White Island Pond

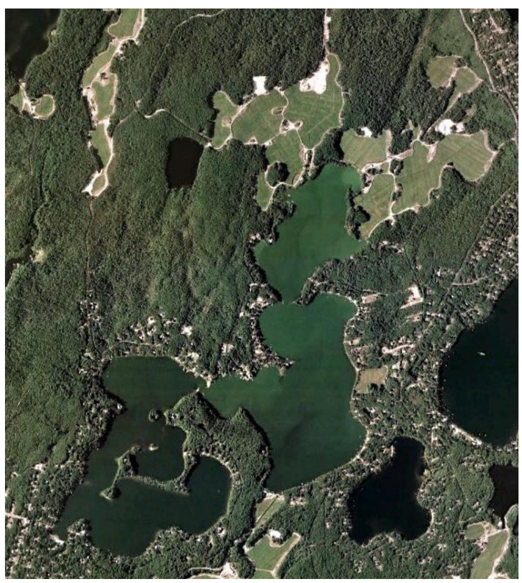
Water Quality and Management Options Assessment
and
Phosphorus Mitigation Program for
Cranberry Bogs on White Island Pond

FINAL REPORT

April, 2012

for the

Cape Cod Cranberry Growers' Association



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Cover photo: July 2007 aerial photograph from Google Earth

Executive Summary

White Island Pond
Water Quality and Management Options Assessment
and
Phosphorus Mitigation Program for Cranberry Bogs on White Island Pond

Final Report
April, 2012

White Island Pond is a 111 ha (291 acre) freshwater pond located mostly within the Town of Plymouth, but with a small southern portion in the Town of Wareham. The pond has two major basins: an eastern basin of 65 ha (167 acres) with an average depth of 3.4 m and a western basin of 46 ha (124 acres) with an average depth of 3.5 m. The pond has two active cranberry bogs located along its northern shoreline. The remainder of the pond shoreline is mostly developed with single family residences. White Island Pond is considered a Great Pond under Massachusetts law and all Great Ponds are "waters of the Commonwealth" and, as such, are publicly owned.

White Island Pond is listed as an "impaired water" on the Massachusetts Department of Environmental Protection's 2010 list of all state surface waters. As state-listed, impaired water, the federal Clean Water Act requires that it have a Total Maximum Daily Load (TMDL) prepared. TMDLs are pollutant limits or thresholds, which when attained will restore the water quality in the listed waters.

In April 2009, MassDEP proposed a TMDL of 19 micrograms per liter (µg/l) total phosphorus (TP) for White Island Pond and this was accepted as the final TMDL by the US Environmental Protection Agency in July 2010. This concentration is accompanied by a whole pond phosphorus loading limit of 147 kg/yr. The TMDL reviewed two MassDEP summer samplings of the pond in 2000 and 2007. The draft TMDL concluded that the primary cause of the water quality impairments in the pond are due to phosphorus additions from the two active cranberry bogs located along the northern shoreline of the eastern basin, but this conclusion was modified after sediment sampling results were obtained through work by the Coastal System Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (SMAST) and the Cape Cod Cranberry Growers' Association (CCCGA). The final TMDL indicates that the sediments are the primary source of phosphorus in the pond.

During the development of the draft TMDL, the Massachusetts Department of Agricultural Resources, MassDEP, CCCGA, and the UMASS Cranberry Station (UMASS-CS) signed a Memorandum of Agreement (MOA) to "work cooperatively with certain cranberry growers in Massachusetts to develop and implement practices with the potential for reducing the discharge of nutrients associated with cranberry cultivation in order to meet applicable water quality standards." A.D. Makepeace Company (ADM) and Federal Furnace Cranberry Company

(FF), which operate the two bogs along the northern edge of White Island Pond, agreed to participate in a pilot program to develop and implement best management practices (BMPs) to reduce their impact on White Island Pond and meet the goals of the White Island Pond TMDL.

In order to help realize the MOA objectives for White Island Pond, CCCGA obtained a Section 319 grant from MassDEP. CCCGA has been assisted in the completion of grant activities by staff from both UMASS-CS and SMAST. All project activities were completed according to procedures under MassDEP's 319 Programmatic Quality Assurance Project Plan (QAPP) and SMAST's Massachusetts Estuaries Project QAPP. At the same time as the 319 grant tasks were progressing, the CCCGA also asked SMAST staff to assist with the development of additional information that would help to better define the White Island Pond system and impairments, as well as helping to provide a reliable basis for development and evaluation of restoration options for the pond. This report documents tasks completed under both the 319 grant and the CCCGA/SMAST project.

In order to better understand the TP concentrations in White Island Pond, SMAST staff developed a new pond watershed based on the US Geological Survey groundwater modeling work completed for the Massachusetts Estuaries Project (MEP). The new pond watershed was further modified to provide subwatersheds to the East and West basins. SMAST staff also used an Automated Underwater Vehicle (AUV) to develop a new bathymetric map and resulting volumes for each of basins. Using the new watershed and pond volumes, residence times have been developed for each basin: 157 days for the East basin and 578 days for the West basin. The new bathymetric map indicates that the pond volume is 38% larger than the volume used in the MassDEP TMDL calculations.

In order to better characterize water quality conditions in White Island Pond after the implementation of MOA activities at the bogs, accompanying data collection in the pond and its nearby areas occurred between July 22, 2009 and November 30, 2010. This data collection included:

1) water quality and field data collection at three basin locations in the pond (North, Middle, and West),
2) sediment cores and incubation measurements of phosphorus regeneration at 13 locations (this is the data used by MassDEP to modify the pond TMDL),
3) continuous streamflow measurements and weekly water quality samples at three downstream/outflow locations, and
4) monitoring of discharges from the cranberry bogs (which continued through 2011).

All water quality samples were analyzed at the SMAST Coastal Systems Program laboratory and sediment cores were incubated by SMAST-CSP staff. Statistical analysis of water quality measures shows that there is no significant difference between conditions in the Middle and North basins and, for this reason, analyses and evaluation of management options focuses on the differences between the West basin and the combined Middle and North basins, which is usually relabeled in this report as the East basin.

Dissolved oxygen data collected during 2009/2010 show that average concentrations in both basins are above and meet the MassDEP 5 ppm regulatory limit (310 CMR 4.05). Both year-round and summer concentrations are above the limit and the only reading below the limit was in August 2009 just above the sediments in the Middle basin. As would be expected, sediment sampling showed that sediment oxygen demand is fairly low. Well oxygenated, deep water inhibits sediment phosphorus regeneration.

Average summer 2009 and 2010 water clarity readings in both portions of the East basin are less than Massachusetts Department of Public Health 4 ft safe swimming limit (105 CMR 405). All clarity readings in the West basin are more than the 4 ft limit and are significantly ($\rho<0.05$) higher than readings in the East basin.

Water quality data shows that 2009/2010 total phosphorus (TP) concentrations in the West basin average 30 µg/l during the summer (June to September), while the Middle and North basins average 59 and 53 µg/l, respectively. The East basin TP averages are significantly higher ($\rho<0.05$) than the West basin and review of other water quality measures seem to confirm that these basins function somewhat separately. No statistically significant differences were found in TP concentrations between the two summers. Review of TP and total nitrogen (TN) data also confirm that phosphorus control is the key to water quality management and restoration in White Island Pond.

The sediment regeneration is the primary source of phosphorus to the East basin, while wastewater is the primary source of phosphorus to the West basin. Phosphorus regenerated from the sediments accounts for 77 to 83% of the summer phosphorus mass in the East basin. Wastewater phosphorus additions account for 54 to 55% of the phosphorus mass in the West basin. Review of sediment core data from both basins show that if the pond develops regular low oxygen conditions, there is significant phosphorus in the sediments that could increase sediment release loads more than 100 times over current conditions. Based on 2009 to 2011 monitoring, the cranberry bogs contribute 0.4% and 17% of the annual East basin watershed load, but contributed less than 3 kg (< 2%) of the average summer mass between 2009 and 2011.

The two cranberry bog operators along the north side of the East basin have implemented a series of management steps to reduce phosphorus additions to the pond: a) reduced their phosphorus fertilizer applications, b) removed one bog cell from production, and c) managed water flows within the bogs to recirculate flows prior to discharge to the pond. These activities have reduced annual phosphorus inputs from the bogs 86% to 97%. Review of these steps show that the reduction in phosphorus fertilizer applications has had the greatest impact, reducing the potential load by 751 kg or 84% of pre-2008 loads. By comparison, the conversion of a portion of the ADM bog to a permanently flooded bog has removed 5.4 kg of potential fertilizer application. Since monitoring of bog discharges was not completed prior to the implementation of the MOA actions, it is not possible to compare the impact on bog phosphorus discharges prior to MOA actions.

Restoration of water quality in the East basin will require action to address phosphorus regeneration from the sediments. Evaluation of an alum treatment or similar sediment treatment approach that can reduce phosphorus regeneration by 90% would eliminate the summer regeneration peaks and reduce the average total phosphorus concentration in the East basin to between 14 and 17 µg/l. This concentration range is less than the TMDL limit.

Water quality conditions in the West basin are not as impaired as the East basin (*e.g.* Secchi clarity is more than twice as deep, summer average TP concentrations are 40 to 60% less). But the average TP concentrations are greater than the TMDL 19 µg/l TP threshold. Review of the watershed, water quality and sediment data show that the West basin has a residence time that extends over more than 1.5 years, so that the mass of phosphorus in water column is directly influenced by watershed and sediment additions during both the previous and current years. Comparison of the water quality data and the net sediment suggest that there might be less regeneration of phosphorus from the sediments during the summer or, given the long residence time, more accretion of phosphorus during the winter. Because temperature influences would cause the sediments to move through a cycle of acting as both a source of phosphorus (regeneration; summer) and as a sink (accretion; winter) during residence time cycle, the management of the West basin is different than in the East basin.

These considerations also raise the level uncertainty associated with the impact of an alum treatment or similar sediment phosphorus inactivation on the water quality in the West basin. Review of the water quality dataset shows that if the single August 2010 summer peak of sediment regeneration were removed from the dataset, the 2009 vs. 2010 averages during the summer, winter, and year-round are all statistically the same. These relationships suggest that the water quality in the West basin is largely controlled by watershed loadings.

If watershed loading is the primary controller of water quality conditions in the West basin, watershed phosphorus loading would need to be reduced by 57% to 69% to meet the TMDL established for the whole pond. Since wastewater constitutes 54 to 71% of the watershed phosphorus load, removing this source would be the most direct way to address the required reduction to meet the TMDL. Removing the wastewater loading would require sewering and roughly estimated cost of $2 to 4 million.

Since this is such a large expenditure, project staff recommend that West basin water quality should be monitored following the implementation of East basin restoration activities. East basin restoration steps are more straightforward and implementation of these steps while continuing to monitor the West basin water quality will clarify the interactions between the basins, as well as clarifying the potential improvements that the West basin may derive from the improvements in the East basin. Further monitoring may also clarify that the two basins are different enough to warrant different TMDLs.

Overall, White Island Pond has impaired water quality caused by excessive phosphorus loads. Water quality in the East basin is more impaired than the West basin and the two basins function mostly separately. Restoration of the water quality in the East basin will require sediment treatment to prevent phosphorus regeneration from the sediments, while West basin restoration strategies should be pursued through an adaptive management approach that uses monitoring results from the implementation of East basin restoration.

Recommendations

Listed below are a summary of recommendations to ensure that water quality in White Island Pond meets state regulatory standards and community goals. Project staff are available to discuss these recommendations with the growers, CCCGA, staff of the involved towns, concerned citizens, and MassDEP and can develop refined cost proposals that will detail the tasks, appropriate schedules and the resulting reports.

1. Develop and Implement an Adaptive Management Plan for White Island Pond

White Island Pond is a dynamic ecosystem subject to fluctuations in a number of factors both natural and induced by those that live and work in its watershed. The data collection documented in this assessment clearly indicates that the overall ecosystem is impaired. MassDEP has selected a target TMDL total phosphorus concentration to remediate the impairments. Because the system is dynamic with multiple controlling factors, efforts to remediate the system have some uncertainty depending on the range of fluctuation in the controlling factors. With this in mind, it is recommended that all involved parties work to develop an adaptive management plan for remediation of White Island Pond.

It is recommended that this plan establish management goals regarding water quality, water levels, use goals, and acceptable land use characteristics. It is clear from the above analysis that sediment treatment to limit phosphorus release is clear, key feature of future management and the plan should incorporate the details of the selected treatment, the follow-up monitoring to assess it efficacy, and criteria and definition of next steps following its completion. The plan should be adaptive to include definitions of what sort of monitoring is necessary to define how the TMDL threshold has been achieved and define the responsibilities of all participants in the regulatory compliance. The plan should also discuss the financial and technical responsibilities to define TMDL compliance. The management plan also offers the opportunity to define community goals regarding use of the lake surface and desired characteristics of the pond.

2. Maintain a Regular Monitoring Program for White Island Pond

Although this assessment includes a detailed and refined monitoring program, it is clear that a regular, on-going monitoring plan of the pond is necessary to: 1) assess fluctuations in the system both before and after implementation of phosphorus reduction strategies, 2) quantify the benefits of any phosphorus reduction strategies, and 3) compare water quality conditions to the TMDL threshold.

Based on the review of the available data, it is recommended that a regular monitoring program be developed for White Island Pond. This program should include the following:

1) Water column profile measurements of dissolved oxygen and temperature and Secchi readings in each of the three basins at the locations sampled during this assessment. There should be a minimum of four sampling events, one each month between June and September.
2) Collection of water samples at each of the three basin locations. At a minimum, samples should be collected at the surface (0.5 m) and one (1) meter off the bottom. Samples should be assayed for at least the following parameters: total phosphorus,

total nitrogen, chlorophyll *a*, pH, and alkalinity. Assays should have protocols and detection limits at least as sensitive as those provided by the SMAST-CSP Analytical Facility.

3) Monthly measurement of pond elevation.
4) Regular training for samplers if sample collection is performed by volunteers.
5) Regular technical oversight in order to facilitate the sampling program and provide rapid feedback on monitoring coordination and results interpretation.
6) An annual brief technical memorandum comparing the past summer's sampling results to previous data.
7) A five-year cumulative review assessing trends and progress toward TMDL compliance.

This monitoring plan could be incorporated into the adaptive management plan, so that responsibilities for the monitoring are clearly established and the feedback loops for monitoring findings are incorporated into management activities.

Recommended Report Citation
Eichner, E., B. Howes, and C. DeMoranville. 2012. White Island Pond Water Quality and Management Options Assessment. Completed for the Cape Cod Cranberry Growers Association. Coastal Systems Program, School of Marine Science and Technology, University of Massachusetts Dartmouth. 108 pp.

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I. Introduction

White Island Pond is a 291 acre freshwater pond located mostly within the Town of Plymouth, but with a small southern portion in the Town of Wareham (Figure I-1). The pond has two major basins: an eastern basin of 167 acres and a western basin of 124 acres. The pond has four cranberry bogs located along its shoreline; two are located on the northern shoreline of the eastern basin, a third is located on the southern shoreline along the stream discharging from the eastern basin and a fourth is located along the eastern shore of the east basin. The remainder of the pond shoreline is mostly developed with single family residences, many of them seasonal. White Island Pond is considered a Great Pond under Massachusetts law[1], which designates any Massachusetts pond greater than 10 acres as a Great Pond. Great Ponds are publicly owned, as "waters of the Commonwealth".

For almost two decades, lakeside property owners, users of the lake, and state officials have been concerned over perceived increasing water quality impairments of White Island Pond, particularly within the eastern basin. Since at least 1998, the Massachusetts Department of Environmental Protection (MassDEP) has officially codified these water quality concerns by including White Island Pond on the list of impaired waters.[2] The current MassDEP integrated list of surface waters places White Island in Category 5, which lists impaired waters.[3] As required under the federal Clean Water Act, waters classified as impaired are required to have a Total Maximum Daily Load (TMDL) prepared.[4] TMDLs set a concentration or load limit for the pollutant causing the impairment of the listed water body.

In order to achieve the Clean Water Act TMDL requirements and begin to address local water quality concerns, MassDEP released a draft Total Maximum Daily Load (TMDL) document in April 2009[5], which was followed by a final TMDL in April 2010.[6] The TMDL reviewed water quality data collected by MassDEP and concluded that the primary cause of the water quality impairments in the pond resulted from elevated phosphorus levels. MassDEP concluded that to restore White Island Pond a total phosphorus concentration limit of 19 micrograms per liter (µg/l) must be met in pond waters. A final TMDL was approved by USEPA in July 2010 indicating a whole pond, annual phosphorus loading limit of 147 kg/yr based on a target pond water concentration of 19 µg/l.[7]

The draft TMDL concluded that impairment was primarily due to phosphorus additions from the two upstream cranberry bogs located along the northern edge of the eastern basin. The final TMDL modified this conclusion to assert that sediment regeneration is the primary source of phosphorus. This modified conclusion was based on sediment sample data collected and documented in this report.

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[1] Massachusetts General Law, Ch. 131, sec. 1

[2] Final Massachusetts Section 303(d) List of Water, 1998. Massachusetts Department of Environmental Protection

[3] Massachusetts Year 2010 Integrated List of Waters. Massachusetts Department of Environmental Protection

[4] Public Law 92-500. Section 303 (D)(1)(c). Federal Water Pollution Control Act Amendments of 1972.

[5] Draft Total Maximum Daily Load of Total Phosphorus for White Island Pond. MassDEP, DWM TMDL Report MA95166-2009-1 CN 330.0 April 14, 2009

[6] Final Total Maximum Daily Load of Total Phosphorus for White Island Pond Plymouth/Wareham, MA. MassDEP, DWM TMDL Report MA95166-201009-1 CN 330.2 April 13, 2010

[7] Approval of the White Island Pond Phosphorus TMDL Report. Letter from Stephen Perkins, Director, EPA Office of Ecosystem Protection to Laurie Burt, Commissioner, MassDEP Available at: http://www.epa.gov/ne/eco/tmdl/pdfs/ma/WhiteIslandPond.pdf.

Coincident with the development of the draft TMDL, the Massachusetts Department of Agricultural Resources, MassDEP, the Cape Cod Cranberry Growers' Association (CCCGA), and the UMASS Cranberry Station (UMASS-CS) signed a Memorandum of Agreement (MOA) in May 2009 to "work cooperatively with certain Cranberry Growers in Massachusetts to develop and implement practices with the potential for reducing the discharge of nutrients associated with cranberry cultivation in order to meet applicable water quality standards." A.D. Makepeace Company and Federal Furnace Cranberry Company, which operate the two upgradient bogs along the northern edge of White Island Pond, agreed to participate in a pilot program to develop and implement best management practices (BMPs) to reduce phosphorus release to White Island Pond and meet the goals of the Final White Island Pond TMDL.

In order to help realize the MOA objectives for White Island Pond, CCCGA obtained a Section 319 grant from MassDEP in September 2009. This grant coordinated monitoring and characterization activities for White Island Pond and its bordering cranberry bogs. CCCGA has been assisted in the completion of grant activities by both UMASS-CES and staff from the Coastal System Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (SMAST). All grant activities are covered under MassDEP's 319 Programmatic Quality Assurance Project Plan (QAPP), approved by USEPA on March 16, 2006 and SMAST's Massachusetts Estuaries Project QAPP, approved by USEPA July 24, 2002.[9]

Specific 319 grant supported tasks for the White Island Pond project include:

1) Collect water quality, soil and plant tissue samples and analyze for nutrients.
2) Assemble scientific data and develop engineered designs for systems that may reduce phosphorus levels from bog outflows and to restore White Island Pond
3) Encourage growers to use low-phosphorus fertilizing regimes in present and subsequent growing seasons.
4) Provide ongoing education and progress reports on the CCCGA website.
5) Conduct a workshop at CCCGA's Winter Meeting to present summaries of the project results and to introduce a new Phosphorus BMP.
6) Post all project materials on the CCCGA and/or the UMass Cranberry Station's website.

At the same time as the 319 grant tasks and MOA tasks were proceeding, the CCCGA also asked SMAST staff to assist with the development of additional information that would help to better understand the water quality in White Island Pond, as well as helping to provide a reliable basis for development and evaluation of restoration options for the pond. The tasks under this related project, which was developed in October 2009, create a comprehensive and cohesive assessment of White Island Pond and provide a quantitative foundation for evaluation of management strategies. The tasks under this parallel project include:

[9] Howes, B.L. and R.I. Samimy. 2002. Quality Assurance Project Plan: The DEP/SMAST Massachusetts Estuaries Project. 157 pp.

Figure I-1. White Island Pond Study Area. The Eastern and Western basins are partially separated by a narrow shallow channel. The northern bogs are within the pond watershed, but the southern bogs along the outlet stream to Red Brook do not contribute to the pond phosphorus balance. The herring run flow is controlled. The pond is mainly in the Town of Plymouth with the southern end of the west basin within the Town of Wareham.

1) collection of pond and outflow stream water quality samples and stream volumetric flow,
2) collection and incubation of pond sediment samples to determine internal nutrient regeneration to pond waters (which are the basis for the revisions in the sediment loads reported in the final TMDL),
3) development of phosphorus and water budgets for White Island Pond, and
4) evaluation of potential phosphorus mitigation strategies for the adjacent bogs and within the pond.

As a result of UMASS Dartmouth relationships, SMAST was also able to leverage additional assistance from the UMASS Dartmouth Advanced Technology and Manufacturing Center and Yellow Springs Instruments, Inc through their partnership agreements with the Coastal Systems Program. As a result, ATMC and YSI used White Island Pond to test an Automated Underwater Vehicle (AUV). The AUV completed a detailed bathymetric survey of the pond, as well as a water quality snapshot of selected parameters on October 5, 2009.

This report documents the results of all these activities and includes a discussion and synthesis of all collected White Island Pond data, as well as evaluation of potential phosphorus mitigation strategies.

II. Water Budget: White Island Pond

A pond water budget accounts for the volume of water in the pond and the balance of flows of water entering and leaving the pond through various pathways. In kettle ponds located within groundwater aquifers, groundwater typically enters the pond along one shoreline from its watershed (*i.e.*, the upgradient side) and a similar amount of pond water discharges from the pond and reenters the aquifer system along the opposite shoreline (*i.e.*, the downgradient side). Water also enters the pond via precipitation on its surface and a portion leaves the pond via evaporation off its surface. Occasionally, there are also surface water inputs or outputs from connecting streams that alter how water enters or leaves the lake. Since the pond is connected to the aquifer, its volume and the average time water stays in the pond (*i.e.*, its residence time) can also be impacted by fluctuations in the surrounding water table.[10]

In simplified equation form, a water budget is typically represented as:

$$IN = OUT + \Delta S$$

IN = groundwater inflow + stream inflow + precipitation
OUT = groundwater discharge + stream outflow + evaporation
Δ S = change in storage, the amount of water held within the pond that is gained or lost as pond level increases or decreases, respectively.

[10] Eichner, E.M., T.C. Cambareri, V. Morrill, and B. Smith. 1998. Lake Wequaquet Water Level Study. Cape Cod Commission. Barnstable, MA.

II.1. Watershed Delineation

White Island Pond is a kettle hole pond located within the Wareham Pitted Plan portion of the Plymouth Carver Aquifer (PCA).[11] Since the pond is located within an unconfined, glacial outwash plain aquifer, the water level in the pond is significantly influenced by the elevation of the surrounding groundwater and its watershed is defined by the topography of the water table rather than the land surface topography.[12]

The US Geological Survey has developed a groundwater model of the PCA system[13] and this model has been used to develop a watershed to White Island Pond (Figure II-1). This watershed is based on a portion of the Wareham River watershed delineation completed under the Massachusetts Estuaries Project.[14] The PCA groundwater model has been used to complete delineation of recharge areas/watersheds to major streams, public water supply drinking water wells, freshwater ponds, and the coastline. As with all groundwater modeling efforts, modeled groundwater recharge area delineations usually need to be adjusted to better reflect the actual shorelines of freshwater ponds, streams, and the estuaries. Groundwater models based on the USGS MODFLOW groundwater modeling code, like the PCA version, are developed as grids, which creates blocky representations of shorelines, coastlines and river geometry. Project staff corrected the recharge areas using USGS topographic quadrangles and aerial photographs to better reflect actual shoreline geometry; this is a standard step in all MEP analyses and includes discussion with the USGS modelers.

Project staff also developed a subwatershed for the western basin to White Island Pond. Based on a review of the water quality data (see Section III), staff determined that this basin generally has significantly different water quality characteristics than the larger eastern basin of the pond. Because both basins of White Island Pond are oriented perpendicular to the primary regional groundwater flow path, the western basin functions somewhat separately from the main portion of the pond. The western basin watershed delineation is based on consideration of the flow paths shown on the outer boundaries of the White Island Pond watershed, a review of the shoreline, the shallow area between the two basins shown on the bathymetry and analysis of other ponds in the region. Further refinement of this delineation would likely require collection of additional groundwater elevation data within the watershed and construction of a subregional groundwater model. The subwatershed areas and projected recharge/groundwater flow volumes based upon the existing USGS groundwater model of the PCA system are shown in Table II-1.

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[11] Masterson, J.P., Carlson, C.S., and Walter, D.A. 2009. Hydrogeology and simulation of groundwater flow in the Plymouth-Carver-Kingston-Duxbury aquifer system, southeastern Massachusetts: U.S. Geological Survey Scientific Investigations Report 2009–5063, 110 p.

[12] Cambareri, T.C. and E.M. Eichner, 1998. Watershed Delineation and Ground Water Discharge to a Coastal Embayment. *Ground Water*. 36(4): 626-634.

[13] Masterson, J.P., Carlson, C.S., and Walter, D.A. 2009.

[14] Howes, et al. under development.

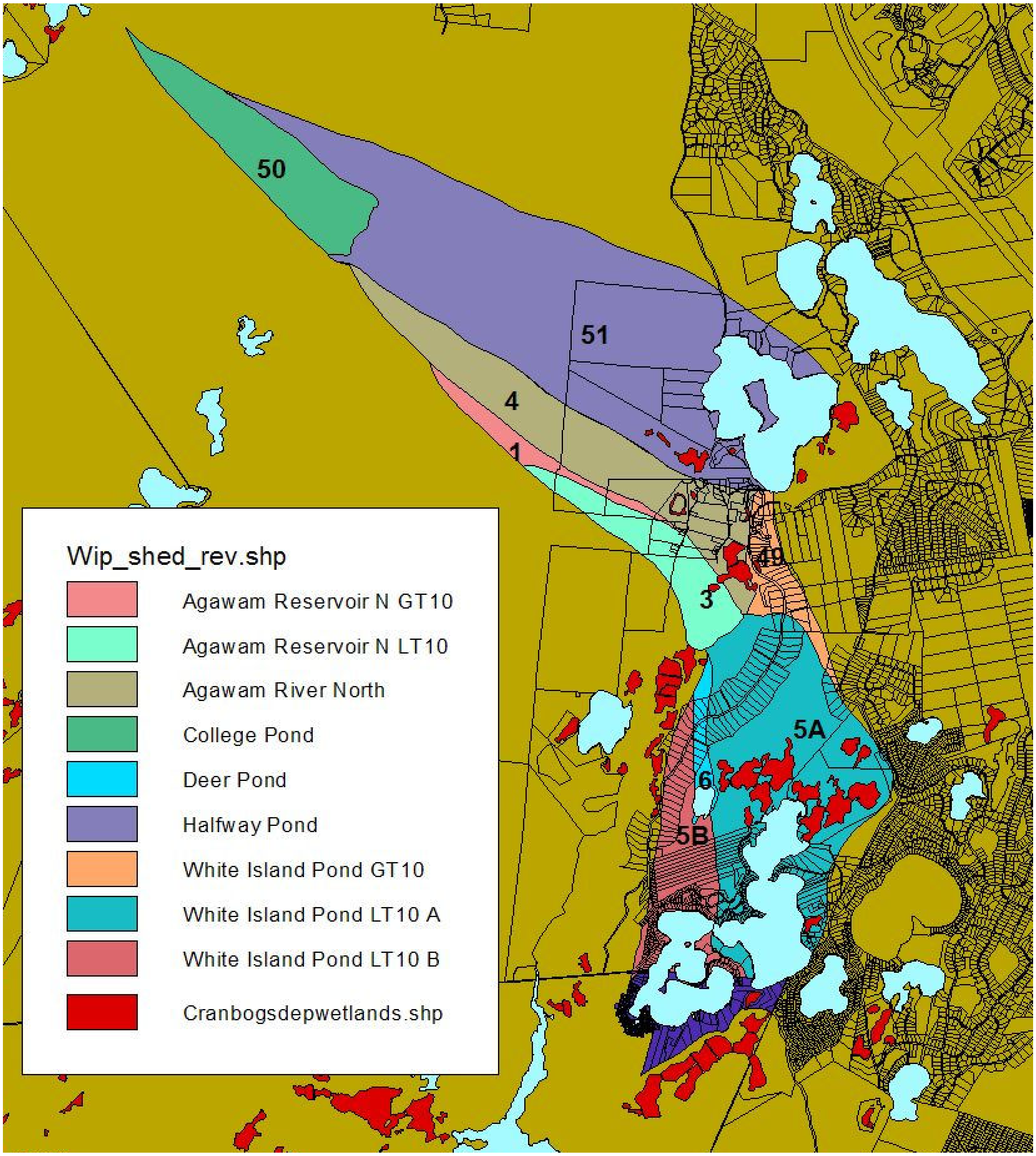


Figure II-1. White Island Pond Watershed. Watershed delineations are based on recharge area outputs from the USGS groundwater model of the Plymouth Carver Aquifer system (Masterson and others, 2009). Separation of the subwatersheds to the two basins of White Island Pond is a refinement of the total recharge area based upon groundwater elevations and analysis of the pond shorelines. Only a portion of the recharge flow from the combined College Pond/ Halfway Pond subwatershed (15%) and Agawam Reservoir subwatershed (73%) contribute flow to the White Island Pond watershed; flows are apportioned based on the percentage of downgradient shoreline of each water body.

Table II-1. White Island Pond Watershed and Subwatershed Areas				
	Total Watershed Area	Pond Surface Area	Land Area	Recharge
Watershed	m^2	m^2	m^2	m^3/yr
WIP LT10 E	3,791,985	646,139	3,145,846	2,332,052
WIP LT10 W	1,512,822	463,347	1,049,476	955,111
White Island Pond GT10	447,723		447,723	307,048
Agawam River North	1,909,406		1,909,406	1,309,471
Deer Pond	201,307	31,856	169,451	132,392
Agawam Reservoir N	73% of sum of portions of College Pond, Halfway Pond shed plus Reservoir N sheds	56,472	2,228,280	1,129,744
TOTAL				6,165,817

Notes:
1) WIP LT10 E is subwatershed to eastern basin shown in Figure I-1. WIP LT10 W is subwatershed to western basin shown in Figure I-1.
2) Total watershed area column includes pond and cranberry bog surface and land area
3) Recharge based on factors utilized in USGS PAC groundwater model: 27 in/yr recharge on land surfaces, net 20 in/yr recharge on water surfaces, and net 10 in/yr recharge on cranberry bog surfaces

II.2. Pond Volume

As mentioned above, SMAST was able to leverage additional data collection through its technical partnership with the UMASS Dartmouth Advanced Technology and Manufacturing Center and Yellow Springs Instruments, Inc. to complete an updated bathymetric survey of White Island Pond. SMAST, ATMC and YSI used an Automated Underwater Vehicle (AUV) to collect thousands of depth soundings and water quality measures. The AUV uses Doppler velocity log and a global positioning system (GPS) to record position and water depth once per second or, at its programmed speed, approximately once every 1 to 2 meters. The AUV was deployed at White Island Pond on October 5, 2009. The depth data collected by the AUV was overlain on a pond outline digitized from MassGIS orthophotographs and pond contours were developed using the Kriging method of interpolation (Figure II-2). The bathymetric map was used to determine a volume of each of the basins for White Island Pond, as well as the volume within each meter of depth in each of the basins (Table II-2). The bathymetric mapping was conducted, due to inconsistencies in historic depth maps and point depth measurements during initial field surveys. The average depth of the East basin is 3.4 m, while the average depth of he West basin is 3.5 m. The total volume of the pond based on the SMAST evaluation is 38% larger than the volume used in the MassDEP TMDL calculations.[15]

The volume of White Island Pond fluctuates based on how groundwater levels in the surrounding watershed fluctuate and the rate of outflow through the herring run and main outlet on the downgradient shoreline. The USGS maintains a long term groundwater elevation

[15] Table 2 (p.33) in Final Total Maximum Daily Load of Total Phosphorus for White Island Pond Plymouth/Wareham, MA. MassDEP, DWM TMDL Report MA95166-201009-1 CN 330.2 April 13, 2010.

monitoring network in the portions of Massachusetts that are outwash plain sediments (*i.e.*, the Plymouth Carver Aquifer and throughout Cape Cod).[16] Observation wells in this network are monitored on varying frequencies: monthly, bimonthly, and continuously. The closest monitoring well to White Island Pond with at least a monthly reading is MA-PWW494, which is located approximately 260 meters to the northeast of College Pond and 6,600 meters (~4 miles) from White Island Pond. Water elevation readings at this well have been measured monthly since May 1989.[17]

Figure II-3 shows median and various percentile groundwater elevations by month at MA-PWW494 over its entire period of record (through October 2010). The average (mean) elevation is 29.18 ft above NGVD29 with a maximum elevation of 33.23 ft and a minimum of 23.27. This period of record shows a maximum difference of 10 ft, but the more common fluctuation (*i.e.*, 75th percentile minus the 25th percentile) is 3.3 feet.

