water column ♦ May decrease sediment oxygen demand	♦ Possible impacts on benthic biota ♦ Longevity of effects not well known ♦ Possible source of nitrogen for blue-green algae
14) Settling agents	♦ Closely aligned with phosphorus inactivation, but can be used to reduce algae directly too ♦ Lime, alum or polymers applied, usually as a liquid or slurry ♦ Creates a floc with algae and other suspended particles ♦ Floc settles to bottom of lake ♦ Re-application typically necessary at least once/yr	♦ Removes algae and increases water clarity without lysing most cells ♦ Reduces nutrient recycling if floc sufficient ♦ Removes non-algal particles as well as algae ♦ May reduce dissolved phosphorus levels at the same time	♦ Possible impacts on aquatic fauna ♦ Possible fluctuations in water chemistry during treatment ♦ Resuspension of floc possible in shallow, well-mixed waters ♦ Promotes increased sediment accumulation

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
15) Selective nutrient addition	♦ Ratio of nutrients changed by additions of selected nutrients ♦ Addition of non-limiting nutrients can change composition of algal community ♦ Processes such as settling and grazing can then reduce algal biomass (productivity can actually increase, but standing crop can decline)	♦ Can reduce algal levels where control of limiting nutrient not feasible ♦ Can promote non-nuisance forms of algae ♦ Can improve productivity of system without increased standing crop of algae	♦ May result in greater algal abundance through uncertain biological response ♦ May require frequent application to maintain desired ratios ♦ Possible downstream effects
	IN-LAKE BIOLOGICAL CONTROLS		
16) Enhanced grazing	♦ Manipulation of biological components of system to achieve grazing control over algae ♦ Typically involves alteration of fish community to promote growth of large herbivorous zooplankton, or stocking with phytophagous fish	♦ May increase water clarity by changes in algal biomass or cell size distribution without reduction of nutrient levels ♦ Can convert unwanted biomass into desirable form (fish) ♦ Harnesses natural processes to produce desired conditions	♦ May involve introduction of exotic species ♦ Effects may not be controllable or lasting ♦ May foster shifts in algal composition to even less desirable forms
16.a) Herbivorous fish	♦ Stocking of fish that eat algae	♦ Converts algae directly into potentially harvestable fish ♦ Grazing pressure can be adjusted through stocking rate	♦ Typically requires introduction of non-native species ♦ Difficult to control over long term ♦ Smaller algal forms may be benefitted and bloom

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
16.b) Herbivorous zooplankton	♦ Reduction in planktivorous fish to promote grazing pressure by zooplankton ♦ May involve stocking piscivores or removing planktivores ♦ May also involve stocking zooplankton or establishing refugia	♦ Converts algae indirectly into harvestable fish ♦ Zooplankton response to increasing algae can be rapid ♦ May be accomplished without introduction of non-native species ♦ Generally compatible with most fishery management goals	♦ Highly variable response expected; temporal and spatial variability may be high ♦ Requires careful monitoring and management action on 1-5 yr basis ♦ Larger or toxic algal forms may be benefitted and bloom
17) Bottom-feeding fish removal	♦ Removes fish that browse among bottom deposits, releasing nutrients to the water column by physical agitation and excretion	♦ Reduces turbidity and nutrient additions from this source ♦ May restructure fish community in more desirable manner	♦ Targeted fish species are difficult to eradicate or control ♦ Reduction in fish populations valued by some lake users (human/non-human)
18) Pathogens	♦ Addition of inocula to initiate attack on algal cells ♦ May involve fungi, bacteria or viruses	♦ May create lakewide "epidemic" and reduction of algal biomass ♦ May provide sustained control through cycles ♦ Can be highly specific to algal group or genera	♦ Largely experimental approach at this time ♦ May promote resistant nuisance forms ♦ May cause high oxygen demand or release of toxins by lysed algal cells ♦ Effects on non-target organisms uncertain
19) Competition and allelopathy	♦ Plants may tie up sufficient nutrients to limit algal growth ♦ Plants may create a light limitation on algal growth ♦ Chemical inhibition of algae may occur through substances released by other organisms	♦ Harnesses power of natural biological interactions ♦ May provide responsive and prolonged control	♦ Some algal forms appear resistant ♦ Use of plants may lead to problems with vascular plants ♦ Use of plant material may cause depression of oxygen levels

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
19a) Plantings for nutrient control	♦ Plant growths of sufficient density may limit algal access to nutrients ♦ Plants can exude allelopathic substances which inhibit algal growth ♦ Portable plant “pods” , floating islands, or other structures can be installed	♦ Productivity and associated habitat value can remain high without algal blooms ♦ Can be managed to limit interference with recreation and provide habitat ♦ Wetland cells in or adjacent to the lake can minimize nutrient inputs	♦ Vascular plants may achieve nuisance densities ♦ Vascular plant senescence may release nutrients and cause algal blooms ♦ The switch from algae to vascular plant domination of a lake may cause unexpected or undesirable changes
19b) Plantings for light control	♦ Plant species with floating leaves can shade out many algal growths at elevated densities	♦ Vascular plants can be more easily harvested than most algae ♦ Many floating species provide valuable waterfowl food	♦ At the necessary density, the floating plants will be a recreational nuisance ♦ Low surface mixing and atmospheric contact promote anoxia
19c) Addition of barley straw	♦ Input of barely straw can set off a series of chemical reactions which limit algal growth ♦ Release of allelopathic chemicals can kill algae ♦ Release of humic substances can bind phosphorus	♦ Materials and application are relatively inexpensive ♦ Decline in algal abundance is more gradual than with algaecides, limiting oxygen demand and the release of cell contents	♦ Success appears linked to uncertain and potentially uncontrollable water chemistry factors ♦ Depression of oxygen levels may result ♦ Water chemistry may be altered in other ways unsuitable for non-target organisms

8.4 Dredging

8.4.1 Introduction

Dredging may be an effective restoration technique since the release of phosphorus from lake sediments can be reduced or controlled by removing layers of enriched materials. This removal may lower in lake phosphorus concentrations and lessen algal production, assuming that there has been adequate control of nutrients from external sources (watershed, septic systems, waterfowl, and active cranberry operations). Even where incoming phosphorus loads are high, dredging can reduce benthic mat formation and related problems with filamentous green and cyanobacteria algae, as these forms may initially depend on nutrient-rich substrates for nutrition. Dredging also removes the accumulated resting cysts deposited by a variety of algae. Although recolonization would be expected to be rapid, some changes in algal composition can result from dredging.

While removing the entire nutrient rich layer of sediment can control algae, dredging is most frequently done to deepen a lake, remove accumulations of toxic substances, or to remove and control macrophytes. Algal control benefits are largely ancillary in these cases. In most cases, the expense of complete soft sediment removal and the more pressing need for watershed management are the primary reasons that dredging is not used more often for algal control. However, sediment removal to retard nutrient release can be effective.

The Eutrophication and Aquatic Plant Management in Massachusetts Final Generic Environmental Impact Report (FGEIR) provides a number of case studies where dredging results in reduction of algal biomass (Mattson et al., 2004). An example is provided by Lake Trummen in Sweden (Andersson, 1988) where the upper 3.3 feet of sediments were extremely rich in nutrients. This layer was removed and the total phosphorus concentration in the lake dropped sharply and remained fairly stable. Algal growth was reduced as a result. Algal abundance also decreased and water clarity increased in Hills Pond in Massachusetts after all soft sediment was removed and a storm water treatment wetland was installed in 1994. Dredging of 6-acre Bulloughs Pond in Massachusetts in 1993 has resulted in abatement of thick green algal mats for over a decade, despite continued high nutrient loading from urban runoff (Wagner, personal observation). These mats had previously begun as spring bottom growths, then they floated to the surface in mid-summer. Table 8-2 provides a summary of the potential issues and concerns associated with dredging. Accordingly, because of the need for mobilization of large equipment, adequate dewatering and disposal areas, transportation concerns, engineering design, and environmental permitting, the long-term benefits of the sediment removal have to be carefully weighed against the feasibility, costs and short and long-term impacts. The following sections consider the technical feasibility, expected water quality improvements, longevity, cost-effectiveness and potential permitting issues associated with Santuit Pond.

8.4.2 Technical Feasibility

Based on the pond and sediment characteristics, hydraulic dredging or wet mechanical dredging (see Table 8-1) would be the only viable dredging options for Santuit Pond. In hydraulic dredging, a suction type dredge with a cutter head removes wet sediment in a slurry from a floating barge platform. Hydraulic dredging is typically the method used for dredging large quantities of wet soft sediment and where water level control is limited, which is the case in Santuit Pond. Wet excavation entails excavation of wet sediment with mechanical equipment (clamshell, dragline, or excavator) and may involve a partial lake drawdown. Dry dredging under drawdown conditions was not further considered for selection as it would be technically difficult to drain Sanuit Pond completely as it is a primarily groundwater fed pond. The first step in scoping such a project is the determination of the total amount of sediment to be removed. Therefore, the depth and area of proposed dredging need to be selected. In many cases, these parameters are based on a relative optimization of the benefits of decreased nutrient levels vs. cost and environmental concerns.

Table 8-2 Key considerations for successful dredging.

Key Considerations for Successful Dredging	
Reasons for Dredging:	**Existing and Proposed Bathymetry:**
Increased depth/access	Existing mean depth
Removal of nutrient reserves	Existing maximum depth
	Proposed distribution of lake area over depth
Control of aquatic vegetation	range
Alteration of bottom composition	Proposed mean depth
Habitat enhancement	Proposed maximum depth

Key Considerations for Successful Dredging

Reduction in oxygen demand

Volume Of Material To Be Removed:
In-situ volume to be removed
Distribution of volume among sediment types
Distribution of volume over lake area (key sectors)
Proposed distribution of area over depth range
Bulked volume (see below)
Dried volume (see below)

Physical Nature of Material To Be Removed:
Grain size distribution
Solids and organic content
Settling rate
Bulking factor
Drying factor
Residual turbidity

Nature of Underlying Material To Be Exposed:
Type of material
Comparison with overlying material

Chemical Nature of Material To Be Removed:
Metals levels
Petroleum hydrocarbon levels
Nutrient levels
Pesticides levels
PCB levels
Other organic contaminant levels
Other contaminants of concern (site-specific)

Dewatering Capacity of Sediments:
Dewatering potential
Dewatering timeframe
Methodological considerations

Flow Management:
System hydrology
Possible peak flows
Expected mean flows
Provisions for controlling water level
Methodological implications

Protected Resource Areas:
Wetlands
Endangered species
Habitats of special concern
Species of special concern
Regulatory resource classifications

Relationship To Lake Uses:
Impact on existing uses during project
Impact on existing uses after project
Facilitation of additional uses

Equipment Access:
Possible input and output points
Land slopes
Pipeline routing
Property issues

Dredging Methodologies:
Hydraulic (or pneumatic) options
Wet excavation
Dry excavation

Potential Disposal Sites:
Possible containment sites
Soil conditions
Necessary site preparation
Volumetric capacity
Property issues
Long term disposal options

Removal Costs:
Engineering and permitting costs
Construction of containment area
Equipment purchases
Operational costs
Contract dredging costs
Ultimate disposal costs
Monitoring costs
Total cost divided by volume to be removed

Applicable Regulatory Processes:
MEPA review (Environmental Notification Form)
Environmental impact reporting (EIR if needed)
Wetlands Protection Act (Order of Conditions)
Dredging permits (Chapter 91)
Aquatic structures permits (Chapter 91)
Drawdown notification (to DFWELE)
Water Management Act (diversion/use permits)
Clean Water Act Section 401 (WQ certification)
Clean Water Act Section 404 (USACE wetlands statute)
Dam safety/alteration permit (DEM)
Waste disposal permit (DEP)
Discharge permits (NPDES, USEPA/DEP)

Other Mitigating Factors:
Necessary watershed management

Uses Or Sale Of Dredged Material:
Possible uses

Key Considerations for Successful Dredging

Possible sale	Ancillary project impacts
Target markets	Economic setting
	Political setting
	Sociological setting

Dredging will be most effective in reducing in-lake phosphorus concentrations if all of the nutrient rich soft sediment is removed. The target depth of the dredging should be the depth until hard bottom or as deep as is technically feasible. The second element determining total sediment to be removed is the area to be dredged – with a potential range of options from the entire pond to a lesser portion of the sediment underlying the deeper portion of the lake. Determination of this target area depends on many factors such as the potential impacts to lake biota and ecosystem function, potential impacts to adjacent areas (including wetlands), impacts to water quality, the size and capacity of the dewatering and disposal areas, interference with other uses of the pond, distance to neighboring residences, truck traffic, and overall costs and benefits.

In Santuit Pond, nutrient rich soft sediment covers approximately 121 acres (71% of the pond). A detailed sediment depth survey would be necessary to determine the depth of the soft sediment over this area. As a starting point, if we assume that the soft sediment depth averages 2 ft, then approximately 390,500 cubic yards of soft sediment would need to be removed from Santuit Pond, which is an extremely large volume of sediment.

Hydraulic dredging or wet mechanical dredging would be logistically feasible as most of the soft sediment is located in depths between 5-9 ft. However, there are many technical constraints to dredging in Santuit Pond, including access, locating dewatering areas, and dredge disposal placement.

First, locating a suitable mobilization/access point(s) may be difficult at Santuit Pond. Considerations when choosing access/mobilization sites include: ability to accommodate large equipment, aesthetic issues (noise, sight, and odor) associated with dredging, traffic volume, and potential for restrictions on areas of lake use. Much of the shoreline of Santuit Pond is private property and steep sloped. Most of the shoreline public lands are not easily accessible with vehicles and are recreational areas. The Town Landing may be a viable option for an access/mobilization location, but the Town Landing is surrounded by residential properties. The increased volume of large truck traffic in and out of the Town Landing will likely raise concern of neighborhood homeowners and will increase wear and tear on the Town roads. Assuming that the 390,500 cubic yards of sediments are 10% solids (90% water) and a dump truck can hold on average 10 cubic yards, approximately 4,000 dump trucks would be needed to remove the dewatered sediments.

Another major technical constraint for dredging is the lack of large, adjacent or nearby areas for dewatering of the sediments. The pumped slurry or excavated load is likely to have 80-90% water content that must be drained and usually treated to meet water quality standards prior to its return to the lake. Mechanisms to dewater sediments include settling basins, geotextile tubes, and mechanical dewatering. All dewatering techniques will likely require a large land area due to the large volume of sediment needing dewatering. Ideal candidate locations for dewatering locations would have a sufficiently-sized, level or gently sloped area, cleared of vegetation, not too high above lake surface elevation, with good access for trucks (for transporting dried material) and not adjacent to residential areas. Inspection of the shoreline areas for Santuit Pond does not show good candidate areas as most of the shoreline is steep, wetland, and/or residential development.

Assuming no limitations on the disposal of dredged material, potential disposal/reuse options include use as topsoil or topsoil amendment, use in compositing or as construction fill, and daily cover at unlined landfills. Potential usage is often dependent on the amount and timing of the material available. Based on typical disposal plans elsewhere, local facilities that could be contacted for potential disposal include the local contractors and landscape firms, the Mashpee Department of Public Works, and local landfills. Other potential destinations could include local golf courses or remediation projects with a need for clean fill. Further information and identification of the disposal destination would be finalized as part of the design, specifications and environmental permitting.

As will be discussed below, there is an extensive amount of environmental permitting required for any dredging operation, regardless of the amount of material removed.

8.4.3 Expected Water Quality or Recreational Improvements

Removal of phosphorus-enriched sediments would be expected to reduce the amount of internal phosphorus cycling. It is expected that the topmost sediments are richer in phosphorus since they reflect recent loadings that have been most affected by anthropogenic influences, but since we do not know the exact source or timing of elevated phosphorus in the sediments, this assumption may or may not be true. Consequently, assuming a 2 ft target depth for dredging may underestimate what is needed to achieve the desired result of internal phosphorus reduction. The exact level of phosphorus reduction is uncertain until the soft sediment depth is determined and the sediment quality underneath the soft sediment layer is sampled. The maximum benefit would assume that the sediments beneath the dredged level are largely sand with low phosphorus content (>75% reduction in internal phosphorus loading). The minimum benefit would occur if the sediments below are equally rich in phosphorus sediment (<50% reduction in internal phosphorus loading). The effect on water quality with the removal of the top 2 ft of soft sediment is uncertain without a detailed sediment study.

8.4.4 Longevity

The short-term impact of dredging should be an immediate (i.e., next growing season) reduction in the amount of phosphorus released from the sediments. If all of the soft phosphorus rich sediments are removed and the underlying sediments are sandy with low levels of phosphorus, then the dredging provides a long-term reduction in phosphorus release from the bottom sediments. Studies in the FGEIR demonstrate that the water quality improvements of dredging can last 20+ years (Mattson et al., 2004). The longevity of dredging to remove sediment depends on the rate of sedimentation. With proper design, dredging can be a long term solution to internal phosphorus loading.

8.4.5 Cost-effectiveness

Dredging is generally an expensive proposition due to its many components (i.e., sediment removal, dewatering, sediment disposal, etc). The FGEIR cites a potential range of $7-20/cubic yard sediment removed, based on several case studies (Mattson et al., 2004). Costs have risen in recent years; it is unusual to dredge for less than $20/cy now, with values on the order of $30/cy more common. In general, the larger the project is, the lower the cost per cubic yard.

Based on the assumptions noted above (2 ft target depth, 390,500 cubic yards removed) and using a cost estimate range of $20-$30/cy, it would cost approximately $8-12 million to dredge, dewater, and dispose of the sediment. The costs associated with transporting the sediments to a potential reuse site were not included in the removal cost due the uncertainty of its location, but were estimated at an additional $10/cy or $4 million. The total cost of dredging and disposal is estimated to be $12-16 million. This cost estimate would be further refined during preliminary design and permitting, but provides an informed order-of-magnitude estimate that would be expected to eliminate dredging from further consideration on financial reasons alone.

8.4.6 Permitting Issues

Dredging is a complicated and highly regulated activity (Table 8-2), and the proposed project is no exception. At a minimum it would require a Wetlands Protection Act Notice of Intent from the Mashpee Conservation Commission, a MDEP 401 Water Quality Certificate, and an Army Corps of Engineers 404 Programmatic General Permit. Since Santuit Pond is a great pond, a Chapter 91 permit would be required as well. Once disposal options have been determined, testing and certification of dredged material quality as non-hazardous would likely be required. It is expected that the cost of obtaining these environmental permits and the design plans will likely to cost $100,000-$200,000 in addition to the dredge and disposal cost estimate.

8.4.7 Evaluation of Potential Applicability of Method for Santuit Pond

Removal of sediments through dredging provides a very direct way of removing a significant amount of phosphorus mass from the pond. However, internal recycling is more dependent on the surface area of enriched phosphorus than the entire mass. Therefore, if removal of the top sediment simply exposes a new layer of phosphorus-enriched sediments then there will be little reduction in the phosphorus regeneration, despite the removal of a large amount of phosphorus mass. To dredge for the desired results, all soft sediment would have to be removed. This technique is not well suited for Santuit Pond due to the lack of access locations, readily accessible dewatering and disposal areas, and the residential setting. Adding the very high cost of the operation, AECOM does not recommend dredging for restoration of Santuit Pond. Other pond restoration options to address internal recycling appear more appropriate and less costly.

8.5 Artificial Circulation

8.5.1 Introduction

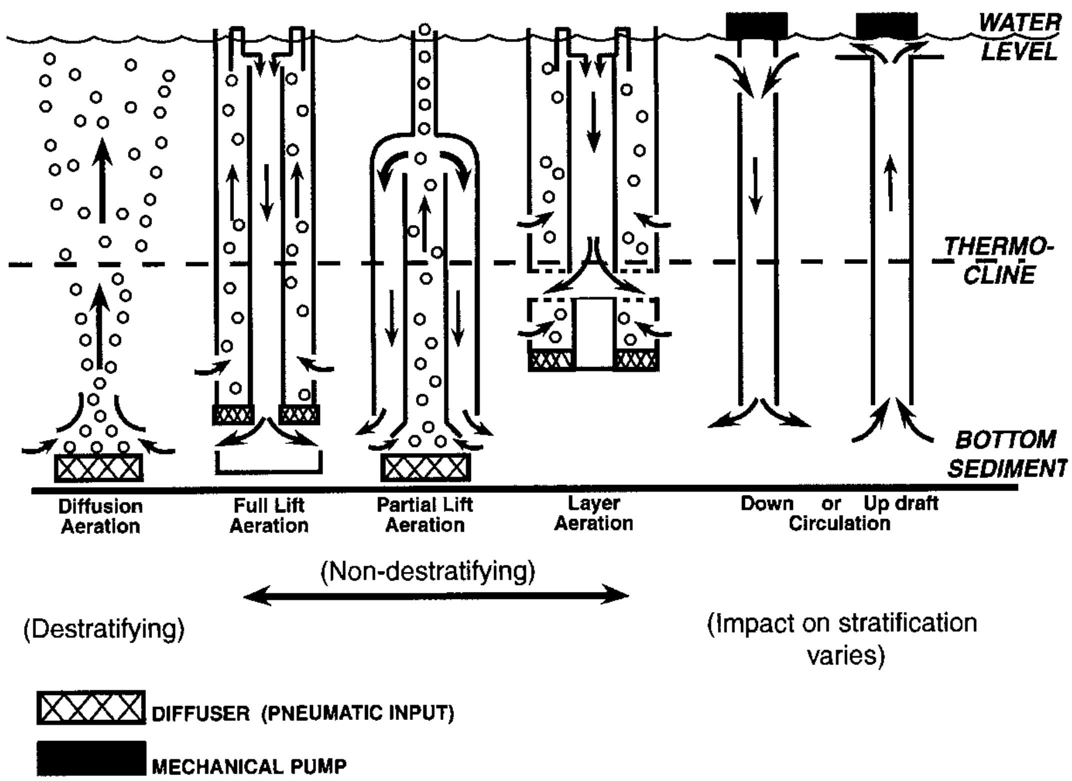
Artificial circulation is another technique that may be used to reduce internal loading in Santuit Pond. Whole lake circulation promotes the introduction of more oxygen into the bottom waters of ponds to limit the amount of phosphorus recycling, potentially controlling algal blooms by reducing phosphorus availability. The type of equipment that is used to produce these types of aeration states varies, with a simple diffuser and both upflow and downflow pumps illustrated in Figure 8-2. Other methods illustrated in Figure 8-2 are for aeration without whole lake mixing, which is not considered applicable to Santuit Pond.

Whole lake circulation provides for complete mixing of the water column and the natural diffusion of atmospheric oxygen in the water column to homogenize pond conditions. Since Santuit Pond is shallow and is not strongly thermally stratified, the pond frequently mixes and homogenizes conditions. However, oxygen depletion is observed in the water column periodically due to the high sediment oxygen demand, especially during calm periods and at night. Placement of artificial circulators would be intended to prevent these stagnant periods of oxygen depletion in the bottom waters. Artificial circulation would be used in Santuit Pond to provide sufficient oxygen to prevent anoxic conditions at the sediment surface and reduce or inhibit phosphorus release from sediments, with the ultimate goal of reducing algal blooms. The method can also increase the carbon dioxide content of the water to lower pH, which is thought to favor development of green algae over cyanobacteria (Mattson et al., 2004).

This technique is typically used in shallow waterbodies (<20 ft) like Santuit Pond. Surface circulators, subsurface diffusers, and water pumps have all been used to mix small ponds and shallow lakes. Some of the devices require electricity while others are self powered by sun or wind. The solar powered surface circulators may be most appropriate for Santuit Pond due to the low maintenance requirements and easier installation process, as no electrical infrastructure is required. The greatest drawback will be the presence of one or more physical structures (the mixers) on the pond surface, a potential aesthetic and navigational interference.

Artificial circulation has had a mixed record with regard to control of algal blooms. As discussed by Cooke et al. (2005), in more than half the cases, water quality conditions did not improve: TP increased or remained the same (65% of studies), SDT depths became more shallow (53%), and phytoplankton did not decrease (>50%). That review, however, represents the history of the technique, not its more recent applications, and reflects a number of implementation problems. The theory of circulation as an algal control technique is sound; actual application is somewhat more complicated and requires adjustment as part of an ongoing management program. The most common failure of circulation to achieve the desired objective is linked to improper sizing or faulty placement of equipment. Underdesign of the mixing system is the major equipment-related cause of failure for this technique.

Figure 8-2 Diagrams of methods of artificial circulation and aeration (adapted from Wagner, 2001).



8.5.2 Technical Feasibility

Artificial circulation was considered technically feasible for Santuit Pond. For Santuit Pond, the elements that favor this technique include: the shallow nature of the pond, a large fraction of the phosphorus budget is due to internal recycling of the sediments, and there is a high sediment oxygen demand. Due to the relatively high amount of iron in the sediments (organic sediments have an average total iron: total phosphorus ratio of 17:1), there is an adequate supply of phosphorus inactivators (iron) present under oxidized conditions. Finally, the pond does not support a coldwater fishery so maintenance of cooler bottom waters is not necessary to maintain the current biological communities.

Due to the shallow nature of Santuit Pond, it becomes only weakly thermally stratified and waters mix during high wind periods. The artificial circulators would continue circulation during calm periods when oxygen demand reduces oxygen levels and phosphorus is released by related chemical and biochemical processes. Manufacturer product information suggests that each surface circulating unit could address circulation needs over 35 acres (14 hectares). In which case, five circulator units would likely be sufficient to cover the entire surface area of the pond.

While artificial circulation is feasible for Santuit Pond, there are some concerns regarding this process. If the artificial circulators do not fully cover the surface area of pond and “dead zones” exist during calm periods, then artificial circulation may not be effective and may actually worsen the algal problems. In these “dead zones” with low oxygen conditions, phosphorus released from the sediment will continue to be mixed into the upper water column during summer and facilitate algal growth. Mixing has to prevent anoxia to limit phosphorus recycling, so proper design and implementation is critical to success. Further study would be necessary to strategically place the units to ensure no “dead zones” exist.