Figure II-3 also shows monthly groundwater elevations at MA-PWW494 during the period that this assessment's water quality and streamflow readings were collected at White Island Pond (2008-2010). As shown in the figure, 2008 monthly water levels were slightly elevated from average conditions; readings were generally between the 75th and 90th percentile. Readings in 2009 generally were slightly higher, but in the same range until late in the year when readings rose above the 90th percentile. Finally, monthly 2010 groundwater levels rose toward the highest recorded at this site, with 6 of the 10 monthly readings during 2010 being the highest on record (1989-2010) for MA-PWW494. These readings are an important consideration for understanding the water quality observations collected during these timeframes.

Comparison of groundwater elevations at MA-PWW494 during 2009 and 2010 to the water elevations during the DEP pond sampling used as the TMDL basis (summers of 2000 and 2007) show that groundwater elevations during summer 2007 were also above average and closely approximate summer elevations during summer 2009 (Figure II-4). Elevations during DEP summer 2000 sampling were below average.

While the water level in White Island Pond cannot fluctuate as much as elevations at MA-PWW494, the groundwater elevations provide a meaningful context for the potential fluctuations in the amount of groundwater discharge and the water level of the pond and how these fluctuations might impact the stream outflow volumes and water quality conditions. Long-term monitoring of groundwater levels on Cape Cod show that groundwater in unconfined aquifers, like the Plymouth Carver Aquifer (PCA) where White Island Pond is located, generally fluctuates less the closer one gets to the coast.[18] White Island is approximately 6 km from Cape Cod Bay, the Cape Cod Canal, and the Wareham River Estuary and approximately 4 km from Buttermilk Bay. MA-PWW494 is approximately 10 km from Cape Cod Bay. Assuming a simple linear relationship based on distance from the coast and using the fluctuations observed at MA-PWW494, a rough estimate of the maximum natural fluctuations in water level at White

[16] USGS Massachusetts-Rhode Island Water Science Center (http://ma.water.usgs.gov/)
[17] http://groundwaterwatch.usgs.gov/AWLSites.asp?S=415217070393102
[18] M.H. Frimpter and G.C. Belfit. 2006. Estimation of High Ground-Water Levels for Construction and Land Use Planning, A Cape Cod, Massachusetts, Example – Updated 2006. Cape Cod Commission Technical Bulletin 92-001.

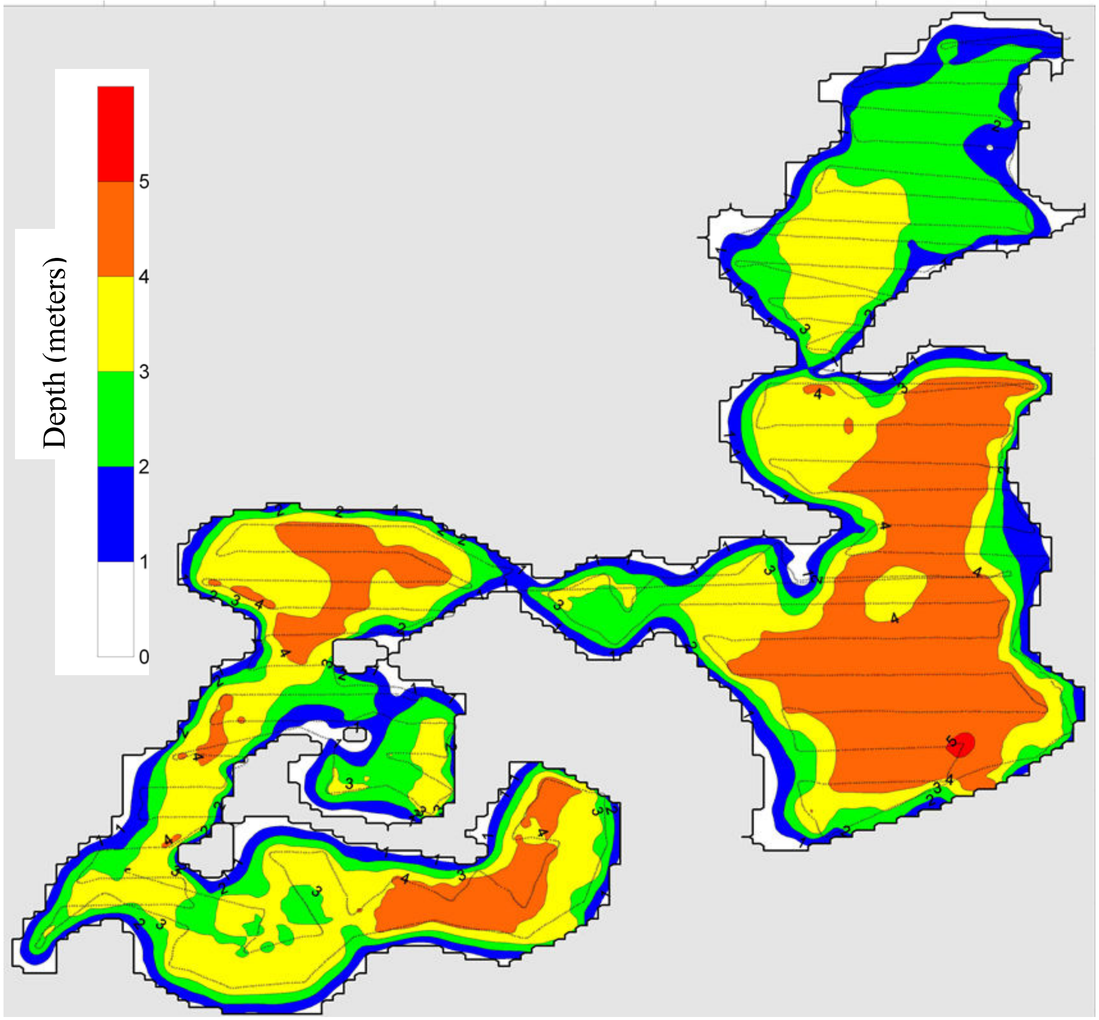


Figure II-2. Bathymetry of White Island Pond. Depth is shown in meters. Bathymetric data points were collected on October 5, 2009 using an Oceanserver IVER AUV, which recorded depth readings approximately every 1-2 meters. AUV tracks are shown in thin black lines. Bathymetric contours were developed using the Kriging method of interpolation.

Table II-2. White Island Pond Bathymetry Volumes

	Volume within contour (cubic meters)						
Basin Name	> 0 m	0 - 1 m	1 - 2 m	2 - 3 m	3 - 4 m	4 - 5 m	5 - 6 m
East/Main	2,222,821	704,847	645,722	505,930	294,077	72,147	99
West/South	1,626,368	524,721	486,909	401,500	202,863	10,376	-
Total Pond	3,849,190	1,229,674	1,132,739	907,215	496,939	82,523	99

Note: all volumes determined using trapezoid rule derived from bathymetric information collected on October 5, 2009. The total pond volume is 38% larger than the volume used by MassDEP in TMDL calculations.

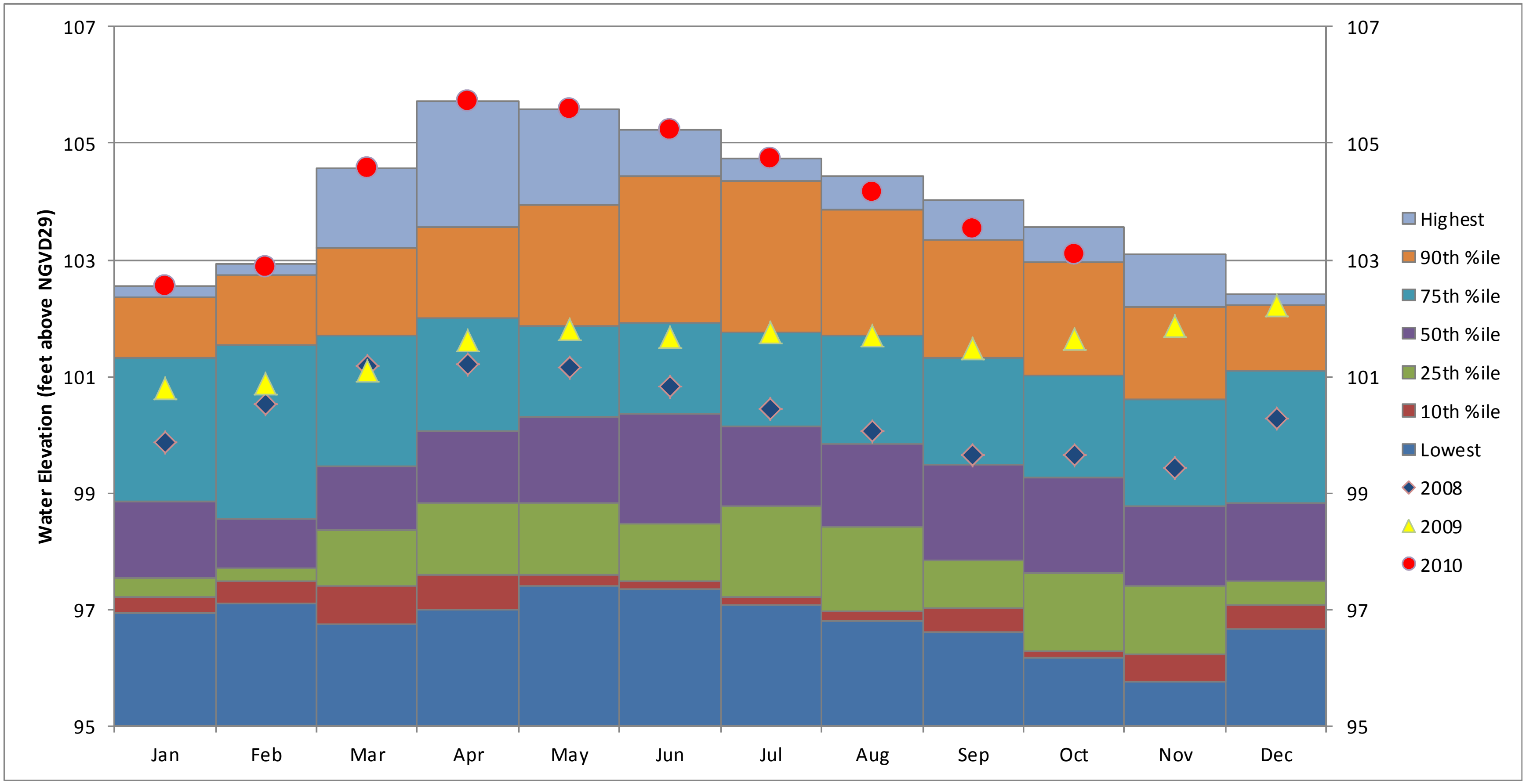


Figure II-3. Comparison of 2008-10 groundwater elevations at MA-PWW-494 to long term readings. Monthly groundwater elevations have been recorded at MA-PWW-494 since 1989; this is the closest monitoring well to White Island Pond in the long-term US Geological Survey groundwater elevation monitoring network. The figure shows percentile breakdowns for each month in the period of record; the maximum fluctuation is 10 ft, but the more usual fluctuation (*i.e.*, 75th percentile minus the 25th percentile) is 3.3 feet. Monthly groundwater elevations in 2008 were above the 50th percentile from the 1989-2010 period of record. Early 2009 elevations followed a similar track with an increase trend starting in April that rose above the 75th percentile in September and to the 90th percentile in December. 2010 elevations generally are among the highest recorded at this site; 6 of the 10 monthly readings during 2010 were the highest recorded monthly elevations from 1989-2010. Based on this information, the maximum estimated fluctuation in the water level of White Island Pond is 6 ft (1.8 m), with more common fluctuation of 2 ft (0.6 m).

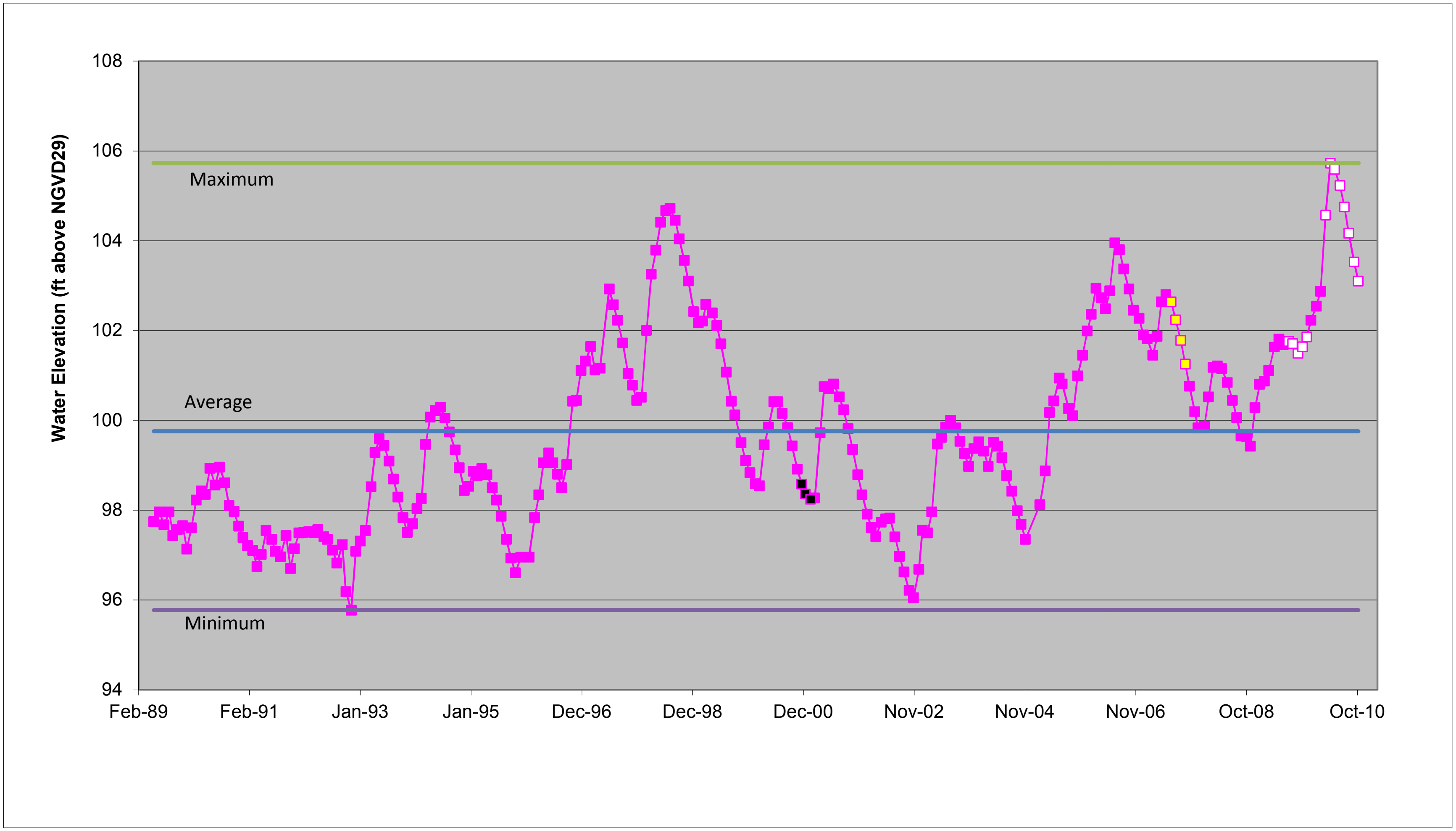


Figure II-4. Groundwater Elevations at MA-PWW-494 and White Island Pond water quality sampling periods. Monthly groundwater elevations at MA-PWW-494 from May 1989 to October 2010 are shown along with the White Island Pond water quality sampling periods: 2000 (black data points), 2007 (yellow data points), and 2009 and 2010 (white data points). Water elevations in 2007, 2009, and 2010 are above average, while 2000 elevations are below average.

Island Pond is 6 ft (1.8 m), with more common fluctuations (25^{th} and 75^{th} percentile) of 2 ft (0.6 m). Observations from Lake Wequaquet in Barnstable suggest that large ponds tend to dampen water table fluctuations, [19] so it might be expected that an estimated 2 ft (0.6 m) fluctuation range at White Island Pond would be more representative of what usually occurs.

Monthly water level readings on White Island Pond by A.D. Makepeace staff between June 2008 and May 2011 are generally consistent with the changes in groundwater elevation data, although not of the same magnitude (Figure II-5). Average elevations for each of the whole years (2009 and 2010) are 49.3 ft (15.0 m) and 48.8 ft (14.9 m) above mean sea level, respectively. The 2009 average is significantly higher ($\rho<0.05$) than the 2010 average with an overall three year average of 48.8 ft (14.9 m). The only elevation reading outside of a two standard deviation range over the whole dataset is the 50.26 ft elevation measured in December 2009. Pond elevations will fluctuate with the groundwater changes, but would also be impacted by stream discharges and the controls on stream discharges.

The increase in levels observed in late 2009/early 2010 is consistent with the higher groundwater elevations in those years observed at PWW-494. It should also be noted that the measured water levels are consistent with the estimated water level modeled by the USGS; Masterson and others (2009) modeled a 50 ft (15.2 m) contour at the northern edge of White Island Pond.[20] This means that the regional groundwater model would have a groundwater elevation in the high 40's ft for White Island Pond, which is consistent with the ADM readings; this elevation would be the same across the whole surface of the pond.

ADM-measured pond levels fluctuated 1.33 ft (0.41 m) in 2009 and 1.25 ft (0.38 m) in 2010, which are the only whole years in the dataset. Using these ranges, the volume of the pond would fluctuate 12% or 11%, respectively, in a given year. The first five months of 2011 fluctuated within a much smaller range (0.16 ft), which suggests that large groundwater elevation fluctuations measured at PWW-494 in 2009 and 2010 impacted water levels too. Of course, this information would have to be combined with stream outflow data, elevations of near shore land, and the overall elevation of the surrounding aquifer in order definitively assess the overall impact on volume, potential impacts on water quality and on management strategies.

II.3. Stream Inflow/Outflow

In kettle-hole ponds, stream inlets tend to focus watershed inflow into a single point, while stream outlets focus pond outflow. A stream outlet functions as a “path of least resistance” where pond water can more easily discharge downgradient rather than flowing back into the aquifer among the sand pore spaces along the pond's downgradient shoreline. For this reason, streams frequently dominate total pond outflow and can have a pronounced effect on the residence time of water in the pond.

[19] Eichner, E.M., T.C. Cambareri, V. Morrill, and B. Smith. 1998. Lake Wequaquet Water Level Study. Cape Cod Commission. Barnstable, MA.
[20] Masterson, J.P., Carlson, C.S., and Walter, D.A. 2009. Hydrogeology and simulation of groundwater flow in the Plymouth-Carver-Kingston-Duxbury aquifer system, southeastern Massachusetts: U.S. Geological Survey Scientific Investigations Report 2009–5063, 110 p.

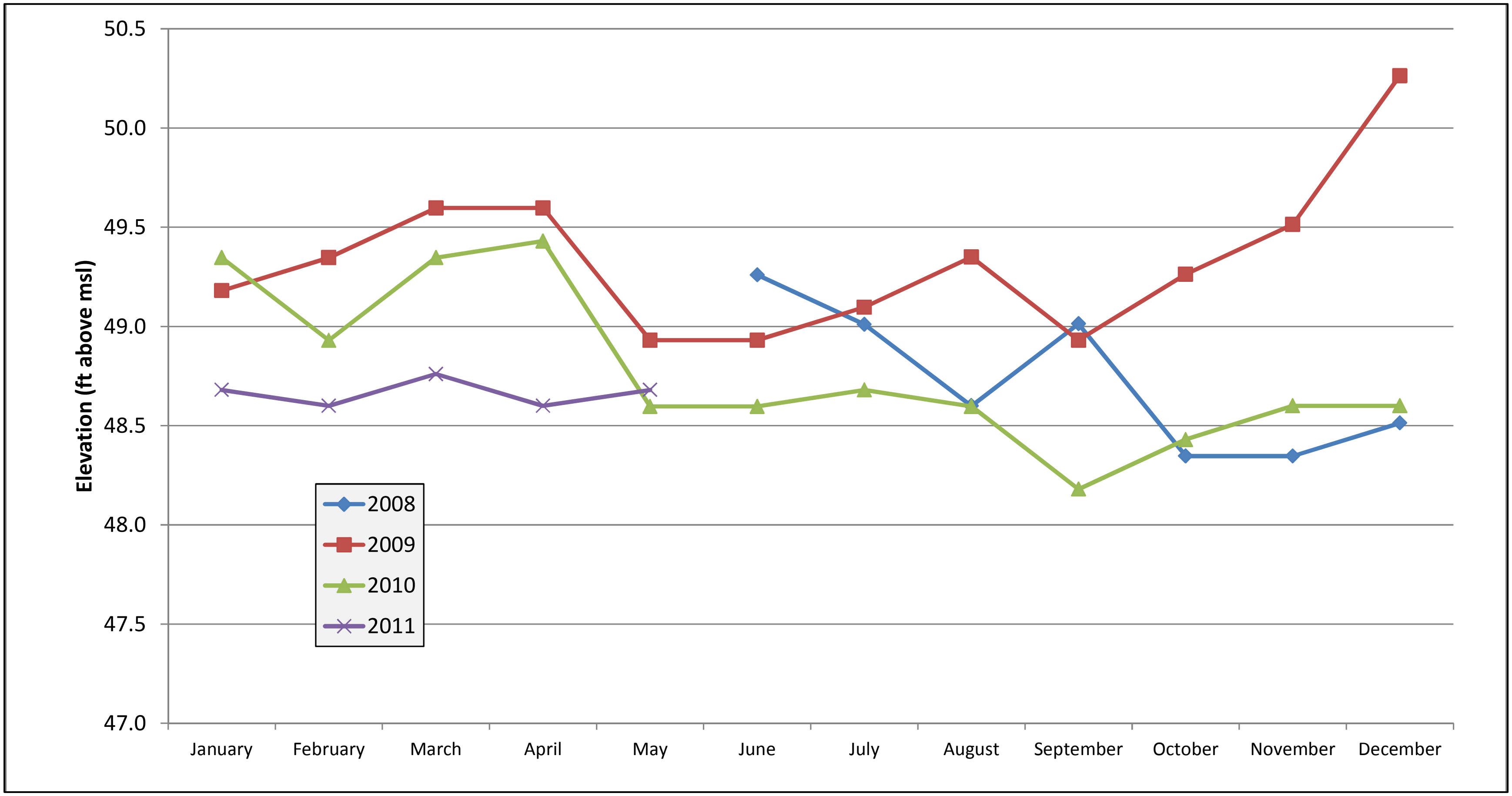


Figure II-5. White Island Pond water levels 2008-2011. Water level elevations collected by A.D. Makepeace staff (personal communication, George Rogers, 5/12/11). Average elevations in 2009 and 2010 (the available whole years) are 49.3 ft (15.0 m) and 48.8 ft (14.9 m) above mean sea level, respectively. The 2009 average is significantly higher (ρ<0.05) than the 2010 average. Water levels fluctuated 1.33 ft in 2009 and 1.25 ft in 2010 with an overall three year average of 48.8 ft (14.9 m). The increase in levels observed in late 2009/early 2010 is consistent with the higher groundwater elevations in those years observed at the closest, long-term USGS water table monitoring well (PWW-494).

In White Island Pond, there are no direct stream inlets and there are two stream outlets. Prior to the activities associated with meeting the terms of the MassDEP MOU, both of the upgradient cranberry bogs along the northern shoreline (see Figure I-1) had direct connections to the pond. These direct connections discharged water from the bogs to the pond that consisted of a mix of water from the pond and watershed water infiltrating into the bogs. These direct surface water connections were modified to controlled release structures in 2008.

Staff measured stream outflow from White Island Pond weekly between October 30, 2009 and November 30, 2010. Measurements were collected at the two adjacent managed stream outlets at the southern downgradient edge of the Eastern basin and at downstream location (WIP Outlet2) where the outlet flows are combined (Figure II-6). The westernmost of the two outlets is a herring run, which is approximately 0.5 m wide, while the easternmost (or main) stream outlet is approximately 4 m across.

Stream measurements at the main outlet were complicated by two sets of control boards: one upstream of the gauge and one downstream of the gauge with a settling pond in between. Measurements at this location did not produce consistent, reliable flows for determining annual flow, although the instantaneous readings are useful for assessing the impact of large flows. Because of the configuration issues, only 16 of the 44 observation dates between January 7 and November 30, 2010 have measured instantaneous flows at this location. The complications with the water level control boards prevented a valid stage/flow relationship from being developed for this gauge site. As a result, it is not possible to determine annual flow through this channel. However, instantaneous flow measurements indicate that flow through the herring run (average 6.88 m^3/d) represents only a minor flow from the pond and that flow through the main outlet is the major stream outlet. The average instantaneous flow average (inclusive of no flow days when the boards had just been raised) was 5,302 m^3/d. However, it is not possible to extrapolate these flows to annual discharge rates.

The third gauge, WIP Outlet2, was placed approximately 1.8 km downstream of the Main/Herring Run outlet within an adjacent cranberry bog. This gauge was placed to assess whether all pond outflow might be captured by this downgradient bog system. Stream flow at this site was continuous and has a reliable stage/flow relationship ($R^2 = 0.95$ between stage and discharge) was developed. The average measured flow at this location between October 30, 2009 and November 30, 2010 is 16,695 m^3/d (Figure II-7).

This cumulative flow from both pond outlets matches the estimated watershed flow for both basins of White Island Pond (16,893 m^3/d in Table II-1). Review of the USGS modeled water table contours and flow paths suggest that the cranberry bog upstream of WIP Outlet 2 should capture most of the discharge from the West basin of White Island Pond. These measurements provide an independent confirmation that the watershed delineation is reasonable.

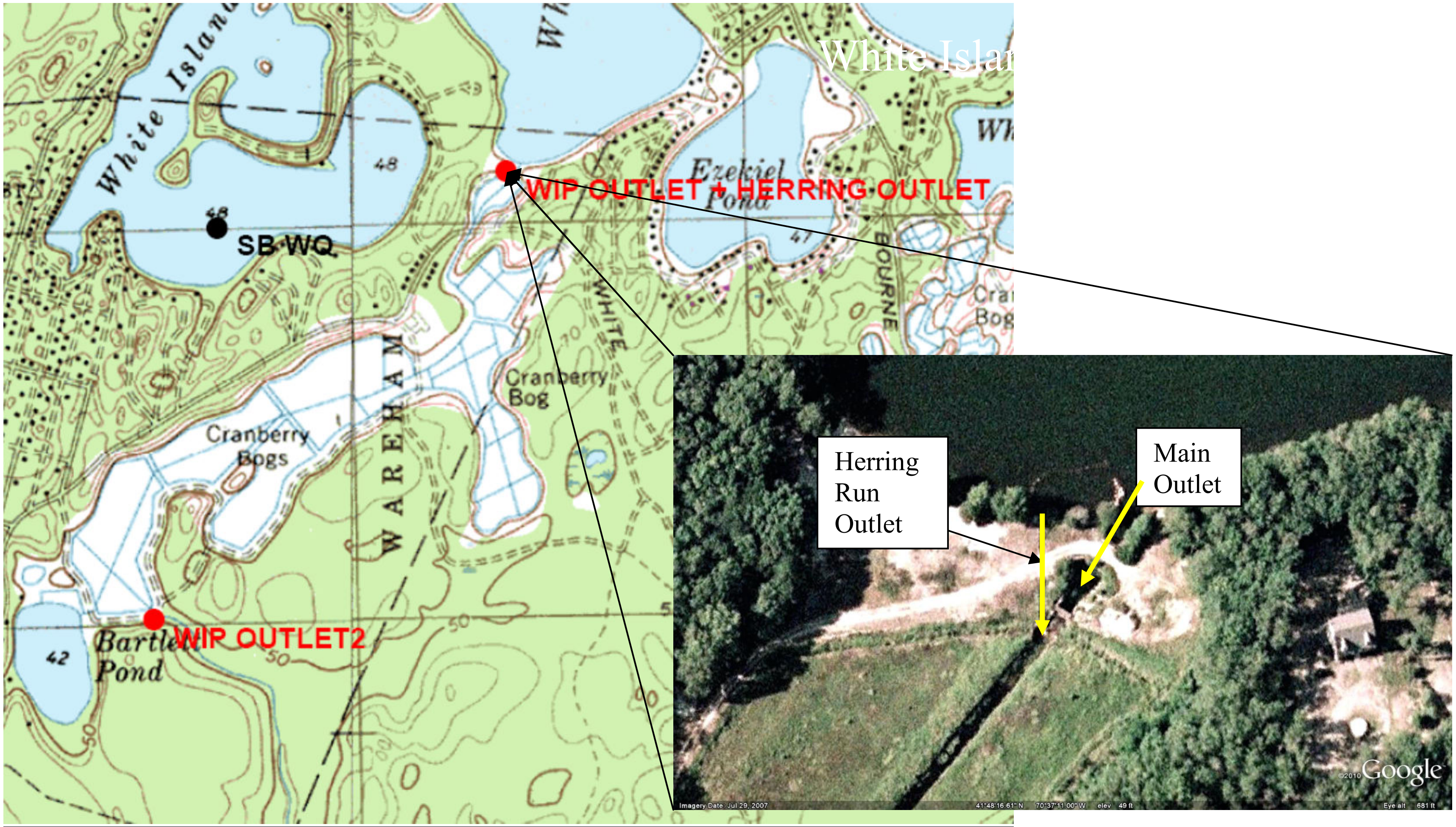
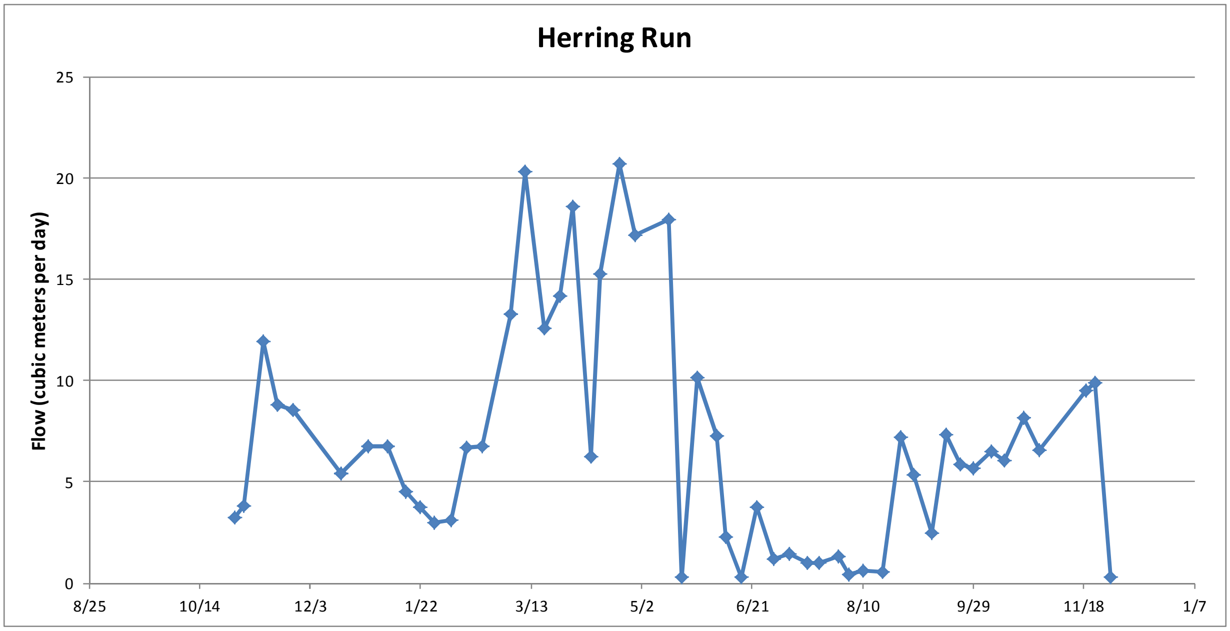


Figure II-6. White Island Pond stream outlets. Herring run and WIP Outlet2 had weekly measured flow and continuously measured stage (for determining flow) between October 30, 2009 and November 30, 2010. The Main outlet adjacent the herring run includes a control structure from which boards are occasionally added or removed rendering less than optimal results at this gauging site. Aerial photograph courtesy of Google Earth.



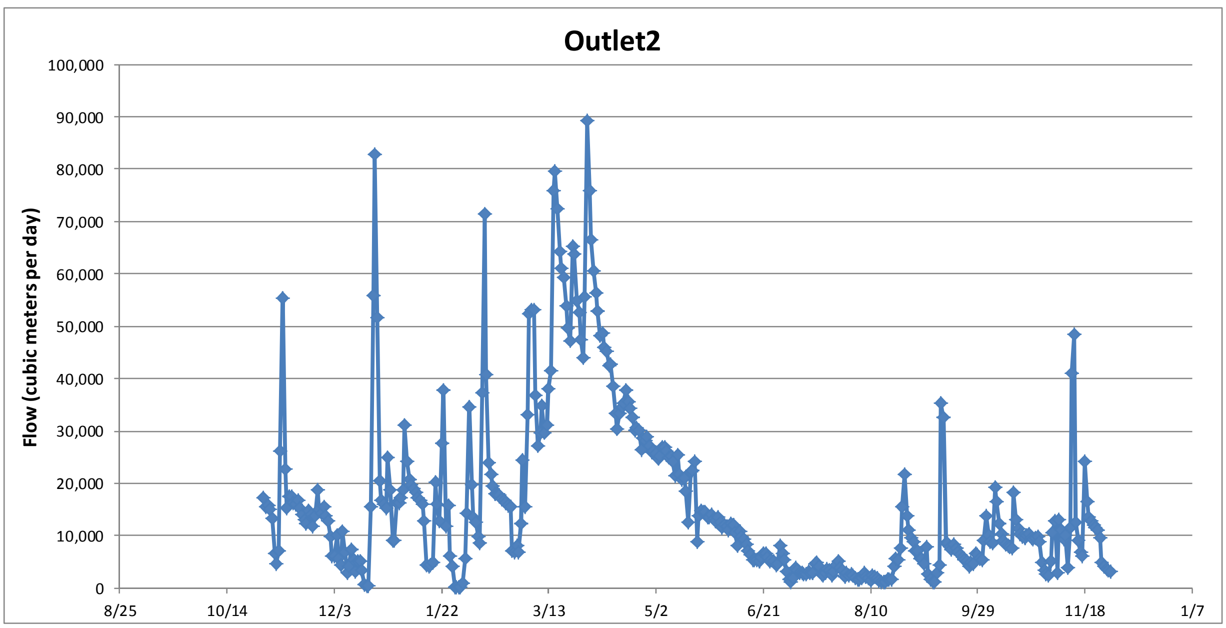


Figure II-7. White Island Pond stream outlet flows. Streamflow discharges from White Island Pond through the herring run and the main outlet. Herring run flows were measured weekly from October 30, 2009 through November 30, 2010; recorded flows averaged 6.88 m^3/d. The main outlet did not have flows for substantial parts of the sampling period and, therefore, average flow could not be reliably calculated. However, recorded main outflow releases were significantly larger than through the herring run. Outlet 2 is located downstream of both the main and herring run outlets and has an average flow of 16,695 m^3/d. Average flows at this location closely approximate the estimated watershed flows from both the East and West Basins of the pond.

Review of the flows at WIP Outlet2 also reveals that the day to day and season to season balancing of flows is complex. As would be expected in a situation where the water level of the pond, groundwater levels in the surrounding aquifer, seasonal precipitation, and use of pond water by the cranberry growers vary by the season and from year-to-year, the resulting water discharge from the pond will also vary. As shown in Figure II-8, high flow readings at WIP Outlet2 occurred during the late winter and early spring of 2010. As noted in Figure II-3, this was also the period of the highest groundwater levels; although this was not noted in the pond water levels (see Figure II-4). This relationship suggests that the upward pressure created by rising groundwater levels around the pond is relieved by increased stream outflow, which consequently keeps the pond water level elevation relatively constant.

When the water volume of the pond increases, if all other factors are held constant, water and nutrients, like phosphorus, will be retained in the pond longer. However, all other factors are rarely held constant, and when the pond volume increases, the measured stream discharge also increases. These offsetting factors tends to keep the residence time fairly constant, but must be accounted for in the longer time timeframes associated with seasonal or year-to-year changes. For example, the high groundwater/high outflow conditions in the late winter/spring of 2010 give way to low flow conditions during the summer (see Figure II-8). During the summer, groundwater levels, on average, tend to decrease and less watershed discharge occurs; these types of conditions would result in lower outflow conditions and favor phosphorus remaining in the pond for longer periods (*i.e.*, rising phosphorus concentrations). More normal groundwater levels (see Figure II-3) would likely result in even lower outflow and even higher phosphorus concentrations. Management strategies should have features that account for these types of natural fluctuations.

II.4. Groundwater Input to Bogs/Elevation Survey (319 bog groundwater and elevation section)

The A.D. Makepeace Company (ADM) and Federal Furnace Cranberry Company (FF) cranberry bogs are located on the upgradient side of the North basin of White Island Pond (see Figure II-1). The peat layers that underlay cranberry bogs are rather impervious, which allows them to hold water and maintain the wetland conditions that cranberry plants prefer. This type of stratigraphy means that groundwater typically discharges into a cranberry bog along the upgradient edge or via a stream that enters along that edge. In isolated bogs, water discharges back to groundwater along the downgradient edge, while in flow-through bogs, the water discharges via an outlet stream. The interactions of bogs with ground and surface water are often also influenced by a number of factors, including: 1) the age of the bog (*i.e*, whether fines have sealed the edge channels), 2) whether the bog was completely constructed or a conversion of a natural system, 3) elevations of the channel bottoms, and 4) elevations of water in the channels.

Given the groundwater flows paths indicated by the USGS watershed lines in Figure II-1, the ADM bogs are directly upgradient of the pond, which means upgradient groundwater either has to flow into the ADM bogs or flow under them to reach White Island Pond. By contrast, the FF bogs are located in a somewhat lateral flow path, meaning that if groundwater is captured by the FF bogs it could flow back into the groundwater along a downgradient side before eventually discharging into White Island Pond. If they capture groundwater, the FF bogs could also discharge the flow to White Island via bog channels provided the channel bottom elevations favor flow to the pond.

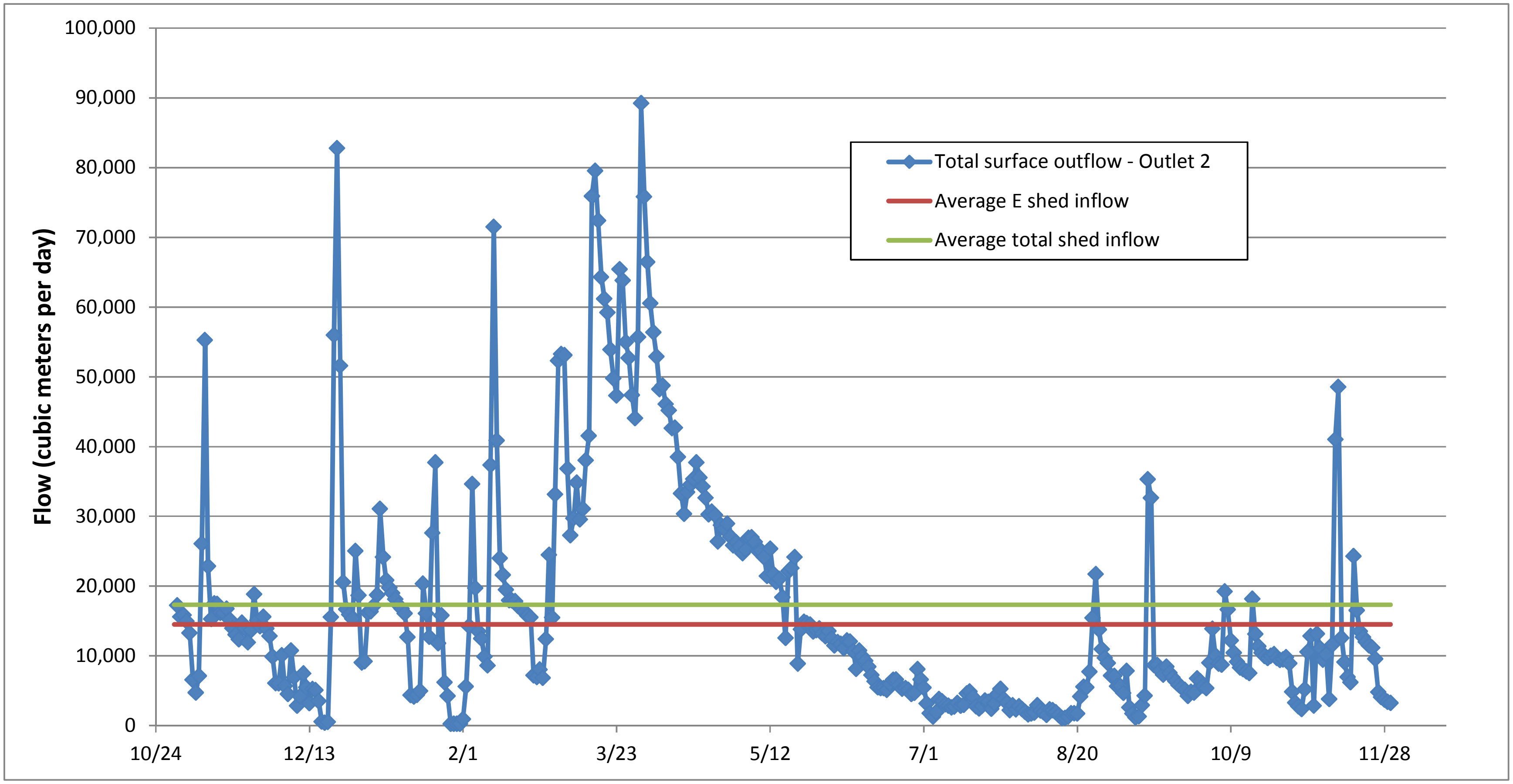


Figure II-8. Comparison of White Island Pond stream outlet flows (2009 -2010) to combined watershed and surface recharge inputs. Blue line shows the Outlet 2 stream discharge, which is estimated to measure stream outflow from the East basin and groundwater outflow from the West basin). Red line shows the average combined watershed and pond surface recharge on the East basin, while the green line shows the average combined watershed and pond surface recharge on the whole pond. Outlet flows exceed the average watershed input during the late winter/spring of 2010 and is less than average input during the summer. On average these inputs and outputs balance, but the graph shows the daily, monthly, and seasonal variations. More refined data would be necessary to assess the effects on phosphorus levels.

One of the steps required under the 319 grant was to complete an elevation survey of the FF bog relative to White Island Pond in order to understand how waters move within the bog channels. Combining this elevation information with some of the watershed and flow information can help understand the interactions of the bogs with groundwater and pond, as well as what management options might be available for transferring water within the area. FF growers have indicated that the pond elevation is often higher than the water level in the bog and strategies that utilize pumping from the bog near the pond may be unduly influenced by pond water.

SMAST staff conducted an elevation survey July 19-20, 2010 using a Leica Viva GNSS/GPS with RTK enabled. A single reference baseline <15km gave elevation accuracies on the order of +/-10 mm. Elevation measurements were made within the ditches and streams throughout the Federal Furnace Bog System. Elevations of the pond surface serve as a reference for the bog drainage system. Within the bog, measurements reflect the elevation of the hard bottom of the ditches/channels. Soft muddy sediments were ignored and the survey rod was allowed to rest on the underlying permeable sand layer. Elevation contours were generated using Surfer Kriging method and nearest neighbor search (Figure II-9).

The elevation survey found that each of the FF bog cells are relatively level. The northernmost bog cells have the highest elevation (15.9 m above sea level), while the southernmost cell has the lowest average elevation (14.5 m). The three largest cells, which are closest to the pond, have average elevations of between 14.6 and 14.7 m. The water level of the pond (14.7 m) during the survey approximates the average pond elevation (14.9 m) measured between 2008 and 2011 (see Figure II-4). Bog channel elevations of less than 14.7 m extend at least 300 m from the pond shoreline and review of the bog elevations show that, if allowed to flow freely, the average pond elevation of 14.9 m would flood all but the northernmost FF bog cells.

As mentioned, the peat layers in bogs and the soft sediments in the bog channels tend to discourage direct groundwater discharge except along the edges of bogs. As a low point in the landscape, however, FF bogs would tend to a favored groundwater discharge zone. The presence of leeches in some of the FF bog channels (personal communication, D. Schlezinger, SMAST) suggests that the bogs do not receive significant groundwater discharge because leeches tend to favor swampy, warm waters.

Review of water pumping records maintained by FF and ADM seem to confirm that the FF and ADM bogs are not a significant groundwater discharge area. Table II-3 shows the water pumped from White Island Pond to the FF bogs, water discharged from the FF bogs to the pond, and water pumped internally from the bogs to an upland area as part of the specified MOA management activities. FF measured water volumes 2009, 2010, and 2011, but volumes were not comprehensively measured except for discharges to the pond. During 2009 and 2011, comparatively little water was discharged from FF bogs to the pond. Volumes during 2010 are the most comprehensive, but 2010 was an exceptional year in the volume of water discharge to and withdrawn from the pond. During 2010, the water pumped from the pond (300,452 m^3) is more than twice as much as is released back to the pond (140,864 m^3). Further, if the added

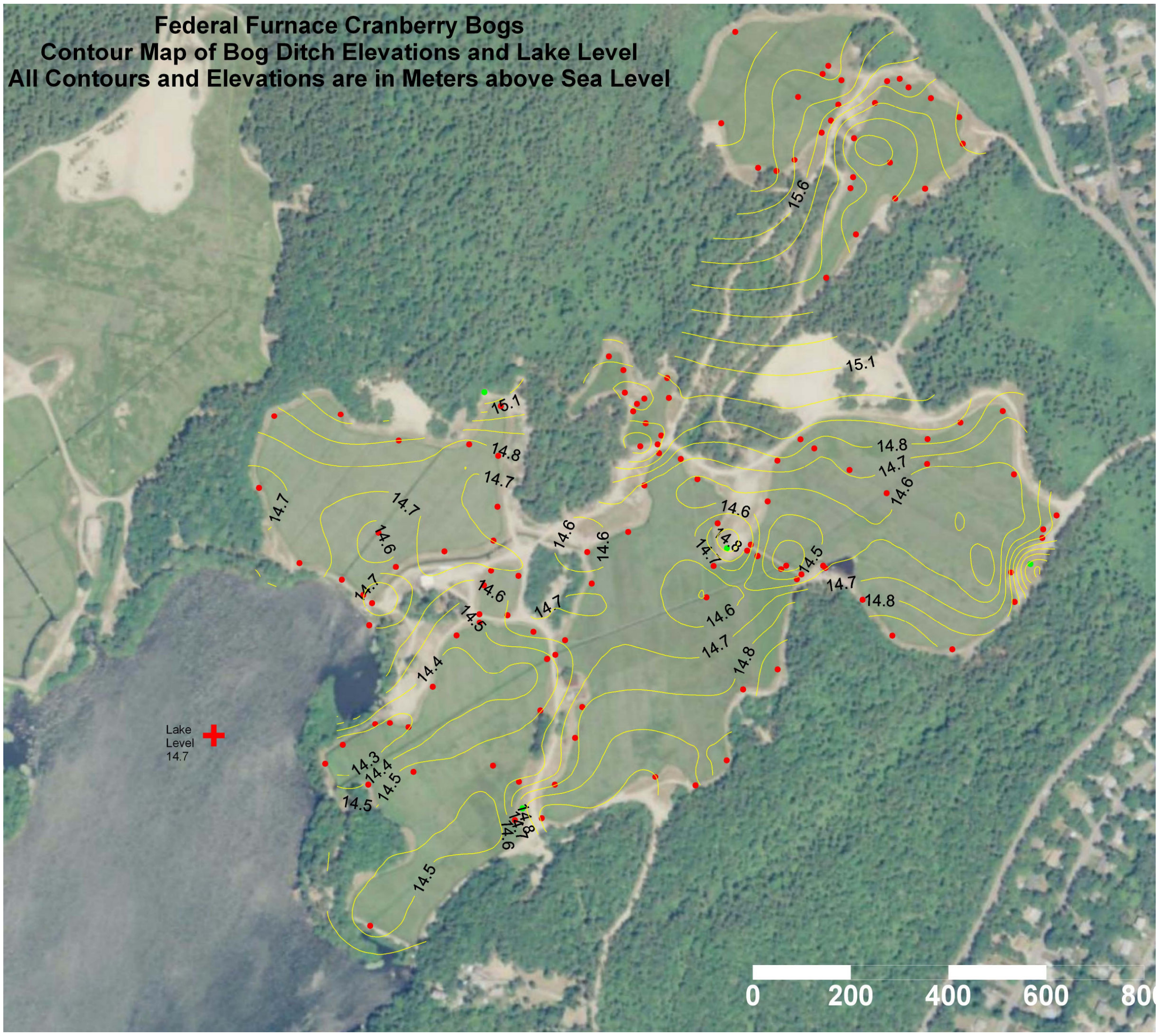


Figure II-9. Elevations in the Federal Furnace Bog. Elevation survey conducted July 19-20, 2010 using a Leica Viva GNSS/GPS with RTK enabled. A single reference baseline <15km gave elevation accuracies on the order of +/-10 mm. Elevation of the pond surface (14.7 m) serves as a reference for the bog drainage system. Within the bog, measurements reflect the elevation of the hard bottom of the ditches and creeks. Soft muddy sediments were ignored and the survey rod was allowed to rest on the underlying permeable sand layer. Elevation contours were generated using Surfer Kriging method and nearest neighbor search. Note that most of bog system is at elevations less than the July 19-20 pond elevation; average pond water level 2008 to 2010 is 14.6 m with maximum pond elevation of 16.1 m in August, 2009.

Table II-3. Water Flows within the Federal Furnace Cranberry Bog System. Flows measured by FF staff from April 2, 2009 to December 31, 2011.						
	Discharge to Pond		Withdrawal/Input from Pond		Pumped to Upland from Bog	
Date	acre-ft	m^3	acre-ft	m^3	acre-ft	m^3
9/12/09	10	12,335			Unmeasured: all harvest water pumped to upland; winter flood in place at year end	
12/15/2009			17.66	21,783		
12/17/2009			11.77	14,518		
1/4/2010	36	44,405				
1/23/2010			47.42	58,492		
2/10/2010	33.6	41,445				
3/10/2010			73.58	90,760		
3/13/2010	32.1	39,595				
3/31/2010	1	1,233				
4/30/2010	1	1,233			63.64	78,494
5/19/2010	0.5	617				
5/31/2010					82.20	101,388
6/30/2010					79.55	98,118
7/31/2010					53.03	65,412
8/30/2010					39.77	49,059
9/30/2010					33.14	40,882
10/5/2010			32.66	40,286		
10/9/2010			89.92	110,915		
10/20/2010					18.33	22,610
12/30/2010	10	12,335				
8/15/2011	2.8	3,454	Unmeasured: no winter flood after Dec 2010 release; Aug 2011 discharge to pond due to excess rainfall			
SUM	130.8	158,182	273.0	336,753	370	455,964
2009 Total	10	12,335	29.4	36,301		
2010 Total	114.2	140,864	243.6	300,452	370	455,964
2011 Total	6.6	8,141				

Notes:

a. Water volumes are based on rated capacity of pump and time pump is operated.
b. Water pumped to upland area includes water from pond, precipitation and groundwater inflow.
c. Total estimated recharge rate to East Basin of White Island Pond is 5,293,198 m^3/yr. Approximately half of the watershed is upgradient of Federal Furnace bog.
d. Estimated annual recharge on the surface of the Federal Furnace bog is between 102,694 and 138,636 m3/yr.

pond water is subtracted from the water pumped to the upland, 296,376 m^3 of additional water was added to the bogs by a combination of groundwater and precipitation.

According to MassDEP records, FF has a surface area of 50 acres. The USGS groundwater model of the area assumes recharge of 27 inches per year (in/yr) on upland areas, 20 in/yr on pond surfaces, and 10 in/yr on cranberry bogs.[21] These rates are based on average precipitation of 44 in/yr. At a recharge rate of 10 in/yr, the FF bogs would receive 51,347 m^3/yr of recharge. If this annual volume of recharge is subtracted from the unaccounted volume pumped around the bogs, the remaining volume should be groundwater recharge. Given the way the watershed to the East basin of the pond and the bogs are situated, a reasonable assumption would be that half of the East basin watershed flows toward the FF bog. Using this volume estimate and the FF cranberry bog recharge volume based on the estimated 2010 bog recharge rate, groundwater recharge to the FF bog would be only 6% of the potential watershed recharge.

A similar analysis on the ADM bogs also shows that they have little groundwater input. ADM discharged a total of 84,666 m^3 of water to White Island Pond in 2010; no water was discharged during 2009. The ADM bogs have a total surface area of 38 acres, but this has been reduced to 21 acres with the flooding of a 17 acre bog cell as part of the 2009 MOA agreement with MassDEP. Using the USGS cranberry bog recharge rate of 10 in/yr, these bogs would receive 56,485 m^3/yr of recharge if the flooded bog is treated as a pond and 39,011 m^3/yr of recharge if all bog cells are considered active. If it is assumed that the difference between the discharged volume and the recharge on the bog surface is groundwater input, the remaining volume would be 1-2% of the potential watershed recharge.

Another way to review this issue is to look at the precipitation measured at the UMASS-Cranberry Station in East Wareham during 2010. During this period, 53 inches of rain (including snow) were recorded (Figure II-10). Evapotranspiration from wetlands can be notably influenced by a number of factors, including: a) the details of the wetland features (standing water, ditches, vegetation type), b) the pattern of precipitation, and c) seasonal temperatures.[22] Evapotranspiration demands during summer months are generally significant; seasonal USGS modeling of summer recharge is negative (e.g., water is removed from the aquifer rather than added during these months).[23] As such, if one looks at the ratio of rain to recharge used by the USGS, 12 inches of recharge on the bogs would be estimated for 2010. Using this rate with the same balancing of measured inputs from the pond and pumped water to the FF upland area, the estimated groundwater recharge again would only be 6% of the potential annual watershed recharge. These calculations strongly suggest that groundwater discharge into the bogs is a small component of the their water flows and that the majority of the watershed flow flows under the bogs.

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[21] Masterson, J.P., Carlson, C.S., and Walter, D.A. 2009. Hydrogeology and simulation of groundwater flow in the Plymouth-Carver-Kingston-Duxbury aquifer system, southeastern Massachusetts: U.S. Geological Survey Scientific Investigations Report 2009–5063, 110 p.

[22] *e.g.*, South, C., C.Susan, B.,Grimmond, and C.P. Wolfe. 1998. Evapotranspiration rates from wetlands with different disturbance histories: Indiana Dunes National Lakeshore. *Wetlands*. 18 (2): 216-229; Lott, R.B. and R.J. Hunt. 2001. Estimating Evapotranspiration in Natural and Constructed Wetlands. *Wetlands*. 21 (4): 614-628.

[23] Masterson, J.P., Carlson, C.S., and Walter, D.A. 2009.

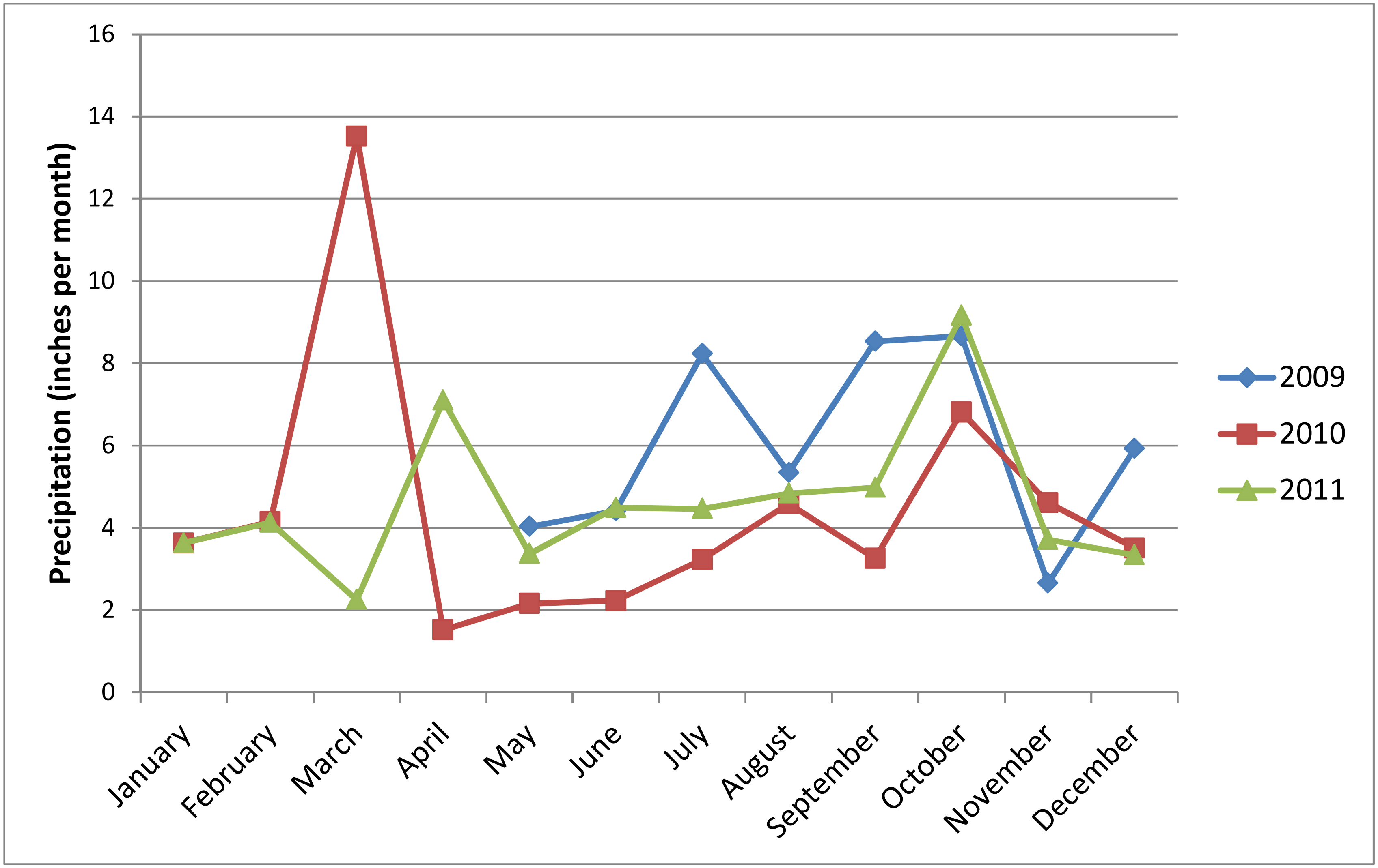

Figure II-10. Precipitation (May 2009 to December 2011) at UMASS-Cranberry Station (East Wareham). Monthly precipitation totals include snow. Note that March 2010 precipitation (13.52 inches) is exceptionally greater than the rest of recorded months. Total annual recorded precipitation during 2010 and 2011 are 53.2 and 55.5 inches. Estimated annual average precipitation used by the US Geological Survey is 44 inches. Most of the recorded discharges from the ADM and FF cranberry bogs to White Island Pond occurred during the 2010 spring.

II.5. White Island Pond Water Budget Summary

Preparation of the water budget for White Island Pond requires the consideration of all the watershed and stream outlet information and, as has been shown from the collected data, the variability in that information. If one considered White Island Pond as a kettle-hole pond without a stream outlet, each day 14,502 m^3 of watershed discharge and net precipitation flows into the combined East (North and Middle) basin and 2,812 m^3 of watershed inflow discharges into the West (South) basin (see Table II-1). Based upon these freshwater input rates and the volume of the pond basins, water remains in or has a residence time in the East basin of the pond for 157 days (or roughly 5 months). For the West basin, without consideration of any connection to the East basin, the residence time is 578 days (~1.6 years) (Table II-4). Given the differences in residence time between the basins, it would be likely that some of the West basin water would be pulled into the East basin but this would be controlled by the relatively shallow bathymetry in the connection area between the two basins.

Overall, there was a good balance between the combined average daily watershed and net precipitation inputs for the whole pond (both basins) and average outflows measured at the downstream WIP Outlet2 gauge. The herring run outlet is an insignificant (<0.05%) portion of the daily watershed inflow to the East basin. The measurements at WIP Outlet2 suggest that all of the pond flow out of the East basin occurs primarily through the main outlet with little to no discharge to groundwater. West basin downgradient groundwater outflow also appears to be captured at the WIP Outlet2. Since the average stream outflow approximately balances the daily watershed inflow, residence times based on the watershed inflow are reasonable.

Review of the streamflow readings and their timing reveals that the day to day and season to season balancing of flows is more complex. Higher than average groundwater levels during 2009-2010 produced stream outflows at WIP Outlet2 that are greater than average watershed and precipitation inputs during the late winter/spring of 2010. This suggests that the outlet acts as a "relief valve" during high groundwater conditions, maintaining water levels in the pond within a relatively small range. During the 2010 summer, stream outflows fell below the average groundwater input level, which would favor more groundwater discharge being retained in the pond. Return of groundwater levels to average conditions will likely result in even lower stream outflows during the summer and higher phosphorus concentrations as water remains in the pond longer. These types of season to season and year to year fluctuations should be addressed in phosphorus management strategies for White Island Pond.

Review of the watersheds and the Federal Furnace and AD Makepeace bog systems show that they are in the direct flow paths for the watershed recharge to the North Basin of White Island Pond. However, review of water flows in the bog systems suggests that the majority of the watershed flow bypasses and likely flows under the bog systems. After accounting for water pumped from the pond to the bogs, water discharged from the bogs to the pond, average precipitation, and water pumped from the bogs to the upland discharge area developed following the MOA with DEP, less than 10% of the potential watershed recharge is captured by the Federal Furnace bog and 1-2% is captured by the AD Makepeace bog.