8.5.3 Expected Water Quality or Recreational Improvements

The ability of artificial circulation to improve water quality has been observed, but the results have varied greatly between waterbodies. In most instances, chemical problems due to low dissolved oxygen have been solved. Circulation should at least prevent the formation of distinct surface scums; although total algal biomass may not be reduced, there is typically a shift away from a cyanobacteria dominated phytoplankton (floating algae assemblage) and a more even distribution within the water column, enhancing appearance.

Systems that pump surface water to the bottom or bottom water to the surface, including solar power circulators, are intended to improve the oxygen level near the bottom. However, these systems may also present unfavorable circulation patterns and deterioration of surface water quality and/or impact to biotic communities if they are insufficiently sized or placed, such that anoxic zones can occur and that poor quality water is then mixed with the rest of the pond. It is desirable to plan for additional mixing capacity with such systems; too much mixing is not a real threat to the pond, but too little mixing must be avoided.

The presence of surface circulators on the pond surface will likely interfere with recreation on Santuit Pond as the surface structures are navigational hazards. They also may be aesthetically displeasing to recreational users and homeowners. The subsurface diffusers would not interfere with recreation or degrade aesthetics as they would be placed on the lake bottom.

There is some uncertainty regarding the amount of predicted improvement to water quality of artificial circulation in Santuit Pond. Based on best professional judgment, we conservatively assumed 67%

reduction in phosphorus recycling. This level of reduction alone would not result in attainment of the target in-lake concentration of 15 µg/L. The estimated in-lake concentration with the artificial circulation implemented is 38 µg/L. Even at this in-lake phosphorus concentration, we would expect an improvement in water quality with an increase in clarity. Also, the internal loading reduction estimate is conservative and a larger reduction may be possible.

8.5.4 Longevity

Since artificial circulation is an active treatment, the equipment must be kept continually running (or ready to be run as needed, with immediate response when natural mixing declines) during the summer months or the oxygenation and associated positive benefits cease. Some shifts in algal communities may persist over several weeks, but the system will eventually return to its currently impacted state unless circulation is maintained. However, there should be no loss in efficiency of such a system operated for several years. Well-maintained systems can last for many years, as evidenced by several locations (primarily drinking water reservoirs) where this method has been successfully used for 20 years or more (Mattson et al., 2004).

8.5.5 Cost-effectiveness

Artificial circulation is much less expensive than dredging and comparable in cost to a phosphorus inactivation chemical treatment. Capital costs include the purchase and installation of the equipment. If an electrical system is chosen, the largest expense is for a properly sized compressor. Installation of piping is relatively easy and can be accomplished by boat. There will be costs for land purchase (if needed), site preparation, building or structure construction, and possibly, extension of power to the site, which can be costly. The major operating cost is the electrical demand, but there are also annual maintenance costs to keep equipment in good repair.

With a solar power system, the costs of land, compressors, and electricity are eliminated. However, maintenance costs still must be considered. Equipment failure, vandalism or damage by boats are the most commonly reported maintenance issues.

AECOM estimated that five solar surface circulator units would cost $200,000 -$300,000 including installation. Maintenance costs will vary, but were estimated at $1,000 per year. For purposes of comparison among various pond restoration methods, we set an expected equipment longevity of 15 years. An approximate cost of purchasing, installing, and maintaining five solar surface circulators over 15 years is expected to be in the range of $215,000-$315,000.

To estimate the cost of subsurface diffusers, AECOM used the cost range for artificial circulation provided in the FGEIR, $20-3,000/acre (Mattson et al., 2004). Assuming that costs have risen 30% since the 2004 FGEIR, the cost for a subsurface diffuser would be in the range of $44,000-$670,000. The subsurface diffusers that would be used in Santuit Pond would likely be on the low end of this range at $44,000-$88,000. Maintenance costs over a 15 year period are estimated to be $166,000-$332,000. Over a 15 year period, AECOM estimates the costs of subsurface diffusers in Santuit Pond will be in the range of $210,000 to $420,000. This cost estimate includes the initial purchase and installation of the pumps, pipes and diffusers as well as annual maintenance and electricity costs.

8.5.6 Permitting Issues

Permits are generally required for circulation projects, but regulatory agencies are familiar with circulation as a lake management technique and it will likely be one of the easier management techniques to get approved. For artificial circulation, the likely requirements for environmental permitting are a Wetland Protection Act Notice of Intent from the Mashpee Conservation Commission. Since Santuit Pond is a Great Pond, a Chapter 91 permit would be required. A 401 Water Quality Certification will also likely be needed. Environmental permitting costs were estimated at approximately $20,000-$50,000 in addition to the capital and maintenance costs discussed above.

8.5.7 Evaluation of Potential Applicability of Method for Santuit Pond

The technical feasibility review indicates that artificial circulation would be a potential option for reducing internal phosphorus recycling. Similar installations have shown that, given sufficient airflow, a waterbody can be made to circulate. The shallow nature of Santuit Pond also makes artificial circulation a viable option because the pond does not strongly thermally stratify.

Artificial circulation is expected to improve water quality in Santuit Pond. If the artificial circulator units provide adequate coverage so that there are no stagnant zones, then the circulator units will likely maintain high oxygen levels during calm periods and help to minimize intense cyanobacteria blooms. It is estimated that the artificial circulation will have a 67% reduction of the internal phosphorus load, which equates to an expected summer in-lake phosphorus concentration of 38 ug/L.

If the solar surface circulators are chosen, the surface structures will interfere with recreation activities on Santuit Pond. The subsurface diffusers would not interfere with recreation or degrade aesthetics as they would be placed on the lake bottom.

The estimated cost of artificial circulation varies depending on the type. Assuming five units are needed, the capital and maintenance costs associated with solar surface circulation will be in the range of $215,000 to $315,000 over a 15 year period. Capital and maintenance costs associated with subsurface diffusion will likely be in the range of $210,000 to $420,000. Environmental permitting is not as extensive as for dredging projects and are estimated to be $20,000-$50,000.

Taking these factors together, AECOM recommends further consideration of artificial circulation for restoration of Santuit Pond.

8.6 Nutrient Inactivation

8.6.1 Introduction

The third technique considered to reduce internal loading is nutrient inactivation. Phosphorus inactivation involves some amount of short-term phosphorus precipitation (flocculation) during or just after application, but mainly aims to achieve long term control of phosphorus release from lake sediments by adding as much phosphorus binder to the lake as possible, within the limits dictated by environmental safety and cost. This technique is most effective after other nutrient loadings from the watershed are sufficiently reduced, as it acts only on existing phosphorus reserves, not new ones added post-treatment.

Good candidate lakes for this procedure are those that have had low levels of external nutrient loads and have demonstrated a high internal phosphorus load (release from sediment). High alkalinity is also desirable (but not essential) to provide buffering capacity. Highly flushed impoundments are usually not good candidates because of an inability to limit phosphorus inputs. Treatment of lakes with low doses of alum may effectively remove phosphorus from the water column, but may be inadequate to provide long term control of phosphorus release from lake sediments.

Aluminum has been widely used for phosphorus inactivation, mostly as aluminum sulfate and sometimes as sodium aluminate, as it binds phosphorus well under a wide range of conditions, including anoxia. In practice, aluminum sulfate (often called alum) is added to the water and colloidal aggregates of aluminum hydroxide (Al(OH)3) are formed. These aggregates rapidly grow into a visible, brownish white floc, a precipitate that settles to the bottom sediments in a few hours to a few days, carrying sorbed phosphorus and bits of organic and inorganic particulate matter in the floc. The floc settling through the water column typically has a very immediate clearing effect on water transparency. After the floc settles to the sediment surface it is incorporated into the sediment matrix where it will continue to bind with phosphorus. If enough alum is added, a layer of 1 to 2 inches of aluminum hydroxide will cover the sediments and significantly retard the release of phosphorus into the water column as an internal load. In lakes where sufficient reduction of external nutrient loading has occurred, this can create a phosphorus limitation on algal growth.

Alum applications for pond restorations are generally made from specially designed barges that can support the dual chemical injection system that extends into the water as well as the large chemical storage tanks (one for alum, one for sodium aluminate). Application of the alum mixture is generally best done by rapid injection and mixing at 10-15 ft depth (if achievable with the injection system). This minimizes the amount of drift of floc material by wind or wave action and also provides a potential refuge for fish in case of aluminum toxicity.

Nutrient inactivation has received increasing attention over the last two decades as long lasting results have been demonstrated in multiple projects, especially those employing aluminum compounds (Welch and Cooke, 1999). The FGEIR provides several examples of New England lakes where alum application has resulted in significant reductions in internal phosphorus loading and subsequent increases in desirable water quality parameters such as SDT depth or amount of hypolimnetic DO including: Annabessacook Lake, ME; Kezar Lake, NH; and Lake Morey, VT (Mattson et al., 2004). Phosphorus inactivation has been successful in treating some shallow lakes (Welch et al., 1988; Gibbons, 1992; Welch and Schrieve, 1994), but has been unsuccessful in cases where the external loads were not controlled prior to inactivation (Barko et al., 1990; Welch and Cooke, 1999).

More locally, alum treatment has been conducted at several lakes on Cape Cod including Hamblin Pond, Barnstable; Ashumet Pond, Mashpee and Falmouth; and Long Pond, Harwich and Brewster. Both Ashumet Pond and Hamblin Pond have shown positive responses to alum treatment in reducing internal phosphorus recycling. Application of alum to the latter resulted in a short-term fish-kill, but is widely recognized as one of the most effective pond restorations on the Cape (CCC, 2006). The September 2007 Long Pond alum treatment successfully reduced internal loading without adverse affects to biota and has improved clarity over the two summers following treatment.

Despite major successes, addition of aluminum salts to lakes does have the potential for serious negative impacts, and care must therefore be exercised with regard to dosage and buffering capacity. The potential for toxicity problems is directly related to the alkalinity and pH of the lake water. In soft (low alkalinity) water, only very small doses of alum can be added before alkalinity is exhausted and the pH falls below 6.0.

At pH 6.0 and below, Al(OH)2 and dissolved elemental aluminum (Al+3) become the dominant forms. Both can be toxic to aquatic species. Soft water lakes must be buffered, either with sodium aluminate or other compounds, to prevent the undesirable pH shift while allowing enough Al(OH)3 to be formed to control phosphorus release. A ratio of aluminum sulfate to sodium aluminate of 2:1 is expected to cause no change in system pH where buffering is needed. Maintenance of the ambient pH is an appropriate goal, unless the pH is especially high as a consequence of excessive algal photosynthesis, which is true of Santuit Pond. Other potential indirect adverse impacts relate to the spread of macrophytes and changes in water chemistry after addition of aluminum compounds. Although the sharp increase in water transparency is viewed as desirable in most cases, it may allow an existing rooted plant infestation to spread into new areas or deeper water. Aluminum sulfate treatments that reduce the pH may cause decalcification in sensitive organisms and may also limit calcium control of phosphorus cycling. Aluminum toxicity to humans has created substantial public controversy in regard to treatment of lakes with aluminum, but concerns have not been supported by the bulk of scientific investigations (Harriger and Steelhammer, 1989).

8.6.2 Technical Feasibility

Treatment of lakes with alum to inactivate phosphorus is an accepted lake remedial strategy and this method is considered very feasible for Santuit Pond. The pond has many of the elements that favor this technique including: a large fraction of the phosphorus budget due to internal recycling of the sediments, and high sediment oxygen demand leading to oxygen depletion in the water column. This technique is most successful when external phosphorus loads are minimized.

A ratio of aluminum sulfate to sodium aluminate of approximately 2:1 (usually closer to 1.8:1) is expected to cause no change in system pH. This type of buffering mixture would be required in Santuit Pond, where surface alkalinities range from 2 to 16 mg/L (as $CaCO3$) and those in the bottom waters range from 4 to 16 mg/L (as $CaCO3$). As with other alum applications in low alkalinity waters, a comprehensive and well-designed monitoring plan will be required to make sure that both pH and aluminum levels are kept in acceptable ranges.

Effectiveness of alum treatment is strongly related to proper assessment of available phosphorus in the sediment, its flux into the overlying water column, and calculation of an appropriate dose of the aluminum binder. Current methods suggest that the dose should be at least ten times and preferably up to 100 times the measured available sediment phosphorus content (Rydin and Welch, 1998; 1999).

The amount of alum/aluminate mixture needed to treat the extremely phosphorus-rich sediments of Santuit Pond was estimated by consideration of the total mass of phosphorus in the top 4 cm of the sediments. Santuit Pond sediments have 1.41-1.77 g available P/m2 in the top 4 cm of sediments (Section 5.2). These phosphorus concentrations are similar to the sediment concentrations found in ponds where alum application has been previously applied on Cape Cod, namely Long Pond. The entire area of soft sediment (~121 acres) in Santuit Pond should be treated due to the presence of phosphorus rich sediments and the potential for water column oxygen depletion due to the sediment oxygen demand during calm periods.

One critical requirement for phosphorus inactivation is for a hard-surface access point for the mobilization of the specialized work barge and for periodic resupply of the barge's chemical storage tanks. Ideally, a large paved boat launch with a parking area is sought, since these units are brought on trailers by large trucks. Although access locations need to be properly vetted, the Town Landing appears to provide an adequate access point for phosphorus inactivation.

Timing of the application should be phased to avoid potential conflicts with ecological resources and recreational users of the pond. The application should occur during a calm period because a stable water column provides a better environment for settling, is conducive to more controlled placement of alum treatment at desired locations, and provides additional safety for aquatic receptors since the aluminum will be confined to certain locations and depth. Due to the timing of the herring run cycles and other spring spawners and the typical summer residence and recreation patterns, an alum application in mid-September to mid-October would be the least disruptive to important interests at Santuit Pond.

8.6.3 Expected Water Quality or Recreational Improvements

Nutrient inactivation has the potential to significantly reduce internal loading, reduce algal densities and provide increased water clarity in Santuit Pond. It is estimated the internal phosphorus load can be reduced between 60 and 90% with nutrient inactivation. AECOM conservatively used a reduction estimate of 75% for comparative purposes. By reducing the significant internal load along with external phosphorus loads, Santuit Pond should experience reduced algal blooms. Phosphorus inactivation presents a valid alternative to either dredging or artificial circulation for reducing phosphorus release from the sediment.

8.6.4 Longevity

Longevity of alum treatments has generally been excellent where external inputs of phosphorus to the system are minimal or have been controlled (Payne et al., 1991). A review of 21 well-studied phosphorus inactivation treatments using aluminum (Welch and Cooke 1999) indicates that longevity of effects is typically 15 years or more for dimictic (summer stratified) lakes and about 10 years for shallow, polymictic (unstratified) lakes. Application of alum to Hamblin Pond in 1995 continues to be effective in providing greatly improved water quality (CCC, 2006). Ashumet Pond's phosphorus levels have also been reduced and water quality and SDT conditions have also improved considerably (AFCEE, 2007), but since additional phosphorus control measures are also in place at this pond, it cannot be attributed to only the alum treatment.

Overall, the potential longevity of the alum treatment should provide relief from problems related to internal phosphorus inputs between 15 – 20+ years depending on the pond. For purposes of direct comparison to other pond restoration options, AECOM conservatively assumed a 15 year period of duration. It is entirely possible that the benefits could extend well beyond that timeframe, as many treated lakes are passing the 25 to 30 year mark post-treatment now, with continued benefits.

8.6.5 Cost-effectiveness

Phosphorus inactivation is much less expensive than dredging and comparable in cost to artificial circulation. The cost of alum treatment was estimated based on AECOM experience with alum treatments. Costs are based on a number of factors including: the alum required, area/depth of application, equipment mobilization, on-lake application days, sediment sampling for dosage calculation, pre and post water quality monitoring, design and planning, and environmental permits. The future cost of chemicals and labor will likely become more expensive, but the following cost estimate provides a means for cost comparison with other in-lake treatment options. Table 8-3 provides a summary of the associated costs of three alum and aluminate dosing scenarios. The scenarios assume treatment of the available phosphorus concentrations in the three soft sediment samples AECOM collected as part of the sediment sampling (Section 3.3). Scenario 1 assumes that the entire 121 acres of soft sediment has the same available phosphorus concentration as SED-1, the sediment sample collected at Central Deep location off Bryants Neck. Scenario 2 assumes SED-3 (North) is representative of the entire soft sediment area and scenario 3 uses the available phosphorus concentration from SED-4 (South). This exercise provides representative high, medium, and low alum/aluminate dosages and associated costing estimates.

Before a phosphorus inactivation treatment, further sediment sampling is recommended in order to better characterize the available phosphorus and refine alum/aluminate dosage calculations. Sediment sampling is also recommended to conduct laboratory bio-assays and jar tests to test the toxicity of alum/aluminate doses. Pre and post treatment biological and water chemistry monitoring is also recommended to quantify the effectiveness of the phosphorus inactivation treatment.

Based on the assumptions outlined in Table 8-3, AECOM estimated that the costs associated with an alum treatment for Santuit Pond would be approximately $180,000 to $200,000.

Table 8-3 Dosing and cost calculations for alum treatment of Santuit Pond.

	SCENARIO		
Dosing Calculation	**1**	**2**	**3**
Mean Available Sediment P (mg/kg DW)	317.0	653.0	492.0
Target Depth of Sediment to be Treated (cm)	4.0	4.0	4.0
Volume of Sediment to be Treated per m2 (m3)	0.040	0.040	0.040
Specific Gravity of Sediment	1.10	1.10	1.10
Percent Solids (as a fraction)	0.12	0.05	0.08
Mass of Sediment to be Treated (kg/m2)	5.3	2.2	3.6
Mass of P to be Treated (g/m2)	1.67	1.44	1.78
Target Area-Soft Sediment (ac)	121	121	121
Target Area (m2)	487903	487903	487903
Aluminum sulfate (alum) @ 11.1 lb/gal & 4.4% aluminum (lb/gal)	0.49	0.49	0.49
Sodium aluminate (aluminate) @ 12.1 lb/gal & 10.38% aluminum (lb/gal)	1.26	1.26	1.26
Stoich. Ratio (ratio of Al to P in treatment)	10	10	10
Resulting areal dose (g Al/m2)	17	14	18
Ratio of alum to aluminate during treatment (volumetric)	1.8	1.8	1.8
Aluminum Load			
Dose (kg/area)	8166	7009	8661
Dose (lb/area)	17966	15420	19054
Dose (gal alum) with Alum only	36785	31573	39013
Application (gal/ac) for alum	304	261	322
Dose (gal alum) @ specified ratio of Alum to Aluminate	15146	13000	16064
Dose (gal aluminate) @ specified ratio of Alum to Aluminate	8415	7222	8924
Application (gal/ac) for Alum in Alum+Aluminate Trtmt	125	107	133
Application (gal/ac) for Aluminate in Alum+Aluminate Trtmt	70	60	74
Anticipated days of treatment	4	3	4
Costing Estimate			
Unit Cost			
Alum	$1.00	$1.00	$1.00
Aluminate	$2.50	$2.50	$2.50
Chemical Cost			
Alum + Aluminate	$36,183	$31,056	$38,374
Labor Cost			
Application (assumes 5,000 gal/day)	$17,646	$15,500	$18,564
Mobilization/Contingencies (assumes 1 day/25 ac)	$24,200	$24,200	$24,200
Monitoring (assumes 1 day/trtmt day + 12 days + 20% for lab costs)	$18,635	$18,120	$18,855
Prep Sampling (bioassays, lab dosing testing)	$50,000	$50,000	$50,000
Subtotal Cost	$146,664	$138,876	$149,993
Future Cost Increases (30%)	30%	30%	30%
Estimated Total Cost	**$190,663**	**$180,539**	**$194,991**

8.6.6 Permitting Issues

For this restoration option, the likely requirements for environmental permitting are an Order of Conditions from the Mashpee Conservation Commission and a Permit to Apply Chemicals from MDEP. A Chapter 91 permit and a 401 water quality certification are not necessary for phosphorus inactivation treatments. Environmental permitting costs were estimated at $20,000-$50,000, which is in addition to the above phosphorus activation treatment cost estimate.

8.6.7 Evaluation of Applicability of Method for Santuit Pond

The technical feasibility review indicates that nutrient inactivation by an alum treatment would be a very effective option to reduce internal phosphorus recycling in Santuit Pond. Alum treatment permanently reduces the root cause of internal recycling by binding up the potentially available phosphorus in the sediments. Reductions in algal blooms and increases in the water clarity have been observed following alum treatment at nearby ponds, including Hamblin, Ashumet, and Long Pond. With nutrient inactivation, the internal phosphorus load is typically reduced between 60 and 90%. AECOM conservatively used an estimate of 75% in order to compare with other in-lake management strategies. There are potential toxicity issues with the use of aluminum chemicals, but the risk of fish kills and other adverse biological side effects can be minimized with the proper dosage of alum and aluminate chemicals. Also, nutrient inactivation treatments do not, of themselves, prevent the development of anoxia although reduction in internal loading to the lake should result in a reduction in algal biomass and associated oxygen demand. Large changes in the amount of available habitat are not expected in Santuit Pond but there may be modest gains in habitat in the deep sections of the lake if the severity of the anoxia is reduced. Toxicity concerns are restricted to the application period and can be controlled for as described above. Once reacted (in a matter of hours), the aluminum settles to the bottom in the form of aluminum hydroxide which is essentially inert with no or low toxicity and a high affinity for phosphorus (Cooke et al. 2005). There would be no long term effects on pH expected related to an alum treatment. An indirect effect could be observed if the reduction in internal phosphorus loading results in a reduction in the frequency and intensity of algal blooms. The high pH values near the water surface associated with blooms (Wetzel 2001) would not occur without the blooms.

Longevity associated with this technique was conservatively estimated at 15 years, but is likely longer. Longevity is inversely proportional to the amount of future loading the pond receives. Generally, the greater external loading of phosphorus, the shorter the effective lifespan of an alum treatment. Based on the assumptions in Table 8-3, the cost for nutrient inactivation at Santuit Pond was estimated to be $180,000-$200,000. Environmental permitting will likely include a Mashpee Conservation Commission Notice of Intent and chemical application permits. The Conservation Commission will likely include a detailed list of monitoring requirements in the Order of Conditions. Permitting is estimated to add an additional $20,000-$50,000 to the project cost.

Given a successful track record of restoring kettlehole pond on Cape Cod, phosphorus inactivation has a high likelihood of successfully reducing the internal loading and has the low cost relative to the three in-lake management options considered. AECOM recommends further consideration of nutrient inactivation for restoration of Santuit Pond.

8.7 Restoration Options Summary

The Santuit Pond restoration plan should include measures to reduce the internal and external phosphorus loading. Reducing external phosphorus inputs (watershed, septic system, active cranberry bog, and waterfowl) are necessary in order to restore desired contact recreation and aquatic habitat uses. Since internal loading represents the largest source (78%) of the entire TP load, the internal loading needs to be addressed in order to make any progress toward pond restoration. AECOM evaluated the three techniques to reduce the internal load of Santuit Pond: 1) dredging, 2) artificial circulation, and 3) nutrient inactivation. A summary of the costs and benefits of the three options is shown in Table 8-4. All of these options have been standardized for a 15 year period of performance.

Table 8-4 Comparison of in-lake management options for Santuit Pond.

Feature	Dredging	Artificial Circulation		Nutrient Inactivation
		Submerged Diffuser	***Solar Surface Unit***	
Capital Cost (Equip, site prep, installation)	$ 12-16 million	$44,000-88,000	$200,000-$300,000	$180,000-200,000
Operation & Maintenance/15 years	0	$166,000-332,000	$15,000	$0
Total Cost/15 years	$ 12-16 million	$210,000-420,000	$215,000-$315,000	$180,000-200,000
Permitting Cost	$100,000-200,000	$20,000-50,000	$20,000-50,000	$20,000-50,000
Area of Pond Treated	71%	100%	100%	71%
Anticipated Internal TP Load Reduction	Varies depending on underlying sediment chemisty	67%	67%	75%
Predicted In-lake TP concentration	-	38 ug/L	38 ug/L	33 ug/L
Potential Toxicity	None	None	None	Possible short-term aluminum toxicity if pH is <6 or >8

Dredging is not well suited for Santuit Pond due to the difficulty in locating a suitable mobilization point, the lack of readily accessible dewatering and disposal areas, and the extremely high cost of dredging and permitting. AECOM does not recommend dredging as a restoration option for Santuit Pond. Artificial circulation and nutrient inactivation area in-lake management options to address internal recycling appear more appropriate and less costly. The artificial circulators would continue circulation during calm periods when oxygen demand reduces oxygen levels and phosphorus is released by related chemical and biochemical processes. Provided proper placement to alleviate any “dead zones,” it is anticipated that artificial circulation will reduce internal loading 67%. The reduction may be greater as the reduction was estimated conservatively due to some uncertainty regarding the amount of predicted improvement with artificial circulation. Also, the surface circulators pose as navigational hazards because they are physical structures placed throughout the waterbody and may impede recreational uses of the pond. Nutrient inactivation is also another technique considered appropriate for Santuit Pond. This technique involves introducing aluminum chemicals to bind phosphorus in the sediments even in anoxic conditions. Phosphorus inactivation treatments also have a good track record in Cape Cod kettlehole ponds for improving water quality. The use of alum chemicals may cause short-term toxicity if improperly planned and pH does not remain between 6 and 8 during the alum/aluminate application. The cost of phosphorus inactivation will likely be lower than artificial circulation over a 15 year period, but the cost estimates for the two techniques are in the same order of magnitude. For comparative purposes, AECOM estimated the internal loading reduction at 75%, but reductions as high as 90% have been observed. AECOM recommends further consideration of artificial circulation and phosphorus inactivation as in-lake management techniques. Regardless of the in-lake technique chosen, the Santuit Pond restoration strategy should include techniques to control and reduce external loading in association with in-lake management techniques.

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Appendix A

Data Collected by AECOM

Abbreviation key for AECOM aquatic macrophyte survey

Abbreviation	**Scientific Name**	**Common Name**
BG	*Cyanophyta*	Cyanobacteria
Bs	*Brasenia schreberi*	Watershield
Cdem	*Ceratophyllum demersum*	Coontail
Dv	*Decodon verticillatus*	Swamp Loosestrife
Ecan	*Elodea canadensis*	Waterweed
Msp	*Myriophyllum sp.*	Native watermilfoil
Nf	*Najas flexilis*	Common naiad
Ni	*Nitella sp.*	Stonewart
No	*Nymphaea odorata*	White water lily
Nv	*Nuphar variegatum*	Yellow water lily
Prob	*Potamogeton robbinsii*	Robbins' pondweed
Usp	*Utricularia sp.*	Bladderwort
Va	*Vallisneria americana*	Water Celery

Results from AECOM aquatic macrophyte survey, Santuit Pond, August 26, 2009

Pt	Lat	Long	Cover	Biov	BG	Bs	Cd	Ec	Dv	Msp	Nf	Ni	No	Nv	Prob	Usp	Va	Mussels Present
1	41.6572585	-70.4632004	1	1	d						t							
2	41.6570125	-70.4632924	1	1	d			t									t	
3	41.6567676	-70.4633015	2	1	d			t									s	
4	41.6567333	-70.4635046	3	2	d						s	s					m	
5	41.6568634	-70.4637022	2	2	d												m	
6	41.6568983	-70.4639232	4	2	d			m						d				
7	41.6567907	-70.4642056	4	2	d		s	m						d				
8	41.6565536	-70.4639787	4	2	d			d					t			t		
9	41.6564275	-70.4642412	4	2	d	s		d						s				
10	41.6552471	-70.4628102	3	2	d												d	
11	41.6544920	-70.4629965	2	2	d												d	
12	41.6533258	-70.4628528	0	0	d													
13	41.6529840	-70.4627314	1	1	d			s									s	
14	41.6526361	-70.4624252	2	2	d												m	
15	41.6523433	-70.4620076	0	0	d													*Pyganodonta cataracta*
16	41.6519677	-70.4615453	3	2	d			t				s					d	
17	41.6517544	-70.4612232	4	2	d			m						d			m	
18	41.6514592	-70.4611002	3	2	d			t	t			d					m	
19	41.6508151	-70.4598096	4	1	d			s				s		d				
20	41.6505211	-70.4593231	1	1	d												s	
21	41.6507079	-70.4588603	4	1	d			s				t		d				
22	41.6512431	-70.4586172	3	2	d			s						m			d	
23	41.6525916	-70.4591450	3	2	d			s	s			m					d	
24	41.6530550	-70.4583511	1	1	d												s	
25	41.6529859	-70.4578059	4	1	d			s				m		d				
26	41.6526915	-70.4570740	3	1	d			s				s	d				s	
27	41.6524027	-70.4564563	4	2	d			m	s			d					m	
28	41.6523074	-70.4564002	3	2	d				s								d	
29	41.6521963	-70.4565516	3	2	d			m				s	d				m	
30	41.6517357	-70.4572564	2	2	d			d				s					m	
31	41.6509800	-70.4568626	4	2	d			m				s		d			d	
32	41.6503714	-70.4570876	3	2	d			d				m		d			d	
33	41.6499829	-70.4576849	1	1	d			s				s	s					
34	41.6495883	-70.4575659	3	2	d			d					s	m				
35	41.6493433	-70.4575094	0	0	d													
36	41.6489935	-70.4574602	3	2	d			m				s					d	*Pyganodonta cataracta*
37	41.6483339	-70.4566923	4	2	d			d					d				m	
38	41.6466760	-70.4537568	3	2	d			s					d				m	
39	41.6472657	-70.4531928	3	3	d			m					m	m			m	
40	41.6475758	-70.4533902	3	2	d			m	s			s					m	
41	41.6477312	-70.4534867	2	1	d			s									s	
42	41.6486394	-70.4522303	4	2	d			d				s		d			d	
43	41.6493496	-70.4523299	3	2	d			m				m					m	
44	41.6501332	-70.4522334	3	2	d			m				s					m	
45	41.6508830	-70.4520552	4	2	d			d						d				
46	41.6522632	-70.4520221	3	2	d			m			s						m	
47	41.6529363	-70.4526116	2	2	d			s									m	
48	41.6530111	-70.4536819	3	2	d			d									d	
49	41.6535715	-70.4555748	3	2	d			m			s						m	
50	41.6543897	-70.4560869	3	2	d			s									m	
51	41.6553349	-70.4566741	1	1	d			s									s	
52	41.6557438	-70.4579094	1	1	d			s							s			
53	41.6574089	-70.4597374	1	1	d												s	
54	41.6582583	-70.4604386	2	2	d			m										
55	41.6585339	-70.4610203	1	1	d												s	
56	41.6593295	-70.4618212	2	1	d			s									m	
57	41.6600588	-70.4625748	2	2	d			m									m	
58	41.6612896	-70.4630540	2	2	d		s	m		t							m	

Pt	Lat	Long	Cover	Biov	BG	Bs	Cd	Ec	Dv	Msp	Nf	Ni	No	Nv	Prob	Usp	Va	Mussels Present
59	41.6614809	-70.4630995	1	1	d			s									s	
60	41.6617966	-70.4629174	2	1	d			m					s	m				
61	41.6620659	-70.4628269	3	2	d			d	m									
62	41.6622739	-70.4631205	1	1	d				m									
63	41.6620391	-70.4636467	2	2	d			m	s									
64	41.6620774	-70.4638064	2	2	d			m									s	
65	41.6618699	-70.4643250	3	2	d			m				s		m				
66	41.6611787	-70.4642239	3	1	d			d										

Results from AECOM in-lake water quality sampling, Santuit Pond. Lab: Berkshire EnviroLabs, Lee, MA.

Site	Site Description	Date	TSS	NH_3-N	$N0_3$-N	TKN	DP	TP	Alkalinity	Dissolved Fe	SDT
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ft
ST-SW-1S	Bryant's Neck Deep Spot-0.5'	7/29/2009	12	<0.05	<0.01	0.84	0.029	0.074	6	0.17	2
		8/26/2009	21	<0.05	<0.01	0.82	0.004	0.109	16	0.55	1.3
		10/1/2009	14	<0.05	<0.01	0.68	0.016	0.088	6	0.23	1.75
		11/3/2009	11	0.05	<0.01	0.98	0.011	0.079	2	0.04	2.5
ST-SW-1B	Bryant's Neck-0.5' from bottom (8.5')	7/29/2009	12	<0.05	<0.01	0.7	0.019	0.068	6	0.27	
		8/26/2009	24	<0.05	<0.01	0.88	0.012	0.113	16	0.21	
		10/1/2009	23	0.06	<0.01	0.52	0.016	0.095	6	0.2	
		11/3/2009	13	<0.05	<0.01	0.8	0.006	0.082	4	0.03	
ST-SW-2S	Town Landing-0.5'	7/29/2009	16	<0.05	<0.01	0.94	0.023	0.084	8	0.05	
		8/26/2009	120	<0.05	<0.01	5.2	0.005	0.402	14	0.68	
		10/1/2009	18	<0.05	<0.01	0.62	0.016	0.103	2	0.19	
		11/3/2009	11	0.05	0.03	0.78	0.008	0.076	2	0.04	
ST-SW-3S	Blank	7/29/2009	<1	<0.05	<0.01	<0.1	<0.003	<0.003	<2	0.23	
		8/26/2009	2	<0.05	<0.01	<0.1	<0.003	<0.003	<2	0.11	
		10/1/2009	1	<0.05	<0.01	<0.1	<0.003	<0.003	<2	0.01	
		11/3/2009	<1	<0.05	<0.01	<0.1	<0.003	0.003	<2	0.01	
ST-SW-4B	Dup of ST-SW-1B	7/29/2009	9	<0.05	<0.01	0.74	0.023	0.069	14	0.29	
		8/26/2009	20	<0.05	<0.01	1.2	0.011	0.102	16	0.16	
		10/1/2009	20	<0.05	0.01	0.6	0.017	0.096	6	0.2	
		11/3/2009	10	<0.05	<0.01	0.74	0.008	0.078	4	0.05	
ST-SW-5S	DEP QA: QC0535N	8/26/2009		<0.05	0.01	0.52		0.040			
ST-SW-6S	DEP QA: QC601600	8/26/2009		<0.05	0.02	0.33		0.020			

Sample		Date	Time	Chl a (ug/L)	Volume Filtered (mL)
ST-Chl-1	Int 0-8.5ft	7/29/2009	8:35	14.0	200
ST-Chl-1I	8.5 ft	7/29/2009	8:29	24.0	90
ST-Chl-1	Int 0-3.25ft	8/26/2009	10:44	89.7	50
ST-Chl-1I	9.0 ft	8/26/2009	10:31	54.5	50
ST-Chl-1	Int 0-4.3ft	10/1/2009	11:15	28.8	50
ST-Chl-1I	8.5ft	10/1/2009	11:16	38.4	50
ST-Chl-1	Int 0-6.25	11/3/2009	9:40	22.4	50
ST-Chl-1I	8.5ft	11/3/2009	9:47	25.6	50

Results from AECOM littoral interstitual porewater (LIP) sampling, Santuit Pond. Lab: Berkshire EnviroLabs, Lee, MA.

Site	Site Description	Number of Samples Composited-July	Number of Samples Composited-September	Lake Bottom Composition	7/28/2009 Ammonia mg/L	7/28/2009 Nitrate mg/L	7/28/2009 DP mg/L	7/28/2009 Dissolved Fe* mg/L	10/1/2009 Ammonia mg/L	10/1/2009 Nitrate mg/L	10/1/2009 DP mg/L	10/1/2009 Dissolved Fe mg/L
ST-GW-1	Low density developed residential shoreline with good buffer- Western shore of Santuit Pond-North of Town Landing-Steep Shore-Docks Present	3	2	Sandy	0.064	0.05	0.023	2.5	0.06	0.62	0.009	0.04
ST-GW-2	Undeveloped shoreline at northern end-Slight/Moderate slope	3	2	Sandy	<0.05	1.76	0.024	0.02	0.08	0.15	0.033	<0.01
ST-GW-3	Eastern Shore Cranberry Bog	3	2	Sandy	0.86	<0.01	0.074	5	1.5	<0.01	0.111	6
ST-GW-4	Low density residential with good shoreline buffer	3	2		0.99	<0.01	0.144	2.2	2	<0.01	0.022	5.2
ST-GW-5	Outlet	3			0.052	<0.01	0.039	0.86				
ST-GW-6	Abandoned Cranberry Bog-Town Owned-Southern End	3	2	Sandy	0.4	0.01	0.06	2	1.15	<0.01	0.024	5.7
ST-GW-7	Bryant's Neck-Densely Developed Residential-Little to No Buffer	3	2	Sandy	0.64	0.01	0.109	1.2	1.15	<0.01	0.093	4.4
ST-GW-10	Vegetated shoreline-Across from Bryant's Neck-Steep Slopes		2	Sandy					0.54	<0.01	0.073	3.6

Site	Site Description	Number of Samples Composited-July	Number of Samples Composited-September	Lake Bottom Composition	7/28/2009 Ammonia mg/L	7/28/2009 Nitrate mg/L	7/28/2009 DP mg/L	7/28/2009 Dissolved Fe* mg/L	10/1/2009 Ammonia mg/L	10/1/2009 Nitrate mg/L	10/1/2009 DP mg/L	10/1/2009 Dissolved Fe mg/L
ST-GW-8	Residential development on hill, Vegetated buffer on Steep Shorline between lakenad home-Docks and Stairs Present	3	2	Sandy	0.6	4.16	0.031	1.6	<0.05	12	0.008	0.15
ST-GW-9	Duplicate of ST-GW-8	3	N/a	Sandy	0.54	4.16	0.033	1.2				

Results of AECOM seepage meter calculations, Santuit Pond

	7/28-29/2009											10/1/2009	
	SP-1A	SP-1B	SP-2A	SP-3A	SP-3B	SP-4A	SP-4B	SP-5A	SP-5B	SP-6A	SP-6B	SP-3	SP-5
Description	NW Shore	NW Shore	N Shore	E Cranberry Bog	E Cranberry Bog	SE Shore	SE Shore	SW Shore-Outlet	SW Shore-Outlet	Bryant's Neck	Bryant's Neck	E Cranberry Bog	SW Shore-Outlet
Depth	2 ft	2 ft	3ft	2-3 ft	2-3 ft	2-3 ft	2-3 ft	2ft	2ft	2-3 ft	2-3 ft	2-3 ft	2-3 ft
Start Time	10:20		11:42	12:49		14:02		15:30		16:10		10:00	10:15
End Time	12:16		12:38	13:08		13:30		13:53		14:17		14:51	15:05
Duration (hrs)	26	26	25	24	24	23	23	22.5	22.5	22	22	5	5
Pre-Volume (mL)	100	100	100	100	100	100	100	100	100	100	100	100	100
Post-Volume (mL)	310	360	100	260	200	70	440	140	155	140	130	260	175
Volume Change (mL)	210	260	0	160	100	-30	340	40	55	40	30	160	75
cu. M or L	0.21	0.26	0	0.16	0.1	-0.03	0.34	0.04	0.055	0.04	0.03	0.16	0.075
Area (sq m.)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Seepage Rate	**0.03**	**0.04**	**0.00**	**0.03**	**0.02**	**-0.01**	**0.06**	**0.01**	**0.01**	**0.01**	**0.01**	**0.13**	**0.06**
L/m2/day	**0.78**	**0.96**	**0.00**	**0.64**	**0.40**	**-0.13**	**1.42**	**0.17**	**0.23**	**0.17**	**0.13**	**3.07**	**1.44**

Results from AECOM wet weather sampling, Santuit Pond. Lab: Berkshire EnviroLabs, Lee, MA.

Date	Site	Site Description	Discharge	Observed Flow into Pond	TSS mg/L	Ammonia mg/L	Nitrate mg/L	TKN mg/L	DP mg/L	TP mg/L	Specific Conductance umhos/cm	Alkalinity mg/L	Field pH s.u.	Field Temp °C
8/29/2009	ST-WW-1	Town Landing Parkinglot	>1 gallon/min	Yes	85	<0.05	0.15	1.2	0.078	0.391	57	10	7.63	21.7
8/29/2009	ST-WW-2a	Hemlock Dr Deadend	>1gallon/min	Flowing into Bog?	20	<0.05	0.3	0.52	0.08	0.174	33	6	7.34	21.5
8/29/2009	ST-WW-3a	Bryant's Neck	>1gallon/min	Yes	446	0.08	0.23	1.25	0.216	0.885	89	20	7.63	
8/29/2009	ST-WW-4	Beechwood Pt Dr	>1gallon/min	No?	5	<0.05	0.03	0.32	0.04	0.085	10	6	7.98	
8/29/2009	ST-WW-5	Cranberry Lane	>1gallon/min	Flowing into Cranberry Bog	28	<0.05	0.08	0.48	0.09	0.145	22	6	7.5	
8/29/2009	ST-WW-6	Blank			<1	<0.05	<0.01	<0.1	<0.003	<0.003	1.7	<2		
11/20/2009	ST-WW-1	Town Landing Parkinglot		Yes	114	<0.05	<0.01	0.8	0.57	0.902	83	<2	5.65	15.1
11/20/2009	ST-WW-2b	Timberline- near Lantern Lane Berm		Yes	162	0.15	0.2	0.54	0.68	0.785	27	<2	5.66	15.4
11/20/2009	ST-WW-3b	Bryant's Neck		Yes	1108	<0.05	<0.01	0.65	0.895	1.728	82	<2	5.43	14.1
11/20/2009	ST-WW-4	Beechwood Pt Dr		No?	22	<0.05	0.06	0.9	0.149	0.199	51	<2	5.73	15.1
11/20/2009	ST-WW-5	Cranberry Lane		Flowing into Cranberry Bog	462	<0.05	<0.01	0.58	0.257	0.798	55	<2	5.45	14.4
11/20/2009	ST-WW-6	Blank			<1	<0.05	<0.01	<0.1	<0.003	<0.003	2	<2		

Results from AECOM cranberry bog sampling, Santuit Pond. Lab: Berkshire EnviroLabs, Lee, MA.

Cranberry Bog Sampling, Baker Bog, October 21, 2009 flood waters

Sample	Description	Date	Time	TSS	NH_3-N	$N0_3$-N	TKN	DP	TP	Alkalinity	Dissolved Fe	Field pH	Water Temp
			EDT	mg/L	mg/L	mg/L	mg/L	ug/L	ug/L	mg/L	mg/L	s.u.	^{o}C
ST-CB-2HB	High Bog	10/21/2009	16:43	<1	<0.05	<0.01	0.92	55	86	75	6	6.4	17.3
ST-CB-2LB	Low Bog		16:52	<1	<0.05	0.93	0.9	24	29	107	4	6.2	12.8
ST-CB-2OW	North End Open Water		17:03	2	<0.05	0.51	0.84	22	46	108	4	5.2	13
ST-CB-1	Blank		17:08	<1	<0.05	<0.01	<0.1	<3	<3	2	<2	5.9	13.4

Cranberry Bog Sampling, Brackett Bog, February 8-9, 2010 flood release

Sample	Description	Date	Time	TSS	NH_3-N	$N0_3$-N	TKN	DP	TP	Alkalinity	Cond	Field pH	Water Temp
			EST	mg/L	mg/L	mg/L	mg/L	ug/L	ug/L	mg/L	umhos/cm	s.u.	^{o}C
ST-BRACKETT-R1B	Bog Floodwaters	2/8/2010	14:50	18	0.06	0.02	0.53	66	75	4	72.7	6.2	4.4
ST-BRACKETT-R1P	Pondside of Outlet		14:50	6	0.06	0.54	0.5	38	48	6	84.4	6	3.8
ST-BRACKETT-R1Q	Replicate of R1B		14:50	<1	0.11	0.02	0.46	77	82	6	65.9	5.6	2.5
ST-BRACKETT-OW	Town Landing		15:30	5	0.10	0.54	0.46	21	40	8	93.5	6	4.7
ST-BRACKETT-R1Q1	Blank		15:30	<1	<0.04	<0.01	<0.2	<3	<3	1	1.9	-	-
ST-BRACKETT-R2B	Bog Floodwaters	2/9/2010	11:30	1	0.06	0.02	0.37	77	106	4	49.8	5.5	1
ST-BRACKETT-R2P	Pondside of Outlet		11:35	1	0.07	0.12	0.41	72	93	4	61.8	5.2	0.9

Results from AECOM in-lake profiles sampling, Santuit Pond

Bryants Neck Deep Spot, 7/29/09 8:50 EDT

Depth ft	Temp °C	Sp Cond uS/cm	DO %	DO mg/L	pH s.u.
0.5	26.1	110	121	9.8	9.19
1	26.1	109	120.7	9.8	9.18
2	26.1	109	120.4	9.76	9.15
3	26	109	119.6	9.7	9.09
4	25.88	109	116.9	9.49	8.93
5	25.5	108	111.3	9.1	8.62
6	25.3	108	110.7	9.11	8.55
7	24.6	109	49.9	4.19	8.12
8	24.1	114	6.2	0.47	7.71
8.5	24.1	118	3.6	0.29	7.56

Town Landing, 7/29/09 10:10

Depth ft	Temp °C	Sp Cond uS/cm	DO %	DO mg/L	pH s.u.
1	26.87	110	133.3	10.66	9.07

Bryants Neck Deep Spot, 10/1/09 11:16

Depth ft	Temp °C	Sp Cond uS/cm	DO %	DO mg/L	pH s.u.
0.5	17.3	102	124	11.87	9.07
1	17.3	102	123	11.84	9.08
2	17.3	102	123	11.82	9.07
3	17.3	102	122	11.7	9.07
4	17.3	102	122	11.7	9.07
5	17.3	102	122	11.7	9.07
6	17.3	102	122	11.7	9.07
6.5	17.2	101	121	11.6	9.04
7	17.3	108	79.2	6.4	7.7
8	17.8	142	50	2.5	7.4
9	17.6	142	81	8.35	7.4

Town Landing, 10/1/09 12:10

Depth ft	Temp °C	Sp Cond uS/cm	DO %	DO mg/L	pH s.u.
0.5	17.4	101	126.1	12.07	8.1

Bryants Neck Deep Spot, 11/3/09 9:47

Depth ft	Temp °C	Sp Cond uS/cm	DO %	DO mg/L	pH s.u.
0.5	12.3	94	100.1	10.7	7.38
1	12.3	94	99.8	10.67	7.37
2	12.3	94	99.5	10.65	7.36
3	12.26	94	99.2	10.64	7.36
4	12.17	94	99	10.63	7.35
5	12.16	94	99	10.64	7.33
6	12.11	94	99	10.64	7.32
7	12.08	94	98.8	10.62	7.3
8	12.08	95	98.5	10.6	7.29
9	12.12	98	97.9	9.83	7.16

Town Landing, 11/3/09 10:10

Depth ft	Temp °C	Sp Cond uS/cm	DO %	DO mg/L	pH s.u.
1	12.26	94	95.8	10.2	7.07

Results from AECOM sediment sampling, Santuit Pond. Lab: Spectrum Analytical, Agawam, MA.

Method / Analyte	Units	SED-1 RDL	SED-2 RDL	SED-3 RDL	SED-4 RDL	SED-1	SED-2	SED-3	SED-4
ASTM D422									
Fractional % Sieve #4 (>4750µm)	% Retained					4.44	2.94	23.7	3.17
Fractional % Sieve #10 (4750-2000µm)	% Retained					20	20.6	11.6	25.4
Fractional % Sieve #20 (2000-850µm)	% Retained					30	29.4	22.4	31.7
Fractional % Sieve #40 (850-425µm)	% Retained					17.8	17.6	31.7	12.7
Fractional % Sieve #60 (425-250µm)	% Retained					8.89	11.8	8.75	4.76
Fractional % Sieve #100 (250-150µm)	% Retained					5.56	5.88	1.55	6.35
Fractional % Sieve #200 (150-75µm)	% Retained					7.78	5.88	0.292	6.35
Fractional % Sieve #230 (less than 75µm)	% Retained					5.56	5.88	0.0972	9.52
ASTM D515-88(A)									
Iron bound Phosphorus as P	mg/kg dry	20.1	51.2	3.01	30.4	316	650	9.9	490
Loosely-sorbed Phosphorus as P	mg/kg dry	2.01	5.12	0.3	3.04	BRL	BRL	BRL	BRL
SM2540 G Mod.									
% Solids	%					12.4	4.9	83	8.2
SW846 6010B									
Aluminum	mg/kg	40.1	101	5.14	56.1	6440	5020	678	7320
Iron	mg/kg	32	80.7	4.11	44.9	16600	22500	1350	17300
Phosphorus as P	mg/kg	43.7	112	6.27	67.5	920	2550	66.4	1270

Waterfowl observation survey, Santuit Pond, Summer 2009
Data collected by Richard and Rita Gollin

Date	Method	Ducks	Geese	Gulls	Swans	Cormorants	Heron	Hawk
7/4/2009	From House	20	7		4			
7/7/2009	From House						1	
7/9/2009	From House					1		
7/10/2009	Shore Survey	39	11					
7/11/2009	Shore Survey	34	12	1				
7/13/2009	Shore Survey	43	12	2		2	1	
7/20/2009	From House	7						
7/21/2009	Shore Survey	5						
7/22/2009	Shore Survey	61	8	1				
7/25/2009	Shore Survey	69	11					
8/1/2009	Shore Survey	61	1	1	1	1		
8/3/2009	Shore Survey	78	2		1	2	2	
8/6/2009	Shore Survey	58		1	1			
8/16/2009	Shore Survey	47	2	1	1	2	1	2
8/26/2009	Shore Survey	31			1	1		
9/1/2009	Shore Survey	48			3		2	
9/7/2009	Shore Survey	12		1	1	3	1	
9/10/2009	Shore Survey	45		1	2	3	1	
Shore Survey Average		**45**	**7**	**1**	**1**	**2**	**1**	**2**

BERKSHIRE ENVIRO-LABS, INC.

CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM L- 5075B

RE: PO #76659, Santuit Pond, Mashpee, MA

SAMPLE NUMBER		187290	187291	187292	187293
DATE COLLECTED		7/28/09	7/28/09	7/28/09	7/28/09
TIME COLLECTED		10:41am	11:58am	1:02pm	2:12pm
COLLECTED BY		S.M./P.W.	S.M./P.W.	S.M./P.W.	S.M./P.W.
DATE ANALYZED		7/29/09	7/29/09	7/29/09	7/29/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l				
Turbidity	NTU				
Ammonia (as N)	mg/l	0.064	<0.05	0.86	0.99
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	0.05	1.76	<0.01	<0.01
Total Kjeldahl (as N)	mg/l				
Dissolved Phosphorus (as P)	mg/l	0.023	0.024	0.074	0.144
Total Phosphorus (as P)	mg/l				
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l				
Dissolved Iron	mg/l	2.5	0.02	5.0	2.2

Sample #187290: ST-GW-1
Sample #187291: ST-GW-2
Sample #187292: ST-GW-3
Sample #187293: ST-GW-4

< = Less Than
> = Greater Than

William S. Enser, Jr.
Director

WATER
WASTEWATER
AND
ENVIRONMENTAL
ANALYSIS
PHYSICAL
CHEMICAL
AND
BACTERIOLOGICAL
TESTING
LABORATORY
AND
FIELD
MEASUREMENTS

BERKSHIRE ENVIRO-LABS, INC.

CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM

L- 5075B

RE: PO,#76659, Santuit Pond, Mashpee, MA

SAMPLE NUMBER		187294	187295	187296	187297
DATE COLLECTED		7/28/09	7/28/09	7/28/09	7/28/09
TIME COLLECTED		3:00pm	3:40pm	4:10pm	4:40pm
COLLECTED BY		S.M./P.W.	S.M./P.W.	S.M./P.W.	S.M./P.W.
DATE ANALYZED		7/29/09	7/29/09	7/29/09	7/29/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l				
Turbidity	NTU				
Ammonia (as N)	mg/l	0.052	0.40	0.64	0.60
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01	0.01	0.01	4.16
Total Kjeldahl (as N)	mg/l				
Dissolved Phosphorus (as P)	mg/l	0.039	0.060	0.109	0.031
Total Phosphorus (as P)	mg/l				
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l				
Dissolved Iron	mg/l	0.86	2.0	1.2	1.6

Sample #187294: ST-GW-5
Sample #187295: ST-GW-6
Sample #187296: ST-GW-7
Sample #187297: ST-GW-8

< = Less Than
> = Greater Than

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Director

WATER WASTEWATER AND ENVIRONMENTAL ANALYSIS
PHYSICAL CHEMICAL AND BACTERIOLOGICAL TESTING
LABORATORY AND FIELD MEASUREMENTS

BERKSHIRE ENVIRO-LABS, INC.

CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM L- 5075B

RE: PO #76659, Santuit Pond, Mashpee, MA

SAMPLE NUMBER		187298			
DATE COLLECTED		7/28/09			
TIME COLLECTED		3:50pm			
COLLECTED BY		S.M./P.W.			
DATE ANALYZED		7/29/09			
ANALYZED BY		W.E.-L.T.			
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l				
Turbidity	NTU				
Ammonia (as N)	mg/l	0.54			
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	4.16			
Total Kjeldahl (as N)	mg/l				
Dissolved Phosphorus (as P)	mg/l	0.033			
Total Phosphorus (as P)	mg/l				
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l				
Dissolved Iron	mg/l	1.2			

Sample #187298: ST-GW-9

< = Less Than
> = Greater Than

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AECOM L- 5075B

RE: PO #2076659, Santuit Pond, Mashpee, MA.

SAMPLE NUMBER		187361	187362	187363	187364
DATE COLLECTED		7/29/09	7/29/09	7/29/09	7/29/09
TIME COLLECTED		8:19am	8:21am	10:00am	8:19am
COLLECTED BY		S.M./P.W.	S.M./P.W.	S.M./P.W.	S.M./P.W.
DATE ANALYZED		7/30/09	7/30/09	7/30/09	7/30/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	12	12	16	<1
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05	<0.05	<0.05	<0.05
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01	<0.01	<0.01	<0.01
Total Kjeldahl (as N)	mg/l	0.84	0.70	0.94	<0.1
Dissolved Phosphorus (as P)	mg/l	0.029	0.019	0.023	<0.003
Total Phosphorus (as P)	mg/l	0.074	0.068	0.084	<0.003
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	6	6	8	<2
Dissolved Iron	mg/l	0.17	0.27	0.05	0.23

Sample #187361: ST-SW-1S
Sample #187362: ST-SW-1B
Sample #187363: ST-SW-2S
Sample #187364: ST-SW-3S

< = Less Than
> = Greater Than

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Director

WATER WASTEWATER AND ENVIRONMENTAL ANALYSIS
PHYSICAL CHEMICAL AND BACTERIOLOGICAL TESTING
LABORATORY AND FIELD MEASUREMENTS

BERKSHIRE ENVIRO-LABS, INC.

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AECOM

L- 5075B

RE: PO #2076659, Santuit Pond, Mashpee, MA.

SAMPLE NUMBER		187365			
DATE COLLECTED		7/29/09			
TIME COLLECTED		8:25am			
COLLECTED BY		S.M./P.W.			
DATE ANALYZED		7/30/09			
ANALYZED BY		W.E.-L.T.			
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	9			
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05			
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01			
Total Kjeldahl (as N)	mg/l	0.74			
Dissolved Phosphorus (as P)	mg/l	0.023			
Total Phosphorus (as P)	mg/l	0.069			
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	14			
Dissolved Iron	mg/l	0.29			

Sample #187365: ST-SW-4B

< = Less Than
> = Greater Than

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266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM L- 5075B

RE: PO #2076659, Santuit Pond, Mashpee, MA

SAMPLE NUMBER		188523	188524	188525	188526
DATE COLLECTED		8/26/09	8/26/09	8/26/09	8/26/09
TIME COLLECTED		10:35am	10:30am	2:38pm	2:40pm
COLLECTED BY		S.M./P.W.	S.M./P.W.	S.M./P.W.	S.M./P.W.
DATE ANALYZED		8/27/09	8/27/09	8/27/09	8/27/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	21	24	120	2
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05	<0.05	<0.05	<0.05
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01	<0.01	<0.01	<0.01
Total Kjeldahl (as N)	mg/l	0.82	0.88	5.2	<0.1
Dissolved Phosphorus (as P)	mg/l	0.004	0.012	0.005	<0.003
Total Phosphorus (as P)	mg/l	0.109	0.113	0.402	<0.003
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	16	16	14	<2
Dissolved Iron	mg/l	0.55	0.21	0.68	0.11

Sample #188523: ST-SW-1S
Sample #188524: ST-SW-1B
Sample #188525: ST-SW-2S
Sample #188526: ST-SW-3S

< = Less Than
> = Greater Than

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Director

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266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM

L- 5075B

RE: PO #2076659, Santuit Pond, Mashpee, MA

SAMPLE NUMBER		188527	188528	188529	
DATE COLLECTED		8/26/09	8/26/09	8/26/09	
TIME COLLECTED		10:32am	2:31pm	2:33pm	
COLLECTED BY		S.M./P.W.	S.M./P.W.	S.M./P.W.	
DATE ANALYZED		8/27/09	8/27/09	8/27/09	
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	20			
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05	<0.05	<0.05	
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01	0.01	0.02	
Total Kjeldahl (as N)	mg/l	1.2	0.52	0.33	
Dissolved Phosphorus (as P)	mg/l	0.011			
Total Phosphorus (as P)	mg/l	0.102	0.040	0.020	
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	16			
Dissolved Iron	mg/l	0.16			

Sample #188527: ST-SW-4B
Sample #188528: ST-SW-5S
Sample #188529: ST-SW-6S

< = Less Than
> = Greater Than

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AECOM

RE: PO #2076657

FOR: Project #13547-001-000 Santuit Pond, Wet Weather, Mashpee, MA

L- 5075B

SAMPLE NUMBER		188637	188638	188639	188640
DATE COLLECTED		8/29/09	8/29/09	8/29/09	8/29/09
TIME COLLECTED		7:35am	7:52am	8:15am	8:48am
COLLECTED BY		P. Winchell	P. Winchell	P. Winchell	P. Winchell
DATE ANALYZED		8/31/09	8/31/09	8/31/09	8/31/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	85	20	446	5
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05	<0.05	0.08	<0.05
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	0.15	0.30	0.23	0.03
Total Kjeldahl (as N)	mg/l	1.2	0.52	1.25	0.32
Dissolved Phosphorus (as P)	mg/l	0.078	0.080	0.216	0.040
Total Phosphorus (as P)	mg/l	0.391	0.174	0.885	0.085
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm	57	33	89	10
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	10	6	20	6
Dissolved Iron	mg/l				

Sample #188637: ST-WW-1
Sample #188638: ST-WW-2
Sample #188639: ST-WW-3
Sample #188640: ST-WW-4

< = Less Than
> = Greater Than

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Director

BERKSHIRE ENVIRO-LABS, INC.

CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM
RE: PO #2076657
FOR: Project #13547-001-000 Santuit Pond, Wet Weather, Mashpee, MA

L- 5075B

SAMPLE NUMBER		188641	188642		
DATE COLLECTED		8/29/09	8/29/09		
TIME COLLECTED		9:00am	9:15am		
COLLECTED BY		P. Winchell	P. Winchell		
DATE ANALYZED		8/31/09	8/31/09		
ANALYZED BY		W.E.-L.T.	W.E.-L.T.		
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	28	<1		
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05	<0.05		
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	0.08	<0.01		
Total Kjeldahl (as N)	mg/l	0.48	<0.1		
Dissolved Phosphorus (as P)	mg/l	0.090	<0.003		
Total Phosphorus (as P)	mg/l	0.145	<0.003		
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm	22	1.7		
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	6	<2		
Dissolved Iron	mg/l				

Sample #188641: ST-WW-5
Sample #188642: ST-WW-6

< = Less Than
> = Greater Than

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Director

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266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM L- 5075B
RE: PO #2076659
FOR: Santuit Pond, Town of Mashpee, MA

SAMPLE NUMBER		190190	190191	190192	190193
DATE COLLECTED		10/1/09	10/1/09	10/1/09	10/1/09
TIME COLLECTED		11:00am	11:05am	9:00am	11:10am
COLLECTED BY		P.W./S.M.	P.W./S.M.	P.W./S.M.	P.W./S.M.
DATE ANALYZED		10/2/09	10/2/09	10/2/09	10/2/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	14	23	1	20
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05	0.06	<0.05	<0.05
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01	<0.01	<0.01	0.01
Total Kjeldahl (as N)	mg/l	0.68	0.52	<0.1	0.60
Dissolved Phosphorus (as P)	mg/l	0.016	0.016	<0.003	0.017
Total Phosphorus (as P)	mg/l	0.088	0.095	<0.003	0.096
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	6	6	<2	6
Dissolved Iron	mg/l	0.23	0.20	0.01	0.20

Sample #190190: ST-SW-1S
Sample #190191: ST-SW-1B
Sample #190192: ST-SW-3S
Sample #190193: ST-SW-4B

< = Less Than
> = Greater Than

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Director

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CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM
RE: PO #2076659
FOR: Santuit Pond, Town of Mashpee, MA

L- 5075B

SAMPLE NUMBER		190194			
DATE COLLECTED		10/1/09			
TIME COLLECTED		12:10pm			
COLLECTED BY		P.W./S.M.			
DATE ANALYZED		10/2/09			
ANALYZED BY		W.E.-L.T.			
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	18			
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05			
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01			
Total Kjeldahl (as N)	mg/l	0.62			
Dissolved Phosphorus (as P)	mg/l	0.016			
Total Phosphorus (as P)	mg/l	0.103			
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	2			
Dissolved Iron	mg/l	0.19			

Sample #190194: ST-SW-2S

< = Less Than
> = Greater Than

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AECOM L- 5075B
RE: PO #2076659
FOR: Santuit Pond, Town of Mashpee, MA

SAMPLE NUMBER		190195	190196	190197	190198
DATE COLLECTED		10/1/09	10/1/09	10/1/09	10/1/09
TIME COLLECTED		8:20am	8:50am	9:15am	10:15am
COLLECTED BY		P.W./S.M.	P.W./S.M.	P.W./S.M.	P.W./S.M.
DATE ANALYZED		10/2/09	10/2/09	10/2/09	10/2/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l				
Turbidity	NTU				
Ammonia (as N)	mg/l	0.06	0.08	1.5	1.15
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	0.62	0.15	<0.01	<0.01
Total Kjeldahl (as N)	mg/l				
Dissolved Phosphorus (as P)	mg/l	0.009	0.033	0.111	0.024
Total Phosphorus (as P)	mg/l				
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l				
Dissolved Iron	mg/l	0.04	<0.01	6.0	5.7

Sample #190195: ST-GW-1
Sample #190196: ST-GW-2
Sample #190197: ST-GW-3
Sample #190198: ST-GW-5

< = Less Than
> = Greater Than

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Director

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CORNER OF MAIN & CENTER STREETS

266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM

RE: PO #2076659

FOR: Santuit Pond, Town of Mashpee, MA

L- 5075B

SAMPLE NUMBER		190199	190200	190201	190202
DATE COLLECTED		10/1/09	10/1/09	10/1/09	10/1/09
TIME COLLECTED		10:40am	11:30am	11:45am	12:00pm
COLLECTED BY		P.W./S.M.	P.W./S.M.	P.W./S.M.	P.W./S.M.
DATE ANALYZED		10/2/09	10/2/09	10/2/09	10/2/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l				
Turbidity	NTU				
Ammonia (as N)	mg/l	2.0	1.15	0.54	<0.05
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01	<0.01	<0.01	12.0
Total Kjeldahl (as N)	mg/l				
Dissolved Phosphorus (as P)	mg/l	0.022	0.093	0.073	0.008
Total Phosphorus (as P)	mg/l				
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l				
Dissolved Iron	mg/l	5.2	4.4	3.6	0.15

Sample #190199: ST-GW-4
Sample #190200: ST-GW-6
Sample #190201: ST-GW-7
Sample #190202: ST-GW-8

< = Less Than
> = Greater Than

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Director

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266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM L- 5075B

RE: PO #2076662

FOR: Santuit Pond, Town of Mashpee, MA Page 1 of 1

SAMPLE NUMBER		190661	190662	190663	190664
DATE COLLECTED		10/21/09	10/21/09	10/21/09	10/21/09
TIME COLLECTED		4:43pm	4:52pm	5:08pm	5:30pm
COLLECTED BY		D.M.B./P.M.	D.M.B./P.M.	D.M.B./P.M.	D.M.B./P.M.
DATE ANALYZED		10/22/09	10/22/09	10/22/09	10/22/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	<1	<1	2	<1
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05	<0.05	<0.05	<0.05
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01	0.93	0.51	<0.01
Total Kjeldahl (as N)	mg/l	0.92	0.90	0.84	<0.1
Dissolved Phosphorus (as P)	mg/l	0.055	0.024	0.022	<0.003
Total Phosphorus (as P)	mg/l	0.086	0.029	0.046	<0.003
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm	75	107	108	2
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	6	4	4	<2
Dissolved Iron	mg/l	0.90	0.11	0.11	<0.01

Sample #190661: ST-CB-2HB
Sample #190662: ST-CB-2LB
Sample #190663: ST-CB-2OW
Sample #190664: ST-CB-1

< = Less Than
> = Greater Than

William S. Enser, Jr.
Director

BERKSHIRE ENVIRO-LABS, INC.

CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM
RE: PO #2076659
FOR: Santuit Pond, Town of Mashpee, MA

L- 5075B

SAMPLE NUMBER		190948	190949	190950	190951
DATE COLLECTED		11/3/09	11/3/09	11/3/09	11/3/09
TIME COLLECTED		9:34am	9:35am	10:10am	8:00am
COLLECTED BY		P.W./S.M.	P.W./S.M.	P.W./S.M.	P.W./S.M.
DATE ANALYZED		11/4/09	11/4/09	11/4/09	11/4/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	11	13	11	<1
Turbidity	NTU				
Ammonia (as N)	mg/l	0.05	<0.05	0.05	<0.05
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01	<0.01	0.03	<0.01
Total Kjeldahl (as N)	mg/l	0.98	0.80	0.78	<0.1
Dissolved Phosphorus (as P)	mg/l	0.011	0.006	0.008	<0.003
Total Phosphorus (as P)	mg/l	0.079	0.082	0.076	0.003
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	2	4	2	<2
Dissolved Iron	mg/l	0.04	0.03	0.04	0.01

Sample #190948: ST-SW-1S
Sample #190949: ST-SW-1B
Sample #190950: ST-SW-2S
Sample #190951: ST-SW-3S

< = Less Than
> = Greater Than

William S. Enser, Jr.
Director

BERKSHIRE ENVIRO-LABS, INC.
CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM
RE: PO #2076659
FOR: Santuit Pond, Town of Mashpee, MA

L- 5075B

SAMPLE NUMBER		190952			
DATE COLLECTED		11/3/09			
TIME COLLECTED		9:36am			
COLLECTED BY		P.W./S.M.			
DATE ANALYZED		11/4/09			
ANALYZED BY		W.E.-L.T.			
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	10			
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05			
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01			
Total Kjeldahl (as N)	mg/l	0.74			
Dissolved Phosphorus (as P)	mg/l	0.008			
Total Phosphorus (as P)	mg/l	0.078			
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm				
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	4			
Dissolved Iron	mg/l	0.05			

Sample #190952: ST-SW-4B

< = Less Than
> = Greater Than

William S. Enser, Jr.
Director

BERKSHIRE ENVIRO-LABS, INC.

CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM L- 5075B
RE: PO #2076657
FOR: Santuit Pond, Town of Mashpee - Wet Weather

SAMPLE NUMBER		191305	191306	191307	191308
DATE COLLECTED		11/19/09	11/19/09	11/19/09	11/19/09
TIME COLLECTED		11:05am	10:57am	10:47am	10:33am
COLLECTED BY		P. Winchell	P. Winchell	P. Winchell	P. Winchell
DATE ANALYZED		11/23/09	11/23/09	11/23/09	11/23/09
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	114	162	1108	22
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05	0.15	<0.05	<0.05
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01	0.20	<0.01	0.06
Total Kjeldahl (as N)	mg/l	0.80	0.54	0.65	0.90
Dissolved Phosphorus (as P)	mg/l	0.570	0.680	0.895	0.149
Total Phosphorus (as P)	mg/l	0.902	0.785	1.728	0.199
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm	83	27	82	51
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	<2	<2	<2	<2
Dissolved Iron	mg/l				

Sample #191305: ST-WW-1
Sample #191306: ST-WW-2
Sample #191307: ST-WW-3
Sample #191308: ST-WW-4

< = Less Than
> = Greater Than

William S. Enser, Jr.
Director

BERKSHIRE ENVIRO-LABS, INC.
CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM L- 5075B
RE: PO #2076657
FOR: Santuit Pond, Town of Mashpee - Wet Weather

SAMPLE NUMBER		191309	191310		
DATE COLLECTED		11/19/09	11/19/09		
TIME COLLECTED		10:15am	11:15am		
COLLECTED BY		P. Winchell	P. Winchell		
DATE ANALYZED		11/23/09	11/23/09		
ANALYZED BY		W.E.-L.T.	W.E.-L.T.		
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	462	<1		
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.05	<0.05		
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01	<0.01		
Total Kjeldahl (as N)	mg/l	0.58	<0.1		
Dissolved Phosphorus (as P)	mg/l	0.257	<0.003		
Total Phosphorus (as P)	mg/l	0.798	<0.003		
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm	55	2		
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	<2	<2		
Dissolved Iron	mg/l				

Sample #191309: ST-WW-5
Sample #191310: ST-WW-6

< = Less Than
> = Greater Than

William S. Enser, Jr.
Director

BERKSHIRE ENVIRO-LABS, INC.
CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM
RE: PO #1424
FOR: Santuit Pond, Mashpee, MA.

L- 5075B

SAMPLE NUMBER		192527	192528	192529	192530
DATE COLLECTED		2/8/10	2/8/10	2/8/10	2/8/10
TIME COLLECTED		2:50pm	2:50pm	2:50pm	3:30pm
COLLECTED BY		D. Ball	D. Ball	D. Ball	D. Ball
DATE ANALYZED		2/9/10	2/9/10	2/9/10	2/9/10
ANALYZED BY		W.E.-L.T.	W.E.-L.T.	W.E.-L.T.	W.E.-L.T.
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	18	6	<1	5
Turbidity	NTU				
Ammonia (as N)	mg/l	0.06	0.06	0.11	0.10
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	0.02	0.54	0.02	0.54
Total Kjeldahl (as N)	mg/l	0.53	0.50	0.46	0.46
Dissolved Phosphorus (as P)	mg/l	0.066	0.038	0.077	0.021
Total Phosphorus (as P)	mg/l	0.075	0.048	0.082	0.040
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm	72.7	84.4	65.9	93.5
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	4	6	6	8
Dissolved Iron	mg/l				

Sample #192527: ST-BRACKET-R1B
Sample #192528: ST-BRACKET-R1P
Sample #192529: ST-BRACKET-R1Q2
Sample #192530: ST-BRACKET-OW

< = Less Than
> = Greater Than

William S. Enser, Jr.
Director

BERKSHIRE ENVIRO-LABS, INC.
CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM L- 5075B
RE: PO #1424
FOR: Santuit Pond, Mashpee, MA.

SAMPLE NUMBER		192531			
DATE COLLECTED		2/8/10			
TIME COLLECTED		3:30pm			
COLLECTED BY		D. Ball			
DATE ANALYZED		2/9/10			
ANALYZED BY		W.E.-L.T.			
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	<1			
Turbidity	NTU				
Ammonia (as N)	mg/l	<0.04			
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	<0.01			
Total Kjeldahl (as N)	mg/l	<0.2			
Dissolved Phosphorus (as P)	mg/l	<0.003			
Total Phosphorus (as P)	mg/l	<0.003			
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm	1.9			
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	1			
Dissolved Iron	mg/l				

Sample #192531: ST-BRACKET-R1Q1

< = Less Than
> = Greater Than

William S. Enser, Jr.
Director

BERKSHIRE ENVIRO-LABS, INC.
CORNER OF MAIN & CENTER STREETS
266 MAIN STREET, LEE, MASS. 01238 (413) 243-1416

AECOM L- 5075B
RE: PO #1424
FOR: Santuit Pond, Mashpee, MA. Page 1 of 1

SAMPLE NUMBER		192545	192546		
DATE COLLECTED		2/9/10	2/9/10		
TIME COLLECTED		11:30am	11:35am		
COLLECTED BY		D. Ball	D. Ball		
DATE ANALYZED		2/10/10	2/10/10		
ANALYZED BY		W.E.-L.T.	W.E.-L.T.		
ANALYSIS	UNITS				
Bacteriological					
E. Coli	/100ml				
Enterococci	/100ml				
Physical-Chemical					
pH	SU				
True Color	Pt. Units				
Apparent Color	Pt. Units				
Total Suspended Solids	mg/l	1	1		
Turbidity	NTU				
Ammonia (as N)	mg/l	0.06	0.07		
Nitrite (as N)	mg/l				
Nitrate (as N)	mg/l	0.02	0.12		
Total Kjeldahl (as N)	mg/l	0.37	0.41		
Dissolved Phosphorus (as P)	mg/l	0.077	0.072		
Total Phosphorus (as P)	mg/l	0.106	0.093		
Total Nitrogen (as N)	mg/l				
Specific Conductance	umhos/cm	49.8	61.8		
Dissolved Aluminum	mg/l				
Alkalinity	mg/l	4	4		
Dissolved Iron	mg/l				

Sample #192545: ST-BRACKET-R2B
Sample #192546: ST-BRACKET-R2P

< = Less Than
> = Greater Than

William S. Enser, Jr.
Director

Report Date:
17-Aug-09 10:51

☑ Final Report
☐ Re-Issued Report
☐ Revised Report

SPECTRUM ANALYTICAL, INC.
Featuring
HANIBAL TECHNOLOGY

Laboratory Report

AECOM Environment
2 Technology Park Drive
Westford, MA 01886-3140
Attn: Sarah MacDougall

Project: Santuit Pond - Mashpee, MA
Project #: 13547-001-200

Laboratory ID	Client Sample ID	Matrix	Date Sampled	Date Received
SA98581-01	ST-SED-1	Soil	29-Jul-09 09:13	30-Jul-09 16:50
SA98581-02	ST-SED-2	Soil	29-Jul-09 10:38	30-Jul-09 16:50
SA98581-03	ST-SED-3	Soil	29-Jul-09 10:10	30-Jul-09 16:50
SA98581-04	ST-SED-4	Soil	29-Jul-09 09:40	30-Jul-09 16:50

I attest that the information contained within the report has been reviewed for accuracy and checked against the quality control requirements for each method. These results relate only to the sample(s) as received.
All applicable NELAC requirements have been met.

Massachusetts # M-MA138/MA1110
Connecticut # PH-0777
Florida # E87600/E87936
Maine # MA138
New Hampshire # 2538
New Jersey # MA011/MA012
New York # 11393/11840
Pennsylvania # 68-04426/68-02924
Rhode Island # 98
USDA # S-51435
Vermont # VT-11393

Authorized by:

Hanibal C. Tayeh, Ph.D.
President/Laboratory Director

Technical Reviewer's Initial:

Spectrum Analytical holds certification in the State of Massachusetts for the analytes as indicated with an X in the "Cert." column within this report. Please note that the State of Massachusetts does not offer certification for all analytes.
Please note that this report contains 7 pages of analytical data plus Chain of Custody document(s). When the Laboratory Report is indicated as revised, this report supercedes any previously dated reports for the laboratory ID(s) referenced above. Where this report identifies subcontracted analyses, copies of the subcontractor's test report is available upon request. This report may not be reproduced, except in full, without written approval from Spectrum Analytical, Inc.

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Please contact the Laboratory or Technical Director at 800-789-9115 with any questions regarding the data contained in this laboratory report.

CASE NARRATIVE:

The sample temperature upon receipt by Spectrum Analytical courier was recorded as 5.1 degrees Celsius. The samples were transported on ice to the laboratory facility and the temperature was recorded at 1.0 degrees Celsius upon receipt at the laboratory. Please refer to the Chain of Custody for details specific to sample receipt times.

An infrared thermometer with a tolerance of +/- 2.0 degrees Celsius was used immediately upon receipt of the samples.

If a Matrix Spike (MS), Matrix Spike Duplicate (MSD) or Duplicate (DUP) was not requested on the Chain of Custody, method criteria may have been fulfilled with a source sample not of this Sample Delivery Group.

See below for any non-conformances and issues relating to quality control samples and/or sample analysis/matrix.

ASTM D515-88(A)

Spikes:

9081116-MS1 *Source: SA98581-01*

The spike recovery was outside acceptance limits for the MS and/or MSD. The batch was accepted based on acceptable LCS recovery.

Loosely-sorbed Phosphorus as P

9081116-MSD1 *Source: SA98581-01*

The spike recovery was outside acceptance limits for the MS and/or MSD. The batch was accepted based on acceptable LCS recovery.

Loosely-sorbed Phosphorus as P

9081125-MS1 *Source: SA98581-01*

The spike recovery for this QC sample is outside of established control limits due to sample matrix interference.

Iron bound Phosphorus as P

9081125-MSD1 *Source: SA98581-01*

The spike recovery for this QC sample is outside of established control limits due to sample matrix interference.

Iron bound Phosphorus as P

Duplicates:

9081116-DUP1 *Source: SA98581-01*

The RPD value for the sample duplicate or MS/MSD was outside the QC acceptance limits due to matrix interference. QC batch accepted based on LCS and/or LCSD recovery and/or RPD values.