Table II-4. White Island Pond Water Budget (Average Conditions)				
Basin	Watershed Recharge m^3/yr	Pond Surface Recharge m^3/yr	Pond Volume m^3	Average Residence Time days
East Basin	5,169,296	328,239	2,222,821	157
West Basin	1,026,228	235,380	1,626,368	578
Whole Pond	6,195,524	563,619	3,849,190	227
Note: This budget is based on average conditions. Pond surface totals do not include other ponds in the watershed, but total watershed recharge flows do. Occasional measured outflows through the main outlet exceed the combined recharge flows and will reduce residence time in the pond (to as little as 49 days in the East basin). More frequent data collection would be necessary to assess the impact of the large outflows on the observed water quality.				

Overall, the current water budget analysis provides a reasonable assessment of average water flows and residence time within the two basins of White Island Pond. On average, the volumes of the basins are relatively stable and fluctuate less than 12%. Comparison of the basin volumes with average watershed and precipitation inputs show that water is in the East basin for 157 days and in the West basin for 578 days. Downstream streamflow readings balance the estimated watershed and precipitation inputs. Since the East basin residence time is longer than a June to September summer period, phosphorus management strategies will also have to address spring inputs and pond conditions.

III. Water Quality Data: White Island Pond

Water quality within lakes and ponds is controlled by the movement of water (residence time, vertical mixing of the water column) coupled with nutrient inputs (inputs from the watershed and atmosphere and internal recycling from sediment sources). Increasing nutrient inputs or increased residence time typically results in diminishing water quality, which generally follows a relatively simple progression that begins with higher nutrient concentrations and ends with low oxygen levels. Higher nutrient levels support more plant growth (either algae or rooted plants), which in turn creates more dead plant material being deposited on the pond bottom, where bacteria consume oxygen and regenerate the nutrients in inorganic forms while decomposing the dead organic material. In addition to being stressful to animals, low oxygen conditions produces chemical changes in the sediments that allow chemically bound nutrients to be released back into the water. These releases of nutrients that the pond has previously captured can support more phytoplankton growth than if watershed were the only source of nutrient inputs. Of course this general description often becomes very complex as the details that are specific to each pond are considered. However, because water quality impacts follow this progression, regular low dissolved oxygen conditions are generally more of a terminal state, while diminishing clarity/Secchi depth and elevated nutrient concentrations are generally the initial stages of water quality degradation.

III.1. 2009-2010 White Island Pond Sampling Plan (319 QAPP summary)

The White Island Pond sampling plan included collection of monthly water quality samples over the deepest point in each of the three main basins of the pond, comprising of the Eastern Pond (north basin, middle basin) and Western Pond (south basin; Figure III-1). Profiles of nutrient-related water quality parameters (dissolved oxygen, temperature, and water samples) were collected at the surface, 1 m, 2 m, 3 m (if depth allowed) and one meter from the bottom in each of the basins. Samples were collected 14 times between July 22, 2009 and November 30, 2010. In addition to the monthly pond profile sampling, weekly stream samples were collected at two outlet locations: main outlet and herring run outlet.

Pond and stream water quality samples were collected with Niskin samplers and sub-samples transferred to dark HDPE acid-washed 1 liter bottles and transported in coolers with ice packs (4°C) to the laboratory. Duplicate quality assurance (QA) samples were collected and analyzed for 19% of the samples. All samples were delivered within six (6) hours of collection to the Coastal Systems Analytical Facility at the School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth in New Bedford. Laboratory procedures are described in the SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (2003).

In parallel with the chemical profiles related to pond water quality, other trophic status metrics were assayed in the field at each basin station by SMAST staff including: Secchi depth and vertical profiles of dissolved oxygen concentration and temperature recorded at 1 meter intervals from surface to within 0.3 m above the sediment. Dissolved oxygen and temperature readings were recorded using an YSI-85 meter calibrated prior to each sampling event. Membranes on the meter probe were changed according to recommendations in the YSI operations manual. Laboratory and field data collected, along with analyte detection limits and accuracy measurements, are shown in Table III-1.

The White Island Pond sampling plan also included the collection and incubation of sediment cores. The sediment analysis determined the rate of nitrogen and phosphorus release from the bottom sediments to the overlying water when pond waters are oxygenated and when they are anoxic. The latter incubation is to assess the amount of iron-bound phosphorus released during periods of bottom water anoxia. Multiple undisturbed sediment cores (15 cm i.d.) samples were collected by SCUBA divers from each basin of the pond and incubated for 24 hours under *in situ* conditions in temperature controlled baths. Cores were transported by boat to a shoreside laboratory for incubation. Cores were maintained from collection through incubation at *in situ* temperatures. Bottom water was collected and filtered from each core site to replace the headspace water of the flux cores prior to incubation. Sediment samples were collected from the North basin (3 sites), the Middle basin (6 sites), and the South basin (4 sites) (see Figure III-1). Sediment cores were collected in shallow (<8 ft) and deep (>10 ft) locations to account for differences in nutrient exchange related to water depth. Previous study of the organic carbon distribution within these basins indicated much higher organic matter levels in the depositional areas of the deeper basin sediments compared to the shallow margin areas. This organic matter gradient suggested *a priori* a potentially higher rate of nutrient release from the deep versus shallow sediments in these basins. The core samples from each site (see Figure III-1) are as follows:

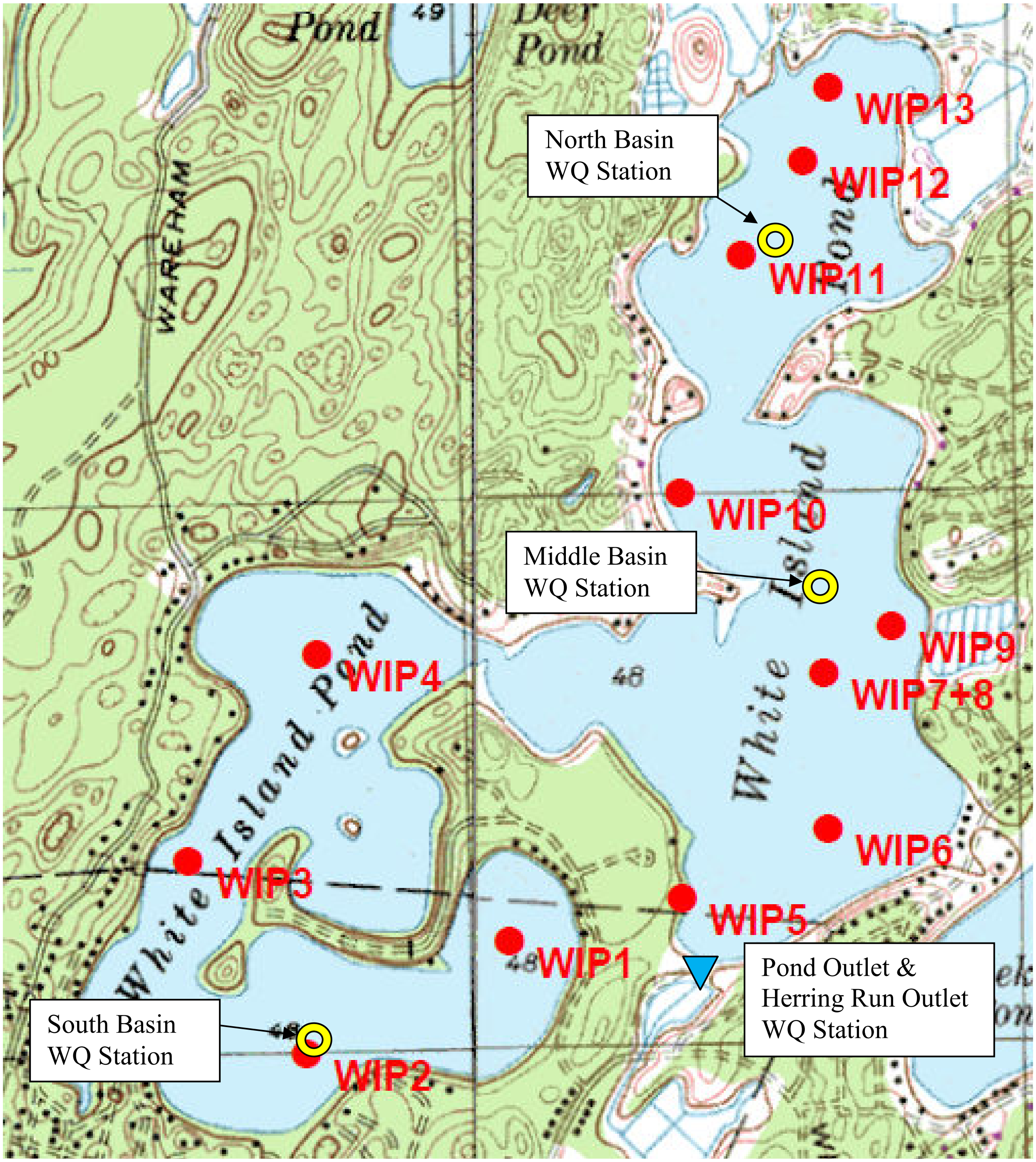

Figure III-1 White Island Pond Water Quality Stations and Sediment Core Collection Sites. Yellow open circles are monthly water column sampling locations, while the blue triangle shows stream sites sampled weekly (main outlet and herring run). The red dots indicate sediment core collection sites for nutrient regeneration assays. Note that the stream sites are only 10 meters apart, but with different control structures.

Table III-1. Field and laboratory reporting units and detection limits for pertinent data collected during the 2010 White Island Pond assessment				
Parameter	Matrix	Reporting Units	Detection Limit	Accuracy (+\-)
Field Measurements				
Temperature	Water	ºC	0.5°C	± 0.3 ºC
Dissolved Oxygen	Water	mg/l	0.5 ppm	± 0.3 mg/l or ± 2% of reading, whichever is greater
Secchi Disk Water Clarity	Water	meters	NA	10 cm
Laboratory Measurements – SMAST				
Alkalinity	Water	mg/l as $CaCO_3$	0.5	80-120% Std. Value
Chlorophyll-*a*	Water	µg/l	0.05	80-120% Std. Value
Nitrogen, Total	Water	µM	0.05	80-120% Std. Value
pH	Water	standard units	NA	80-120% Std. Value
Phosphorus, Total	Water	µM	0.1	80-120% Std. Value
Note: All SMAST laboratory measurement information from SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (January, 2003); all other laboratory measurement information from laboratory results and method listings.				

White Island Pond – North Basin Benthic Nutrient Regeneration Cores

- WIP13 (shallow)
- WIP12 (mid)
- WIP11 (deep)

White Island Pond – Middle Basin Benthic Nutrient Regeneration Cores

- WIP10 (mid)
- WIP9 (shallow)
- WIP8 (deep)
- WIP7 (deep)
- WIP6 (deep)
- WIP5 (shallow)

White Island Pond – South Basin Benthic Nutrient Regeneration Cores

- WIP4 (deep)
- WIP3 (mid)
- WIP2 (mid)
- WIP1 (deep)

Sediment sampling was distributed throughout the pond system and the results for each site are combined for calculating the net nutrient regeneration rates for determining pond nutrient balances. Sediment-water column exchange follows the methods of Jorgensen (1977), Klump and Martens (1983), and Howes (1998) for nutrients and metabolism. Upon return to the field laboratory temporarily set up adjacent the Pond, the cores were transferred to pre-equilibrated temperature baths. The headspace water overlying the sediment was replaced, magnetic stirrers emplaced, and the headspace enclosed. Periodic 60 ml water samples were withdrawn (volume replaced with filtered water), filtered into acid leached polyethylene bottles and held on ice for nutrient analysis. Ammonium (Scheiner, 1976) and ortho-phosphate (Murphy and Reilly, 1962) assays were conducted within 24 hours and the remaining samples frozen (-20°C) for assay of nitrate + nitrite (Cd reduction: Lachat Autoanalysis), and DON (D'Elia *et al*., 1977). Rates were determined from linear regression of analyte concentrations through time. The laboratory followed standard methods for analysis and sediment geochemistry as currently employed by the Coastal Systems Analytical Facility at SMAST-UMassD. These sediment sampling procedures have been approved MassDEP in the Massachusetts Estuaries Project QAPP. Sediment sampling results were incorporated into the MassDEP final TMDL for White Island Pond.

III.2. Field Collected Water Quality Data

III.2.1. Dissolved Oxygen and Temperature

Pond and lake ecosystems are controlled by interactions among the physical, chemical, and biological factors within a given lake. Light availability, water transparency, and nutrient availability can control the distribution of plants, both rooted and planktonic. The availability of oxygen often determines invertebrate animal habitat quality and the distributions of various mobile and sessile animal species living within a lake, with some species being sensitive to even small levels of oxygen depletion, while others are more tolerant of periodic low oxygen concentrations. Oxygen concentrations also determine the solubility of many inorganic elements; elevated concentrations of phosphorus, nitrogen, and iron, among other constituents, can occur in the deeper portions of ponds when anoxic conditions convert chemically-bound, solid forms in the sediments into soluble forms that are then released into the water column.

Oxygen solubility is physically controlled by water temperature, but biological interactions can modify oxygen concentrations especially during summer months. Higher temperature water holds less dissolved oxygen, but during the biologically active summer months, oxygen levels are primarily determined by a balance of production through photosynthesis, consumption by respiration and air-water exchange (ventilation). Ventilation is controlled by the pond's physical characteristics, such as depth, surface area, and its orientation to predominant winds. Since oxygen is one of the main byproducts of photosynthesis, a vigorous phytoplankton population can raise oxygen concentrations above those expected based simply on temperature/solubility interactions alone. Where these impacts occur in the water column is based on the amount of available nutrients and light. Conversely, as the phytoplankton populations die, they fall to the sediments where bacterial populations consume oxygen as they recycle this biomass. Too much plant growth can thus lead to anoxic sediment and near-sediment water conditions and a release of recycled nutrients back into the pond water from the sediments. The effects of this biological activity can be moderated by air-water exchange; excess oxygen can be ventilated to the atmosphere and sediment oxygen demand can be met by imports of atmospheric oxygen. The deeper the water the slower the rate vertical mixing, so deeper ponds will be more likely to have oxygen depletion of pond bottom waters. Since high biological activity is frequently caused by high rates of nutrient input (external and internal), deeper ponds are more sensitive to increased nutrient inputs.

The state surface water regulations (314 CMR 4) [24] have numeric standards for both dissolved oxygen and temperature. Under these regulations, ponds that are not used for drinking water supply are required to have a dissolved oxygen concentration of not less than 6.0 mg/l in cold water fisheries and not less than 5.0 mg/l in warm water fisheries. These regulations also require that temperature not exceed 68°F (20°C) in cold-water fisheries or 83°F (28.3°C) in warm water fisheries. There are additional provisions in the regulations that allow lower levels of oxygen or higher temperatures if it can be determined that these represent natural background conditions.

Given its depth and temperature regime, White Island Pond would be classified by the state as a warm water fishery and, thus, would have a minimum dissolved oxygen concentration of 5.0 mg/l as its regulatory limit. The regular occurrence of concentrations less than this limit can have profound impacts on fish and other animals in a pond ecosystem even if they rarely occur. Studies of fish populations have shown decreased diversity, total species, fecundity, and survival at regular low dissolved oxygen concentrations.[25,26,27] Concentrations of less than 1 ppm are generally lethal, even on a short-term basis, for most species.[28,29]

Shallow ponds in southeastern Massachusetts, those generally less than 9 meters (~30 ft) in depth, tend to have well-mixed water columns because typical winds blowing across the region generally have sufficient energy to move deeper waters up to the surface (*e.g.* vertically mixing).[30] In these ponds, both temperature and dissolved oxygen readings tend to be constant from surface to bottom and summer dissolved oxygen concentrations remain near saturation, in equilibrium with the atmosphere, and above MassDEP regulatory limits.

Statistical analysis of average summer (June – September) temperature and dissolved oxygen concentrations do not indicate significant differences ($\rho<0.05$) between the 2009 and 2010 summers or between the MassDEP 2000 data and the 2009 and 2010 summers. Comparison between the dissolved oxygen (DO) averages in each of the basins at select depths during the 2010 summer, however, do indicate some significant differences. The data show that the North and Middle Basin 2010 DO averages at 0.5 m, 1 m, and 2 m are significantly <u>higher</u> ($p<0.05$) than the West Basin. A similar, but non-significant, pattern was observed in 2009. Review of oxygen saturation percentages in 2010 confirm that while the West Basin typically are at equilibrium (~100%) with the atmosphere, the North and Middle Basins are higher at 0.5 m, averaging 114% and 108% of air equilibration, respectively. Saturation above 100% is generally

[24] Massachusetts Surface Water Quality Standards, 314 Code of Massachusetts Regulations 4.00, Department of Environmental Protection.

[25] Killgore, K.J. and J.J. Hoover. 2001. Effects of Hypoxia on Fish Assemblages in a Vegetated Waterbody. *Journal of Aquatic Plant Management*. 39: 40-44.

[26] Fontenot, Q.C., D.A. Rutherford, and W.E. Kelso. 2001. Effects of Environmental Hypoxia Associated with the Annual Flood Pulse on the Distribution of Larval Sunfish and Shad in the Atchafalaya River Basin, Louisiana. *Transactions of the American Fisheries Society*. 130: 107-116.

[27] Thurston, R.V., G.R. Phillips, R.C. Russo, and S.M. Hinkins. 1981. Increased Toxicity of Ammonia to Rainbow Trout (Salmo Gairdneri) Resulting from Reduced Concentrations of Dissolved Oxygen. *Canadian Journal of Fisheries and Aquatic Sciences*. 38(8): 983-988.

[28] Wetzel, R. G. 1983. Limnology. Second Edition. CBS College Publishing, New York.

[29] Matthews, K.R. and N.H. Berg. 1997. Rainbow trout responses to water temperature and dissolved oxygen stress in two southern California stream pools. *Journal of Fish Biology*. 50: 50-67.

[30] Eichner, E. 2008. Lake Wequaquet Water Quality Assessment. Completed for the Town of Barnstable and the Cape Cod Commission. Coastal Systems Program, School of Marine Science and Technology, University of Massachusetts Dartmouth.

due to large phytoplankton populations creating more dissolved oxygen in the water than would be expected based solely on temperature-controlled equilibrium. These results support the contention that it is reasonable to group the North and Middle Basins together and treat the West Basin separately.

Review of 2009 and 2010 dissolved oxygen and temperature readings in White Island Pond generally show that all basins of the pond tend to be vertically well mixed except for July and August in 2009 and to a lesser degree in July and August 2010. The temporary summer stratification can be seen in the temperature profiles in 2009 and have corresponding oxygen depletion of bottom waters (Figure III-2), both of which indicate that the water column is not mixing vertically. In addition, on August 19, dissolved oxygen concentrations in the deepest waters of the Middle portion of the East basin were below the 5 mg/l MassDEP limit for warm water fisheries. A similar oxygen depression is seen in the North basin data, although the concentration remains above the 5 mg/l MassDEP limit. During the same period in 2010, temperature readings indicate well-mixed, isothermic conditions, and while dissolved oxygen concentrations show the impact of sediment oxygen demand, the levels remained above the 5 mg/l limit. Dissolved oxygen concentrations at all depths during all other sampling dates were above the 5 ppm limit and concentrations at the West and North basins were always above the 5 ppm limit.

The temporary stratification in the Middle Basin in August 2009 suggests that some different conditions occurred within the pond in 2009. Shallow ponds, like White Island Pond, sometimes experience temperature layering during quiescent or cloudy weather conditions or if the volume of the pond substantially increases. Review of Plymouth weather data during July and August (precipitation, wind speed and gusts, temperatures, sun vs. clouds) do not suggest any meaningful differences between 2009 and 2010.[32] Review of pond water level data and accompanying total depths at the water quality monitoring stations show that 2009 in general and August, in particular, pond levels were elevated (see Figure II-4). With a greater pond depth, more wind energy would be necessary to sufficiently mix the water column and replenish oxygen consumed from the water column by sediment oxygen demand. Whatever the specific cause of the low oxygen event, it suggests that the pond is sufficiently nutrient and organic matter enriched that even short-term stratification can result in unacceptable bottom water oxygen levels. Additional nutrient inputs in this situation will generally result in more frequent and more pronounced levels of oxygen depletion.

Since MassDEP also recorded a 5.2 mg/l concentration in September 2000 near the deep location in the East Basin[33], the available data suggests that sediment oxygen demand periodically causes deep dissolved oxygen concentrations in the East Basin to fall below the MassDEP 5 mg/l regulatory limit. Readings show that this condition is not sustained and anoxic concentrations that would allow the majority of the sediment phosphorus are not attained. Since dissolved oxygen concentrations are on average above the 5 ppm limit, even during the higher temperature summer, one could make the case that White Island Pond should not be classified as an impaired water based strictly on the MassDEP dissolved oxygen criterion alone.

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[32] http://www.wunderground.com/history/airport/KPYM/

[33] Final Total Maximum Daily Load of Total Phosphorus for White Island Pond Plymouth/Wareham, MA. MassDEP, DWM TMDL Report MA95166-201009-1 CN 330.2 April 13, 2010.

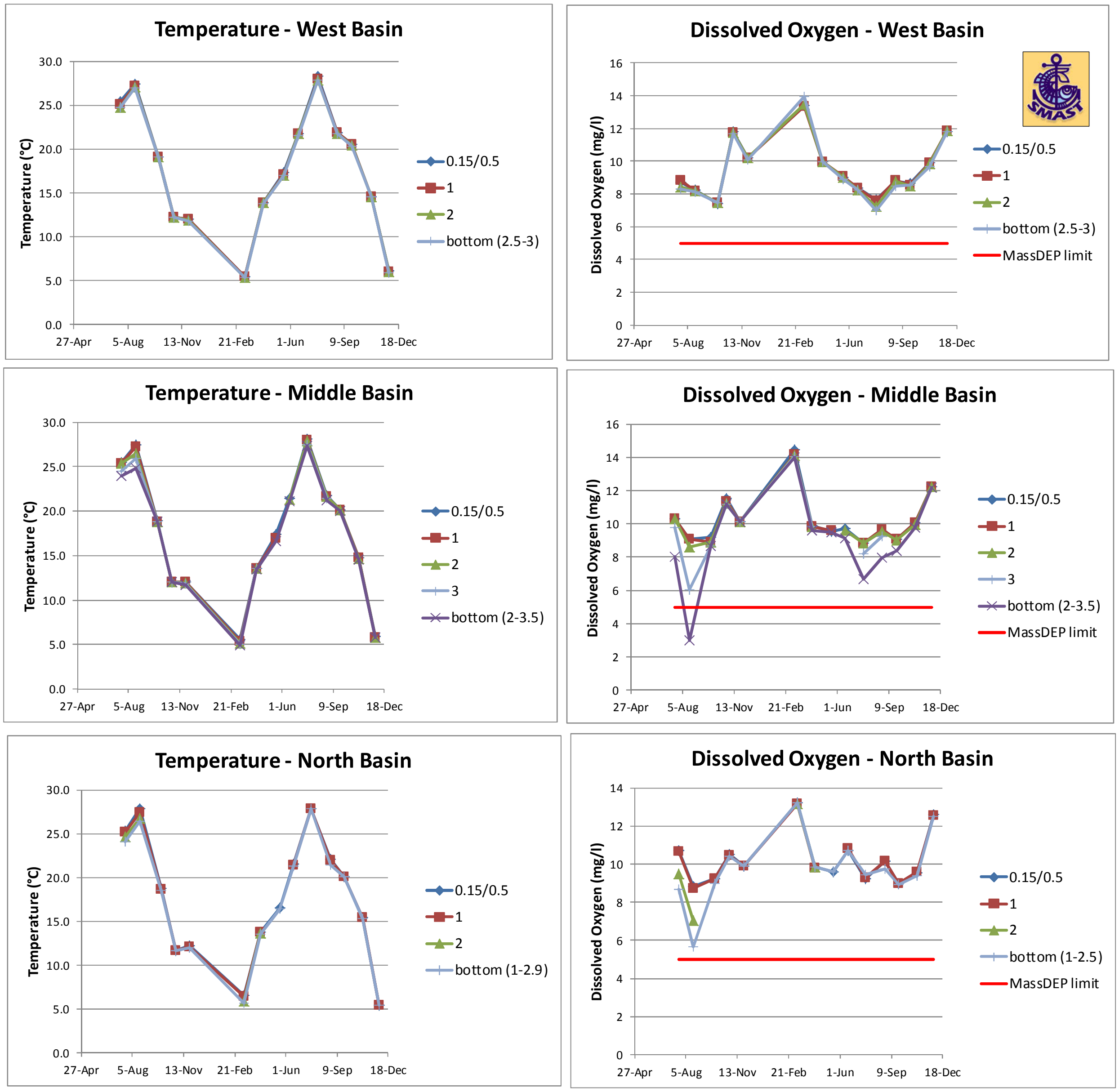

Figure III-2. 2009-2010 Temperature and Dissolved Oxygen at North, Middle, and West Basins in White Island Pond. Temperature (°C) and dissolved oxygen (mg/l) readings collected in 14 monthly samplings between July 22, 2009 and November 30, 2010 at the indicated sampling depths (m) in each basin are shown. All three basins show temperature maximums and dissolved oxygen minimums in June, July, and August. Both sets of readings generally indicate well-mixed water columns in all basins with similar measurements at all depths except for the Middle Basin in July and August 2009 (both temperature and dissolved oxygen) and July and August 2010 (dissolved oxygen). Decreased dissolved oxygen during the summer is consistent with increased summer sediment oxygen demand and lower dissolved oxygen capacity. All dissolved oxygen concentrations are above the MassDEP minimum limit for warm water ponds of 5 mg/l (314 CMR 4), which is indicated by a red line, except for the deepest (3.8 m) August 19, 2009 reading.

III.2.2. Secchi Depth

A Secchi disc is a 20 cm disc with black and white quadrants used to determine transparency, or light penetration, of water in ponds or lakes. Differences in Secchi depths are linked to fluctuations in concentrations of plankton, detritus, or inorganic particles. Therefore, a Secchi reading is an aggregate, general measure of water clarity generally related to nutrient related water quality and is especially useful if data is collected over multiple years.

Because of its ease of collection and its generalized nature, Secchi readings have been linked through a variety of analyses to trophic status of lakes.[36] Secchi depth is also related to the overall depth of a pond; if the pond is relatively shallow, the disk may be visible on the bottom even with significant algal densities within the watercolumn. Relative Secchi readings, which compare the Secchi depth to total depth at the sampling location, have also been used to assess the condition of a pond ecosystem. Since ponds in southeastern Massachusetts generally have very limited inorganic particles (which tend to be associated with stream or river inputs), Secchi readings in the region tend to be directly linked to algal populations or the resulting organic detritus, which are, in turn, linked to nutrient concentrations. The state does not have regulatory standards related to the water quality transparency of surface waters. The only state regulation related to water clarity is a state safe swimming clarity limit of 4 feet (105 CMR 435).[37]

Secchi readings were collected monthly between July 22, 2009 and November 30, 2010 over the deepest point in each of the three basins in White Island Pond (see Figure III-1 for sampling points). Secchi readings in both the North and the Middle Basins averaged less than the 4 ft (1.2 m) safe swimming limit during both the 2009 and 2010 summer (June through September), while the all readings in the West Basin were above the 4 ft limit (Figure III-3). There were clear differences in transparency between the basins. The western pond (South Basin) had significantly ($p<0.05$) higher transparency during the summer and year-round than the eastern Pond (North and Middle Basins). These findings suggest that nutrient concentrations and accompanying chlorophyll *a* concentrations should be lower in the South Basin.

Ecologically, the Secchi readings are indicative of how deeply light can penetrate into the pond water column and, thus, how much of the pond bottom and pond volume plants can get enough light to grow. On average during the 2010 summer (June through September) light could penetrate 63% of the 3.7 m water column within the West Basin, ranging from 47% to 73%. This is significantly ($\rho<0.05$) deeper light penetration than in the North or Middle Basins. The North Basin averaged 26% of its 3.1 m water column with a range of 23% to 32%. The Middle Basin averaged 23% of its 4.2 m water column with a range of 20% to 26%. 2009 readings are similar. The lack of a significant difference between the averages for the North and Middle basins reinforces that these basins should be combined for assessment and management purposes. It is clear that the western pond and eastern pond differ in water clarity, as well as

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36 Carlson, R.E. 1977. A trophic state index for lakes. *Limnology and Oceanography*. 22: 361-369.

37 Minimum Standards for Swimming Pools (State Sanitary Code: Chapter V), 105 Code of Massachusetts Regulations 405, Department of Public Health.

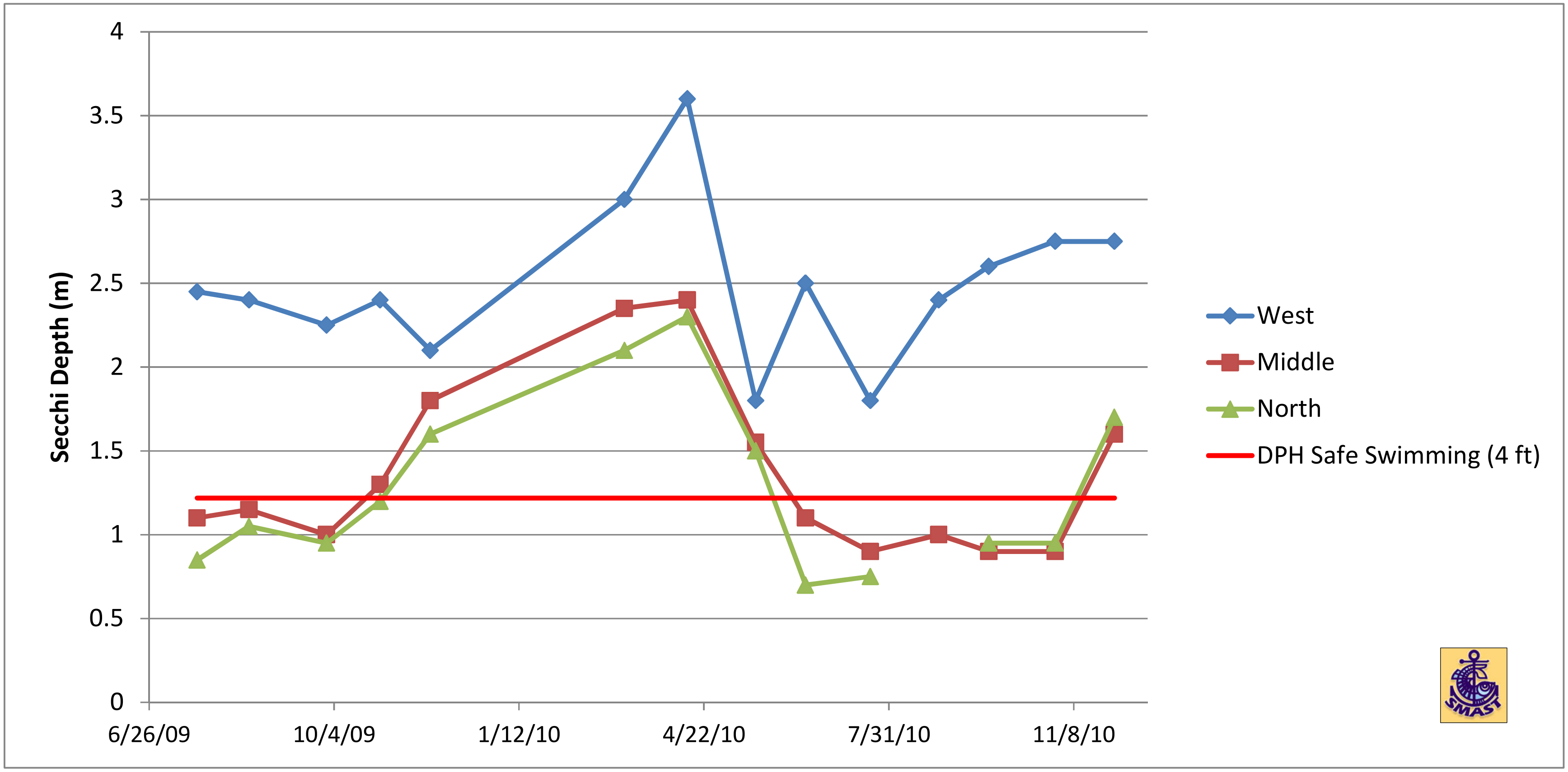

Figure III-3. 2009-2010 Secchi Readings in White Island Pond. The western pond supported clearer waters than the eastern pond (middle and north basins) throughout the July 22, 2009 to November 30, 2010 sampling period The eastern pond basins failed to meet the Massachusetts Department of Public Health limit of 4 ft (1.2 m) for safe swimming (105 CMR 405) during the summer months in 2009 and 2010.

extent of periodic oxygen depletion, consistent with the western pond being less nutrient impacted than the eastern pond.