Loosely-sorbed Phosphorus as P

SW846 6010B

Blanks:

9080064-BLK1

The method blank contains analyte at a concentration above the MRL; however, concentration is less than 10% of the sample result, which is negligible according to method criteria.

Iron

Sample Identification	Client Project #	Matrix	Collection Date/Time	Received
ST-SED-1 SA98581-01	13547-001-200	Soil	29-Jul-09 09:13	30-Jul-09

CAS No.	*Analyte(s)*	*Result*	*Flag*	*Units*	**RDL*	*Dilution*	*Method Ref.*	*Prepared*	*Analyzed*	*Batch*	*Cert.*
Total Metals by EPA 6000/7000 Series Methods											
7429-90-5	Aluminum	6,440		mg/kg dry	40.1	1	SW846 6010B	03-Aug-09	05-Aug-09	9080064	
7439-89-6	Iron	16,600		mg/kg dry	32.0	1	"	"	07-Aug-09	"	
7723-14-0	Phosphorus as P	920		mg/kg dry	43.7	1	"	07-Aug-09	10-Aug-09	9080134	
General Chemistry Parameters											
	12-hour Drying @ 60 C	Completed		N/A		1	Yankee QAPP	03-Aug-09	03-Aug-09	9081165	
	% Solids	12.4		%		1	SM2540 G Mod.	03-Aug-09	"	9080089	
	Iron bound Phosphorus as P	316		mg/kg dry dry	20.1	50	ASTM D515-88(A)	16-Aug-09	16-Aug-09	9081125	
	Loosely-sorbed Phosphorus as P	BRL		mg/kg dry dry	2.01	5	"	15-Aug-09	16-Aug-09	9081116	
Toxicity Characteristics											
Grain Size - Reported as % retained.											
Prepared by method General Preparation											
	Fractional % Sieve #4 (>4750µm)	4.44		% Retained		1	ASTM D422	10-Aug-09	10-Aug-09	9080589	
	Fractional % Sieve #10 (4750-2000	20.0		% Retained		1	"	"	"	"	
	Fractional % Sieve #20 (2000-850µ	30.0		% Retained		1	"	"	"	"	
	Fractional % Sieve #40 (850-425µm	17.8		% Retained		1	"	"	"	"	
	Fractional % Sieve #60 (425-250µm	8.89		% Retained		1	"	"	"	"	
	Fractional % Sieve #100 (250-150µ	5.56		% Retained		1	"	"	"	"	
	Fractional % Sieve #200 (150-75µm	7.78		% Retained		1	"	"	"	"	
	Fractional % Sieve #230 (less than 75µm)	5.56		% Retained		1	"	"	"	"	

Sample Identification	Client Project #	Matrix	Collection Date/Time	Received
ST-SED-2 SA98581-02	13547-001-200	Soil	29-Jul-09 10:38	30-Jul-09

CAS No.	*Analyte(s)*	*Result*	*Flag*	*Units*	**RDL*	*Dilution*	*Method Ref.*	*Prepared*	*Analyzed*	*Batch*	*Cert.*
Total Metals by EPA 6000/7000 Series Methods											
7429-90-5	Aluminum	5,020		mg/kg dry	101	1	SW846 6010B	03-Aug-09	05-Aug-09	9080064	
7439-89-6	Iron	22,500		mg/kg dry	80.7	1	"	"	07-Aug-09	"	
7723-14-0	Phosphorus as P	2,550		mg/kg dry	112	1	"	07-Aug-09	10-Aug-09	9080134	
General Chemistry Parameters											
	12-hour Drying @ 60 C	Completed		N/A		1	Yankee QAPP	03-Aug-09	03-Aug-09	9081165	
	% Solids	4.9		%		1	SM2540 G Mod.	03-Aug-09	"	9080089	
	Iron bound Phosphorus as P	650		mg/kg dry dry	51.2	50	ASTM D515-88(A)	16-Aug-09	16-Aug-09	9081125	
	Loosely-sorbed Phosphorus as P	BRL		mg/kg dry dry	5.12	5	"	15-Aug-09	16-Aug-09	9081116	
Toxicity Characteristics											
Grain Size - Reported as % retained.											
Prepared by method General Preparation											
	Fractional % Sieve #4 (>4750µm)	2.94		% Retained		1	ASTM D422	10-Aug-09	10-Aug-09	9080589	
	Fractional % Sieve #10 (4750-2000	20.6		% Retained		1	"	"	"	"	
	Fractional % Sieve #20 (2000-850µ	29.4		% Retained		1	"	"	"	"	
	Fractional % Sieve #40 (850-425µm	17.6		% Retained		1	"	"	"	"	
	Fractional % Sieve #60 (425-250µm	11.8		% Retained		1	"	"	"	"	
	Fractional % Sieve #100 (250-150µ	5.88		% Retained		1	"	"	"	"	
	Fractional % Sieve #200 (150-75µm	5.88		% Retained		1	"	"	"	"	
	Fractional % Sieve #230 (less than 75µm)	5.88		% Retained		1	"	"	"	"	

Sample Identification	Client Project #	Matrix	Collection Date/Time	Received
ST-SED-3 SA98581-03	13547-001-200	Soil	29-Jul-09 10:10	30-Jul-09

CAS No.	Analyte(s)	Result	Flag	Units	*RDL	Dilution	Method Ref.	Prepared	Analyzed	Batch	Cert.
Total Metals by EPA 6000/7000 Series Methods											
7429-90-5	Aluminum	678		mg/kg dry	5.14	1	SW846 6010B	03-Aug-09	05-Aug-09	9080064	
7439-89-6	Iron	1,350		mg/kg dry	4.11	1	"	"	07-Aug-09	"	
7723-14-0	Phosphorus as P	66.4		mg/kg dry	6.27	1	"	07-Aug-09	10-Aug-09	9080134	
General Chemistry Parameters											
	12-hour Drying @ 60 C	Completed		N/A		1	Yankee QAPP	03-Aug-09	03-Aug-09	9081165	
	% Solids	83.0		%		1	SM2540 G Mod.	03-Aug-09	"	9080089	
	Iron bound Phosphorus as P	9.90		mg/kg dry dry	3.01	50	ASTM D515-88(A)	16-Aug-09	16-Aug-09	9081125	
	Loosely-sorbed Phosphorus as P	BRL		mg/kg dry dry	0.30	5	"	15-Aug-09	16-Aug-09	9081116	
Toxicity Characteristics											
Grain Size - Reported as % retained.											
Prepared by method General Preparation											
	Fractional % Sieve #4 (>4750µm)	23.7		% Retained		1	ASTM D422	10-Aug-09	10-Aug-09	9080589	
	Fractional % Sieve #10 (4750-2000	11.6		% Retained		1	"	"	"	"	
	Fractional % Sieve #20 (2000-850µ	22.4		% Retained		1	"	"	"	"	
	Fractional % Sieve #40 (850-425µm	31.7		% Retained		1	"	"	"	"	
	Fractional % Sieve #60 (425-250µm	8.75		% Retained		1	"	"	"	"	
	Fractional % Sieve #100 (250-150µ	1.55		% Retained		1	"	"	"	"	
	Fractional % Sieve #200 (150-75µm	0.292		% Retained		1	"	"	"	"	
	Fractional % Sieve #230 (less than 75µm)	0.0972		% Retained		1	"	"	"	"	

Sample Identification	Client Project #	Matrix	Collection Date/Time	Received
ST-SED-4 SA98581-04	13547-001-200	Soil	29-Jul-09 09:40	30-Jul-09

CAS No.	Analyte(s)	Result	Flag	Units	*RDL	Dilution	Method Ref.	Prepared	Analyzed	Batch	Cert.
Total Metals by EPA 6000/7000 Series Methods											
7429-90-5	Aluminum	7,320		mg/kg dry	56.1	1	SW846 6010B	03-Aug-09	05-Aug-09	9080064	
7439-89-6	Iron	17,300		mg/kg dry	44.9	1	"	"	07-Aug-09	"	
7723-14-0	Phosphorus as P	1,270		mg/kg dry	67.5	1	"	07-Aug-09	10-Aug-09	9080134	
General Chemistry Parameters											
	12-hour Drying @ 60 C	Completed		N/A		1	Yankee QAPP	03-Aug-09	03-Aug-09	9081165	
	% Solids	8.2		%		1	SM2540 G Mod.	03-Aug-09	"	9080089	
	Iron bound Phosphorus as P	490		mg/kg dry dry	30.4	50	ASTM D515-88(A)	16-Aug-09	16-Aug-09	9081125	
	Loosely-sorbed Phosphorus as P	BRL		mg/kg dry dry	3.04	5	"	15-Aug-09	16-Aug-09	9081116	
Toxicity Characteristics											
Grain Size - Reported as % retained.											
Prepared by method General Preparation											
	Fractional % Sieve #4 (>4750µm)	3.17		% Retained		1	ASTM D422	10-Aug-09	10-Aug-09	9080589	
	Fractional % Sieve #10 (4750-2000	25.4		% Retained		1	"	"	"	"	
	Fractional % Sieve #20 (2000-850µ	31.7		% Retained		1	"	"	"	"	
	Fractional % Sieve #40 (850-425µm	12.7		% Retained		1	"	"	"	"	
	Fractional % Sieve #60 (425-250µm	4.76		% Retained		1	"	"	"	"	
	Fractional % Sieve #100 (250-150µ	6.35		% Retained		1	"	"	"	"	
	Fractional % Sieve #200 (150-75µm	6.35		% Retained		1	"	"	"	"	
	Fractional % Sieve #230 (less than 75µm)	9.52		% Retained		1	"	"	"	"	

Total Metals by EPA 6000/7000 Series Methods - Quality Control

Analyte(s)	Result	Flag	Units	*RDL	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit
Batch 9080064 - SW846 3050B										
Blank (9080064-BLK1)										
Prepared: 03-Aug-09 Analyzed: 05-Aug-09										
Iron	7.14	QB1	mg/kg wet	3.90						
Aluminum	BRL		mg/kg wet	4.88						
Reference (9080064-SRM1)										
Prepared: 03-Aug-09 Analyzed: 07-Aug-09										
Iron	10200		mg/kg wet	4.00	9640		105	50.4-148.9		
Aluminum	6660		mg/kg wet	5.00	5700		117	55.7-143.6		
Reference (9080064-SRM2)										
Prepared: 03-Aug-09 Analyzed: 07-Aug-09										
Iron	10100		mg/kg wet	4.00	9570		105	50.4-148.9		
Aluminum	6600		mg/kg wet	5.00	5660		117	55.7-143.6		
Batch 9080134 - SW846 3050B										
Blank (9080134-BLK1)										
Prepared: 07-Aug-09 Analyzed: 10-Aug-09										
Phosphorus as P	BRL		mg/kg wet	5.93						
Duplicate (9080134-DUP1)	**Source: SA98581-02**									
Prepared: 07-Aug-09 Analyzed: 10-Aug-09										
Phosphorus as P	2700		mg/kg dry	121		2550			6	20
Matrix Spike (9080134-MS1)	**Source: SA98581-03**									
Prepared: 07-Aug-09 Analyzed: 10-Aug-09										
Phosphorus as P	213		mg/kg dry	6.80	142	66.4	104	75-125		
Matrix Spike Dup (9080134-MSD1)	**Source: SA98581-03**									
Prepared: 07-Aug-09 Analyzed: 10-Aug-09										
Phosphorus as P	205		mg/kg dry	6.89	144	66.4	96	75-125	4	20
Reference (9080134-SRM2)										
Prepared: 07-Aug-09 Analyzed: 10-Aug-09										
Phosphorus as P	193		mg/kg wet	6.00	169		114	39.6-138		

General Chemistry Parameters - Quality Control

Analyte(s)	Result	Flag	Units	*RDL	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit
Batch 9080089 - General Preparation										
Duplicate (9080089-DUP1)	**Source: SA98581-01**									
Prepared & Analyzed: 03-Aug-09										
% Solids	13.2		%			12.4			6	20
Batch 9081116 - Phosphorus Fractionation										
Blank (9081116-BLK1)										
Prepared: 15-Aug-09 Analyzed: 16-Aug-09										
Loosely-sorbed Phosphorus as P	BRL		mg/kg dry we	0.25						
LCS (9081116-BS1)										
Prepared: 15-Aug-09 Analyzed: 16-Aug-09										
Loosely-sorbed Phosphorus as P	25.6		mg/kg dry we	0.50	25.0		102	90-110		
Duplicate (9081116-DUP1)	**Source: SA98581-01**									
Prepared: 15-Aug-09 Analyzed: 16-Aug-09										
Loosely-sorbed Phosphorus as P	1.86	J,QR3	mg/kg dry dry	2.01		0.00				35
Matrix Spike (9081116-MS1)	**Source: SA98581-01**									
Prepared: 15-Aug-09 Analyzed: 16-Aug-09										
Loosely-sorbed Phosphorus as P	1.55	QM7	mg/kg dry dry	2.01	172	0.00	0.9	80-120		
Matrix Spike Dup (9081116-MSD1)	**Source: SA98581-01**									
Prepared: 15-Aug-09 Analyzed: 16-Aug-09										
Loosely-sorbed Phosphorus as P	0.73	QM7	mg/kg dry dry	2.01	183	0.00	0.4	80-120	72	35
Batch 9081125 - Phosphorus Fractionation										
Blank (9081125-BLK1)										
Prepared & Analyzed: 16-Aug-09										
Iron bound Phosphorus as P	BRL		mg/kg dry we	2.50						
LCS (9081125-BS1)										
Prepared & Analyzed: 16-Aug-09										
Iron bound Phosphorus as P	23.0		mg/kg dry we	2.50	25.0		92	90-110		
Duplicate (9081125-DUP1)	**Source: SA98581-01**									
Prepared & Analyzed: 16-Aug-09										
Iron bound Phosphorus as P	435		mg/kg dry dry	20.1		316			32	35
Matrix Spike (9081125-MS1)	**Source: SA98581-01**									
Prepared & Analyzed: 16-Aug-09										
Iron bound Phosphorus as P	440	QM1	mg/kg dry dry	20.1	172	316	72	80-120		
Matrix Spike Dup (9081125-MSD1)	**Source: SA98581-01**									
Prepared & Analyzed: 16-Aug-09										
Iron bound Phosphorus as P	365	QM1	mg/kg dry dry	20.1	183	316	27	80-120	19	35

Notes and Definitions

QB1	The method blank contains analyte at a concentration above the MRL; however, concentration is less than 10% of the sample result, which is negligible according to method criteria.
QM1	The spike recovery for this QC sample is outside of established control limits due to sample matrix interference.
QM7	The spike recovery was outside acceptance limits for the MS and/or MSD. The batch was accepted based on acceptable LCS recovery.
QR3	The RPD value for the sample duplicate or MS/MSD was outside the QC acceptance limits due to matrix interference. QC batch accepted based on LCS and/or LCSD recovery and/or RPD values.
BRL	Below Reporting Limit - Analyte NOT DETECTED at or above the reporting limit
dry	Sample results reported on a dry weight basis
NR	Not Reported
RPD	Relative Percent Difference
J	Detected but below the Reporting Limit; therefore, result is an estimated concentration (CLP J-Flag).

A plus sign (+) in the Method Reference column indicates the method is not accredited by NELAC.

Laboratory Control Sample (LCS): A known matrix spiked with compound(s) representative of the target analytes, which is used to document laboratory performance.

Matrix Duplicate: An intra-laboratory split sample which is used to document the precision of a method in a given sample matrix.

Matrix Spike: An aliquot of a sample spiked with a known concentration of target analyte(s). The spiking occurs prior to sample preparation and analysis. A matrix spike is used to document the bias of a method in a given sample matrix.

Method Blank: An analyte-free matrix to which all reagents are added in the same volumes or proportions as used in sample processing. The method blank should be carried through the complete sample preparation and analytical procedure. The method blank is used to document contamination resulting from the analytical process.

Method Detection Limit (MDL): The minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix type containing the analyte.

Reportable Detection Limit (RDL): The lowest concentration that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions. For many analytes the RDL analyte concentration is selected as the lowest non-zero standard in the calibration curve. While the RDL is approximately 5 to 10 times the MDL, the RDL for each sample takes into account the sample volume/weight, extract/digestate volume, cleanup procedures and, if applicable, dry weight correction. Sample RDLs are highly matrix-dependent.

Surrogate: An organic compound which is similar to the target analyte(s) in chemical composition and behavior in the analytical process, but which is not normally found in environmental samples. These compounds are spiked into all blanks, standards, and samples prior to analysis. Percent recoveries are calculated for each surrogate.

Validated by:
Hanibal C. Tayeh, Ph.D.
June O'Connor
Nicole Leja

SA 98581 (P)

SPECTRUM ANALYTICAL, INC.
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HANIBAL TECHNOLOGY

CHAIN OF CUSTODY RECORD

Page 1 of 1

Special Handling:
☒ Standard TAT - 7 to 10 business days
☐ Rush TAT - Date Needed: ______
- All TATs subject to laboratory approval. Min. 24-hour notification needed for rushes.
- Samples disposed of after 60 days unless otherwise instructed.

Report To: Sarah MacDougall
2 Technology Park Drive
Westford, MA 01886

Project Mgr.: D. Mike Ball
Telephone #: 978-589-3431

Invoice To: ______

P.O. No.: TBA   RQN: 86818

Project No.: 13547-001-200
Site Name: Santuit Pond
Location: Mashpee   State: MA
Sampler(s): SM, PW

1=$Na_2S_2O_3$ 2=HCl 3=H_2SO_4 4=HNO_3 5=NaOH 6=Ascorbic Acid 7=CH_3OH
8= $NaHSO_4$ 9=______ 10=______ 11=______

DW=Drinking Water GW=Groundwater WW=Wastewater
O=Oil SW= Surface Water SO=Soil SL=Sludge A=Air
X1=______ X2=______ X3=______

G=Grab C=Composite

List preservative code below:

Lab Id:	Sample Id:	Date:	Time:	Type	Matrix	# of VOA Vials	# of Amber Glass	# of Clear Glass	# of Plastic	Grain Size	Phosphorus as P	Loosely-sorbed P	Fe-band P	Total Aluminum	Total Iron	% Solids
98581-01	ST-SED-1	7/29/09	9:13		SO		3			X	X	X	X	X	X	X
-02	ST-SED-2	↓	10:38		↓		3			↓	↓	↓	↓	↓	↓	↓
-03	ST-SED-3	↓	10:10		↓		3			↓	↓	↓	↓	↓	↓	↓
-04	ST-SED-4	↓	9:40		↓		3			↓	↓	↓	↓	↓	↓	↓

QA/QC Reporting Notes: (check as needed)
☐ Provide MA DEP MCP CAM Report
☐ Provide CT DPH RCP Report
QA/QC Reporting Level
☐ Standard ☐ No QC
☐ Other ______
State specific reporting standards: ______

EDD Format ______
☒ E-mail to Sarah.macdougall@aecom.com

Condition upon receipt: ☐ Iced ☐ Ambient ☒ °C 5.1

Relinquished by:	Received by:	Date:	Time:
Sarah E MacDougall	[signature]	7/29/09	15:53
[signature]	[signature]	7/30/09	12:50
[signature]	[signature]	7/30/09	16:50

1.0°C

Appendix B

Complementary Study Data

Results from Massachusetts Department of Public Health 2009 Santuit Pond study at the Mashpee Town Landing.

Collection Date	Time	Analyzed by:	Total Count (cells/ml)	Species Count (cells/ml) and ID	Species Count (cells/ml) and ID	Species Count (cells/ml) and ID	Species Count (cells/ml) and ID	Toxin Test	Toxin Conc.
6/18/2009	10:23	NE Labs/Spectrum	152 colonies/ml	96 colonies Chroococcus	40 Microcystis	16 Anabaena		Microcystin	<1 ppb
6/24/2009	9:22	NE Labs/Spectrum	160 colonies/ml	120 colonies Microcystis	32 Coelosphaerium	8 Spirulina		Microcystin	<1 ppb
6/30/2009	9:55	NE Labs/Spectrum	276 colonies/ml	220 Microcystis	56 Coelosphaerium			Microcystin	<1 ppb
7/6/2009	12:20	NE Labs/Spectrum	21,580	14,200 Microcystis	5,400 Coelosphaerium	1,900 Aphanocapsa	80 Anabaena	Microcystin	<1 ppb
7/7/2009	9:08	NE Labs/Spectrum	128,310	102,000 Microcystis	24,800 Coelosphaerium	1,350 Aphanocapsa	160 Anabaena	Microcystin	<1 ppb
7/14/2009	8:03	NE Labs/Spectrum	63,200	48,000 Microcystis	10,400 Aphanocapsa	2,400 Nostoc	2,400 Coelosphaerium	Microcystin	<1 ppb
7/21/2009	8:05	NE Labs/Spectrum	164,000	100,000 Microcystis	28,000 Coelosphaerium	26,000 Aphanothece	10,000 Aphanocapsa	Microcystin	<1 ppb
7/28/2009	7:44	NE Labs/Spectrum	Hold time exceeded					Microcystin	<1 ppb
8/4/2009	7:12	NE Labs/Spectrum	50,800	20,000 Aphanocapsa	16,000 Coelosphaerium	14,000 Microcystis	800 Aphanizomenon	Microcystin	<1 ppb
8/11/2009	7:40	NE Labs/Spectrum	100,000	54,000 Aphanocapsa	34,000 Microcystis	13,000 Coelosphaerium		microcystin	<1 ppb
8/18/2009	7:38	NE Labs/Spectrum	120,000	79,000 Microcystis	45,000 Aphanocapsa			Microcystin	<1 ppb
8/25/2009	10:00	NE Labs/Spectrum	278,800	120,000 Microcystis	120,000 Aphanocapsa	38,000 Coelosphaerium	800 Dactylococcopsis	Microcystin	<1 ppb
9/1/2009	9:30	NE Labs/Spectrum	101,000	93,000 Aphanocapsa	8,000 Microcystis			Microcystin	<1 ppb
9/8/2009	9:15	NE Labs/Spectrum	66,000	45,000 Aphanocapsa	16,000 Microcystis	4,800 Anabaena		Microcystin	<1 ppb
9/15/2009	9:48	NE Labs/Spectrum	69,000	38,000 Microcystis	31,000 Aphanocapsa				
9/22/2009	10:30	NE Labs/Spectrum	78,000	48,000 Aphanocapsa	30,000 Microcystis				
9/28/2009	10:24	NE Labs/Spectrum	89,000	Aphanocapsa					
10/6/2009	9:55	NE Labs/Spectrum	29,000	Aphanocapsa					
10/14/2009	11:49	NE Labs/Spectrum	43,000	40,000 Aphanocapsa	2,500 Anabaena				

Results from Massachusett

Collection Date	Time	Temp. °C	DO % Sat.	DO mg/l	Sp. Cond.	Salinity ppt	Chlorophyll a (ug/L)	Urea (mg/L)	Air Temp °C	pH	Turbidity	Secchi Depth	Nitrate/ Nitrite	Ammonium	TKN	Total P	TSS	Latitude	Longitude
6/18/2009	10:23	20.7		8.81	90	0.05	8.8	1.3	18.7	7.49	6.31	36	0.09	0.18	0.28	0.078	6		
6/24/2009	9:22	17.53	89	8.49	92	0.05	430	0.61	16.9	7.38	9.24	35	0.129	0.11	0.77	0.048	9		
6/30/2009	9:55	21.43	108	9.55	85	0.04	346	7.05	20.9	8.7	17.7	32	0.0142	0.805	1.86	0.036	20		
7/6/2009	12:20	23.12	75.3	6.45	104	0.05	1,380	<0.21	23.48	7.63	30.2	5	<0.01	0.28	2.17	0.161	32	41.65745	-70.46368
7/7/2009	9:08	24.03	123.1	10.36	91	0.04	592	0.433	23.6	8.81	12.4	22	<0.01	<0.10	1.82	0.082	18	41.65738	-70.46371
7/14/2009	8:03	22.36	106.2	9.06	87	0.04	321	<0.21	21.2	6.17	12.9	22	<0.01	0.14	0.98	0.076	14	41.65743	-70.46368
7/21/2009	8:05	24.97	98.8	8.17	96	0.04	143	11.4	20.5	8.98	16.9	25	<0.01	0.105	1.26	0.183	19	41.65739	-70.46227
7/28/2009	7:44	24.95	110.1	9.1	86	0.04	150	0.97	23.2	7.74	16.3	20	<0.01	<0.10	1.89	0.127	41	41.65744	-70.46355
8/4/2009	7:12	26.69	110.2	8.86	106	0.05	98	114	24	8.16	15.7	22	<0.01	0.105	1.61	0.134	29	41.65742	-70.46375
8/11/2009	7:40	25.86	123	9.94	111	0.05	784	<0.21	25.5	8.83	46.6	7	<0.01	0.175	3.36	0.272	55		
8/18/2009	7:38	26.7	128.9	10.32	108	0.05	1950	<0.21	29.7	9.43	14.4	15 in	<0.01	<0.1	1.47	0.114	23		
8/25/2009	10:00	26.88	78.7	6.28	114	0.05	1112	<0.21	26.1	9.12	31.1	12 in	<0.015	<0.1	2.8	0.182	37		
9/1/2009	9:30						1,888	<0.21					<0.01	0.21	2.24	0.226	44		
9/8/2009	9:15	21.8				0.04			19.6										
9/15/2009	9:48	22				0.03			21.3										
9/22/2009	10:30	19.6				0.02			22										
9/28/2009	10:24	19				0.03			19.7										
10/6/2009	9:55																		
10/14/2009	11:49																		