Review of historic relative Secchi readings show that transparency in the eastern pond has not changed significantly between 2000 and 2010, but conditions in the western pond appear to fluctuate over a greater range. Comparisons between average summer (June to September) relative Secchi readings in the eastern pond (North/Middle basins) show no significant interannual differences ($\rho<0.05$) between readings collected in 2000, 2007, 2009, and 2010, averaging 26%, 20%, 29%, and 26%, respectively. In the western pond, there are no significant differences ($\rho<0.05$) between summer average relative Secchi readings in 2000 and 2007 or 2000 and either 2009 or 2010, but 2009 and 2010 averages are significantly higher than those in 2007. Review of the monthly results show that year-to-year fluctuations in clarity range from 33% to 82% in the West basin, but only 15% to 27% in the East Basin. These findings reinforce the West Basin differences from year-to-year, while indicating the consistently impaired conditions in the East Basin.

It should also be noted that the MassDEP sampling locations are not the same as those used during the 2009-2010 SMAST monitoring. The most significant difference is the location of the West station with the MassDEP station on the north side of the peninsula that divides the southern lobe of White Island and the 2010 station is on the southern side

III.3. Laboratory Water Quality Data

As mentioned above, unfiltered water samples were collected in the ponds 14 times at depths specified under the sampling plan. Water samples were analyzed at the SMAST Coastal Systems Analytical Facility Laboratory at UMASS Dartmouth for 16 constituents, including: total phosphorus (TP), total nitrogen (TN), pH, alkalinity, and chlorophyll *a*.

III.3.1. Total Phosphorus (TP) (319 Phosphorus Water Quality Data: In Pond)

Phosphorus is the key nutrient for management in ponds and lakes because additions of this nutrient result in algal blooms and eutrophication in freshwater systems. Typical plant organic matter contains phosphorous, nitrogen, and carbon in a ratio of 1P:7N:40C per 500 wet weight.[39] Therefore, if the other constituents are present in excess, phosphorus, as the limiting nutrient, can theoretically produce 500 times its weight in algae or phytoplankton. Because it is the "limiting" nutrient, 90% or more of the phosphorus occurs in organic forms (plant and animal tissue or plant and animal wastes) and any available inorganic phosphorus [mostly orthophosphate (PO_4^{-3})] is quickly taken up by the biota in a lake. Extensive research has been directed towards trying to determine the most important phosphorus pool for determining the overall productivity of lake ecosystems, but to date, most of the work has found that a measure of total phosphorus is the best predictor of productivity of lake ecosystems.[40] The laboratory analysis techniques for total phosphorus (TP) include all the various forms of phosphorus

[39] Wetzel, R. G. 1983. Limnology. Second Edition. CBS College Publishing, New York.
[40] Vollenweider, R.A. 1968. Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. Paris, Rep. OECD, DAS/CSI/68.27.

including ortho-phosphorus, total dissolved phosphorus, and particulate organic phosphorus (*i.e.*, all phosphorus incorporated into organic matter, including phytoplankton.

The most extensive water quality datasets for ponds comparable to White Island Pond are from Cape Cod ponds.[41] These ponds are predominantly kettle hole ponds created by glacial ice blocks that were surrounded by outwash sediments during retreat of the ice sheets toward the end of the last ice age approximately 12,000 years ago. These ponds tend to have low phosphorus concentrations due to the lack of phosphorus in the surrounding glacially-derived sands that make up the outwash sediments.

The median surface TP concentration in 175 Cape Cod ponds sampled during the summer of 2001 is 16 ppb (or µg/l).[42] A more limited sampling of 60 Cape Cod lakes in 1997 and 1998 found a similar mean TP concentration in surface waters of 14 ppb.[43] Using the US Environmental Protection Agency method[44] for determining nutrient thresholds and the data from 2001 sampling of Cape Cod ponds and lakes, Cape Cod Commission staff determined that a healthy Cape Cod freshwater pond should generally have a surface TP concentration no higher than 10 ppb.[45]

MassDEP has not promulgated TP limits in the state surface water regulations for different types of freshwater ponds and instead is developing TP limits based on assessments of individual lake water quality and whether those assessments indicate impaired water quality and the need for a TMDL. MassDEP sampled White Island Pond three times in 2000 (once each in July, August, and September) and five times in 2007 (once each in June, July, August, September, and October). Based on the collected information, MassDEP determined that the Pond has impaired water quality due to elevated phosphorus levels. Under the Clean Water Act, any waters classified by a state as being "impaired" must have a TMDL developed.[46]

In order to select the total phosphorus (TP) TMDL concentration for White Island Pond, MassDEP reviewed a number of sources. According to the draft TMDL, MassDEP staff reviewed: 1) the 1986 USEPA "Gold Book"[47] which generally recommends 25 ppb TP for warm water fisheries lakes, 2) the 1994 USEPA ecoregion assessment that recommended a range of 10 to 19 ppb for ponds in the White Island Pond region[48] and 3) the 2001 USEPA Nutrient Criteria guidance for the White Island Pond Ecoregion which recommends 8 ppb TP as a

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[41] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA. 299 pp.

[42] *Ibid.*, pp. 23-25.

[43] Ahrens, T.D., and P.A. Siver. 2000. Trophic conditions and water chemistry of lakes on Cape Cod, Massachusetts, USA. Lake and Reservoir Management. 16(4): 268-280.

[44] United States Environmental Protection Agency. 2000. Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs. First Edition. EPA-822-B00-001. US Environmental Protection Agency, Office of Water, Office of Science and Technology. Washington, DC.

[45] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA. pp. 23-25.

[46] Public Law 92-500. Section 303 (D)(1)(c). Federal Water Pollution Control Act Amendments of 1972

[47] US Environmental Protection Agency. 1986. Quality Criteria for Water. EPA 440/5-86-001.

[48] Griffith, G.E., J.M. Omernik, S.M. Pierson, and C.W. Kiilsgaard. 1994. Massachusetts Ecological Regions Project. USEPA Corvallis. Massachusetts DEP, DWM Publication No. 17587-74-70-6/94-D.E.P.

reference condition.[49] MassDEP does not have a numerical standard for phosphorus in surface waters in the current state surface water regulations, but does have narrative standards for nutrients that say, in part, "all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses."[50] MassDEP concluded the following in setting the 19 ppb TP limit for White Island Pond:

> "Thus the target is set at the upper range of the Griffith et al., (1994) and Rohm et al., (1995) ecoregion concentrations for this area, specifically, 0.019 mg/l as an overall average for the two basins. In order to ensure that the lake meets water quality standards, the overall average should be lower than the 0.025 mg/l Gold Book number and is set to 0.019 mg/l as a margin of safety."[51]

All three of the White Island Pond stations sampled in the summers of 2009 and 2010 (June to September) have average surface concentrations exceeding the TMDL 19 µg/l total phosphorus threshold: North respective averages are 54 and 52 µg/l, Middle respective averages are 62 and 57 µg/l, and South respective averages 28 and 32 µg/l (Figure III-4). The lowest single surface concentration during this period is 21.4 µg/l recorded September 23 at the South station. Of the 165 TP concentrations measured in 2009 and 2010, seven (4%) were less than 19 µg/l and only one was recorded during the summer.

All White Island Pond basins display an average summer gradient of rising TP concentrations with depth; this is indicative of significant sediment release of phosphorus. The greatest vertical gradient is in the Middle basin, which is expected since this is the deepest basin and likely has the highest rate of organic matter deposition. Average deep summer concentration in the Middle basin is 85 µg/l based on combined 2009 and 2010 data, while comparable concentrations are 66 µg/l in the North basin and 51.2 µg/l in the West basin. Statistical analysis shows no significant difference between surface and bottom summer or year-round averages in either the Middle or North basins in 2009 or 2010. This finding suggests that TP regenerated from the sediments is being mixed throughout the water column, which is consistent with the Secchi readings and the temperature and dissolved oxygen profiles.

Average summer surface concentrations at the West basin are significantly lower ($\rho<0.05$) than the corresponding Middle station average during both 2009 and 2010, while the differences with North basin are just short of statistical significance ($\rho<0.12$ and $\rho<0.08$, respectively). There is no significant differences between summer surface or deeper average concentrations between the North and Middle stations; again reinforcing that these portions of the pond can be grouped together and treated as a single representation of the eastern pond. However, the differences in TP (and other parameters) between the western and eastern ponds indicate that while these basins are hydraulically connected they represent two different systems in terms of water quality.

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[49] US Environmental Protection Agency. 2001. Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria, Lakes and Reservoirs in Nutrient Ecoregion XIV. EPA 822-B-01-011.
[50] Massachusetts Surface Water Quality Standards, 314 CMR 4.05(5)(c).
[51] Final Total Maximum Daily Load of Total Phosphorus for White Island Pond Plymouth/Wareham, MA. MassDEP, DWM TMDL Report MA95166-201009-1 CN 330.2 April 13, 2010. pg. 35.

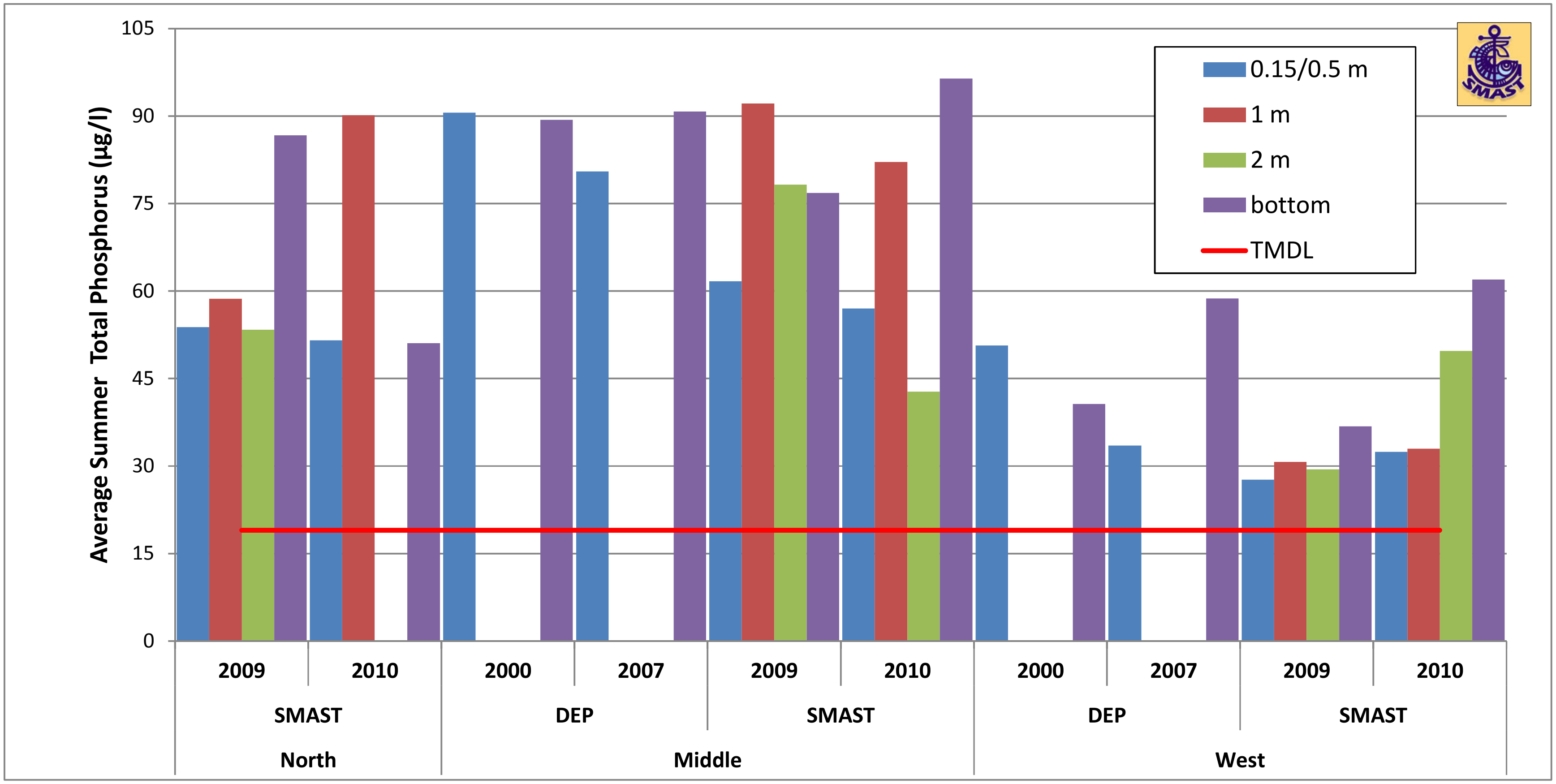

Figure III-4. Average summer total phosphorus concentrations in White Island Pond: 2000, 2007, 2009, and 2010. Averages are based on June through September total phosphorus concentrations; 2000 and 2007 data is from MassDEP draft TMDL, while 2009 and 2010 data were collected for this assessment. The red line is the MassDEP TMDL total phosphorus concentration of 19 µg/l. In general, the surface (0.15/0.5 m) average concentrations were similar from year to year, except the 2000 MassDEP average in the Middle Basin is significantly higher (t-test, $\rho<0.005$) than the 2009 and 2010 averages. In contrast, deep waters in the West station in 2007 and 2010 have significantly higher TP levels than in 2000 and 2009 (t-test, $\rho<0.05$). West station surface averages in 2009 and 2010 are significantly (t-test, $\rho<0.05$) lower than corresponding averages in the Middle Basin; there are no significant differences between the 2009 and 2010 averages in the Middle and North basins at any of the depths.

Comparison of average summer TP concentrations in 2009 and 2010 generally show no significant differences at any depth except for the deep reading in the West basin. Summer average 2009 TP concentration (37 µg/l) at the deep station in the West basin is significantly ($\rho<0.05$) lower than 2010 average (62 µg/l). This is consistent with the higher TP concentrations at all depths in 2010 versus 2009 in the West basin. However, it is notable that 2010 deep station TP average is not significantly different from the 2007 average (59 µg/l) measured by MassDEP, yet is significantly higher than the 2000 average (41 µg/l).

In the East basin, comparisons of summer 2000, 2007, 2009 and 2010 TP data generally show no significant differences with the exception of average surface TP concentrations in 2000 and both 2009 and 2010. East basin average surface TP concentration in 2000 as measured by MassDEP is 90.6 µg/l.[52] This TP concentration is significantly higher than average summer surface concentrations measured in 2009 in the combined North and Middle basins (58 µg/l) and in 2010 (54 µg/l).

Aside from measuring how much TP is in White Island Pond, in order to develop a reasonable phosphorus budget we should also measure how much is leaving the pond via the surface water outlets. TP concentrations in the two outlets generally are similar (Figure III-5). The herring run outlet had continuous flow throughout 2010, but there is no flow from the main outlet after April 29, except for a September 10 event (see Figure II-6). TP concentrations at the two outlets for the period up to April 29 are not significantly different; the herring run averaging 33.6 µg/l and the main outlet averaging 26.1 µg/l. The TP average for the herring run over the entire year is 55.5 µg/l and 63.7 µg/l for the June to September period. As would be expected, the summer average concentration at the herring run outlet is not significantly different from the average surface concentration at the Middle Station in the pond, which is the closest water quality station to the outlet.

III.3.2. Total Nitrogen (TN)

Nitrogen is one of the primary macro-nutrients in surface water systems (phosphorus and potassium being the other two). Nitrogen is transferred between a number of chemical species (nitrate, nitrite, ammonium, nitrogen gas, and organic nitrogen) depending on a number of factors, including dissolved oxygen, pH, and biological uptake and respiration.[53] Nitrate-nitrogen is the fully oxidized form of nitrogen, while ammonium-nitrogen is the fully reduced (*i.e.*, low oxygen) form. Fixed inorganic nitrogen generally enters ponds in the nitrate-nitrogen form, is incorporated into pond biota, forming organic nitrogen, and then is converted back to inorganic forms (nitrate- and ammonium-nitrogen) in the excreta from plankton or organisms higher up the food chain or from bacteria decomposing dead plankton in the sediments. Total Kjeldahl nitrogen (TKN) is a combined measure of organic nitrogen and ammonium forms. Total nitrogen (TN) is generally reported as the addition of TKN and nitrate-nitrogen concentrations.

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[52] Final Total Maximum Daily Load of Total Phosphorus for White Island Pond Plymouth/Wareham, MA. MassDEP, DWM TMDL Report MA95166-201009-1 CN 330.2 April 13, 2010. Appendix I.

[53] Stumm, W. and J.J. Morgan. 1981. *Aquatic Chemistry*. John Wiley & Sons, Inc., New York, NY.

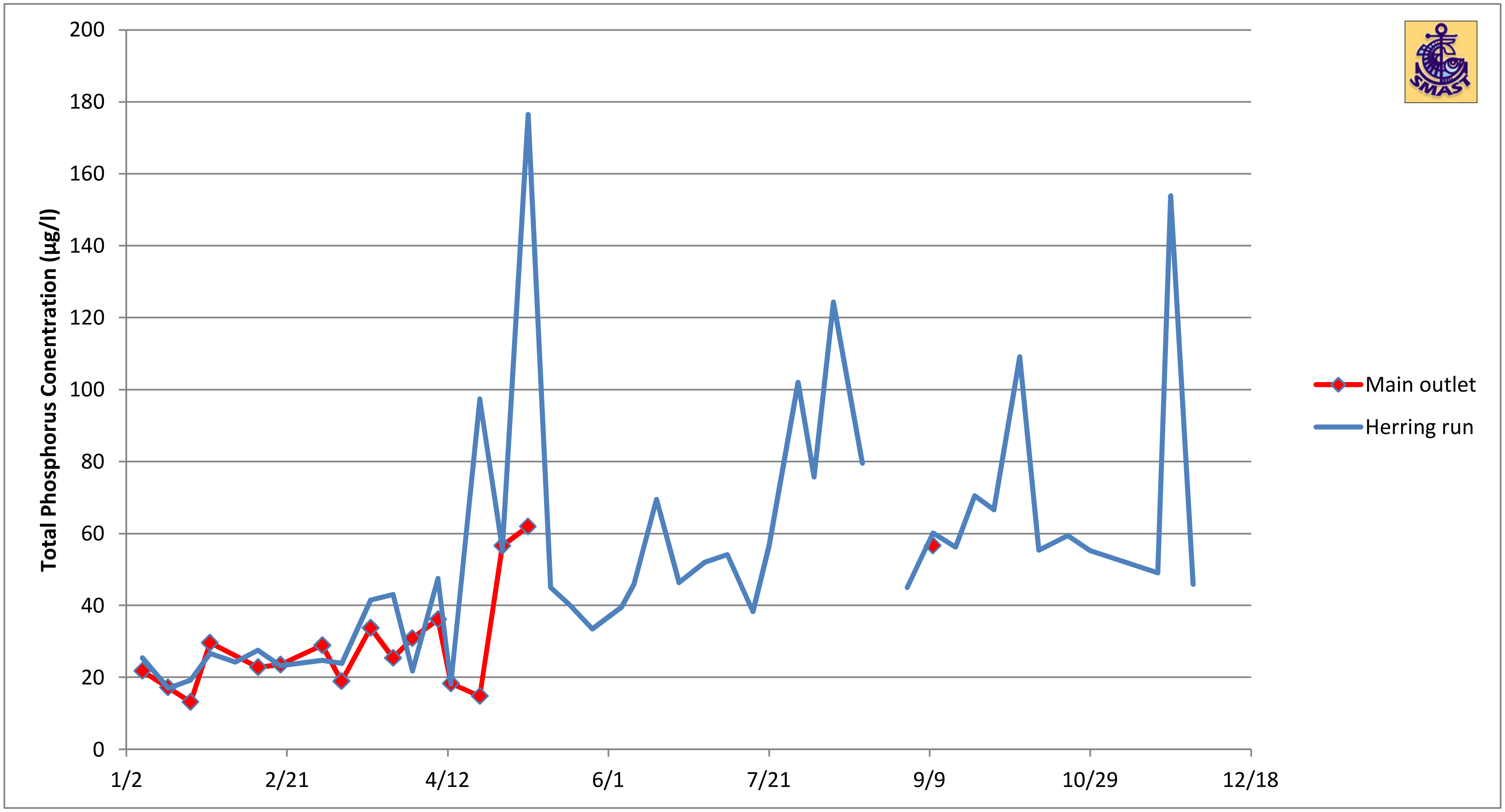

Figure III-5. Total phosphorus concentrations in White Island Pond stream outlets: 2010. The herring run outlet has continuous flow throughout 2010, but there is no flow from the main outlet after April 29, except for on September 10. TP concentrations at the two outlets for the period up to April 29 are not significantly different. The TP average for the herring run over the entire year is 55.5 µg/l and it is 63.7 µg/l for the June to September period. The summer average concentration at the herring run outlet is not significantly different from the average surface concentration at the closest in-pond station, Middle Basin.

Nitrogen is not usually the nutrient that limits growth in freshwater ponds, but ecosystem changes during the course of a year or very high phosphorus loads without associated nitrogen inputs can create conditions where it is the limiting nutrient to plant growth. In very productive or eutrophic lakes, phytoplankton that can extract nitrogen directly from the atmosphere, which is approximately 75% nitrogen gas, often have a strong competitive advantage and tend to dominate the pond ecosystem. These blue-green phytoplankton, often also known as cyanophytes or blue green bacteria, are generally indicators of excessive nutrient loads. MassDEP does not have a numerical standard for nitrogen in surface waters in the state surface water regulations, but does have narrative standards for nutrients that say, in part, "all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses."[55]

Nitrogen is a primary pollutant associated with wastewater. Septic systems, the predominant wastewater treatment technology throughout southeastern Massachusetts, generally introduce treated effluent to the groundwater with total nitrogen concentrations between 20 and 40 ppm: Massachusetts Estuaries Project watershed nitrogen loading analyses use 26.25 ppm as an effective TN concentration for septic system treated wastewater.[56] Because septic systems are abundant sources of nitrogen, ponds and lakes in southeastern Massachusetts tend to have relatively high concentrations of nitrogen; the 184 Cape Cod ponds with TN concentrations sampled in the 2001 PALS Snapshot had an average surface water TN concentration of 0.58 ppm [or milligrams per liter (mg/l)].[57] Using the EPA method for determining nutrient thresholds[58] and the data from the 2001 PALS Snapshot data, Cape Cod Commission staff determined that healthy freshwater ponds on Cape Cod should generally have a surface TN concentration no higher than 0.31 ppm.[59] USEPA development of ecoregion specific reference concentrations generally agree with the Cape Cod estimate and recommend a TN concentration of 0.32 ppm.[60]

Average summer surface concentrations at the three White Island Pond stations using combined 2009 and 2010 readings are: North average is 0.97 mg/l, Middle average is 0.90 mg/l, and South average is 0.65 mg/l. There is generally no significant difference between the average summer TN concentrations in 2009 and 2010 within each of the basin except for the significantly ($\rho<0.05$) higher concentration in 2010 at the 3 m depth in the Middle basin (Figure III-6). Surface and deep readings at the stations are not statistically different, which is indicative of vertically well-mixed conditions. Year-round averages are generally lower than summer

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[55] Massachusetts Surface Water Quality Standards, , 314 CMR 4.05(5)(c).

[56] *e.g.,* Howes, B., H.E. Ruthven, J. S. Ramsey, R. Samimy, D. Schlezinger, J. Wood, and E. Eichner. 2006. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Centerville River System, Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

[57] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

[58] United States Environmental Protection Agency. 2000. Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs. First Edition. EPA-822-B00-001. US Environmental Protection Agency, Office of Water, Office of Science and Technology. Washington, DC.

[59] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

[60] US Environmental Protection Agency. 2001. Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria, Lakes and Reservoirs in Nutrient Ecoregion XIV. EPA 822-B-01-011.

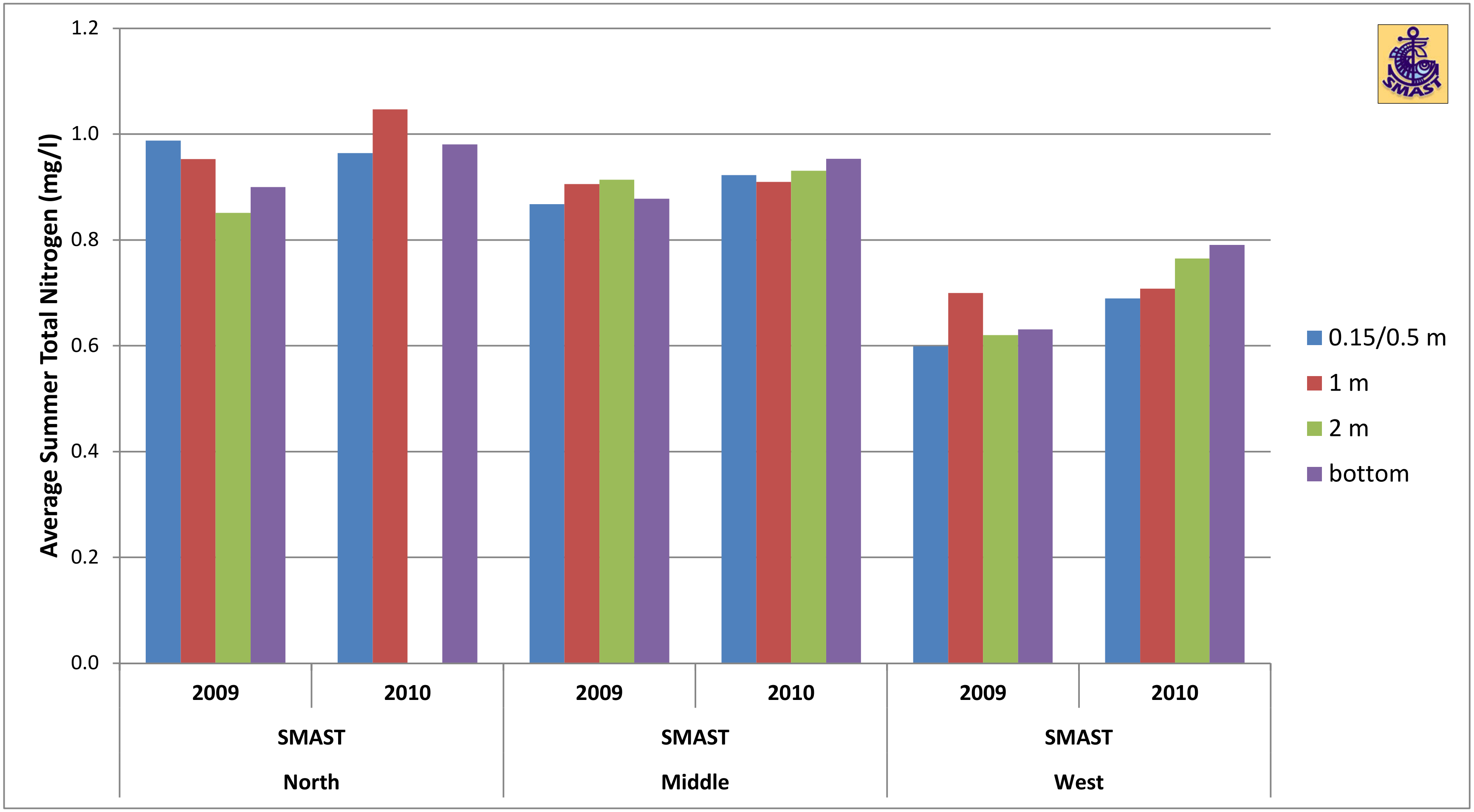

Figure III-6. Average total nitrogen concentrations in White Island Pond: 2009 and 2010. Averages summer (June through September) total nitrogen concentrations collected by SMAST in 2009 and 2010 for this assessment. Average TN concentrations were significantly higher in the Eastern pond (Middle and North stations) than the Western pond (South station) in both 2009 and 2010. Similarly, in 2010 TN at all depths at the West basin are significantly ($\rho<0.05$) lower than the corresponding Middle basin averages and both of the shallow depths at the North basin. Similar relationships exist in 2009 and for year-round concentration averages.

averages which is indicative of either summer sediment regeneration or higher seasonal loading, but these differences are generally not statistically significant.

Comparisons between the basins shows that the West Basin has significantly lower average summer TN concentrations and generally insignificant differences between the North and Middle Basins. Average summer 2010 TN concentrations at all sampling depths in the West Basin are significantly lower ($\rho<0.05$) than corresponding averages in the Middle Basin and the top two depths are significantly lower than the corresponding averages in the North Basin. These relationships are comparable to those measured in 2009 and when year-round averages are compared. As with the total phosphorus concentrations, there is generally no significant difference between average summer concentrations at the Middle and North stations at all depths except for surface concentrations in 2009 (0.87 mg/l and 0.99 mg/l, respectively). These results further suggest that these portions of the pond can be grouped together and treated as a single eastern pond basin. Overall, these differences in the averages between the West and combined East basins suggest that there is differential nitrogen loading to each basin.

TN is not among the analytes reported by MassDEP in the either the 2000 or 2007 samplings of White Island Pond. MassDEP has not promulgated a numeric TN limit in the state surface water regulations and did not include a TN limit in the TMDL for White Island Pond. It is notable that average 2010 TN concentrations at all stations and all depths in White Island Pond are above the available recommended TN limits developed for ponds in the same ecoregion.[61]

TN concentrations in the two outlets generally are similar (Figure III-7). The herring run outlet has continuous flow throughout 2010, but there is no flow from the main outlet after April 29, except for the September 10 (see Figure II-6). TN concentrations at the two outlets for the period up to April 29 are not significantly different; the herring run averages 0.51 mg/l and the main outlet averages 0.52 mg/l. The TN average for the herring run over the entire year is 0.79 mg/l and it is 0.96 mg/l for the June to September period. The summer average concentration at the herring run outlet is not significantly different from the average surface concentration at the Middle Station in the pond.

III.3.3. Alkalinity and pH

pH is a measure of acidity; pH values less than 7 are considered acidic, while pH values greater than 7 are considered basic, 7 is neutral. pH is the negative log of the hydrogen ion concentration in water (*e.g.*, water with a H^+ concentration = $10^{-6.5}$ has a pH of 6.5). pH is determined by the interaction of all of the ions with carbon species, like carbon dioxide, carbonate, and bicarbonate, having the most direct effect.[62] The natural pH of rainwater, in equilibrium with carbon dioxide in the atmosphere, is 5.65. Photosynthesis takes carbon dioxide and hydrogen ions out of the water causing pH to increase, so more productive, higher nutrient lakes will tend to have higher pH measurements. Alkalinity is a measure of the compounds that shift pH toward more basic values, is mostly determined by the concentrations of bicarbonate, carbonates, and hydroxides, and is a measure of the capacity of waters to buffer acidic inputs.

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[61] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

[62] Stumm, W. and J.J. Morgan. 1981. Aquatic Chemistry. John Wiley & Sons, Inc., New York, NY.

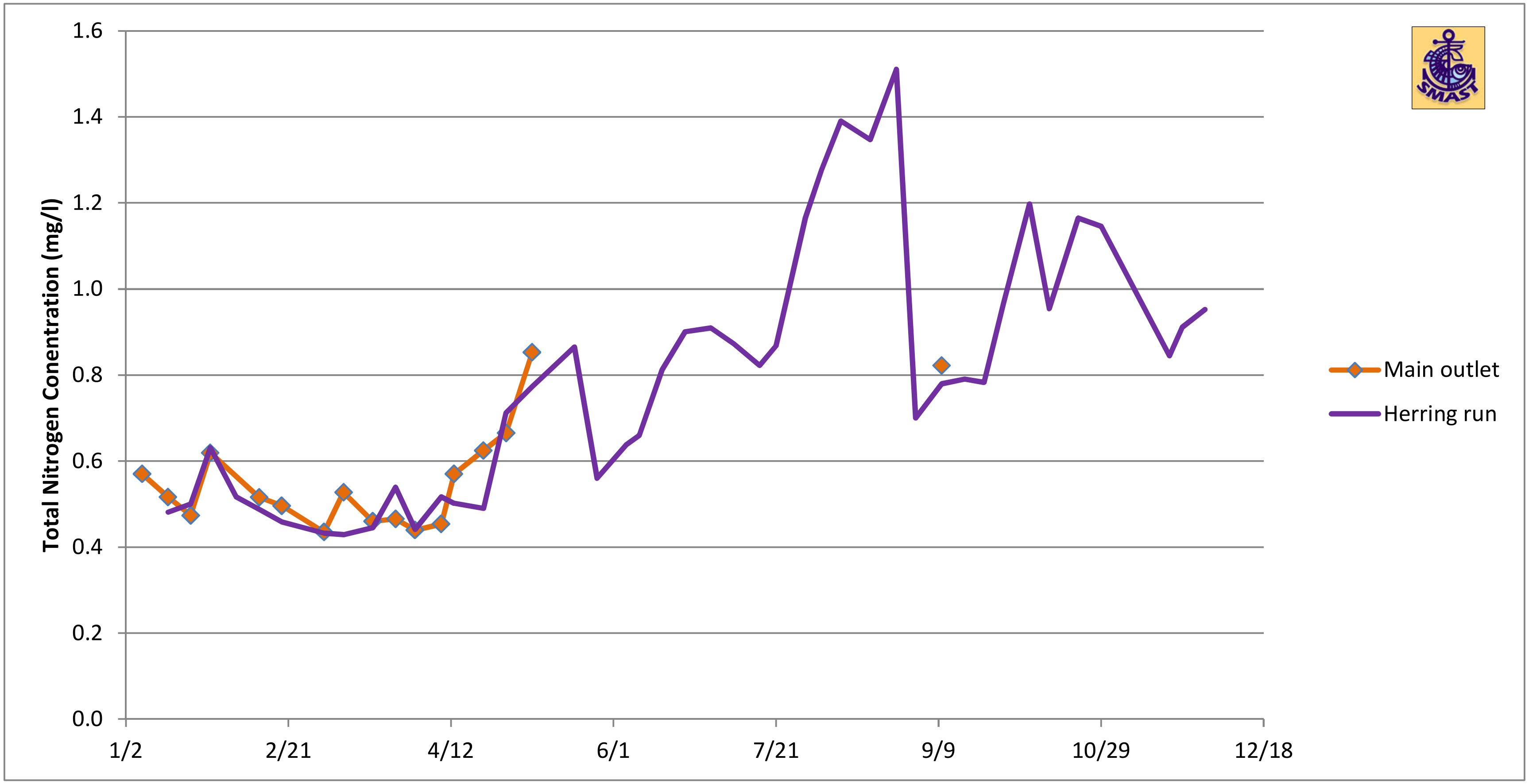

Figure III-7. Total nitrogen concentrations in White Island Pond stream outlets: 2010. The herring run outlet has continuous flow throughout 2010, but there is no flow from the main outlet after April 29, except for a September 10 event (see Figure II-6). TN concentrations at the herring run and main outlet for the period up to April 29 are not significantly different, averaging 0.51 mg/l and 0.52 mg/l, respectively. The annual TN average for the herring run is 0.79 mg/l and 0.96 mg/l for the June to September period. The summer average concentration at the herring run outlet is similar to the nearest pond water quality station, Middle station 0.92 mg/l.

Since both alkalinity and pH are related to the same chemical species, pH and alkalinity are linked values.

Since the sand deposited in southeastern Massachusetts during the last glacial period does not have carbonate minerals, these soils have low alkalinity and little capacity to buffer the naturally acidic rainwater. Available groundwater data in southeastern Massachusetts, the most extensive of which is from Cape Cod, shows this; groundwater pH on Cape Cod is generally between 6 and 6.5. Late 1970s sampling of groundwater from 202 Cape Cod wells found a median pH of 6.1.[66] Since the ponds in these soils are tightly connected to the groundwater, the pH in the ponds closely approximates groundwater pH unless nutrients have made the pond more productive. The average surface pH of 193 Cape Cod ponds sampled in the 2001 PALS Snapshot is 6.16 with a range of 4.38 to 8.92, while the average alkalinity is 7.21 mg/L as $CaCO_3$ with a range of 0 to 92.1.[67]

MassDEP has a numerical standard for pH in surface waters in the state surface water regulations; Class A and B fresh surface waters "Shall be in the range of 6.5 through 8.3 standard units and not more than 0.5 units outside of the natural background range. There shall be no change from natural background conditions that would impair any use assigned to this Class."[68] The MassDEP TMDL includes pH data from 2000, but it is not analyzed in the water quality review of the document.[69]

Surface pH readings at the three White Island Pond stations during the 2009 and 2010 summers (June through September) are: North averages are 7.1 and 8.4, Middle averages are 7.4 and 7.3, and South averages are 6.4 and 6.6 (Figure III-8). Summer surface averages based on MassDEP 2000 data are: Middle, 6.8 and West, 6.3; MassDEP did not collect water quality samples in the North basin in 2000. Given the variability in the data, there is no significant difference among these yearly averages in each of the basins, although the trend is consistent with the other water quality parameters (see above) indicating more eutrophic conditions in the eastern versus western pond basins.

The average summer 2010 readings in the western pond (South station), at all depths, are significantly lower ($\rho<0.05$) than the corresponding eastern pond (Middle or North station) averages. In contrast, there were no significant differences between basins in 2009 and 2000. Since higher pH is related to the amount of photosynthesis and the phytoplankton population, these readings suggest that the summer of 2010 had a greater difference between the phytoplankton growth in the eastern pond than western pond.

Alkalinity concentrations are more stable than pH readings, likely due to the dominance of carbonates and bicarbonates in determining alkalinity concentrations in the range of observed

66 Frimpter, M.H. and F.B. Gay. 1979. Chemical Quality of Ground Water on Cape Cod, Massachusetts. Water Resources Investigations 79-65. US Geological Survey. Boston, MA.

67 Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

68 Massachusetts Surface Water Quality Standards, 314 CMR 4.05(3)(a)3 and 314 CMR 4.05(3)(b)3.

69 Appendix I. Final Total Maximum Daily Load of Total Phosphorus for White Island Pond Plymouth/Wareham, MA. MassDEP, DWM TMDL Report MA95166-201009-1 CN 330.2 April 13, 2010.

Figure III-8. Average summer pH readings in White Island Pond: 2000, 2009, and 2010. Averages are based on June through September pH readings; 2009 and 2010 data was collected for this assessment, while 2000 data was collected by MassDEP. Red lines bound the state regulatory range (310 CMR 4). Average 2010 readings at all depths in the western pond (South station) are significantly lower [t-test ($\rho<0.05$)] than the eastern pond (Middle or North station). None of the corresponding 2009 readings are significantly different between the basins and the difference between the West and Middle basins in 2000 is also not significant.

pHs[72], but the alkalinity relationships between the basins are similar to those for pH. Average surface alkalinity concentrations at the three White Island Pond stations during the 2010 summer (June through September) are: North average is 5.6, Middle average is 5.3, and South average is 4.4. These concentrations are generally higher than those collected by MassDEP in 2000[73], but not at the $\rho<0.05$ significance level. MassDEP did not analyze water samples for alkalinity in 2007. The average summer and year-round concentrations at the South station, at all depths, are significantly lower ($\rho<0.05$) than the corresponding Middle or North station averages. The Middle and North station summer and year-round averages are generally not significantly ($\rho<0.05$) different except for the significantly higher summer average concentration at the 1 m depth at the North station.

III.3.4. Chlorophyll *a* (CHL-a)

Chlorophyll is the primary photosynthetic pigment in plants, both phytoplankton and macrophytes (*i.e.*, any aquatic plants larger than microscopic phytoplankton, including rooted aquatic plants). Because of its prevalence, measurement of chlorophyll can be used to estimate how much phytoplankton biomass is present in collected water samples. Chlorophyll-*a* is a specific type of chlorophyll pigment and plays a primary role in photosynthesis.[74]

Laboratory procedures for chlorophyll can be somewhat complicated because its breakdown products have very similar characteristics; for this reason SMAST labs also quantify pheophytin-*a*, the primary initial breakdown product of chlorophyll-*a*. Since chlorophyll-*a* is a measure of active photosynthetic pigment, pheophytin-*a* is sometime characterized as “dead” chlorophyll.

Since most southeastern Massachusetts ponds and lakes have relatively low phosphorus inputs, rooted plant populations tend to be small and phytoplankton populations are sparse. Because phytoplankton populations are the source of chlorophyll in pond waters, chlorophyll concentrations also tend to be low. Cape Cod has the largest number of ponds sampled in the southeastern Massachusetts ecoregion; the median surface concentration in the 191 Cape Cod ponds sampled for chlorophyll-*a* during the 2001 Pond and Lake Stewards (PALS) Snapshot is 3.6 ppb (or µg/l) with a range from below detection limit to 86 ppb.[75] A more limited sampling of 60 Cape ponds found a similar mean chlorophyll-*a* concentration of 3.07 ppb with a range of 0.51 to 19.25 µg/l.[76]

[72] Stumm, W. and J.J. Morgan. 1981. Aquatic Chemistry. John Wiley & Sons, Inc., New York, NY.

[73] Appendix I. Final Total Maximum Daily Load of Total Phosphorus for White Island Pond Plymouth/Wareham, MA. MassDEP, DWM TMDL Report MA95166-201009-1 CN 330.2 April 13, 2010

[74] United States Environmental Protection Agency. 2000. Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs. First Edition. EPA-822-B00-001. US Environmental Protection Agency, Office of Water, Office of Science and Technology. Washington, DC.

[75] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

[76] Ahrens, T.D., and P.A. Siver. 2000. Trophic conditions and water chemistry of lakes on Cape Cod, Massachusetts, USA. Lake and Reservoir Management. 16(4): 268-280.

As with TP and TN, Cape Cod Commission staff also used the US Environmental Protection Agency method[77] for determining nutrient thresholds and the 2001 PALS Snapshot data to determine that healthy freshwater ponds on Cape Cod, and, by reasonable extension, any in southeastern Massachusetts, should generally have a surface chlorophyll *a* concentrations no higher than 1.7 ppb. This same analysis also found that the most protected or pristine ponds on Cape Cod have surface chlorophyll *a* concentrations of no higher than 1.0 ppb.[78] Pheophytin was not considered in this analysis. USEPA development of ecoregion specific reference concentrations for ponds and lakes recommends a chlorophyll-*a* concentration of 2.9 ppb.[79]

Average surface chlorophyll-*a* concentrations at the three White Island Pond stations during the 2009 and 2010 summers (June through September) are, respectively: North 39.2 and 7.6 µg/l, Middle 27.1 and 13.6 µg/l, and West 11.1 and 11.6 µg/l (Figure III-9). There is no statistically significant ($\rho<0.05$) difference among any of depths or between any of the stations except for two 2009 significantly lower average concentrations at the West basin compared to: 1) the North basin at the 0.5 m depth and 2) the Middle basin at the 1 m depth. The lack of statistically significantly differences is in large part due to the variability of chlorophyll-*a* during summer.

MassDEP measured chlorophyll-*a* concentrations in 2000 and 2007, but samples were integrated samples throughout the water column instead of collection at discrete depths. The average concentrations are shown in the shallow category in Figure III-9. MassDEP average concentrations in the Eastern pond (Middle basin) and Western pond are generally the same as those collected in 2009 and 2010 with similar fluctuations.

Figure III-10 shows that chlorophyll-*a* concentrations during July 2009 in the Eastern pond (Middle and North stations) are among the highest recorded for White Island Pond, as high as the 2007 MassDEP record for the Eastern pond. The July spikes were followed by declining concentrations that generally mirror those measured in 2010. The high 2009 chlorophyll-a concentrations generally correspond to the low oxygen levels and temperature layering that apparently associated with temporary stratification (see Section III-2 for discussion). Concentrations in each basin in 2010 have a May/June spike followed by a July decline and then an August/September spike followed by an October decline. This type of fluctuation is usually seen in lakes where availability of a key growth factor fluctuates[80] and is common in eutrophic lakes.[81] Average 2009 and 2010 chlorophyll-*a* concentrations at all stations in White Island Pond are above available recommended limits and are an unequivocal indicator of nutrient enrichment.

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[77] United States Environmental Protection Agency. 2000. Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs. First Edition. EPA-822-B00-001. US Environmental Protection Agency, Office of Water, Office of Science and Technology. Washington, DC.

[78] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

[79] US Environmental Protection Agency. 2001. Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria, Lakes and Reservoirs in Nutrient Ecoregion XIV. EPA 822-B-01-011.

[80] Wetzel, R. G. 1983. *Limnology*. Second Edition. CBS College Publishing, New York.

[81] Marshall, C.T. and R.H. Peters. 1989. General Patterns in the Seasonal Development of Chlorophyll a for Temperate Lakes. *Limnology and Oceanography*. 34(5): 856-867.

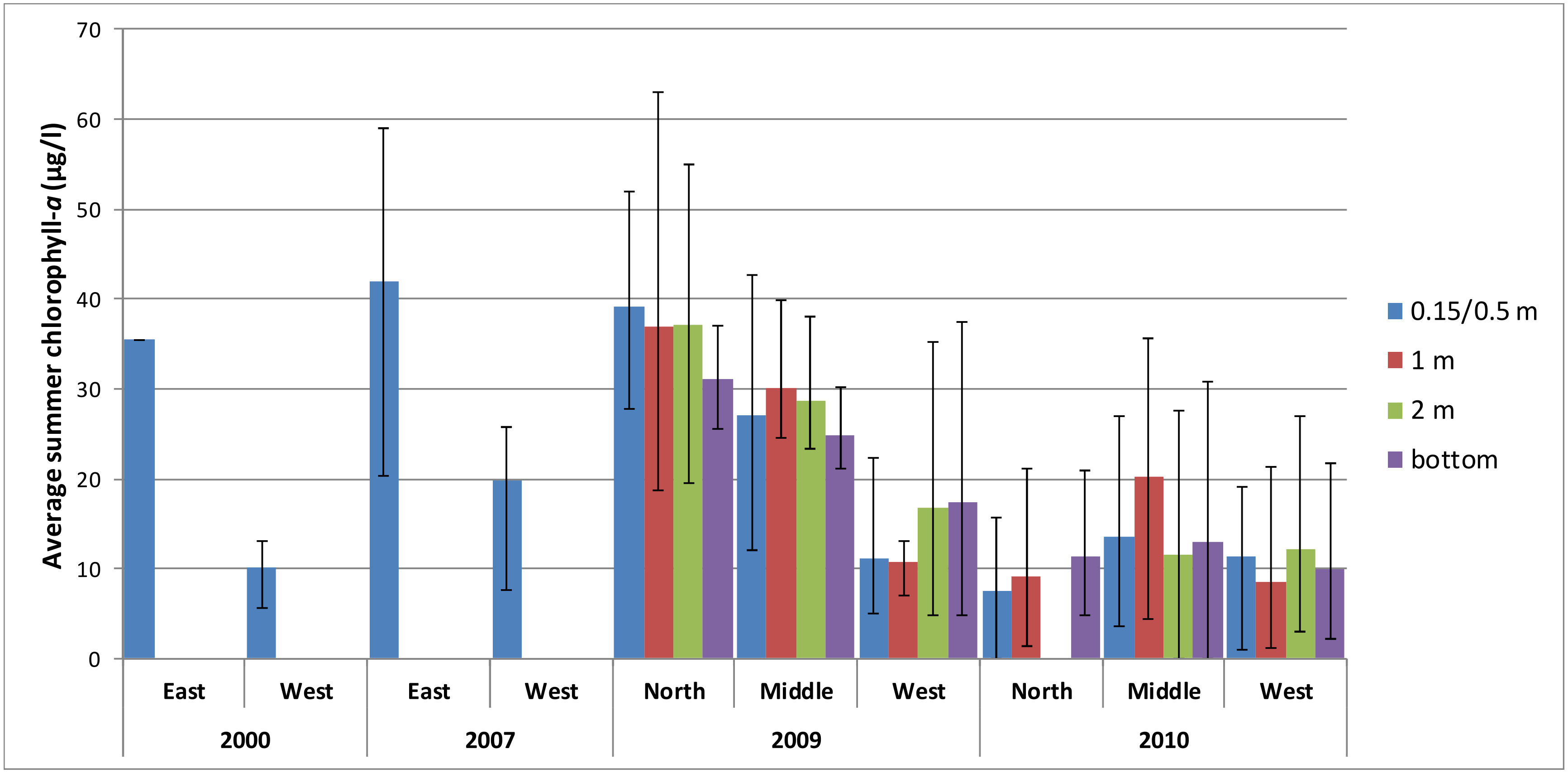

Figure III-9. Average summer chlorophyll-*a* concentrations in White Island Pond: 2000, 2007, 2009, and 2010. Averages are based on June through September chlorophyll-*a* readings; 2000 and 2007 data are based on water column-integrated samples collected by MassDEP, while 2009 and 2010 samples were collected for this assessment. Error bars are maximum and minimum concentrations; averages generally based on four samples. There is no statistically significant ($\rho<0.05$) difference among any of depths or any of the stations either in summer or year-round time periods, except for comparison of the 2009 West basin averages to: 1) the North basin at the 0.5 m depth and 2) the Middle basin at the 1 m depth. Available chlorophyll-*a* limits for ponds in the White Island Pond ecoregion are 1.7 and 2.9 µg/l. The high 2009 chlorophyll-a concentrations in the North and Middle basins generally correspond to the low oxygen spikes and temperature layering that occurred during July and August 2009, but it is also notable that these averages are approximately the same as those measured by MassDEP in 2000 and 2007.

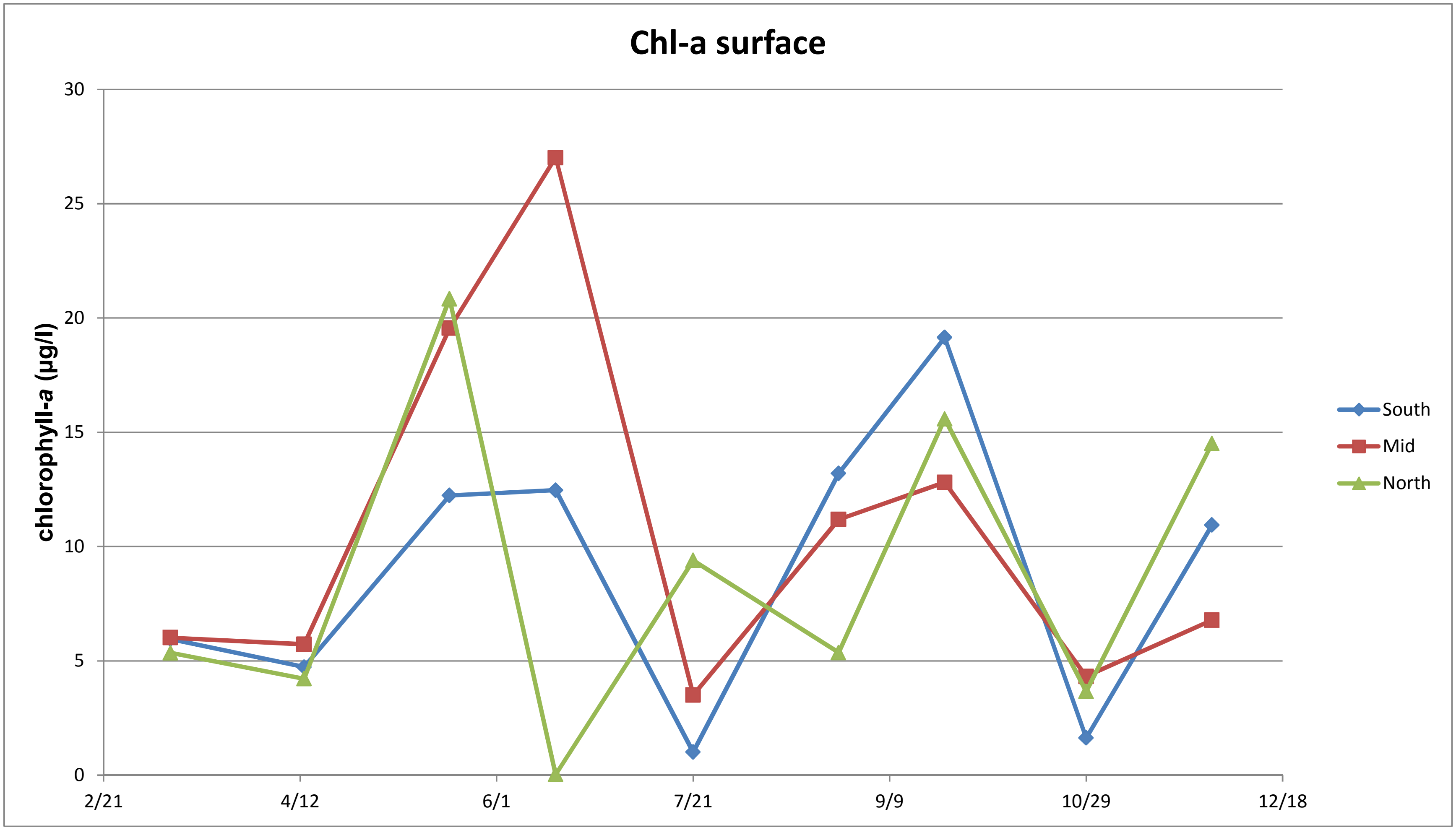

Figure III-10. Surface chlorophyll-*a* concentrations in White Island Pond in 2010. Fluctuations in chlorophyll-*a* concentrations do not correspond to fluctuations in any of the laboratory or field data. The average chlorophyll-a levels, as well as almost all individual samples greatly exceed available chlorophyll-*a* limits for ponds in the White Island Pond ecoregion: 1.7 and 2.9 µg/l (Eichner and others, 2003 and USEPA, 2001, respectively).

Comparison of 2010 concentrations to MassDEP concentrations[83] is limited due to the different techniques used. MassDEP collected chlorophyll-a samples in 2000 and 2007, but only utilized depth-integrated samples over the whole water column. Comparison of the two years of MassDEP sampling show higher concentrations in the eastern pond compared to the western pond, but comparison of these MassDEP concentrations to 2010 samples collected for this assessment show that the average 2010 surface readings are significantly ($\rho<0.05$) lower than 2000 MassDEP average and lower, but not significant at the $\rho<0.05$ level than the 2007 MassDEP average. In general, the chlorophyll-*a* data shows a similar but less pronounced enrichment of the eastern versus the western pond, compared to the TN, TP and Secchi data collected by both MassDEP and SMAST.

III.4. Sediment Sampling

As plants and animals die or are consumed by heterotrophs and excreted in fecal pellets within a pond or lake, organic matter is deposited to the bottom sediments where it decomposes. As a result, the sediments are a reflection of the history of a pond ecosystem, collecting information on conditions both within the pond and, indirectly, within its watershed. Since bacterial decay processes can release the nutrients stored in this plant and animal matter, a portion of the nutrient load deposited to the sediments in organic forms is released back to the water column in inorganic forms. Once back in the water column, these nutrients can prompt the growth of more plants and animals. Given a significant source of regenerated sediment nutrients, phytoplankton populations can increase substantially and cause poorer water quality conditions than if the watershed is the predominant source of nutrients. In some lakes the sediment release of nutrients can exceed the input from the watershed during the warmer, high productivity months. Unfortunately, pond sediment sampling is not consistently done in lake assessments and data, especially historic data, is usually limited.

As described in Section III.1, sediment cores were collected at 13 stations in White Island Pond during the summer of 2009. These cores were incubated under three different redox conditions to evaluate gross nutrient releases that potentially could be encountered in White Island Pond: aerobic, chemical release, and anaerobic. Sediment sampling and incubation are based on procedures in SMAST's Massachusetts Estuaries Project QAPP, approved by USEPA July 24, 2002.[84] Sediment sampling results were used by MassDEP in the final TMDL for White Island Pond.

Aerobic release of nutrients from the sediments occurs in the entire pond for most if not all of the warmer months and results from the remineralization of organic nutrients and the subsequent release of inorganic forms. Chemical release occurs after oxygen is depleted (anoxia) and is dominated by the desorption of bound orthophosphate from iron oxyhydroxides in the surface sediments. Unlike aerobic and anaerobic releases where the inorganic release is primarily from recent decomposition, chemical release relates to inorganic phosphorus that has been bound to the sediments in some case during several years of remineralization. As a result,

[83] Appendix I. Final Total Maximum Daily Load of Total Phosphorus for White Island Pond Plymouth/Wareham, MA. MassDEP, DWM TMDL Report MA95166-201009-1 CN 330.2 April 13, 2010

[84] Howes, B.L. and R.I. Samimy. 2002. Quality Assurance Project Plan: The DEP/SMAST Massachusetts Estuaries Project. 157 pp.

chemical releases can be very large compared to aerobic or anaerobic releases. Anaerobic release is similar to aerobic release in being driven by recent decomposition reactions, except that these releases occur in the absence of oxygen.

To quantify the different releases, the redox conditions are stepped sequentially with aerobic release occurring with fully oxygenated water overlying the sediment surface (*i.e.*, saturated with oxygen), followed by the chemical release phase occurring under initial onset of anaerobic conditions, when prevalent metals (such as iron and manganese) are mobilized from oxygen-containing compounds (*e.g.*, iron hydroxide) and finally anaerobic release when no oxygen is available, but after the bound phosphorus has been mobilized. Multiple water samples were collected from each core during the aerobic and anaerobic phases (n=4 to 6); the chemical release phase proceeded so rapidly that only one sample could be collected from each core. Aerobic samples were analyzed for sediment oxygen demand, ammonium-nitrogen, ortho-phosphate, nitrate-nitrogen, total dissolved nitrogen, and total dissolved phosphate. Chemical release samples were analyzed for ammonium-nitrogen, ortho-phosphate, total dissolved phosphate, iron and manganese. Anaerobic samples were analyzed for ammonium-nitrogen, ortho-phosphate, and total dissolved phosphate. Gross release rates were determined on a mass per square meter basis and sediment fluxes were determined for each basin based on the depths of samples and corresponding bathymetry (Table III-2).

Table III-2. White Island Pond Gross Summer Sediment Nutrient Flux Summary.								
Aerobic Release (kg/d)								
Basin	Basin area (m2)	NH4-N	PO4	NO3-N	TDN	TDP		
North	193,799	29.1	1.2	1.5	32.8	1.6		
Middle	452,340	96.7	2.2	9.8	103.9	2.7		
South	463,347	24.0	0.4	1.9	30.9	1.7		
Chemical Release (kg/d)								
Basin		NH4-N	PO4			TDP	Fe	Mn
North		918	539			433	4,043	281
Middle		1,594	1,096			1,061	10,546	804
South		1,382	365			352	5,666	481
Anaerobic Release (kg/d)								
Basin		NH4-N	PO4			TDP		
North		3,854	249			829		
Middle		9,813	1,553			1,658		
South		5,702	295			576		
Note: These values are gross summer sediment releases that have not been corrected for resettling. Each basin value is a depth-weighted average of all sampling sites within that basin. NH4-N = ammonia-nitrogen, PO4 = ortho-phosphate, NO3-N = nitrate-nitrogen, TDN = total dissolved nitrogen, TDP = total dissolved phosphorus, Fe = dissolved iron, Mn = dissolved manganese								

Since White Island Pond generally has aerobic conditions in the waters overlying the sediments, except for rare localized short-term hypoxic events (see Figure III-2 and TMDL), the aerobic release results should be the primary focus of reviews of existing conditions in the pond.

However, it should be noted that if water quality conditions in White Island Pond worsen and dissolved oxygen concentrations in bottom waters become near anoxic for any prolonged period, the core incubation results show that there will be a major release of nitrogen and phosphorus, almost two orders of magnitude higher than under present aerobic release rates. Since phosphorus available in low oxygen conditions is more than 100 times greater than what is available in the normal aerobic conditions found in the pond, management strategies for the pond should ensure the maintenance of aerobic conditions as a priority.

The data in Table III-2 are gross sediment fluxes that have not been corrected for the settling of constituents from the water column back to the sediments. Given the focus of the White Island Pond TMDL on phosphorus, staff determined net fluxes for each of the basins and generally found that both basins are releasing 0.46 kg/d of phosphorus. The net release from the East basin is smaller than the West basin, but the larger area of the East Basin results in similar daily rates.

III.5. Pond Water Quality Assessment Summary

White Island Pond water quality is largely determined by excessive phosphorus with significantly higher concentrations in the East basin. Review of 2009 and 2010 water quality data shows that total phosphorus (TP) concentrations in the West basin average 30 µg/l during the summer (June to September), while the Middle and North basins average 59 and 53 µg/l, respectively. Chlorophyll and clarity readings are generally consistent with these differences.

Dissolved oxygen data show that, on average, both basins of White Island Pond are well oxygenated with occasional summer declines associated with sediment oxygen demand. Temperature data shows well-mixed conditions with no differences with increasing depth. Average summer dissolved oxygen concentrations are above the MassDEP regulatory limit. Sediment testing confirms that sediment oxygen demand is usually fairly low. Well oxygenated, deep water inhibits sediment phosphorus regeneration, but aerobic regeneration is 70% higher in the East basin than the West basin. Sediment incubation also shows that a very large pool of phosphorus is available in the sediments if aerobic conditions occur. Summer TP concentrations generally increase with depth, which is consistent with sediment regeneration and, combined with the temperature data, are indicative of mixing of this regenerated TP into the entire water column.

Comparison of complementary data (2009, 2010) from the current assessment to MassDEP data used for the White Island TMDL (2000, 2007) generally shows that water quality conditions are not significantly different. Notable exceptions are the average surface TP concentration in 2000 being significantly higher in the East Basin and significantly lower in the West Basin than the averages in 2009 and 2010.

III.5.1. Ecosystem Status/Carlson Trophic State Index

Assessing the ecosystem status of pond usually starts from trying to develop an understanding what the system would be like if it did not have the impacts of development within its watershed and surrounding land uses. This understanding virtually always has to be developed by looking at similar, unimpacted ponds and historic, available water quality measurements from the same pond. In southeastern Massachusetts, developing this understanding by comparing monitoring results to other ponds is hindered a bit more than in other portions of the country since the region's geology and climatic environment are relatively unique.

Carlson (1977) developed a comparative index (also termed a "trophic status index") for water quality conditions in lakes that has been used extensively throughout the world. The trophic state of a pond is the total amount of living biological material (*i.e.*, biomass) in the ecosystem and Carlson's index uses various, easily accessible, water quality measures to provide a single index number that corresponds to a trophic category (Table III-3). Carlson designed the system to utilize a selected measure to classify the trophic state index (TSI) of a pond or lake on a scale of 0 to 100 (Carlson and Simpson, 1996). Although the Carlson indices were developed for use in northern temperate lakes and do not work well in lakes where macrophytes (*i.e.*, rooted aquatic plants) dominate the ecosystem, these indices have been used extensively and use of this index provides a common touchstone for comparing White Island Pond to other ponds.