Results of PALS water quality sampling at the deep spot of Santuit Pond

											0.5 Meters											1.0 Meters			1.5 Meters		
		Water		Wind		Floating	Emerg.		Secchi		Temp	DO	DO	Alk	pH	Chl a	TP	Phaeo	TP	TN	TN	Temp	DO	DO	Temp	DO	DO
Date	Time	Color	Weather	(mph)	Lillies	Algae	Gr/Sedge	Other	Depth (m)	Total (m)	°C	mg/L	% Sat	mg CaCo		ug/L	ug/L	ug/L	uM	uM	mg/L	°C	mg/L	% Sat	°C	mg/L	% Sat
2001		blu/grn	clear	lt brz	< 1%	< 1%	< 1%	< 1%	2.3	2.5	20.6	8.17		10.8	6.48	2.23	17.345	1.04	0.56	46.6	0.6527	20.6	8.15		20.7	8.13	
2002		brn/grn	o'cast	0	10%	< 1%	< 1%	< 1%		2.5	21.5	7.21		11.2	6.7	6.45	23.23	0.67	0.75	37.1	0.5197	21.3	7.38		21.3	7.32	
4/28/2003	14:00	br	clear	strong	< 1%	< 1%	< 1%	< 1%	1.95	2.6	13.3	11.61	111.5									13.2	11.76	112.5	13.2	11.73	112.3
5/16/2003	8:30	br	o'cast	lt br	< 1%	< 1%	< 1%	< 1%	1.9	2.8	16.5	9.3	95									16.6	9.3	95.2	16.6	9.19	94.3
7/3/2003	7:43	grn	pt cldy	lt brz	< 1%	< 1%	< 1%	< 1%	1.1	2.6	25.4	10.63	130									25.4	10.69	130.3	25.4	10.68	129.3
8/28/2003	7:36	grn	clear	lt brz	< 10%	< 1%	< 1%	< 1%	0.75	2.5	24.4	8.11	96.8	1.71	7.03	11.36	55.753	0.36	1.8	69.6	0.9749	24.5	8.03	96.3	24.5	7.95	95.2
10/6/2003	8:45	grn	clear	lt brz	< 1%	< 1%	< 1%	< 1%	0.65	2.4	15.7	9.08	91.5									15.8	9.3	93.6	15.7	9.27	93.5
4/30/2004	9:57	blu/brn	pt cldy	stdy wn	< 1%	< 1%	< 1%	< 1%	1.95	2.6	13.7	10.9	97.8									13.5	10.33	98.9	13.4	10.46	100.3
6/2/2004	14:02	br/grn	clear	lt-stdy	< 1%	< 1%	< 1%	< 1%	1.97	2.55	18.1	8.95	94.7									18.1	8.95	94.7	18	8.9	95.2
6/29/2004	9:47	grn	pt cldy	stdy wn	< 1%	< 1%	< 1%	< 1%	0.65	2.3	23.3	9.8	115.4									23.3	10.11	119	23.3	9.86	115.5
7/17/2004	7:10	br	clear	lt brz	< 1%	< 1%	< 1%	< 1%	0.38	2.5	22.9	7.9	92									23	7.98	94.5	23	8	92
8/17/2004	11:00	br	pt cldy	calm	< 1%	< 1%	< 10%	< 1%	0.75	2.72	23.1	7.81	90.9	26.84	6.73		74.337		2.4	76.82	1.076	22.9	7.04	81.1	22.8	6.73	78.3
9/7/2004	8:33	grn	o'cast	lt brz	< 1%	< 1%	< 1%	< 1%	0.42	2.5	22.4	9.7	110	22	7.88	6.27	96.019	<0.05	3.1	98.25	1.3762	22.4	9.41	107	22.4	9.29	106.2
10/15/2004	7:49	grn	o'cast	lt brz	< 1%	< 1%	< 1%	< 1%	0.32	2.4	14.8	11.8	116.6									14.7	11.83	116.1	14.5	11.52	112.5
5/24/2005	8:50	brn	int rain	1-3	< 1%	< 1%	< 1%	< 1%	0.94	2.58	13.7	9	87									13.7	9.08	87.2	13.6	9.04	87
6/17/2005	9:26	brn	o'cast	1-3	< 1%	< 1%	< 1%	< 1%	0.95	2.75	20.9	8.34	93.6									21	8.37	93.9	21	8.27	92.6
7/7/2005	8:47	brn	fog/haze	4-7	< 1%	< 1%	< 1%	< 1%	0.92	2.7	23.2	7.41	86.8									23.2	7.59	88.4	23.2	7.51	88.1
8/4/2005	7:39	brn	clear	0	< 1%	> 10%	< 1%	< 1%	0.8	2.5	26.1	8.28	102.1									26.1	8.32	102.8	26.1	8.29	102.3
8/30/2005	9:00	brn	int rain	lt brz	< 1%	< 1%	< 1%	< 1%	0.65	2.45	25.1	7.27	87.8	29.06	6.83	31.96	71.24	6.3	2.3	68	0.9525	25.1	7.27	88.3	25.1	7.1	86.2
9/28/2005	9:35	vry grn	clear	1-3	< 1%	> 10%	< 1%	< 1%	0.62	2.5	21	9.8										21	9.3		20.8	8.3	
10/18/2005	13:38	brn/grn	pt cldy	8-12	< 1%	< 1%	< 1%	< 1%	0.75	2.5	14.8	10.76	106.1									14.8	10.8	106.2	14.8	10.87	107.3
5/17/2006	8:35	blu/grn	clear	4-7	< 1%	< 1%	< 1%	< 1%	1.65	2.5	13.8	10.5	101									13.8	10.52	101.6	13.8	10.5	101.6
6/13/2006	8:15	brn	pt cldy	0	<10%	<10%	<1%	<1%	0.6	2.65	19.3	9.79	105.5									19.2	9.97	107.6	19	9.97	107.6
7/12/2006	7:31	brn	o'cast	1-3	< 1%	< 1%	< 1%	< 1%	0.65	2.4	25.4	7.49	91.7									25.4	7.58	92.5	25.4	7.49	91.3
8/16/2006	8:38	grn	clear	0	<10%	<10%	<1%	<1%	0.34	2.3	23.2	8.87	104.5	26.44	8.93	77.47	83.629	3.29	2.7	127.72	1.789	23.2	9.51	111.7	23.2	9.25	108
9/13/2006	9:50	vry grn	pt cldy	0	< 1%	<10%	<1%	<1%	0.55	2.44	18.7	10.94	117.2									18.7	10.92	117.2	18.7	10.74	114.9
10/10/2006	9:50	brn/grn	clear	0	< 1%	<10%	<1%	<1%	0.58	2.3	16.1	10.3	104.6									16.1	10.5	105.9	16.1	10.8	108.1
5/11/2007	8:58	brn	fog/haze	1-3	< 1%	< 1%	< 1%	< 1%	1.35	2.4	19	9.38	101									19	9.51	102.4	19	9.49	102.1
6/7/2007	8:22	brn	clear	1-3	< 1%	< 1%	< 1%	< 1%	0.82	2.57	20.4	8.53	94.3									20.4	8.45	93.6	20.4	8.43	92.8
6/29/2007	8:05	brn	o'cast	4-7	< 1%	< 1%	< 1%	< 1%	0.72	2.65	24.4	7.13	84.8									24.4	7.12	85.3	24.4	6.99	83.8
7/28/2007	7:50	brn	o'cast	1-3	< 1%	< 1%	< 1%	< 1%	0.98	2.25	26.5	7.84	97.1									26.5	7.82	96.6	26.4	7.8	96.3
8/27/2007	7:51	brn/grn	pt cldy	1-3	<10%	< 1%	< 1%	< 1%	0.615	2.7	24.5	9		14.10	8.74	51.94	37.634	11.94	1.2	69.01	0.9666	24.5	9.4		24.5	9.5	
9/25/2007	8:05	brn/grn	clear	4-7	< 1%	< 1%	< 1%	< 1%	0.91	2.21	20.7	8.3	92.3									20.7	8.45	94.1	20.7	8.43	94
5/16/2008	8:30	brn	o'cast	1-3	< 1%	< 1%	< 1%	< 1%	1.03	2.7	14.5	10.51	102.6									14.5	10.53	103.1	14.5	10.51	102.9
6/20/2008	7:45	brn/grn	cldless	1-3	< 1%	< 1%	< 1%	< 1%	0.97	2.27	23.5	7.65	89.4									23.5	7.68	90	23.5	7.63	89.5
7/18/2008	7:12	grn	pt cldy	0	< 1%	< 10%	< 1%	< 10%	0.62	2.3	28.1	9.93	127.4									28.1	9.98	127.6	27.8	8.73	111.6
8/13/2008	7:17	vry grn	pt cldy	0	< 1%	>50%	< 1%	< 10%	0.5	2.5	22.9	6.3	73.1									22.9	6.41	74.5	22.9	6.34	73.5
9/2/2008	7:45	vry grn	pt cldy	1-3	< 1%	>50%	< 1%	< 1%	0.45	2.5	22.6	8.93	103.2	15.20	7.20	58.88	33.792	6.37	1.09	94.03	1.3171	22.6	8.9	102.8	22.6	8.86	103
10/8/2008	8:45	vry grn	pt cldy	1-3	< 1%	>50%	< 1%	< 1%	0.66	2.6	15	10.68	106.9									15	10.78	106.6	15	10.74	105.8
12/29/2008	17:00	brn/clr																									
5/15/2009	8:45	brn	lt rain	8-12	< 1%	< 1%	< 1%	< 1%	0.95	2.3	16.5	9.12	93.2									16.5	9.2	93.7	16.5	9.2	93.6
6/14/2009	8:37	brn/grn	o'cast	1-3	< 1%	< 1%	< 1%	< 1%	1.075	2.55	20.4	7.88	87.2									20.4	7.86	86.8	20.4	7.71	85.3
7/7/2009	8:10	very grn	fog/haze	1-3	< 1%	< 1%	< 1%	< 1%	0.725	2.6	23.5	9.79	113.5									23.5	9.98	117.1	23.4	9.75	113.7
8/7/2009	7:40	very grn	cldless	4-7	< 1%	< 1%	< 1%	< 1%	0.46	2.38	24.9	6.87	82.9									24.9	6.7	80.7	24.9	6.85	82.6
9/1/2009	7:50	very grn	pt cldy	0	< 1%	< 1%	< 1%	< 1%	0.38	2.57	21.6	7.01	79.4									21.6	7	79.4	21.6	6.91	78.2
10/6/2009	8:45	brn/grn	cldless	4-7	< 1%	< 1%	< 1%	< 1%	0.47	2.14	16.8	10.05	103.6									16.9	10.09	104.1	16.9	10.07	103.6

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New Bedford, MA 02744

Results of PALS wa		2.0 Meters			2.5 Meters			3.0 Meters											
		Temp	DO	DO	Temp	DO	DO	Temp	DO	DO	pH	Alk	Chl a	Phaeo	TP	TP	TN	TN	Comments
Date	Time	°C	mg/L	% Sat	°C	mg/L	% Sat	°C	mg/L	% Sat		mg CaCo	ug/L	ug/L	uM	ug/L	uM	mg/L	
2001		20.7	8.16		20.7	7.87					6.54	11.1	2.71	0.5	0.61	18.894	32.9	0.4608	
2002		21.3	7.3		21.3	7.29					6.64	11.2	6.12	1.33	0.69	21.372	40.3	0.5645	
4/28/2003	14:00	13.2	11.79	112.6	13.1	11.89	113.1												1 foot thick bottom weed
5/16/2003	8:30	16.6	9.12	93.4	16.6	9.03	92.2									30.974	14.007		
7/3/2003	7:43	25.2	10.33	125.8	22.5	0.67	9.1												hvy btm weeds,@2.25m23.6C,DO3.67,44.1%
8/28/2003	7:36	24.4	6.95	82.8	24	4.55	53.5				6.78	1.7	11.97	3.18	1.5	46.461	65.5	0.9175	
10/6/2003	8:45	15.7	9.43	94.4															hvy btm weeds, pin head sized algal clumps in pond-wide bloom
4/30/2004	9:57	13.4	10.51	101	13.4	10.5	100.1												
6/2/2004	14:02	18	8.9	94.2	18	8.91	94												hvy btm weeds, pin head sized algal clumps in pond-wide bloom
6/29/2004	9:47	23.2	8.85	105.8	23	6.89	81												hvy btm weeds, pin head sized algal clumps in pond-wide bloom
7/17/2004	7:10	23	8.1	93	22.9	7.9	90												hvy btm weeds, pin head sized algal clumps in pond-wide bloom
8/17/2004	11:00	22.7	6.27	73.2	22.7	5.86	68.3				6.79	27.04			2.5	77.434	81.95	1.1479	hvy btm weeds, pin head sized algal clumps in pond-wide bloom
9/7/2004	8:33	22.4	8.81	101	22.3	7.58	85.5				7.22	22.4	16.03	<0.05	3.1	96.019	98.25	1.3762	hvy btm weeds, pin head sized algal clumps in pond-wide bloom
10/15/2004	7:49	14.5	11.62	113.1															hvy btm weeds, pin head sized algal clumps in pond-wide bloom
5/24/2005	8:50	13.6	9.1	86	13.6	9	86												
6/17/2005	9:26	20.9	7.79	87.4	20.8	6.82	76	20.6	5.65	63.5									
7/7/2005	8:47	23.2	7.49	87.7	23.2	7.49	87.6	23.2	7.41	87									
8/4/2005	7:39	25.4	3.56	44	24.8	1.43	18.3												
8/30/2005	9:00	25.1	7.05	85.7							6.92	28.25	30.85	7.45	2.3	71.24	68.29	0.9565	
9/28/2005	9:35	20.5	8.2		20.5	6.7													
10/18/2005	13:38	14.8	10.83	107.1	14.8	10.82	106.7												
5/17/2006	8:35	13.8	10.5	101.5	13.8	10.49	101.2												
6/13/2006	8:15	18.7	9.95	105.5	18.4	9.78	104.1												
7/12/2006	7:31	25.4	7.4	90.3	25.3	7.19	87												
8/16/2006	8:38	23.1	9	106.1	23.1	8.94	104.7				8.88	26.23	73.49	<0.05	2.8	86.727	114.85	1.6087	No anchor weed, water like pea soup, height 0.88
9/13/2006	9:50	18.6	10.53	113.1	18.6	10.34	110												anchor muck
10/10/2006	9:50	16.1	10.1	102.8	15.9	9.6	97.1												
5/11/2007	8:58	18.9	9.47	102	18.9	9.4	101.1												anchor muck
6/7/2007	8:22	20.4	8.36	92.6	20.3	8.23	91.5												anchor muck& decayed vegetation, pond gage @1.1 dam boards higher than pond level
6/29/2007	8:05	24.4	6.85	81.5	24.3	6.14	73.5												
7/28/2007	7:50	26.2	7.62	94	25.2	4.64	56												elodea floating @ ramp height 0.99 fishway water only
8/27/2007	7:51	23.9	7.8		23	3.4					7.00	14.20	75.81	17.47	1.9	57.337	75.36	1.0556	
9/25/2007	8:05	20.6	8.34	92.9															
5/16/2008	8:30	14.5	10.58	103.6	14.4	10.46	102.5												anchor clean
6/20/2008	7:45	23.4	7.29	85.1															anchor clean
7/18/2008	7:12	26.8	5.21	65.4															anchor clean,2 adult 7 young swans defecate all over ramp, water thru ladder only
8/13/2008	7:17	22.9	6.31	73.5	22.8	4.72	67												anchor clean,2 adult 7 young swans defecate all over ramp, water thru ladder only, height 0.95 feet
9/2/2008	7:45	22.5	8.53	98.5	22.4	8.33	97.2				6.98	14.80	50.88	7.79	1.94	60.057	88.10	1.234	anchor clean,2 young swans , water thru ladder only, height 0.78 feet, 3 1/2 inch dam bd exposed
10/8/2008	8:45	14.9	10.6	105.1	14.9	10.47	102.7												anchor clean,11 swans , water thru ladder only, height 0.94 feet, 1/2 inch dam bd exposed
12/29/2008	17:00															91		1.1	ice on pond
5/15/2009	8:45	16.5	9.18	93.7															anchor little mud and few dead weed strands,2 gulls, 8 loons or brant
6/14/2009	8:37	20	6.53	70.4	19.7	4.96	54.3												
7/7/2009	8:10	23.4	9.37	110.3	22.4	2.6	33.8												
8/7/2009	7:40	24.9	6.73	81.4	24.9	6.68	80.5												
9/1/2009	7:50	21.5	6.85	77.4	21.5	6.72	76.2												
10/6/2009	8:45	16.8	10.03	103.4															

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Results from Mashpee Wampanoag Tribe/Town of Mashpee Collaborative Water Quality Monitoring Program

Date mo/day/yr	Hrs. EST	Location Santuit Pond	Total Depth cm	Secchi Depth cm	Sample Depth cm	Depth ft	Temp. °C	Specific Conductivity uS	DO %	DO mg/L	pH	Chl ug/L	TKN mg/L	TP mg/L	PO4 mg/L	NO3 mg/L	PAR 1 spherical umol/m2/s	PAR 2 flat sensor umol/m2/s	Pond Level gauge feet	Algae - most abundant
10/16/08	1646	N 41o39.306'	295	85	236	7.7	16.6	0.11	115.3	11.23	8.61	7.3								Microcystis (cyanophyte)
		W 70o27.562'				0.0														
11/21/08	1436	deep area	280	100	10	0.3	5	0.109	103.1	13.16										Fragilaria, Asterionella (diatoms)
					260	8.5	5.06	0.109	103.1	13.14										Fragilaria, Asterionella
12/29/08	1540	deep area	280	100	10	0.3	5.46	0.102	104.1	13.14			1.1	0.091						Asterionella, Fragilaria
					260	8.5	5.5	0.102	103.5	13.04										
01/14/09	1708	E. of Landing	216		50	1.6	4.4	0.108	110.4	14.32										
					200	6.6	4.91	0.116	88.7	11.23										
02/10/09	1745	Pond at dam			10	0.3	5						1.5	0.04					0.18	Fragilaria, Asterionella
02/11/09	1645	Pond at dam				0.0													0.22	
02/26/09	1415	Pond at dam				0.0													0.62	
02/27/09	1730	Pond at dam			10	0.3													0.65	Asterionella, Fragilaria
03/06/09	1450	Pond at dam				0.0	5												0.74	Asterionella, Fragilaria
03/12/09	1605	deep area	276	120	10	0.3	7.22	0.103	117	14.12										Asterionella, Fragilaria
	1608				50	1.6	7.23	0.103	116.4	14.05										
	1609				100	3.3	7.15	0.103	116.1	14.04										
	1611				200	6.6	6.99	0.103	115.2	13.98										
	1613				260	8.5	6.85	0.103	113.7	13.86										Asterionella, Fragilaria
03/13/09	1600	deep area			30	1.0							1.8	0.049						
						0.0														
03/18/09	1405	deep area	275		air												2875	1127		
					10	0.3											999	723		
					100	3.3											428	230		
					200	6.6											163	98		
					250	8.2											99	61		
	1420				30	1.0	8.28	0.104	118.5	13.93										
	1422				100	3.3	8.29	0.104	118	13.87										
	1224				200	6.6	8.27	0.104	117.7	13.85										
	1426				260	8.5	8.28	0.104	117.5	13.82										
03/27/09	1700	N 41o39.302'		150		0.0														
		W 70o27.560'				0.0														
04/01/09	1100	N 41o39.210'	242	170	30	1.0	8.44	0.105	108.4	12.7			2.2	0.057						
	1102	W 70o27.482'			50	1.6	8.44	0.105	108.2	12.68										
	1103				100	3.3	8.44	0.105	108.2	12.68										
	1104				200	6.6	8.43	0.105	107.7	12.62										
	1107				220	7.2	8.43	0.105	107.5	12.6										
	1217				219	7.2	8.3	0.107	105.8	12.43	7.45	9.8								
	1115				air												845	361		
					10	0.3											312	235		
					100	3.3											156	104		
					200	6.6											80	51		
					230	7.5											58	36		
05/11/09	1724	Pond at dam			10	0.3	16.69	0.105	114.8	11.16									0.83	Asterionella, Fragilaria
	1725				30	1.0	16.66	0.105	114.6	11.15										
5/15/2009		Pond at dam				0.0													0.66	
05/19/09	1530	N 41o39.212'	280	120	10	0.3							1.5	0.14						colonial flagellates, Fragilaria, Asterionella
		W 70o27.479'				0.0														
05/20/09	1100	N 41o39.210'	277		10	0.3														Microcystis
	1116	W 70o27.482'			17	0.6	17.73	0.109	118.2	11.25	8.54	14.2								
	1146				216	7.1	16.93	0.109	110	10.64	8.52	17.3								
6/14/2009		Pond at dam				0.0													0.78	
06/29/09	1900	N 41o39.260'	263	100	30	1.0							2.2	0.08	0.022					
		W 70o27.482'			250	8.2							1.7	0.079	0.02					
	1903				10	0.3	22.43	0.107	134.1	11.62										Microcystis, Anabaena
	1906				50	1.6	22.44	0.107	134.1	11.62										
	1910				100	3.3	22.26	0.105	124.9	10.87										
	1912				150	4.9	21.73	0.105	116.1	10.2										
	1915				200	6.6	20.48	0.107	78.2	7.04										
	1918				250	8.2	19.46	0.115	22	2.02										Microcystis, Fragilaria
	1923				260	8.5	19.38	0.117	16.4	1.51										
7/7/2009		Pond at dam				0.0													0.75	

Results from Mashpee Wampan

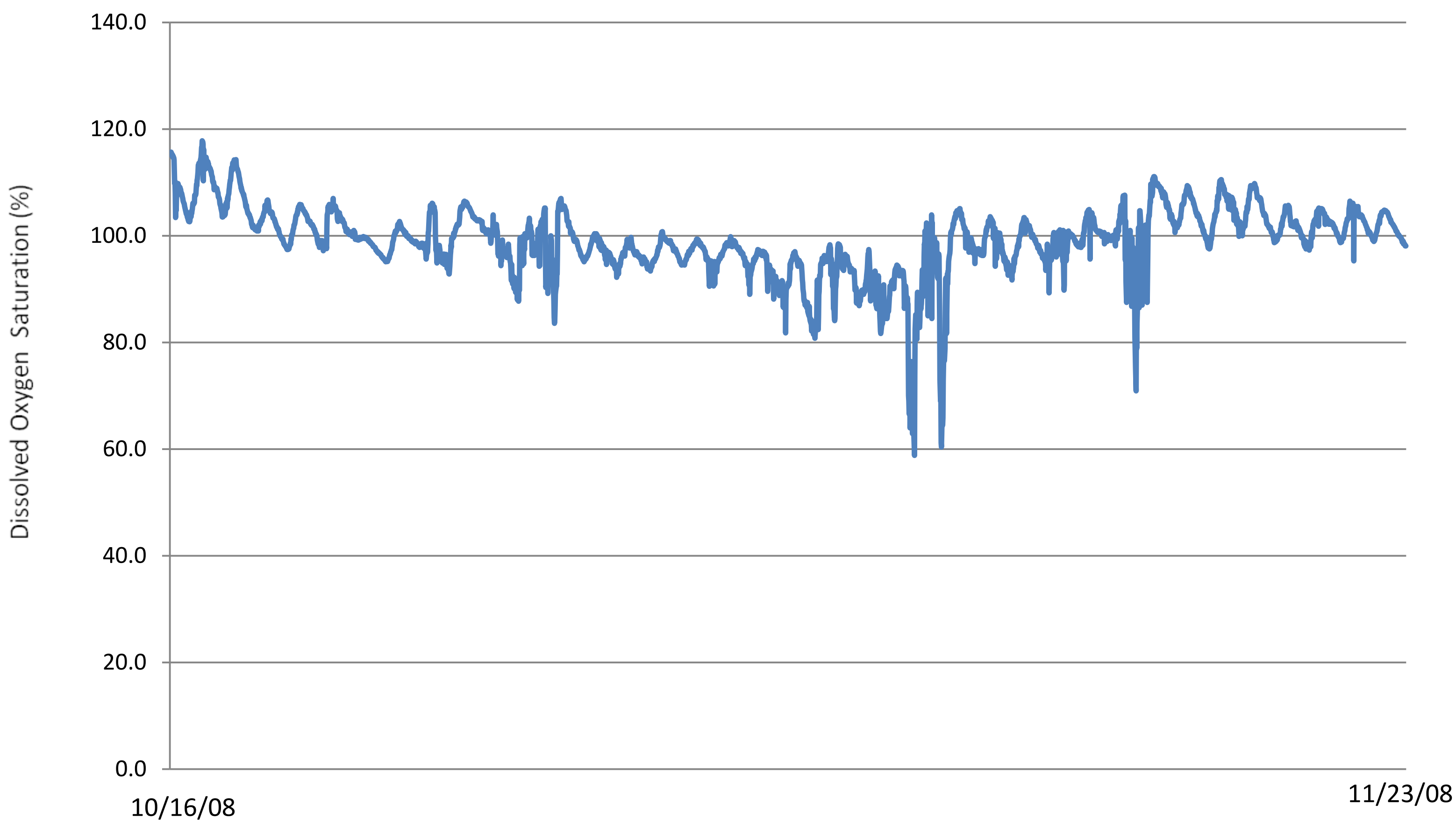
Date mo/day/yr	Hrs. EST	Location Santuit Pond	Weather	Meter type	Notes (Data from Mashpee Town/Wampanoag Tribe WQ Monitoring except where noted otherwise) GPS = Garmin GPSmap 76 CS
					Total depths measured with Secchi disk on bottom except where noted otherwise.
10/16/08	1646	N 41o39.306'	64F, 28.92"BPSL, SSW10, Mostly Cloudy	YSI 6600 V2	YSI 6600 V2 sonde mooring site (deep area) first deployment, Optical probes at 234 cm depth
		W 70o27.562'			(YSI 6600 V2 used for mooring (unattended) data, other meters used for handheld profiles)
11/21/08	1436	deep area	28F, 30.05"BPSL, NNW6, Mostly Cloudy	YSI 600 R	No Microcystis or Anabaena 1/100 ml sample
				YSI 600 R	No Microcystis or Anabaena 1/100 ml sample
12/29/08	1540	deep area	37F, 29.80"BPSL, W13, Overcast	YSI 600 R	
				YSI 600 R	
01/14/09	1708	E. of Landing	18F, 30.12"BPSL, NW5, Mostly Cloudy	YSI 600 R	Cut hole in ice to take readings
				YSI 600 R	
02/10/09	1745	Pond at dam	39F, 30.15"BPSL, SE9, Overcast	Lab thermometer	N 41o38.796'/W 70o27.222' Stop lowering pond level (add boards), very low flow out of pond
02/11/09	1645	Pond at dam			
02/26/09	1415	Pond at dam			Pond mostly iced over
02/27/09	1730	Pond at dam			No ice
03/06/09	1450	Pond at dam		Lab thermometer	
03/12/09	1605	deep area	41F, 30.32"BPSL, W10, Scattered Clouds	YSI 600 R	
	1608			YSI 600 R	
	1609			YSI 600 R	
	1611			YSI 600 R	
	1613			YSI 600 R	
03/13/09	1600	deep area			
03/18/09	1405	deep area	52F, 30.11"BPSL, SSW17, Overcast	Licor LI-1000	Photosynthetically Active Radiance (Sunlight) Sensor 1=flat spherical, Sensor 2=flat surface
				Licor LI-1000	
				Licor LI-1000	
				Licor LI-1000	
				Licor LI-1000	
	1420			YSI 600 R	
	1422			YSI 600 R	
	1224			YSI 600 R	
	1426			YSI 600 R	
03/27/09	1700	N 41o39.302'			
		W 70o27.560'			
04/01/09	1100	N 41o39.210'	41F, 30.28"BPSL, S8, Overcast	YSI 600 R	Sonde mooring - new site (deep area), deployed, Optical probes at 219 cm depth
	1102	W 70o27.482'		YSI 600 R	
	1103			YSI 600 R	
	1104			YSI 600 R	
	1107			YSI 600 R	
	1217			YSI 6600 V2	
	1115			Licor LI-1000	
				Licor LI-1000	
				Licor LI-1000	
				Licor LI-1000	
				Licor LI-1000	
05/11/09	1724	Pond at dam	54F, 30.02"BPSL, WSW11, Mosly Cloudy	YSI 600 R	
	1725			YSI 600 R	
5/15/2009		Pond at dam			Data from Mashpee Environmental Coalition (MEC) Ed Baker
05/19/09	1530	N 41o39.212'			
		W 70o27.479'			
05/20/09	1100	N 41o39.210'	73F, 30.35"BPSL, W9, Mostly Cloudy		Sonde deployed, optical probes at 216 cm depth, Total depth calculated from sonde data
	1116	W 70o27.482'		YSI 6600 V2	Microcystis surface film at landing
	1146			YSI 6600 V2	
6/14/2009		Pond at dam			Data from MEC
06/29/09	1900	N 41o39.260'	70F, 29.49"BPSL, S6, Partly Cloudy		
		W 70o27.482'			
	1903			YSI 600 R	
	1906			YSI 600 R	
	1910			YSI 600 R	
	1912			YSI 600 R	
	1915			YSI 600 R	
	1918			YSI 600 R	
	1923			YSI 600 R	
7/7/2009		Pond at dam			Data from MEC