Use of the Carlson Trophic State Index on average 2009 and 2010 chlorophyll-*a* surface readings generally places all of White Island Pond in the eutrophic category (Figure III-11). Although there are differences in how these samples were collected by MassDEP in 2000 and 2007, these MassDEP data also generally are classified within the same category albeit at a higher index number. As a point of comparison, Lake Wequaquet, a 600 acre pond in the Town of Barnstable with similar dissolved oxygen profiles, has surface chlorophyll *a* concentrations that generally place it in Carlson's mesotrophic category, which is indicative of less nutrients.[85]

Data from the 2001 Cape Cod PALS Snapshot indicated that a "healthy" freshwater pond in the same ecoregion as White Island Pond would have a threshold concentration of 1.7 µg/l for chlorophyll-*a*, which translates to a TSI of 35.8, while the cleanest, and presumably pristine, Cape Cod ponds have a TSI of 30.6.[86] These TSI levels are in the oligotrophic category (see Table IV-1 for generalized conditions). Average 2010 chlorophyll-*a* TSI readings in White Island Pond basins ranged between 50 and 56.

Comparison of index averages for summers of 2000, 2007, 2009, and 2010 show that the Main basin index has a peak in 2007 with subsequent declines in 2009 and another in 2010. Although the averages decline, there are no statistically significant differences when comparing the summer index averages between any of the years. Similarly, the West basin also has an index average peak in 2007, but comparison of all of the summer averages do not have any statistically significant differences. In the North basin, the 2009 average summer index is significantly ($\rho \leq 0.05$) higher than the 2010 summer average, however, the North basin was not sampled by MassDEP in 2000 and 2007, so longer term comparisons are not available.

III.5.2. Limiting Nutrient

The amount of biomass in pond and lake ecosystems is usually limited by a key nutrient; if more of the nutrient becomes available, the biomass will increase. In ponds and lakes, the key nutrient is usually phosphorus; rapid introduction of phosphorus usually leads to algal blooms, while more gradual increases can prompt the change in the dominant plant community from one

[85] Eichner, E. 2008. Lake Wequaquet Water Quality Assessment. Completed for the Town of Barnstable and the Cape Cod Commission. Coastal Systems Program, School of Marine Science and Technology, University of Massachusetts Dartmouth.
[86] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

dominated by algae to one dominated by rooted plants. In ponds and lakes that are phosphorus limited, addition of phosphorus begins a cascade of events that leads to excessive oxygen demand and failure to meet state water quality standards. Phosphorus additions increase available concentrations, causing an increase in algal biomass, which, in turn, leads to additional organic loading to the sediments, which eventually overwhelms natural bacterial regeneration processes and leads to anoxic sediment conditions.[87] The onset of anoxia then creates of pulse release of even more phosphorus to the overlying waters from the sediments resulting in further biomass product and further water quality decline. This latter phosphorus pulse with anoxia accelerates eutrophication.

Table III-3. – Carlson Trophic State Index (TSI)

TSI Calculations	
TSI(SD) = 60 - 14.41 ln(SD)	SD = Secchi disk depth (meters)
TSI(CHL) = 9.81 ln(CHL) + 30.6	CHL = Chlorophyll *a* concentration (µg/l)
TSI(TP) = 14.42 ln(TP) + 4.15	TP = Total phosphorus concentration (µg/l)

TSI Values	Chl a (µg/l)	SD (m)	TP (µg/l)	Pond Attributes	Fisheries & Recreation
<30	<0.95	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic	Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Hypolimnetic anoxia results in loss of salmonids.
50-60	7.3-20	2-1	24-48	Eutrophy: Anoxic hypolimnia, macrophyte problems possible	Warm-water fisheries only. Bass may dominate.
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	Hypereutrophy: (light limited productivity). Dense algae and macrophytes	
>80	>155	<0.25	192-384	Algal scums, few macrophytes	Rough fish dominate; summer fish kills possible

after Carlson and Simpson (1996);
Note: Carlson TSI developed in algal dominated, northern temperate lakes

[87] Wetzel, R. G. 1983. *Limnology*. Second Edition. CBS College Publishing, New York.

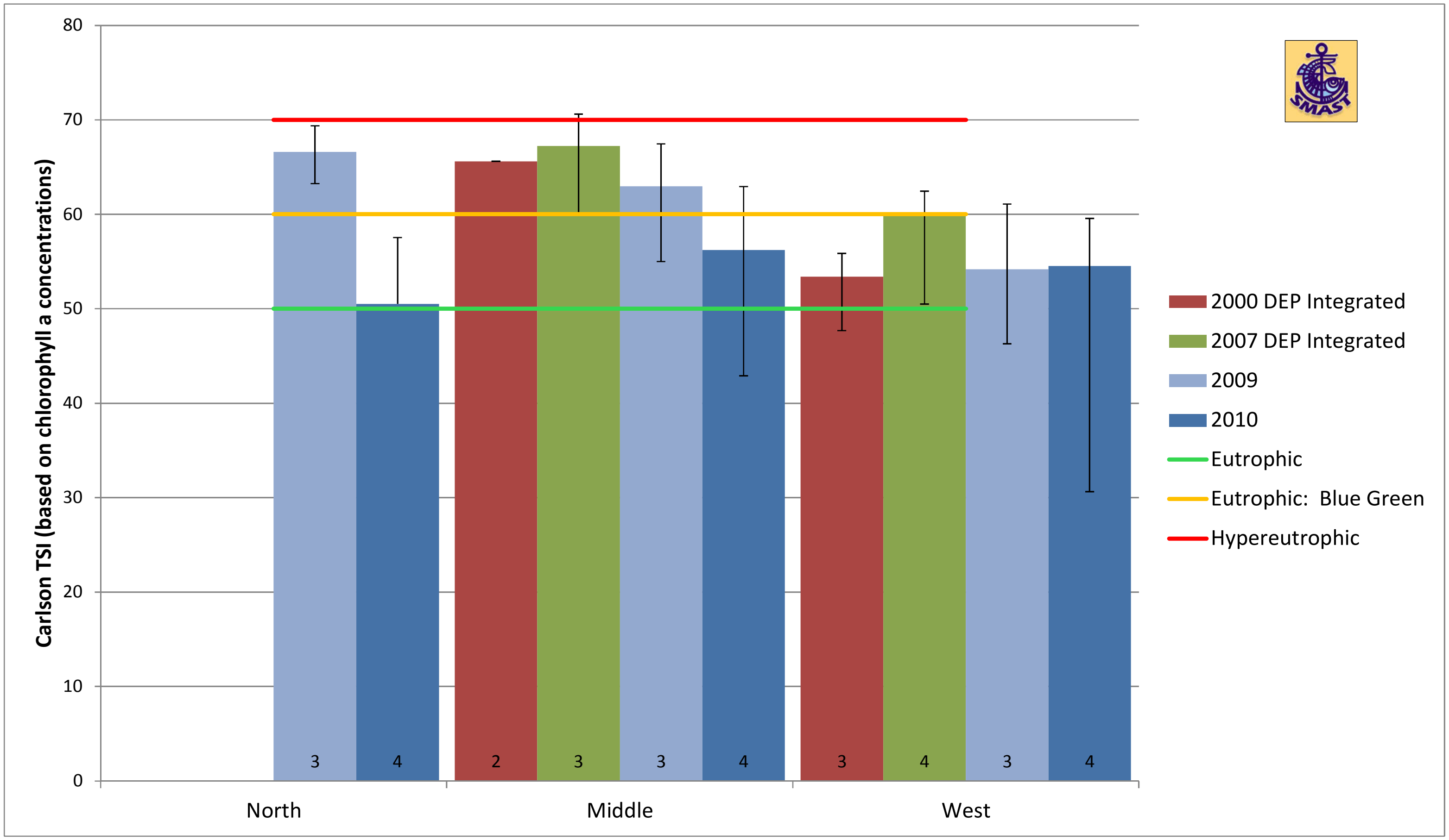

Figure III-11. Average Carlson Trophic Status Index in White Island Pond: 2000, 2007, and 2010. 2009 and 2010 Carlson TSI's are based on chlorophyll *a* concentrations from samples collected between June and September (Carlson, 1996). 2000 and 2007 MassDEP results are based on samples integrated throughout the entire water column. Error bars are maximum and minimum readings. Number of readings used to calculate the averages are shown in the base of each bar. The green line is the mesotrophic/eutrophic boundary in Carlson's calculations, while the yellow line indicates internal mesotrophic category boundary where bluegreen plankton become dominant. The red line indicates the eutrophic/hypereutrophic boundary. On average, White Island Pond is within the eutrophic category. There are no statistically significant ($\rho \leq 0.05$) differences between the averages in any of the years in either the Middle or the West basins. The 2009 summer index average in the North basin is significantly ($\rho \leq 0.05$) higher than the 2010 average; MassDEP did not sample the North basin in 2000 or 2007.

One way to assess whether a lake is limited by phosphorus is to review the balance between phosphorus and nitrogen. As a rule of thumb, if the ratio between nitrogen and phosphorus is greater than 16 (also known as the Redfield ratio), phosphorus is the limiting nutrient.[88] It should be noted that this approach to determining nutrient limitation also needs to take into account phototrophs that have the ability to utilize organic phosphorus, not just inorganic phosphorus. For this reason, phosphorus-limited systems generally have N to P ratios that are 3-5 times the Redfield ratio of 16.

White Island Pond N to P average ratios clearly indicate phosphorus limitation and confirm that phosphorus should be the primary management target for water quality management in the pond. The West basin ratios are consistently higher than those in the Middle or North basin, which is generally indicative of better water quality conditions. The average summer 2010 surface N:P ratio in the West basin is 54, 42 in the North basin, and 36 in the Middle basin. Summer 2009 ratios were similar to 2010 being 48, 46, and 32, respectively (Figure III-12). These readings are consistent with lower phosphorus loading to the Western pond and is also consistent with the water column phosphorus and chlorophyll-*a* concentrations. Since total nitrogen concentrations in the Western pond are significantly lower than those in the Eastern pond (Middle or North basins), it also confirms that phosphorus is not only more limited than nitrogen in the Western pond, but it is also comparatively more limited than in the Eastern pond.

[88] Redfield, A.C., B.H. Ketchum, and F.A. Richards. 1963. The influence of organisms on the composition of sea-water, in The Sea, (M.N. Hill (ed.). New York, Wiley, pp. 26-77.

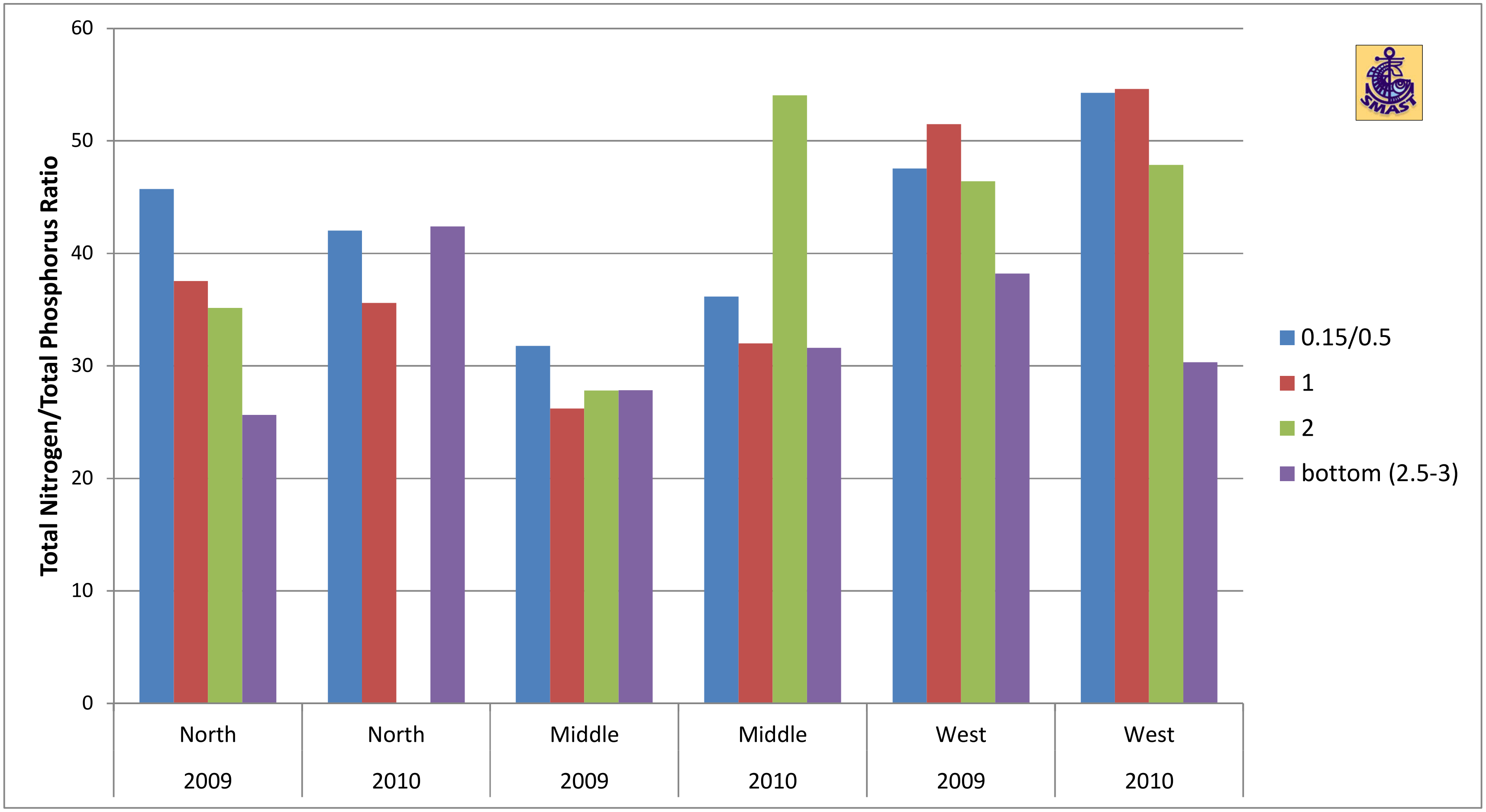

Figure III-12. Average Nitrogen to Phosphorus Ratios in White Island Pond 2009 and 2010. Average surface TN:TP ratios were higher in the western pond than the eastern pond (North and Middle stations) in both 2010 and 2009. The western basin TN:TP averaged 54 and 48 in 2010 and 2009, respectively and in the Eastern pond: 42 and 46 in the North basin and 36 and 32 in the Middle basin. These results confirm that phosphorus is the nutrient to be managed to control the water quality in White Island Pond, as well as that the Middle basin has greater phosphorus loading and larger sediment release. Deep station N to P average summer ratios in all basins are generally between 25 and 35, which is also indicative of preferential phosphorus regeneration from the sediments.

IV. Phosphorus Management Model/Budget

Because phosphorus is the limiting nutrient in White Island Pond and, therefore largely determines the water quality of the system, a phosphorus budget, which accounts for all the phosphorus sources, is useful for evaluating options to restore water quality in the pond. The phosphorus budget for White Island Pond accounts for each of the primary sources of phosphorus, including wastewater, road runoff, fertilizers, atmospheric deposition and internal sediment regeneration. If phosphorus reduction strategies are desired, the phosphorus budget is used to determine targeted management strategies that will reduce the loads to acceptable levels in the most cost-effective fashion.

Although phosphorus is the key nutrient determining water quality in White Island Pond, it should also be noted that the lake is also a component of the Wareham River estuary watershed. This estuary has been identified as being impaired by excessive nitrogen by the Massachusetts Estuaries Project[91] and the MEP-prepared nitrogen thresholds will be the basis for TMDLs that will be developed by MassDEP to satisfy provisions of the Clean Water Act. Although nitrogen is not the limiting nutrient for the lake, it is for the downstream estuary and the pond plays an important role in removing a portion of nitrogen that enters the pond from its watershed, thus preventing it from further increasing nitrogen related impairments in the downgradient marine waters. The MEP assessment assumed that White Island Pond removed 50% of the watershed nitrogen based on conservative assessment of ponds in similar settings; the data collected during this project could be used to develop a pond-specific nitrogen budget that could be used to focus nitrogen management strategies for land uses within the White Island Pond watershed, as relates to the Town's estuarine waters.

Development of a phosphorus budget White Island Pond begins by reviewing the phosphorus mass that is in the pond and then reviewing all the phosphorus sources that could contribute to this mass, including sources the land use within the watershed to the pond and the internal regeneration of phosphorus from the sediments. The watershed delineation is described in Section II and the sediment sampling results are described in Section III.4.

The phosphorus mass in White Island Pond is based on the phosphorus levels from the water column sampling[92] and the volume of the pond.[93] Since samples are collected at approximately one meter intervals, phosphorus concentrations can be assigned to layers within the pond and assuming the volume remains the same, the phosphorus mass in the pond can be determined on each sampling date. It should also be noted that the pond was sampled monthly and this is the basis for the phosphorus mass calculations; this frequency is likely to catch some portion of peaks in phosphorus loads due to sediment regeneration, but may miss the peak itself. Figure IV-1 shows the mass of phosphorus in the East and West basins of White Island Pond on each of the sampling dates in 2009 and 2010.

Review of the 2010 data in the East basin (which is composed of the North and Middle basins) shows a progressive rise in phosphorus mass from the first sampling in March to a peak in August followed by mass fluctuating between 109 and 142 kg. Phosphorus mass in the East

[91] Wareham River MEP Nitrogen Threshold report is in preparation.
[92] Discussed in Section III.3.1.
[93] Discussed in Section II.2..

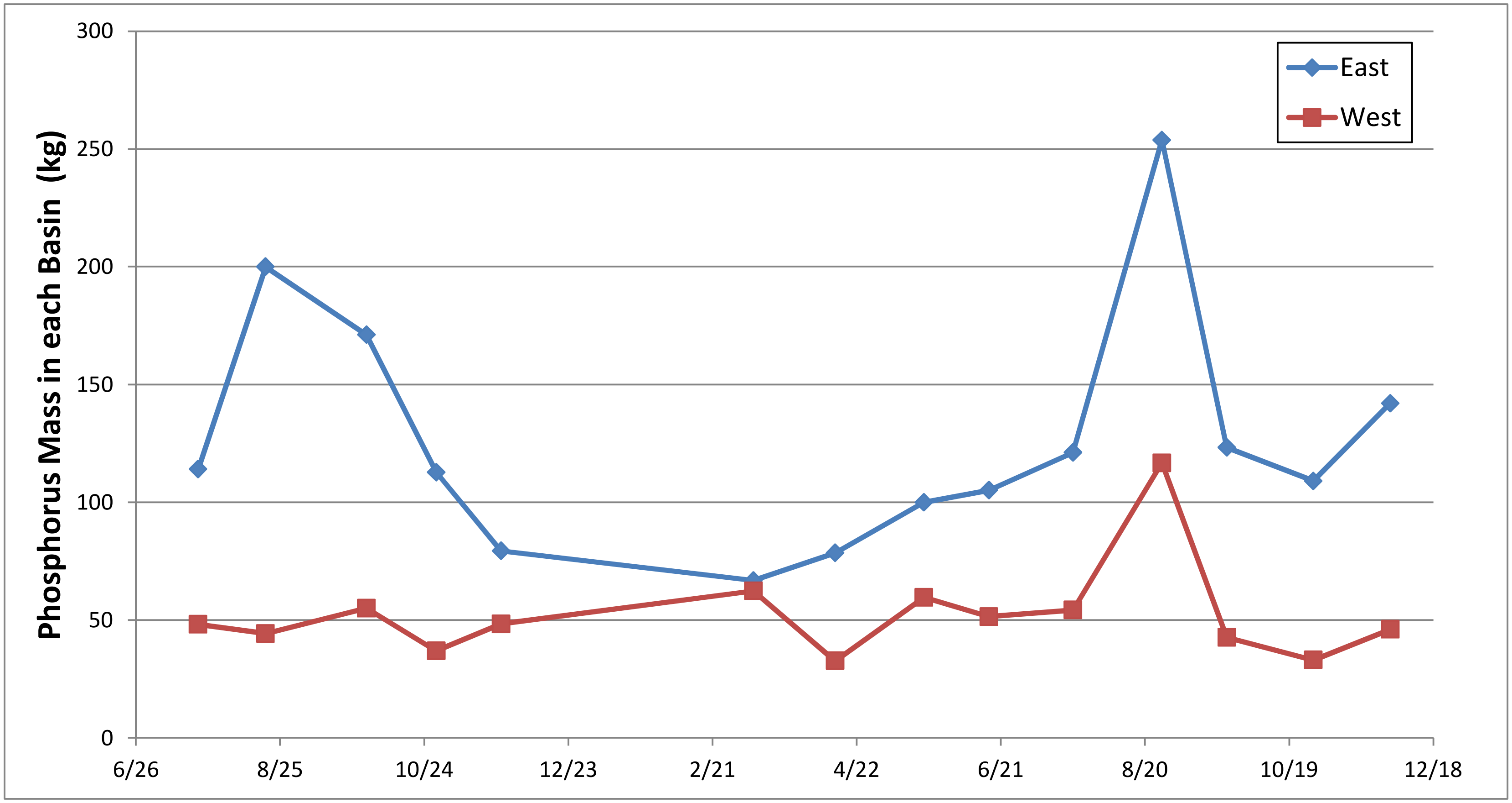

Figure IV-1. Phosphorus Mass in White Island Pond Basins: 2009 and 2010. Mass is based on measured phosphorus concentrations and basin volumes; phosphorus concentrations at depths in the water column on each sampling date are assigned to corresponding volumes based on bathymetric measurements.

basin averaged 162 kg in summer 2009 and 151 kg in summer 2010. There is no significant difference (ρ<0.05) between these summer averages; the average mass using both summer's data is 156 kg. The East basin has large peaks of phosphorus mass in August of both years: 200 kg on 8/19/09 and 254 kg on 8/27/10. The large peaks correspond to the temperature maximums during each of the years.

Review of the 2010 data in the West basin shows the phosphorus mass fluctuating between 33 and 62 kg between March and July, peaking to 117 in August, and then fluctuating between 33 and 46 between September and November. The West basin summer average is averaged 49 kg in summer 2009 and 66 kg in summer 2010. There is no significant difference (ρ<0.05) between these summer averages; the average mass using both summer's data is 59 kg or 49 kg if the August 2010 peak is excluded as exceptional. The maximum phosphorus mass of 117 kg is measured on 8/27/10, but no similar peak was measured in summer 2009. If the August 2010 peak is excluded, the average mass in the West Basin in the summer and throughout the year are essentially the same (49 and 47 kg, respectively). This finding suggests relatively constant loading to the West basin from both its watershed and sediments with exceptional conditions existing in August 2010.

The rise in phosphorus mass in the Eastern pond and the August peaks in both basins would be consistent with temperature-dependent sediment regeneration of phosphorus. Regenerated phosphorus is an addition to the more or less consistent summer loading coming from the watershed. Using the mass data as a guide and subtracting out the sediment regeneration, the mass of phosphorus attributable to the Eastern pond watershed ranges between approximately 70 and 100 kg, while the Western pond watershed mass is approximately 50 kg. A source of uncertainty would be related to how sediment regeneration may be mixed into these masses on any of the sampling dates and how seasonal watershed loading may impact the measured masses.

In order to begin to evaluate the magnitude of the various phosphorus sources from the watershed, project staff collected town assessor's records and digital parcels from the Towns of Plymouth and Wareham. Assessor's data includes traditional information about the parcel area, size and age of buildings, and tax assessor's classifications of types of land use.[94] This information can be used to determine which parcels are developed and which have the largest potential phosphorus loads to the pond.

As groundwater flows into kettlehole ponds along the upgradient shoreline, it brings phosphorus from the pond watershed. Phosphorus moves slowly in sandy soils because soil chemistry favors bound rather than soluble forms in well-oxygenated waters.[95] One of the most common binding partners for phosphorus is iron and because iron particles tend to coat the sands of outwash plains, phosphorus introduced into the groundwater system tends to create insoluble iron/phosphorus complexes.[96] Still, the binding capacity of aquifer soils is finite and once iron-

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[94] Massachusetts Department of Revenue. June, 2009. Property Type Classification Codes, Non-arms Length Codes and Sales Report Spreadsheet Specifications. Prepared by the Bureau of Local Assessment.

[95] Stumm, W. and J.J. Morgan. 1981. *Aquatic Chemistry*. John Wiley & Sons, Inc., New York, NY.

[96] Walter, D.A., B.A. Rea, K.G. Stollenwerk, and J. Savoie. 1996. Geochemical and Hydrologic Controls on Phosphorus Transport in a Sewage-Contaminated Sand and Gravel Aquifer Near Ashumet Pond, Cape Cod, Massachusetts. US Geological Survey Water-Supply Paper 2463. US Geological Survey and National Guard Bureau. Northborough, MA.

binding sites have bound sufficient phosphorus, the next phosphorus ion traveling with the groundwater moves beyond this site and is bound by the next set of binding sites. In this way, phosphorus moves with the groundwater away from its source, but only very slowly. Phosphorus associated with small sources, like septic systems, may move 3-5 meters per year in sandy soil-based groundwater systems, like Plymouth, phosphorus from septic systems for seasonal homes will move even more slowly.[97] By contrast, a general regional groundwater flow rate is approximately 20 times faster: one ft/day (or 111 meters/year). Because of the slow movement of phosphorus, most of the sources of phosphorus entering ponds in the White Island Pond ecoregion are from properties abutting the pond shoreline; previous analysis of Cape Cod ponds and Maine lake protection guidance focus on properties within 250 to 300 ft of the shoreline.[98,99,100]

For White Island Pond, project staff began the development of the watershed portion of the phosphorus budget by looking at properties within 300 ft of the pond shoreline based on the land use database. The list of these properties was then adjusted to review properties only if they were on the upgradient shoreline of the pond where groundwater is flowing into the pond rather than the downgradient side where lake water is flowing back into the groundwater and away from the pond (Figure IV-2). Aerial photographs of the properties were reviewed and loads were only assigned to developed properties with houses or other structures within the 300 ft boundary. Properties included in the loading calculations were adjusted, as described below, based on best professional judgment of likely groundwater flow characteristics near the various basins of the pond. Watershed phosphorus loads were developed based on the factors in Table IV-1. Review of the watershed sources and the phosphorus factors is discussed below.

IV.1. Wastewater Phosphorus Loading Factor

Given that wastewater is usually a significant component of the overall phosphorus load to a pond, staff reviewed the factors traditionally used for phosphorus loading analyses. For wastewater, previous analyses in southeastern Massachusetts typically use the septic system loading rate developed by the Maine Department of Environmental Protection.[101] The MEDEP factor assumes one pound of phosphorus annually for each septic system in sandy soils bordering a pond or lake. Staff have reviewed a number of studies and this factor is reasonable.

Because of phosphorus' chemical characteristics, field studies of phosphorus loads have typically had varied results that are very dependent on the individual characteristics of the resource being evaluated. Evaluation of available studies has shown that phosphorus loads range from 1.1[102,103] to 1.8 pounds per capita per year.[104] When the range of potential phosphorus

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97 Robertson, W.D. 2008. Irreversible Phosphorus Sorption in Septic System Plumes? Ground Water. 46(1): 51-60.

98 Eichner, E. 2008. Lake Wequaquet Water Quality Assessment. Completed for the Town of Barnstable and the Cape Cod Commission. Coastal Systems Program, School of Marine Science and Technology, University of Massachusetts Dartmouth. 81 pp.

99 Eichner, E. 2009. Dennis Freshwater Ponds: Water Quality Status and Recommendations for Future Activities. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA. 106 pp.

100 Maine Department of Environmental Protection. 1989. Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development.

101 Ibid.

102 Reckhow, K.H., M.N. Beaulac and J.T. Simpson. 1980. Modeling phosphorus loading in lake response under uncertainty—A manual and compilation of export coefficients. U.S. Environmental Protection Agency, EPA–440/5–80–011.

soil retention factors (0.5 to 0.9) are applied,[105] the resulting annual per capita load ranges between 0.11 and 0.9 lb. If one uses the average occupancy in the Town of Plymouth during the 2000 Census (2.43 people per house), the average septic system annual load has a range of 0.3 to 2.2 lbs. Given that the MEDEP load falls into the range, project staff proceeded with this factor as the initial phosphorus load for septic systems.

Table IV-1. Phosphorus Loading Factors for White Island Pond Phosphorus Budget

Factor	Value	Units	Source
Wastewater P load	1	lb P/ septic system	MEDEP, 1989; modified for house age; seasonality based on whether residence classified as owner occupied (value of 0.5 lb assigned)
Road surface P load	5.3	lb P/ac	MEDEP, 1989
Roof surface P load	3.5	lb P/ac	MEDEP, 1989
Building Area	Actual value 1,362 avg (E shed) 1,406 avg (W shed)	ft2	Town assessor data for individual parcels; single family residence averages by watershed are shown
Road Area	Estimated based on centerline measurement	ft2	Town of Plymouth does not have digital road areas (assume 20 ft road width)
Lawn Factors			
Area per residence	5,000	ft2	Standard MEP assumption based on field measurements in 4 Cape Cod towns
Fertilizer lawn load - high	0.3	lb P/ac	MEDEP, 1989
Fertilizer lawn load - low	0.003-0.034 (0.019-0.210)	mg/l (lb/ac)	Sharma, *et al*., 1996; 0.02 lb P/ac used as low estimate
Waterfowl Factors			
P load - high	0.156	g/m2/yr	Scherer, *et al*., 1995
P load - low	0.9	kg/pond	Eichner, 2008
New P load	13	%	Scherer, *et al*., 1995
Atmospheric deposition on pond surface			
P load - high	0.3	kg/ha	Reckhow *et al*., 1980
P load - low	0.05	kg/ha	Cadmus, 2007

[103] Panuska, J.C., and J.C. Kreider. 2002. Wisconsin lake modeling suite program documentation and user's manual, Version 3.3 for Windows: Wisconsin Department of Natural Resources PUBL–WR–363–94. 32 p. (Available online through the Wisconsin Lakes Partnership: http://www.dnr.state.wi.us/org/water/fhp/lakes/laketool.htm).

[104] Garn, H.S., D.L. Olson, T.L. Seidel and W.J. Rose. 1996. Hydrology and water quality of Lauderdale Lakes, Walworth County, Wisconsin, 1993–94. US Geological Survey Water-Resources Investigations Report 96–4235. 29 p.

[105] Robertson, W.D. 2008. Irreversible Phosphorus Sorption in Septic System Plumes? *Ground Water*. 46(1): 51-60.