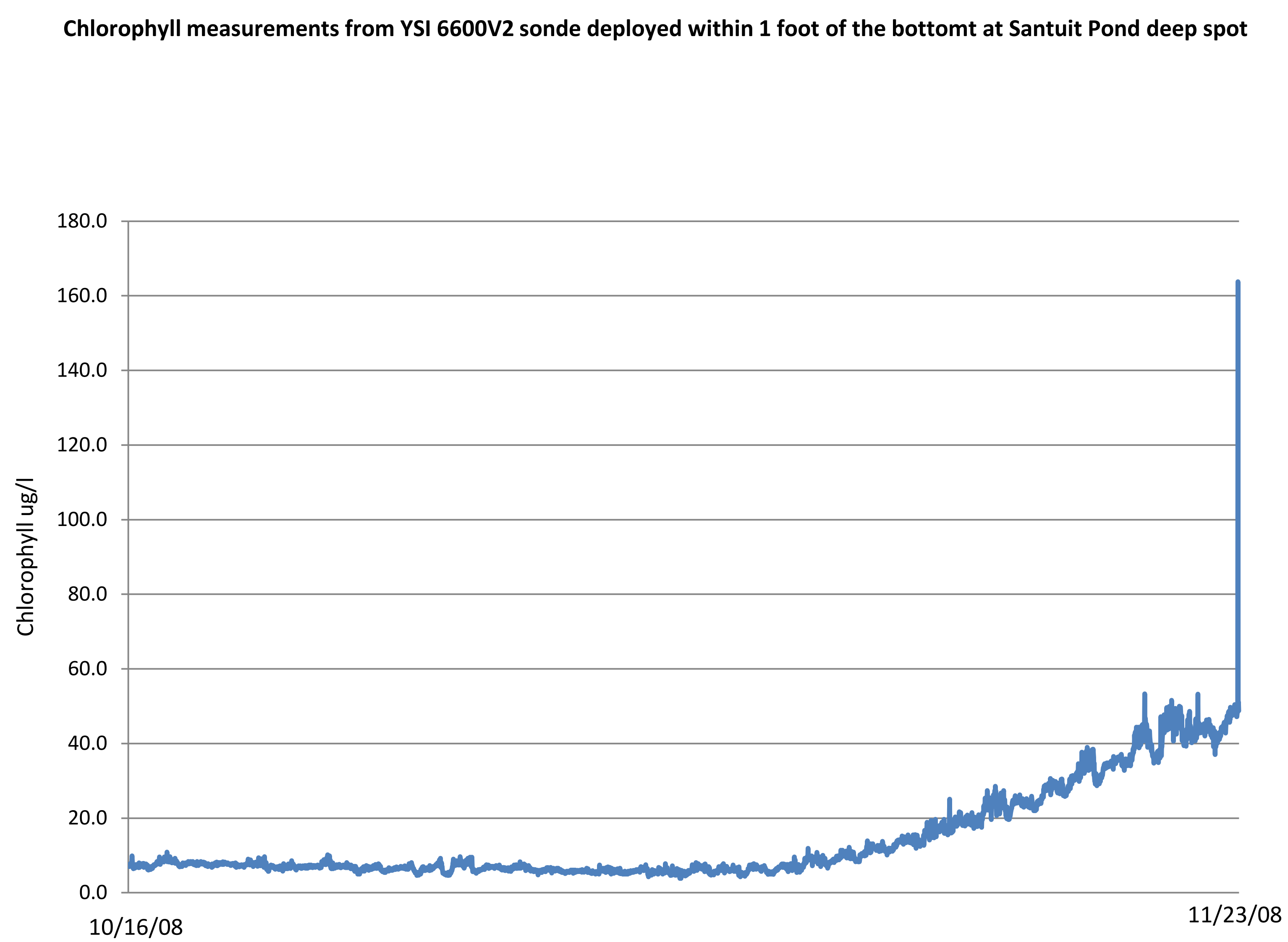
Date	Hrs.	Location	Total Depth	Secchi Depth	Sample Depth	Depth	Temp.	Specific Conductivity	DO	DO	pH	Chl	TKN	TP	PO4	NO3	PAR 1	PAR 2	Pond Level	Algae - most abundant
mo/day/yr	EST	Santuit Pond	cm	cm	cm	ft	°C	uS	%	mg/L		ug/L	mg/L	mg/L	mg/L	mg/L	spherical	flat sensor	gauge	
07/31/09	1138	N 41o39.260'	260	60	20	0.7	26.5		112.3											
	1131	W 70o27.482'			50	1.6	26.3		109.3											
	1133				100	3.3	26.2		105											
	1135				150	4.9	26.1		95.6											
	1137				200	6.6	25.5		46.6											
	1142				240	7.9	24.2		10.2											
08/05/09	1700	N 41o39.216'	260	60	20	0.7	27.1		116.6											Microcystis
		W 70o27.477'			50	1.6	27.1		115.1											
					100	3.3	26.9		107.2											
					150	4.9	26		99.6											
					200	6.6	24.9		9.7											
					220	7.2	24.8		9.4											Microcystis
	1746				27	0.9	27.03	0.108	117.6	9.37	8.83	8.3								
	1801				262	8.6	25.21	0.114	10.1	0.83	6.48	8.1								
8/7/2009		Pond at dam				0.0													0.66	
9/1/2009		Pond at dam				0.0													0.78	
10/6/2009		Pond at dam				0.0													0.43	
10/08/09	1525	deep area	255	55	20	0.7	16.53	0.1	111	10.88							58	36		
					50	1.6	16.33	0.1	110.5	10.83										
					100	3.3	16.32	0.1	110.1	10.79										
					200	6.6	16.32	0.1	109.3	10.71										
					250	8.2	16.32	0.1	108.9	10.68										
09/09	1608 EST	Pond at dam			20	0.7	16	0.099	105.7	10.44									0.3	
22/09	1530 EST	N 41o39.153'	280	80	20	0.7	12.28	0.099	108.3	11.6										
	1516	W 70o27.370'			216	7.1	11.91	0.1	104	11.22	7.29	3.9								
02/02/10	1630	Pond at dam			20	0.7	4												1.16	Dinobryon, Asterionella

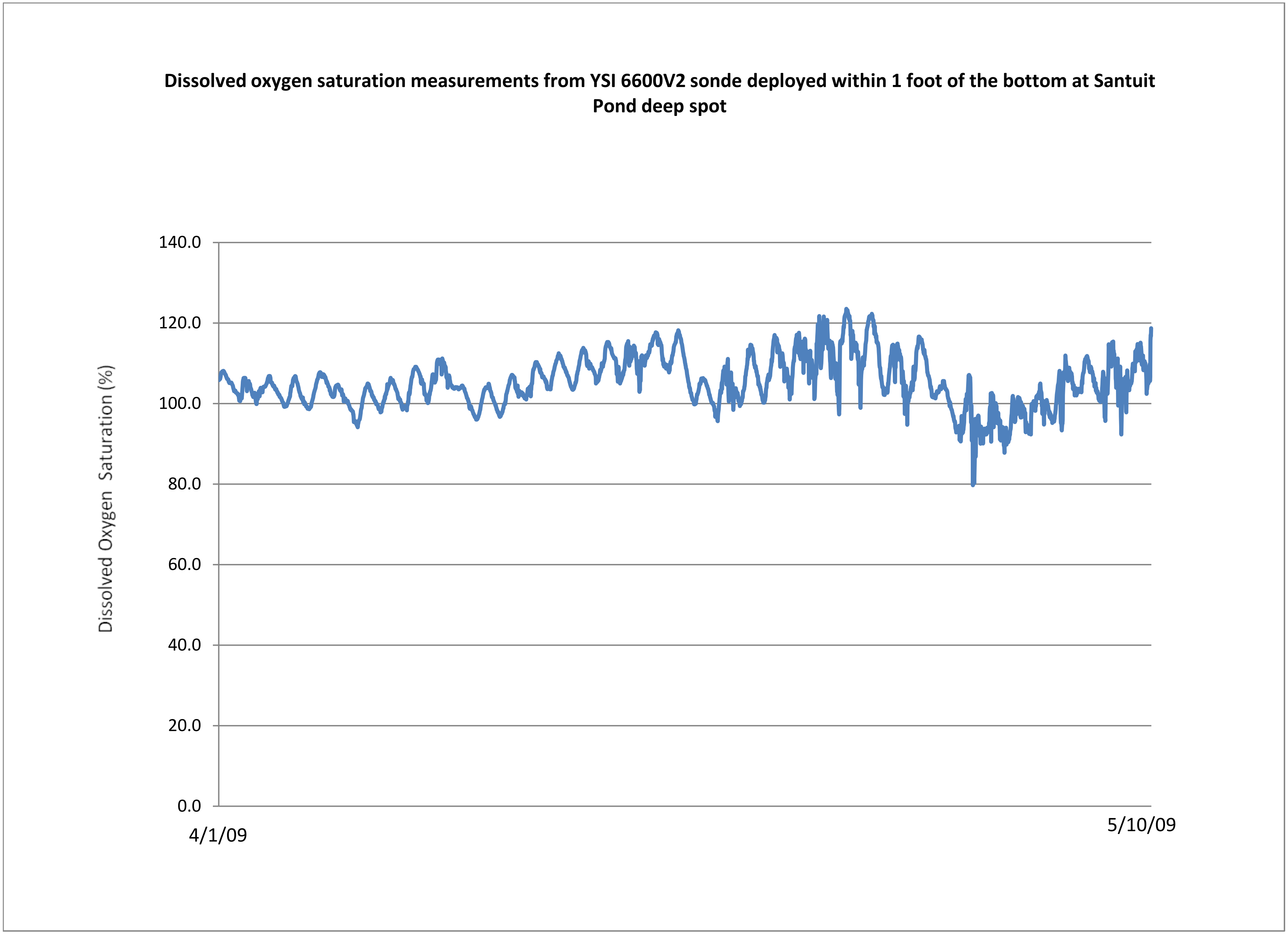
Date	Hrs.	Location	Weather	Meter type	Notes (Data from Mashpee Town/Wampanoag Tribe WQ Monitoring except where noted otherwise)
mo/day/yr	EST	Santuit Pond			GPS = Garmin GPSmap 76 CS
07/31/09	1138	N 41o39.260'	75F, 29.87"BPSL, S14-24, Cloudy	YSI 55	
	1131	W 70o27.482'		YSI 55	
	1133			YSI 55	
	1135			YSI 55	
	1137			YSI 55	
	1142			YSI 55	
08/05/09	1700	N 41o39.216'	77F, 29.84"PBSL, SSW12, Mostly Cloudy	YSI 55	Sonde mooring - new site (deep area), deployed, optical probes at bottom in water
		W 70o27.477'		YSI 55	(sonde mooring anchor partially sunk in bottom mud)
				YSI 55	
				YSI 55	
				YSI 55	
				YSI 55	
	1746			YSI 6600 V2	
	1801			YSI 6600 V2	
8/7/2009		Pond at dam			Data from MEC
9/1/2009		Pond at dam			Data from MEC
10/6/2009		Pond at dam			Data from MEC (calculated)
10/08/09	1525	deep area		YSI 600 R	Pond level low
				YSI 600 R	
				YSI 600 R	
				YSI 600 R	
				YSI 600 R	
09/09	1608 EST	Pond at dam	45F, 30.03"BPSL, Calm, Mostly Cloudy	YSI 600 R	Pond dam boards missing - vandalism. Install new boards
22/09	1530 EST	N 41o39.153'	52F, 30.07"BPSL, SSW4, Overcast	YSI 600 R	Sonde mooring - new site (deep area), deployed, optical probes at 216 cm depth
	1516	W 70o27.370'		YSI 6600 V2	
02/02/10	1630	Pond at dam	Cloudy		Pond iced over

Dissolved oxygen and chlorophyll data from sonde deployments at Santuit Pond are presented graphically in Appendix B. Complete datasets from the continuous monitoring effort are included as an electronic attachment to the final report.

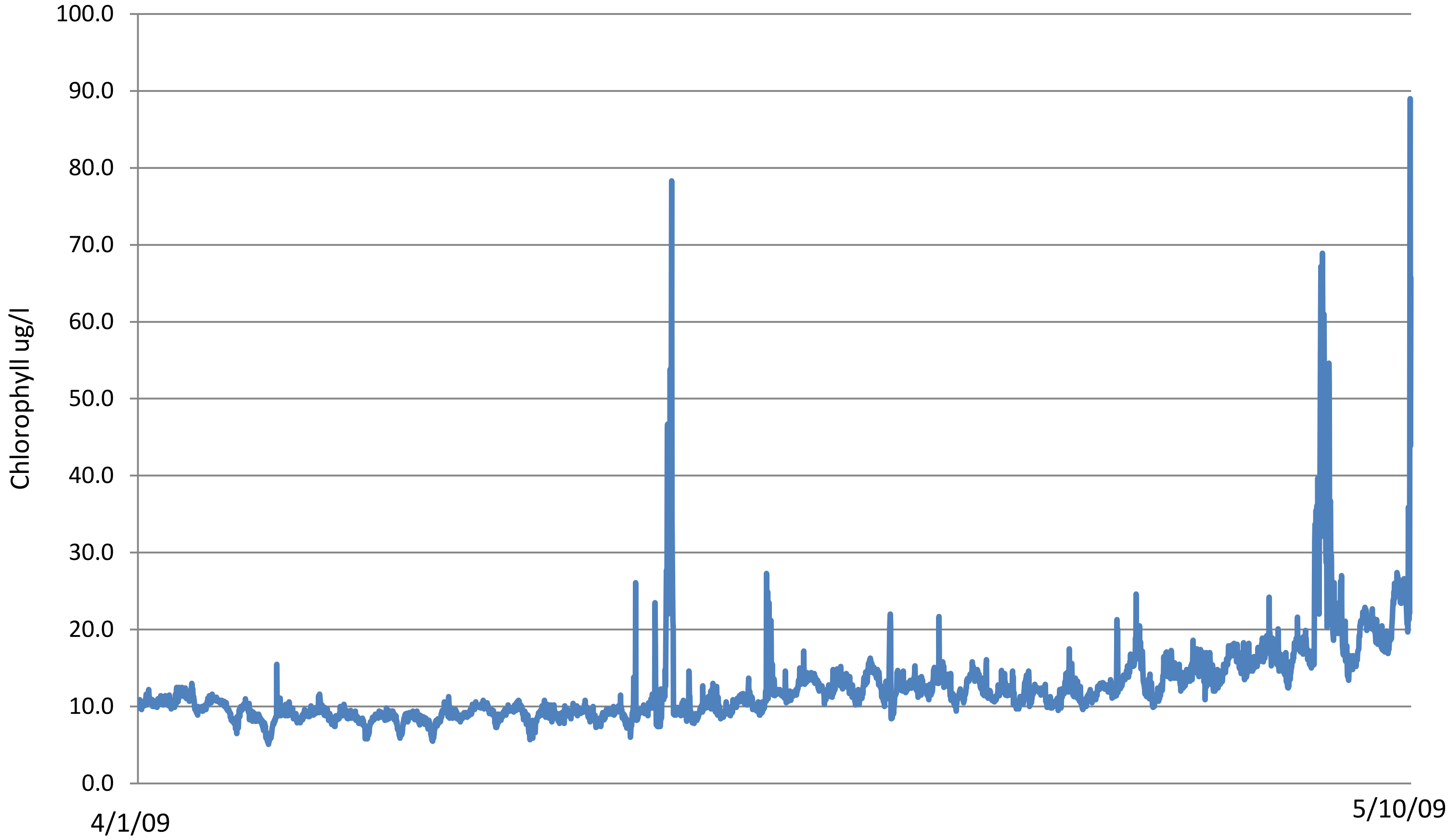
Dissolved oxygen saturation measurements from YSI 6600V2 sonde deployed within 1 foot of the bottom at Santuit Pond deep spot

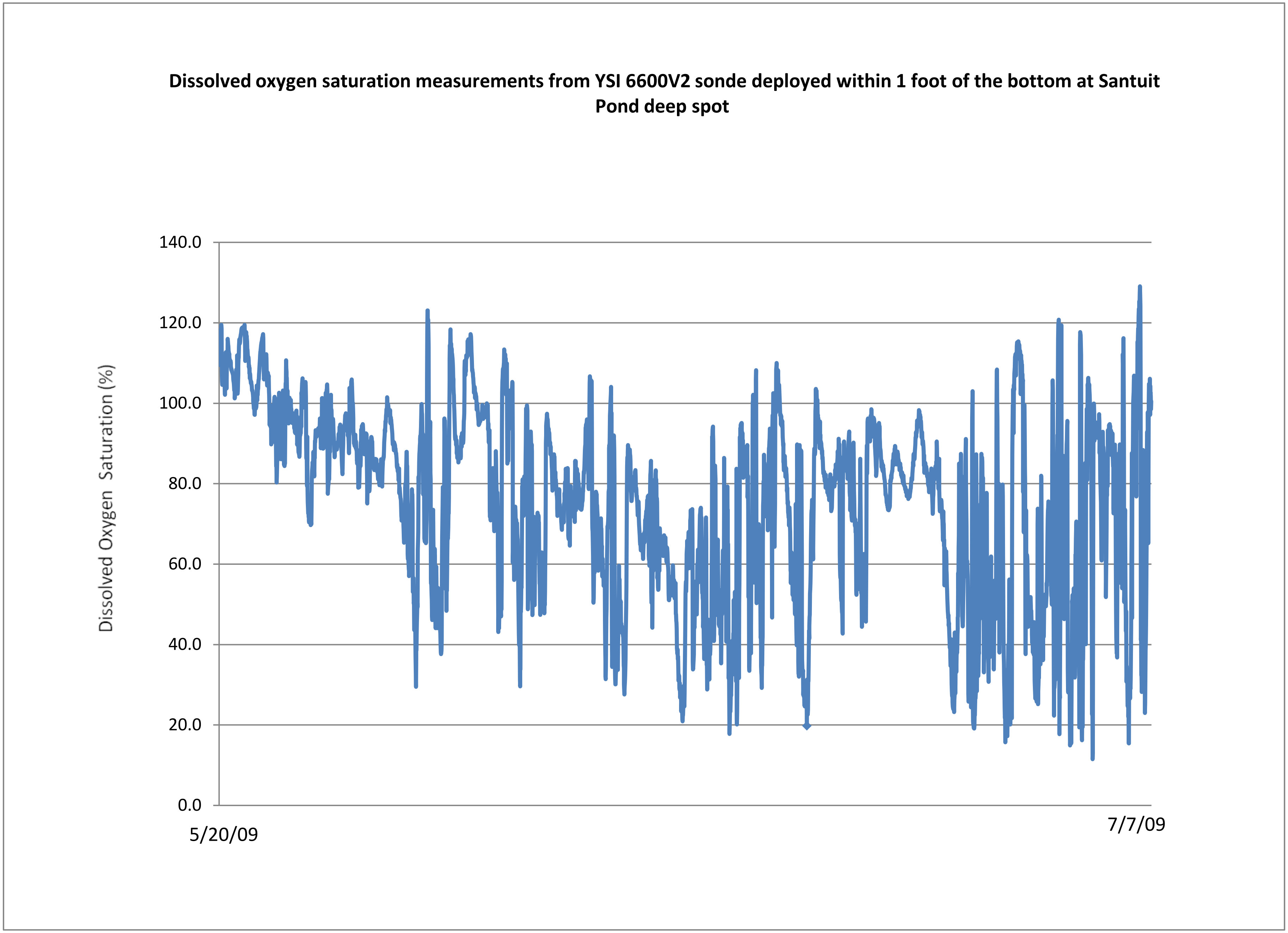



Chlorophyll measurements from YSI 6600V2 sonde deployed within 1 foot of the bottomt at Santuit Pond deep spot
Chlorophyll ug/l
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
10/16/08
11/23/08

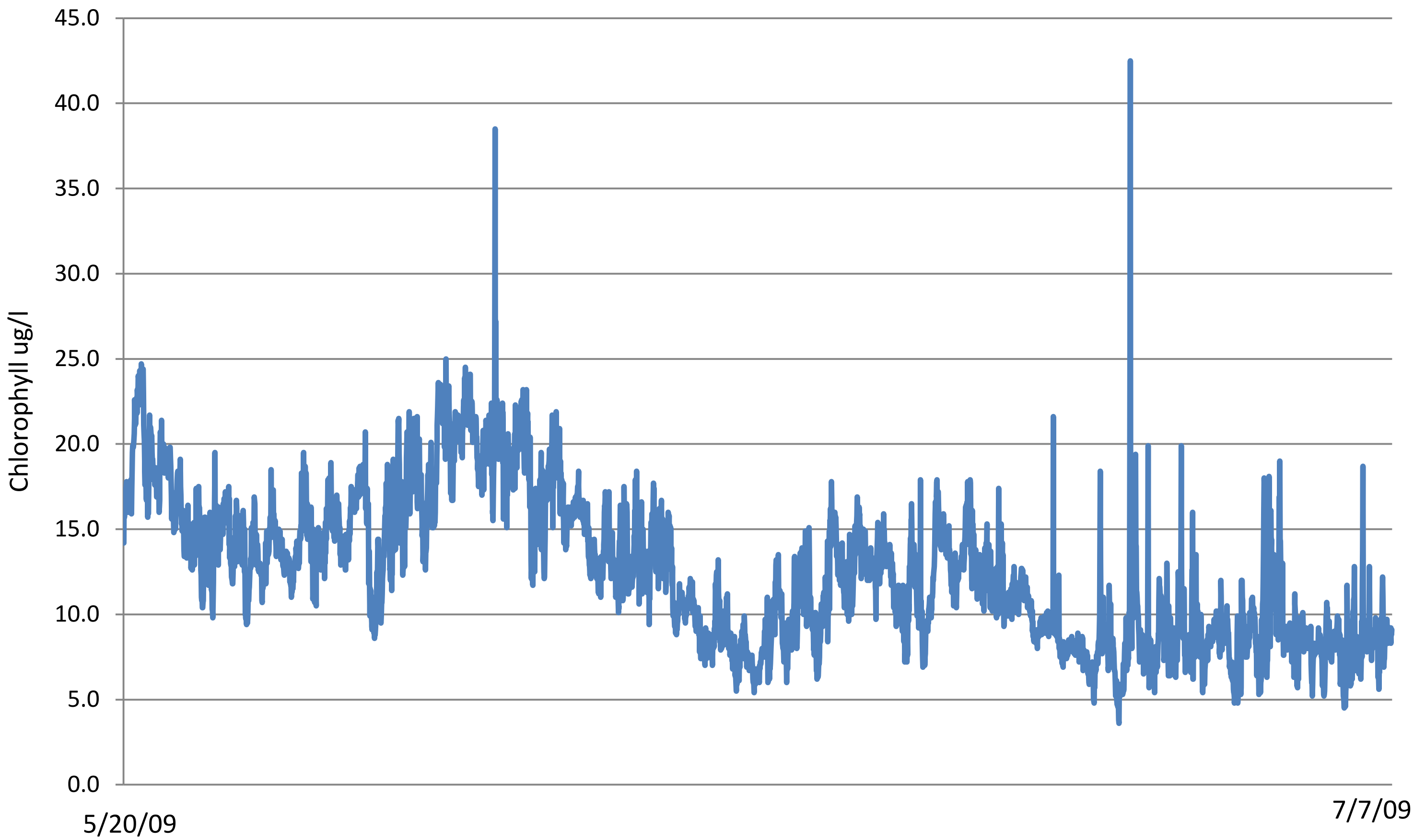

Dissolved oxygen saturation measurements from YSI 6600V2 sonde deployed within 1 foot of the bottom at Santuit Pond deep spot
Dissolved Oxygen Saturation (%)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
4/1/09
5/10/09

Chlorophyll measurements from YSI 6600V2 sonde deployed within 1 foot of the bottom at Santuit Pond deep spot

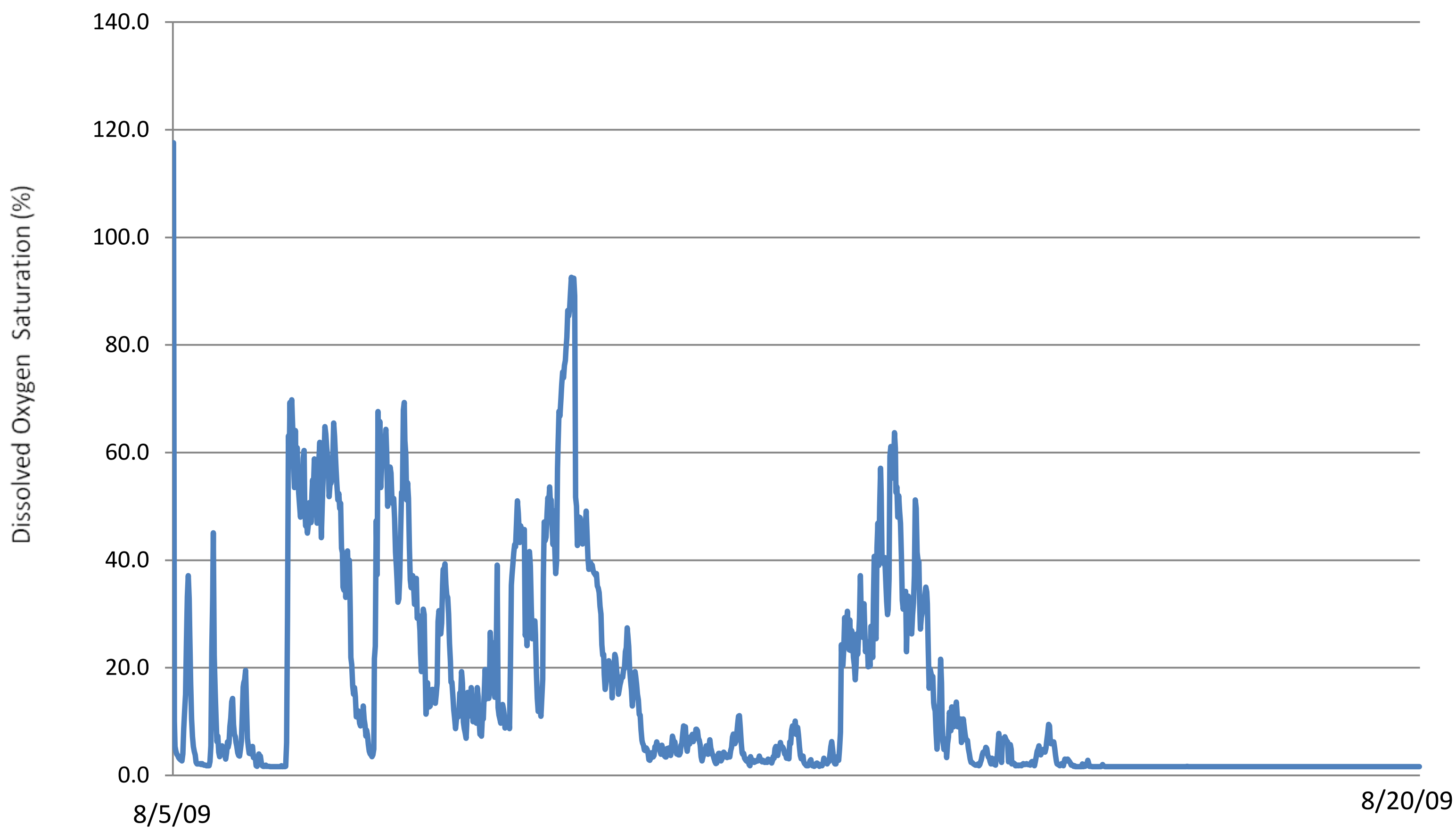


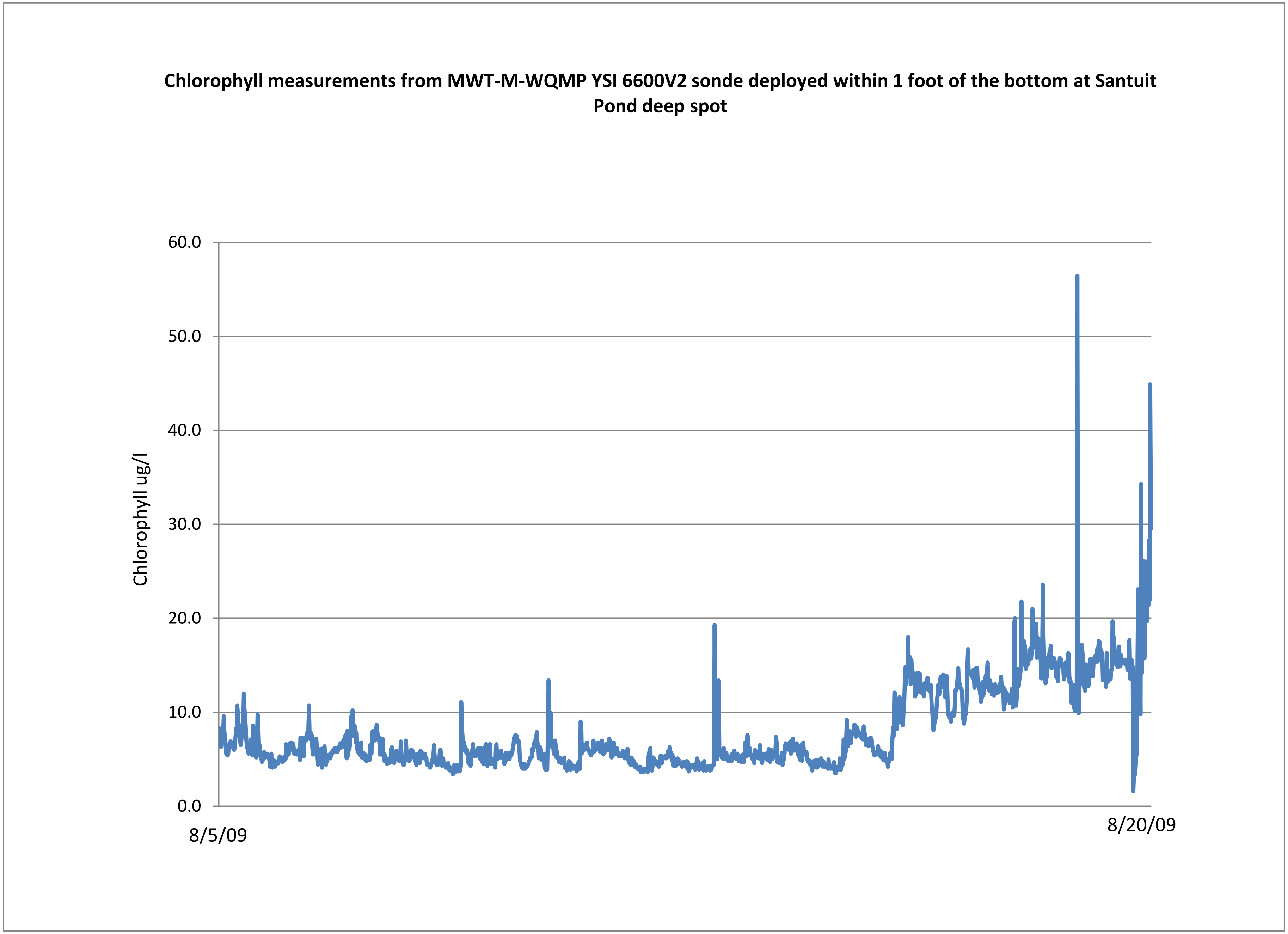

Dissolved oxygen saturation measurements from YSI 6600V2 sonde deployed within 1 foot of the bottom at Santuit Pond deep spot
Dissolved Oxygen Saturation (%)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
5/20/09
7/7/09

Chlorophyll measurements from YSI 6600V2 sonde deployed within 1 foot of the bottom at Santuit Pond deep spot

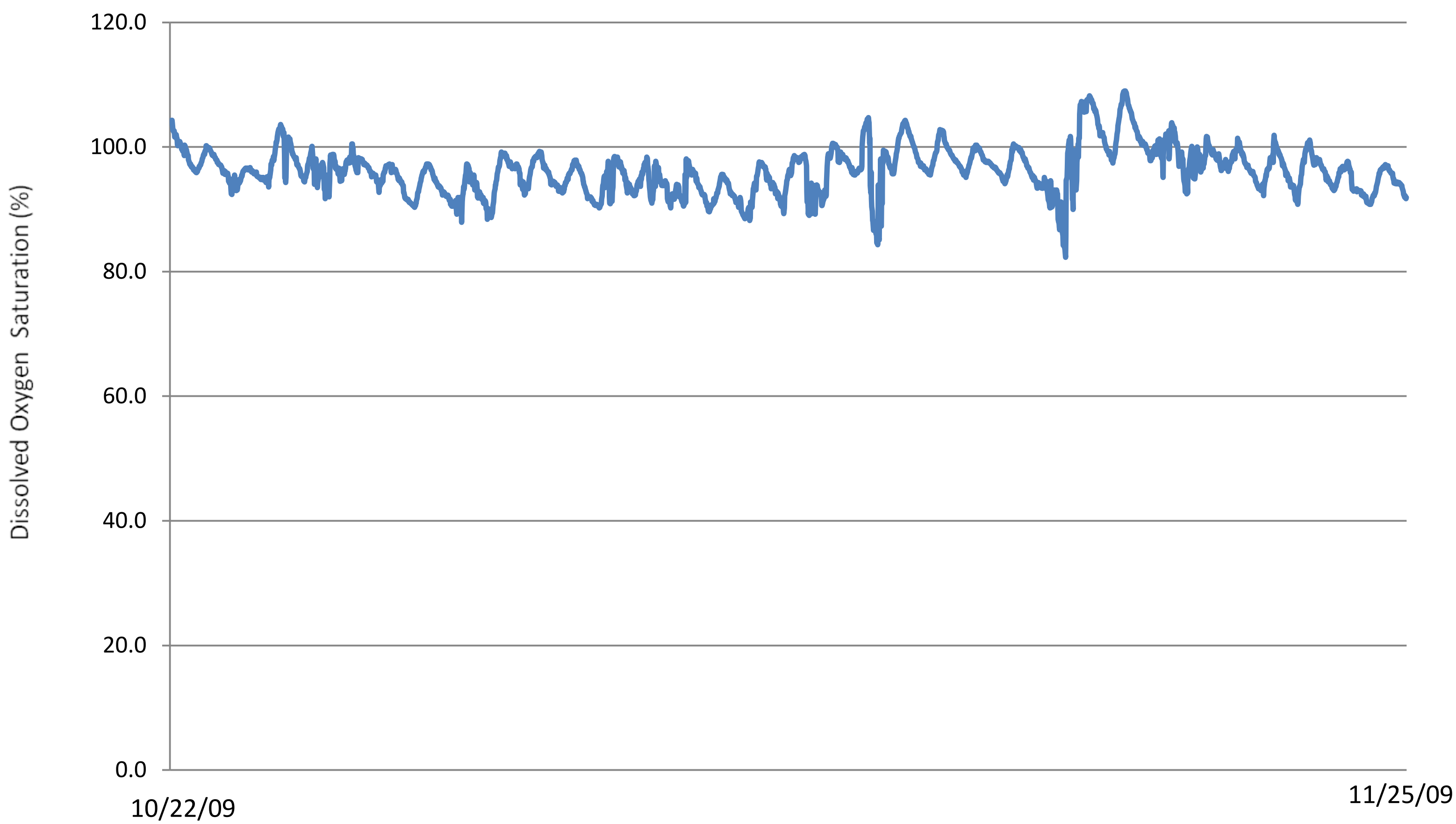


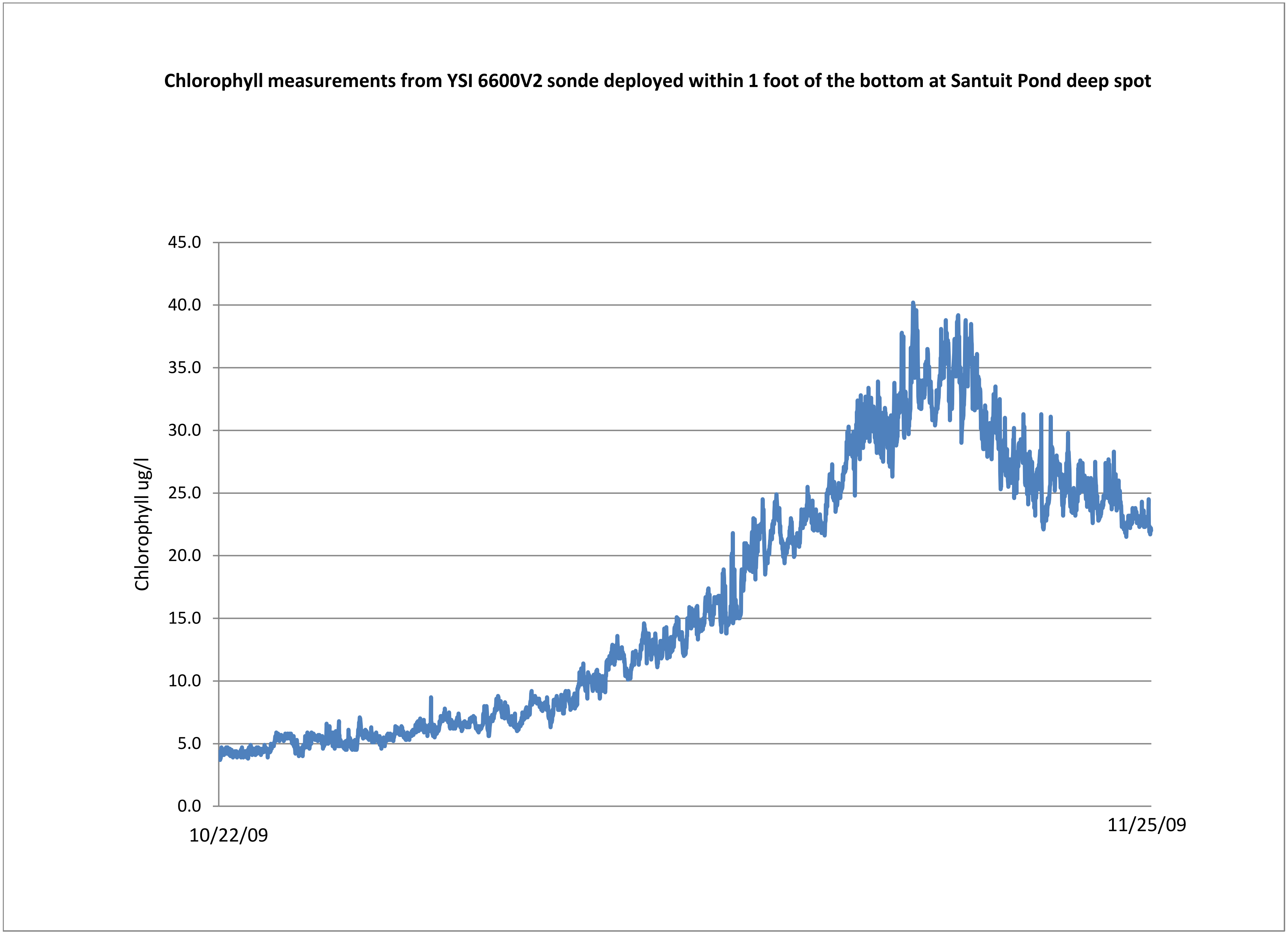
Dissolved oxygen saturation measurements from YSI 6600V2 sonde deployed within 1 foot of the bottom at Santuit Pond deep spot




Chlorophyll measurements from MWT-M-WQMP YSI 6600V2 sonde deployed within 1 foot of the bottom at Santuit Pond deep spot
Chlorophyll ug/l
60.0
50.0
40.0
30.0
20.0
10.0
0.0
8/5/09
8/20/09

Dissolved oxygen saturation measurements from YSI 6600V2 sonde deployed within 1 foot of the bottom at Santuit Pond deep spot




Chlorophyll measurements from YSI 6600V2 sonde deployed within 1 foot of the bottom at Santuit Pond deep spot
Chlorophyll ug/l
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
10/22/09
11/25/09

Appendix C

Response to Comments

Comment Type	Page	Paragraph	Comment	Response
Specific	ES-1	4	Change toxin producing to potentially toxic	Text was changed.
Specific	1-1	3	Change toxin producing to potentially toxic	Text was changed.
Specific	5-2	1	Change “when respiration exceeds photosynthesis” to “when respiration continues after photosynthesis ceases”	Text was changed.
Specific	5-6	6	Change TKN concentrations from ug/L to mg/L	Text was changed.
Specific	5-7	1	Change TKN concentrations from ug/L to mg/L	Text was changed.
Specific	5-12 and 5-13	Table 5-5	Change title from Results of Santuit Pond wet weather sampling to Results of stormwater runoff wet weather sampling	Text was changed.
Specific	5-19	3	Change “The weekly MDPH toxicity testing indicates that microcystin levels remained below 1ppb at the Town Landing over the entire summer.” To “The weekly MDPH toxicity testing did not detect microcystin at or above the detection limit of 1 ppb at the Town Landing over the entire summer.”	Text was changed.
Specific	5-19	5	Change “Some of the cyanobacteria species present are toxin producers even though MDPH detected extremely low levels of microcystins, a hepatotoxin (liver toxin).” To “Some of the cyanobacteria species present are capable of producing toxin even though MDPH did not detect microcystins, a hepatotoxin (liver toxin).”	Text was changed
Specific	10 - 19		Table caption change “sonde deployed at 7.1 ft” to “sonde deployed within 1 foot of the bottom”	Text was changed
Specific	8-34	2	"Also, nutrient inactivation treatments do not prevent development of anoxia and will not directly result in a significant amount of habitat for fish and other aquatic organisms." Are words missing from this sentence? How would the treatment affect habitat? Would the aluminum directly or indirectly degrade habitat, or create anoxia by reducing photosynthesis while benthic respiration continues? Would this increase the risk of low pH and aluminum toxicity?	The sentence has been replaced with the following: " Also, nutrient inactivation treatments do not, of themselves, prevent the development of anoxia although reduction in internal loading to the lake should result in a reduction in algal biomass and associated oxygen demand. Large changes in the amount of available habitat are not expected in Santuit Pond but there may be modest gains in habitat in the deep sections of the lake if the severity of anoxia is reduced. Toxicity concerns are restricted to the application period and can be controlled for as described above. Once reacted (in a matter of hours),

Comment Type	Page	Paragraph	Comment	Response
				the aluminum settles to the bottom in the form of aluminum hydroxide which is essentially inert with no or low toxicity and a high affinity for phosphorus (Cooke et al. 2005). There would be no long term direct effects on pH expected related to an alum treatment. An indirect effect could be observed if the reduction in internal phosphorus loading results in a reduction in the frequency and intensity of algal blooms. The high pH values near the water surface associated with blooms (Wetzel 2001) would not occur without the blooms."
General	Not Applicable	Not Applicable	The hydrologic and nutrient budgets I expected to see in the report are either incomplete or not presented. Table 6 - 1 has the hydrologic input but does not contaln hydrologic output or losses. In a similar fashion, the nutrient budget suffers from the same problem table 7 -- 1 contains the phosphorus inputs but the loss you would expect to the ground and surface water outflows are not included.	Because the hydrologic budgets and phosphorus loads are presented on an annual basis and modeled as a well mixed system and there is no change in storage from year to year, the outflow volume of water is assumed to be equal to the inflow volume and the average annual concentration of phosphorus in the outflow water is assumed to be equal to the average annual in-lake concentration. The in-lake predictions of phosphorus are the same whether the water (and phosphorus) leaves the lake via the outlet or groundwater. The empirical models used to estimate average annual loads use inflow concentration, flow and physical characteristics of the lake to predict average annual in-lake concentration.
General	Not Applicable	Not Applicable	With an average phosphorus concentration of 81 mcg per liter and a pond volume of 870,974 m3 there are roughly 70 kg of phosphorus in solution at any one time. With an annual phosphorus input of 380 kg in a roughly 120 day turnover time the relationship between concentration and nutrient input is unclear. Undoubtedly, both ground and surface water out flow and a high sedimentation rate play a role in the numbers. A discussion of this relationship would be helpful in the report.	Lakes retain a portion of the phosphorus that enters them in the sediments. This phosphorus retention is taken into account in the empirical relationships used to predict average annual in-lake phosphorus concentrations from annual loading.
Specific	6-11	Table 6-6	Table 6 -- 6 would benefit from the inclusion of variables definitions. For example, Z = average	Definitions added to table.

Comment Type	Page	Paragraph	Comment	Response
			depth in meters, etc.	
General	Not Applicable	Not Applicable	The groundwater information in the report seems to have some typographical errors. The data sheets for July 28 indicate measurements at sites one through nine inclusive, yet there is no site nine in figure 3 - 2. Also the data sheets for October 1 indicate a measurement at site five yet there is no site five in figure 3 - 3. There is no site 10 in the data sheets although it is listed in table **5** -- 4. The average calculation for site 7 in table *5* -- 4 is incorrect.	Data for 9 sites includes duplicate data for ST-GW-8 (which was named ST-GW-9). Similarly, for ST-SW-4B was a duplicate sample of ST-SW-1B. The lab data for 10/1/2009 lists ST-GW-7 which is named ST-GW-10 in the table because it is different from the site named ST-GW-7 in the earlier sampling. ST-GW-5 is not shown on the map, it should be shown over in front of the cranberry bogs.
General	Not Applicable	Not Applicable	I think there should be some discussion of the fact that the largest percentage of water input to the pond is groundwater and all of the numbers in table 5 -- 4 exceed the proposed 15 mcg per liter phosphorus target.	Added to the end of the last paragraph of section 6.4, Land Use Export: "Although groundwater water inputs represent a large percentage of the water budget, due to the high iron content of the groundwater, much of the phosphorus that enters the pond through groundwater is not immediately available. A portion of this phosphorus becomes available under anoxic conditions and is accounted for in the internal loading fraction of the nutrient budget."
General	Not Applicable	Not Applicable	Although not a large part of the input to the pond, I am concerned about the amount of input from cranberry bogs. I know that fertilizer recommendations from a dozen years ago for well producing bogs was 20 pounds of phosphorus per acre per year with higher volumes recommended for sand-based bogs. Applications did not start until late spring. Intensive sprinkler irrigation is common during dry periods during the warmer months. It is reasonable to anticipate both seepage and some surface out flow from the bog channels during irrigation and rain events.	We have acknowledged that cranberry bog management should be targeted towards minimizing future phosphorus inputs from this source. A forensic evaluation of past loadings is not possible with the existing data. While it is likely that past cranberry management activities contributed to the current phosphorus reserves in the sediments, current levels of input suggested by the data and future reductions through changes in future management of the bogs to further reduce phosphorus export to the lake coupled with in-lake management to address release of historic sediment phosphorus provides a road map to recovery.
General	Not Applicable	Not Applicable	In light of existing recommendations to substantially increase the width of the outlet damn coupled with anecdotal evidence the pond is being maintained at a higher level than in the past, perhaps reducing the pond level of a few	The effect of reducing the depth of the lake by a few inches may result in a very small increase in the phosphorus export from the pond if the lowering occurs during a time when phosphorus concentrations are high in the pond. Lowering the pond would also

Comment Type	Page	Paragraph	Comment	Response
			inches and conducting partial drawdowns might have some small beneficial impact on turnover time and pond safety considerations.	slightly increase the flushing rate of the pond which would result in a slightly higher flushing rate and a lower retention of phosphorus in the lake. The scale of such a change in water levels would have a negligible effect on in-lake phosphorus concentrations.
General	Not Applicable	Not Applicable	The discussion on the longevity of alum treatments talks to Ashumet and Hamblen ponds. It should be noted that due to existing conditions in Ashumet pond planning for a repetition of the 2001 September alum treatment is underway. Phosphorus inputs to Hamblen pond prior to the alum treatment from a then existing duck farm ceased with the elimination of the farm.	In order to maximize the longevity of a potential alum treatment we recommend implementing watershed control prior to conducting alum treatment. The two examples illustrate the importance of this to the success of the technique.
General	Not Applicable	Not Applicable	In the section discussing waterfowl control it would be helpful to include comments suggesting a recommended difference in height between the water surface and the tops of structures such as docks and walkways, Waterfowl tend to congregate on structures with minimal height differences to the pond surface.	The text has been modified to incorporate this suggestion.
Specific	ES-2	3	The three external source reduction recommendations 1) watershed management, 2) septic system management and upgrade, 3) cranberry bog management, and 4) waterfowl control should be expanded and placed in bold as they are vital to the successful restoration of the pond.	The text has been modified to incorporate this suggestion.