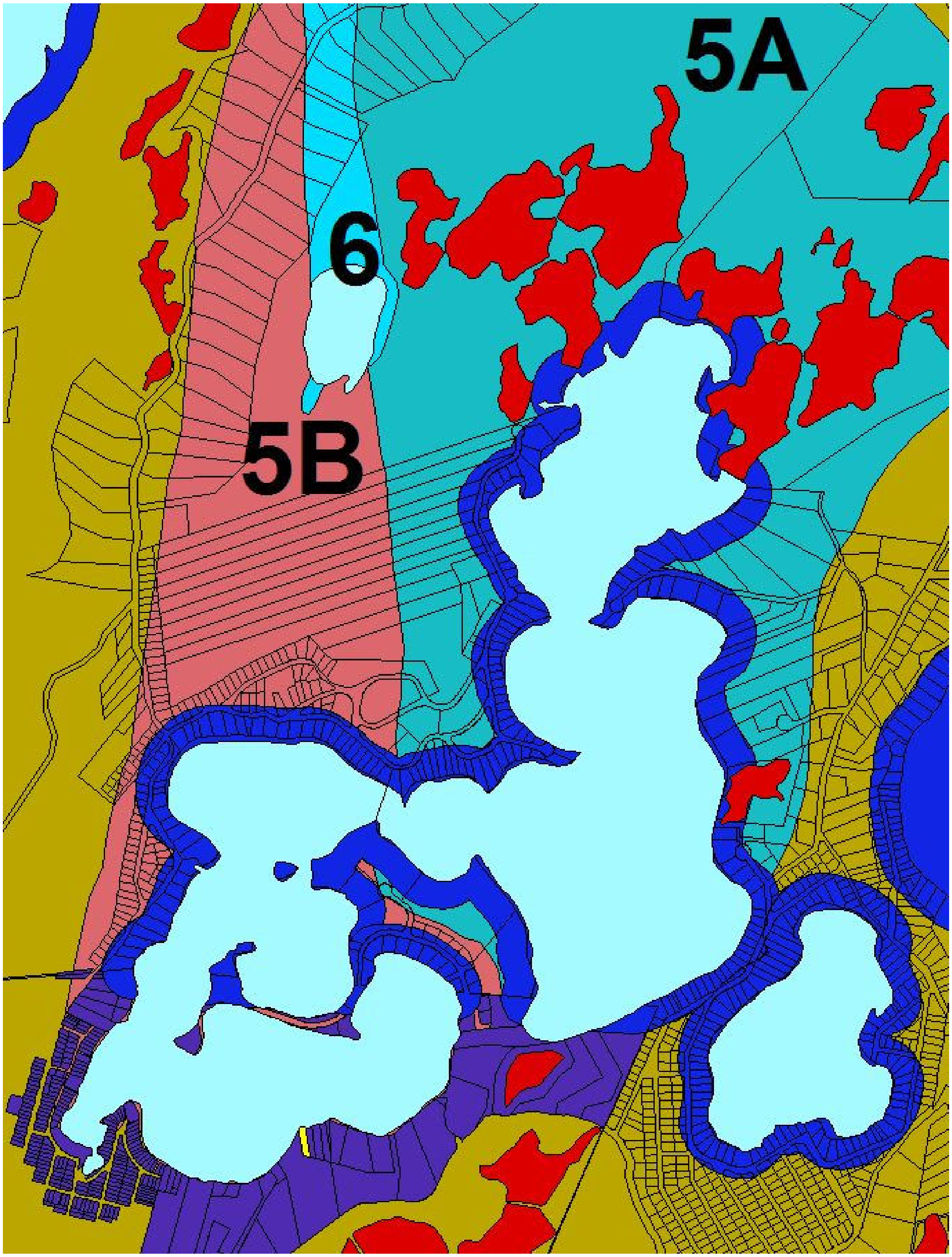

Figure IV-2. Watershed Properties Included in the White Island Pond Watershed Phosphorus Loading Analysis. Properties colored blue are partially or completely within a 300 ft buffer area to White Island Pond and are on the upgradient side of the pond. Phosphorus loading from land uses on these properties is the basis for the watershed phosphorus loading in this report.

Project staff also reviewed the assessor's information for parcels within the Town of Plymouth and adjusted the wastewater loads based on the age of the house and whether it was classified as owner-occupied. Robertson (2008) reviewed retardation factors for phosphorus in sandy soils and based on these analyses, estimated that it takes between 20.6 and 30.5 years for phosphorus to travel 300 ft. This travel time range was compared to the age of the developed parcels within 300 ft of the upgradient shoreline of White Island Pond. The differences in age provided the high and low estimates for the wastewater component of the watershed phosphorus loading.

The East Basin has 121 single family residences within 300 ft of the upgradient shoreline of White Island Pond with 54 labeled owner occupied, or year-round, residences by the town assessor. There are another 31 parcels of various other land uses, including two multi-use properties, a multi-family property, and the two cranberry bogs. Of the 70 parcels with other land uses, six (6) are categorized as developable residential parcels (land use code 130) by the town assessor. The average building size of the single family residences is 1,329 square feet and the average year built is 1964. There are 108 of the 121 (89%) residences that are older than the 20.6 year travel time for phosphorus and 103 (85%) that are older than the 30.5 year travel time. Incorporating the range of travel times and accounting for seasonal occupancy of 67 parcels, phosphorus loads from wastewater into the East Basin are estimated to be between 48 and 50 kg/yr. If the load is calculated slightly differently (assigning 0.5 kg/y to seasonal dwellings and 1.0 kg/y to year-round dwellings), the wastewater load is 40 kg/yr. At steady-state, when wastewater phosphorus from all existing houses reaches the pond, the wastewater phosphorus load to the East Basin is estimated to be 56 kg/yr. House runoff is estimated to add approximately 6 kg/y and roads are estimated at most to add 2 to 3 kg/yr (many of the road surface in the study area are sand).

The West Basin has 127 single family residences within 300 ft of the upgradient shoreline of White Island Pond with 50 labeled owner occupied, or year-round, residences by the town assessor. There are another 49 parcels of various other land uses, including ten categorized as developable residential parcels (land use code 130 or 131) by the town assessor. The average building size of the single family residences is 1,406 square feet and the average year built is 1964. There are 77 of the 127 (61%) residences that are older than the 20.6 year travel time for phosphorus and 72 (57%) that are older than the 30.5 year travel time. Incorporating the range of travel times and accounting for seasonal occupancy of 77 parcels, phosphorus loads from wastewater into the West Basin are estimated to be between 33 and 35 kg/yr. If the load is calculated slightly differently (assigning 0.5 kg/y to seasonal dwellings and 1.0 kg/y to year-round dwellings), the wastewater load is 40 kg/yr. At steady-state, when wastewater phosphorus from all existing houses reaches the pond, the wastewater phosphorus load to the West Basin is estimated to be 58 kg/yr. House runoff is estimated to add approximately 7 kg/y and roads are estimated to add 4 to 5 kg/yr.

IV.2. Lawn Fertilizer Phosphorus Loading Factor

Lawn fertilizers are nutrients added to lawn grasses to prompt growth and the portions of the applications that are not utilized by the lawn have the potential to leach to the groundwater and reach surface waters. Reviews of fertilizer application rates on Cape Cod have generally found that homeowners do not fertilize lawns as frequently as recommended by lawn care guidelines unless commercial companies tend the lawns.[110] In addition, these surveys have found that many Cape Codders do not use lawn fertilizers at all. These findings create some uncertainty about the potential loading associated with lawns.

MEDEP (1989) assumes that lawns in sandy soils contribute 0.3 pounds per acre. Sharma and others (1996) reviewed phosphorus concentrations in soils beyond lawn root zones and found a range, the low end of which is approximately one tenth of the MEDEP load, while the high end of the range approximates the MEDEP load. Because of this range, project staff used both low and high estimates in calculating the lawn phosphorus load.

Project staff also reviewed properties for lawns based on aerial photos. Although these do not provide definitive information about fertilizer activities, properties within the 300 ft buffer without significant lawns did not have lawn loads assigned. Properties with lawns on the downgradient shoreline were not assigned lawn phosphorus loads; review of downgradient shores generally had low relief and it was thought that overland flow from lawns would not be likely.

Based on a review of the parcels within 300 ft of White Island Pond and the low and high lawn phosphorus loading factors, lawns are estimated to add between 0 and 4 kg/yr to each of the East and West basins.

IV.3. Bird Phosphorus Loading Factor

Phosphorus loading from birds has been a difficult factor to resolve for ponds in southeastern Massachusetts. Previous analyses completed by SMAST staff have relied on the factors shown in Table IV-1; which rely extensively on a highly detailed study of birds and pond water quality from Seattle, Washington.[111] This study evaluated bird counts for a large pond (259 acres), phosphorus loads per species, and the percentage of the phosphorus load from each species that was new addition to the pond and how much was reworking of existing phosphorus sources already in the pond. This study concluded that the annual average general phosphorus load from birds is 0.156 grams of P per square meter and that 13% of this load as new P being added to the lake. Because this load is determined by the area of the pond, applying this factor would result in larger ponds having greater mass of phosphorus loading from birds.

In order to provide some sense of how well these assumptions compare to southeastern Massachusetts ponds, project staff reviewed bird counts from the annual Cape Cod Bird Club surveys.[112] These surveys are usually conducted during the first week of December, have been done since 1984, and generally collect data from over 300 ponds. In the 26 surveys since 1984, the counts have averaged 33 birds per pond with an overall range of averages of 18 to 48. If the phosphorus content of droppings from Scherer and others (1995) are used with the average Cape Cod bird count and it is further assumed that December counts are representative of year-round

[110] See for summary discussion: Chapter 4 in Howes, B., H.E. Ruthven, J. S. Ramsey, R. Samimy, D. Schlezinger, J. Wood, and E. Eichner. 2006. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Centerville River System, Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

[111] Scherer, N.M., H.L. Gibbons, K.B. Stoops, and M. Muller. 1995. Phosphorus loading of an urban lake by bird droppings. *Lake and Reservoir Management*. 11(4): 317 - 327.

[112] www.capecodbirds.org/waterfowl.htm

populations, the resulting southeastern Massachusetts average per pond load of new phosphorus is 0.9 kg/yr.

These two estimates approaches arrive at quite different bird P loads for White Island Pond; the bird count estimate is 7-10% of the areal estimate. The low estimate for bird phosphorus loading to the Eastern pond is 1 kg/y, while the high estimate is 13 kg/yr. The comparable Western pond estimates are 1 and 9 kg/yr, respectively.

Further refinement of these loads could be accomplished through a more comprehensive site-specific survey of bird populations on the pond. SMAST staff have recently completed a volunteer-based, year-round survey of a Cape Cod pond to try to evaluated the large range in phosphorus loading from birds. On this pond, a volunteer team completed 54 counts between October 10, 2010 and September 30, 2011. The average number of birds on the lake was 34 with a range of 0 to 167 birds. Overall, Mallards (*Anas platyrhynchos*) were the most frequent birds (55%) on the lake with Herring Gulls (*Larus smithsonianus*) as the next most frequent (33%). Using the species-specific loads from Scherer and others (1995), this survey indicated an annual phosphorus load of approximately 0.5 kg.[113] If bird counts and species are similar on White Island Pond, the bird load for both portions of the pond are more likely to match the low phosphorus loading estimates.

IV.4. Atmospheric Loading

For the current project, phosphorus loading from precipitation is based on two measures: 0.05 and 0.085 kg P/ha/yr. The 0.085 kg P/ha/yr is based on analysis completed for Hamblin Pond in Barnstable. The 0.05 kg P/ha/yr rate is based on the atmospheric TP input value assigned in the Northeast AVGWLF Nonpoint Source Pollution, Watershed Model. This input value is based on a review of available regional data from the USGS National Water Information System. This range of loads produces a phosphorus loading range of 3 to 6 kg/yr for the East Basin and 2 to 4 kg/yr for the West Basin.

IV.5. Non-Cranberry Bog Phosphorus Loading Summary

Overall, the annual phosphorus load to the East Basin of White Island Pond from watershed development other than the cranberry bogs is estimated to be between 61 and 82 kg. The wastewater component of the load is the least variable: 5% difference between minimum and maximum estimates. The primary source of the variability is the loading estimate is associated with the other sources (lawns, birds, and surface precipitation) with the bird loading having the greatest variability.

Overall, the annual phosphorus load to the West Basin of White Island Pond from watershed development is estimated to be between 46 and 64 kg. The wastewater component of the load is the least variable: 7% difference between minimum and maximum estimates. The primary source of the variability is the loading estimate is associated with the other sources (lawns, birds, and surface precipitation) with the bird loading having the greatest variability.

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[113] Eichner, E. and B. Howes. February 23, 2012. Technical Memorandum for Scargo Lake Technical Support Project to Virginia Esau, Chair, Town of Dennis Water Quality Advisory Committee and Karen Johnson, Director of Natural Resources.

IV.6 Cranberry Bogs Loading (319 section: Bog phosphorus levels)

Two cranberry bogs are located along the north shoreline of the north basin (see Figure I-1). The bog to the east is operated by Federal Furnace Cranberry Company (FF), while the bog to the west is operated by A.D. Makepeace Company (ADM). Based on MassDEP area measurements, the FF bog has a total of 50 acres of bog surface, while the ADM bog has 38 acres of bog surface.

In order to begin to comply with the terms of the May 2009 MOA with MassDEP, ADM and FF began to implement a series of monitoring and management activities to try to limit phosphorus impacts from the bogs on White Island Pond. These activities included limiting phosphorus fertilizer applications, reducing the area of the bogs (ADM), collecting in-bog water and discharging it to upland (FF), and monitoring movement of water and water quality within the bogs. Much of the monitoring work was funded through a MassDEP 319 grant and this section addresses most of the required reporting tasks under the grant.

Both bogs began limiting phosphorus fertilizer additions in 2008 (Figure IV-3). ADM average phosphorus application rate between 2005 and 2007 is 14.2 lb/ac, while FF is 28.6 lb/ac. FF has reduced their average application rate between 2008 and 2010 by 76% (to 6.9 lb/ac), while ADM has reduced their average application rate during the same period by 80% (to 2.9 lb/ac).

With the assistance of UMASS-CS staff, ADM and FF also monitored phosphorus concentrations in flows between the bog cells and into the pond (Figure IV-4). Regular visits to the bogs noted when flow from the bogs to the pond was occurring (Table IV-2). The internal bog sampling results were generally not accompanied by measures of flow unless discharge was occurring into the pond. For this reason, the mass of internal phosphorus loads can only be estimated.

Also as a result of the MOA terms, ADM removed a portion (17 ac) of their bog from production and flooded it for use as a large holding pond. This flooded bog cell has an unrestricted surface water connection to an irrigation pond that is adjacent to, but blocked from direct discharge to, White Island Pond. Water can also flow from the flooded bog cell via an adjacent bog cell to a pump house near White Island Pond, where water can also be pumped into the irrigation pond. ADM pump water (ADM7) has an average TP of 230 µg/l, which is diluted in the holding pond water (ADM4) that has an average concentration of 129 µg/l (Figure IV-5). Samples collected at an in-pond, nearshore locations (ADM1) has an average concentrations (92 µg/l) that is higher than the average year-round concentration measured at North Basin sampling location within the Eastern pond (45 µg/l). The high concentration at the ADM7 pump is likely due to higher phosphorus sediment being mobilized by the pump action.

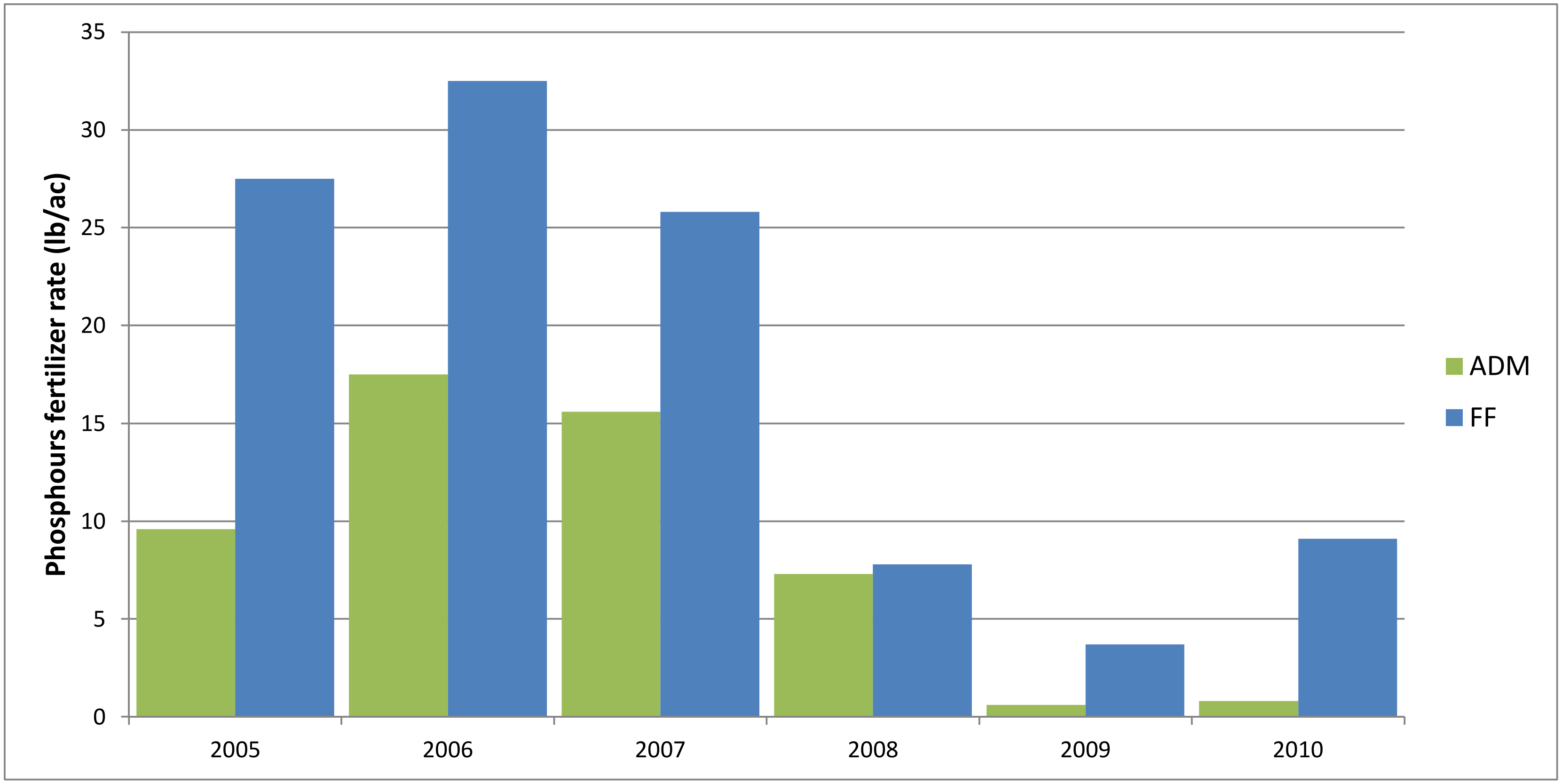


Figure IV-3. Phosphorus Fertilizer Applications to Cranberry Bogs North of White Island Pond: 2005-2010. Federal Furnace Cranberry Company (FF) and A.D. Makepeace Company (ADM) operate cranberry bogs north and upgradient of the North basin of White Island Pond. Both companies began reducing phosphorus fertilizer additions to their bogs in 2008. ADM average phosphorus application rate between 2005 and 2007 is 14.2 lb/ac, while FF is 28.6 lb/ac. FF has reduced their average application rate between 2008 and 2010 by 76% to 6.9 lb/ac, while ADM has reduced their average application rate during the same period by 80% to 2.9 lb/ac.

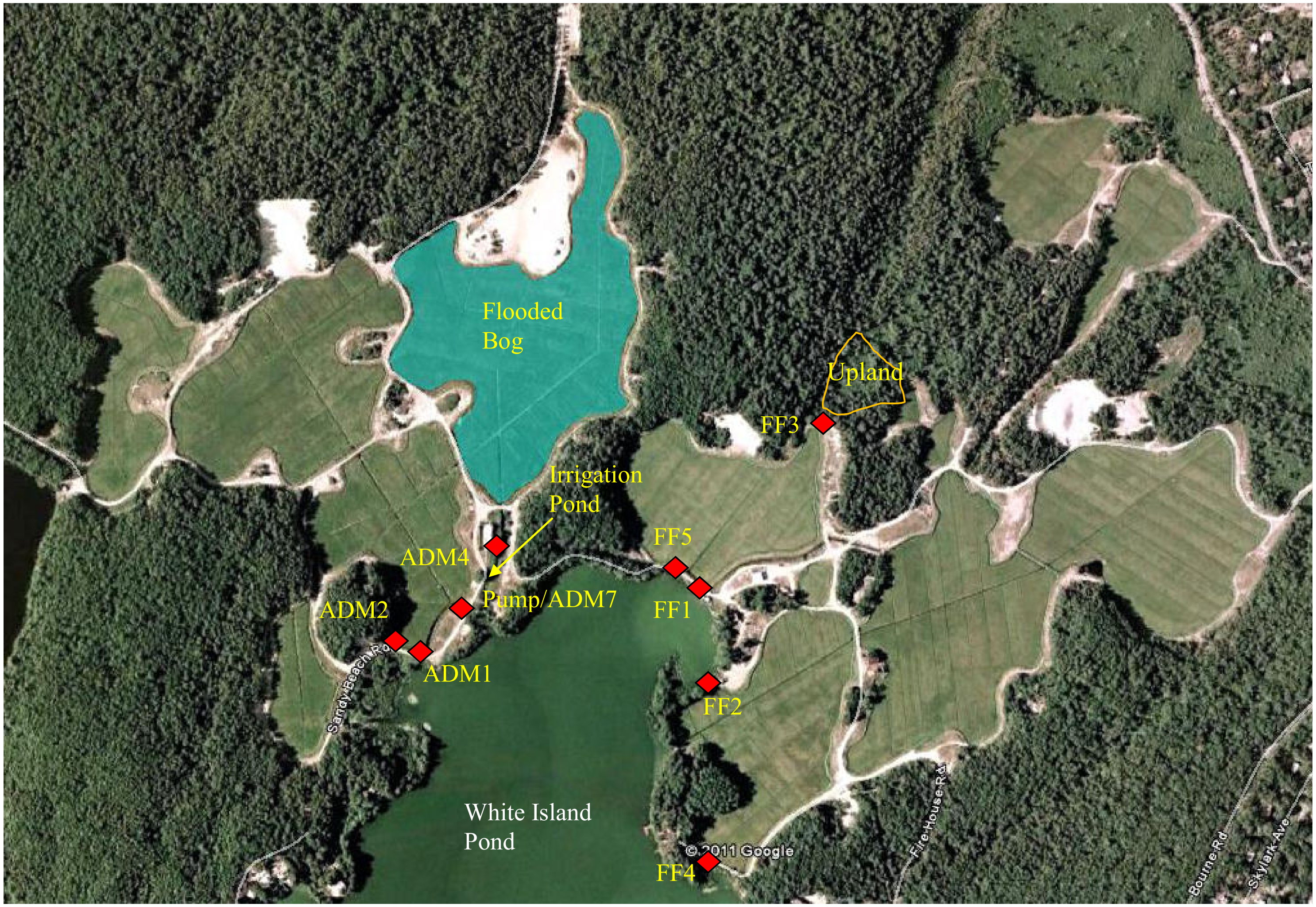


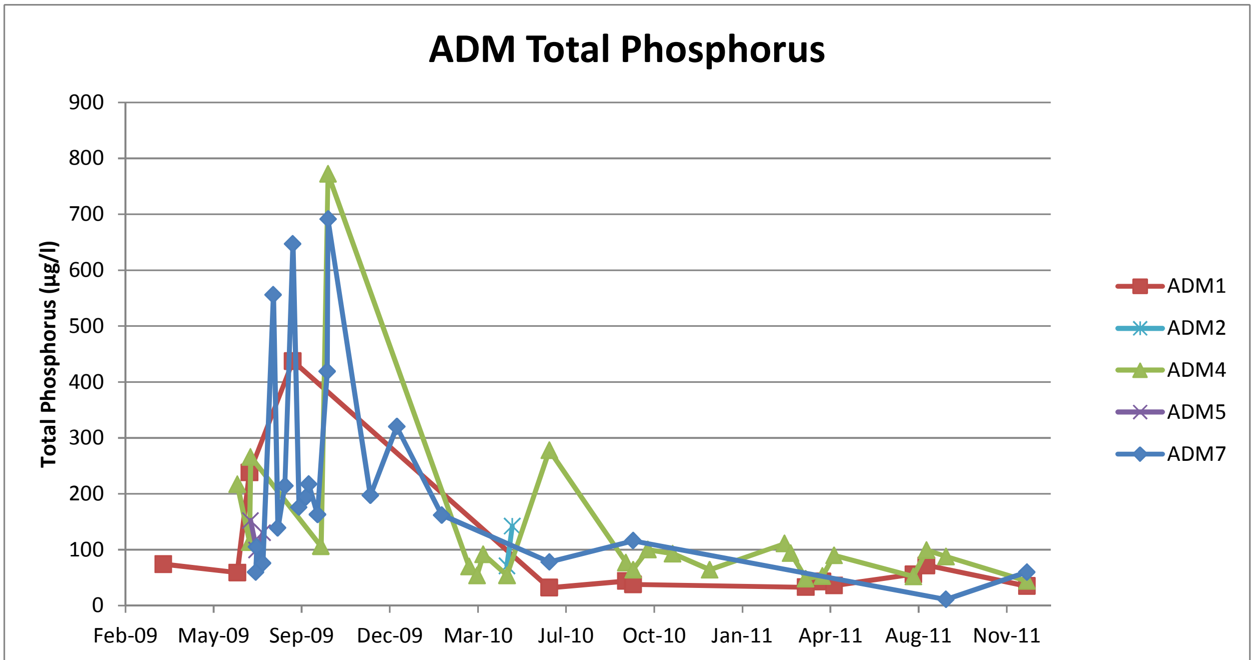
Figure IV-4. Water Quality Monitoring Locations within Federal Furnace Cranberry Company (FF) and A.D. Makepeace Company (ADM) Bogs at White Island Pond. ADM has flooded a 17 ac bog segment to act as a holding pond. The holding pond is connected via an unrestricted surface water connection to the irrigation pond (ADM4) shown in the figure. Water flows from the flooded bog to the adjacent bogs to the west and is then pumped back (ADM7) to the irrigation pond or discharged to White Island Pond. FF has installed a pumping system that recovers bog waters near the pond (FF2) and pumps these waters to the indicated upland area upgradient of the bogs (FF3).

Table IV-2. Cranberry Bog Monitoring Site Visits. UMASS-CS staff visited the Federal Furnace Cranberry Company (FF) and A.D. Makepeace Company (ADM) bogs on the listed dates over a two year period (April 2009 to December 2011). Staff collected water quality samples and noted whether water was flowing into White Island Pond (yellow shaded boxes), flowing away from the pond (blue shaded boxes) or not flowing (unshaded boxes). Note that discharges from the two bogs occurred mostly in the early part of 2010 with only limited discharges in 2009 and 2011.

2009	ADM	FF
Apr-02	x	
May-20		x
Jun-25	x	x
Jul-09	x	
Jul-10	x	
Jul-16	x	
Jul-17	x	
Jul-24	x	x
Aug-05	x	x
Aug-10	x	
Aug-18	x	
Aug-21		x
Aug-27	x	x
Sep-03	x	x
Sep-11	x	x
Sep-14	x	x
Sep-24	x	
Sep-25		x
Sep-28	x	x
Sep-29		x
Sep-30		x
Oct-01		x
Oct-02		x
Oct-05	x	x
Oct-06	x	x
Oct-07		x
Oct-08		x
Oct-13		x
Nov-23	x	x
Dec-23	x	

2010	ADM	FF
Jan-04		x
Feb-10		x
Feb-12	x	x
Mar 13-14		x
Mar-15	x	x
Mar-18	x	
Mar-24	x	
Mar 29-30		x
Mar-31	x	x
Apr-26		x
Apr-27	x	
May-03	x	x
May-19		x
Jun-14	x	x
Sep-09	x	
Sep-17	x	x
Oct-04	x	x
Oct-20		x
Oct-21		x
Nov-01	x	x
Nov-04		x
Nov-11	x	
Dec-13	x	x
Dec-30		x

2011	ADM	FF
Mar-08	x	x
Mar-15	x	
Apr-01	x	x
Apr-20	x	
May-03	x	
May-18		x
Aug-01	x	
Aug-16	x	x
Aug-18		x
Sep-07	x	
Oct-07		x
Nov-23		x
Nov-29		x
Dec-08	x	



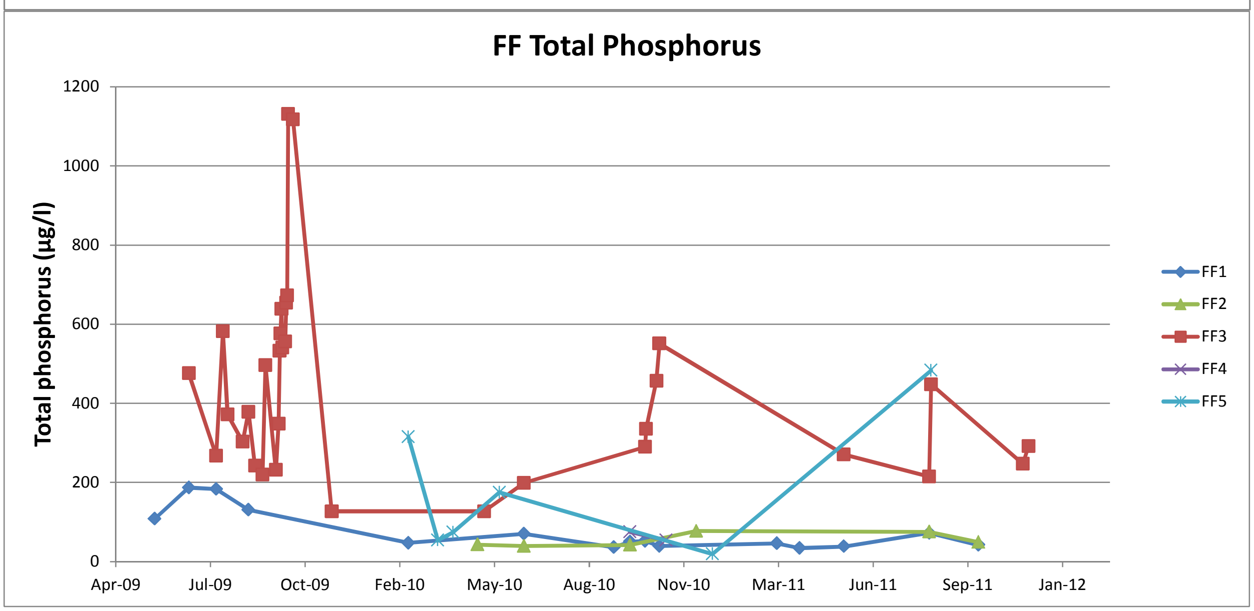


Figure IV-5. Total Phosphorus Concentrations at Federal Furnace Cranberry Company (FF) and A.D. Makepeace Company (ADM) bogs monitoring locations. Locations labeled in graphs are indicated in Figure IV-4. FF1 and ADM1 are nearshore pond samples with average TP concentrations (76 µg/l and 92 µg/l, respectively) that are higher than the average year-round concentrations measured in surface waters of the North Basin (45 µg/l). ADM pump water (ADM7) has an average TP of 230 µg/l, which is diluted in the holding pond water (ADM4) that has an average concentration of 129 µg/l. FF water collected by the upland pump in a basin at FF2 has an average TP concentration of 54 µg/l, while the discharge water (FF3) has an average TP concentration of 434 µg/l. This increase in TP concentration suggests that the FF pump is mobilizing sediment TP, likely in the same way as the pump at ADM7 is. It should be noted that flow information was collected for discharges to White Island Pond, but not for the internal movements of water, so mass transfers to accompany these concentrations are not available.

As part of the MOA agreement, FF installed a pump to collect water that had flowed via gravity to the lowest point in the bog, which is also near the pond (FF2 as shown in Figure IV-4). Pipes were installed to pump water collected at FF2 to an upland area on the bog property (FF3). The water collected at FF2 has flowed through the bog system and collected any residual phosphorus; FF2 flows also include precipitation and groundwater input, as discussed in Section II.4. The year-round average TP concentration at FF2 is 54 µg/l and 434 µg/l at FF3. The concentration at FF2 is lower than the average TP concentration at the in-pond, nearshore sampling site (FF1), which averaged 76 µg/l. The high average concentration at FF3 suggests that the pump at FF2 is mobilizing and collecting sediment in much the same way as seen at the ADM pump (ADM7).

During the monitoring for this project, the FF pumping system was adequate to prevent releases to the pond with the following exceptions: 1) winter flood water was returned to the pond and 2) instances where heavy rain overwhelmed the capacity of the pumping system. In these later events, water was released to the pond to prevent the bogs from submerging and suffering crop damage. The rain-related releases were as follows:

1) Release in 2009. On September 12, more than 7 inches of rain was recorded at the Cranberry Station during a 24 hour period. Despite the pumping system being engaged, the FF bogs were beginning to submerge with the danger of damage to the fruit on the plants. The flume to the pond was opened for ~12 hours to allow the bogs to drain. As soon as the pumping system was able to keep up, the flume was re-closed. The estimated release was ~10 acre feet, with remaining rain water pumped through to the upland. No samples were collected during the release, but pumping system water collected on September 11 had a TP of 0.220 ppm. Using this concentration, the estimated phosphorus mass of the September 12 release is 2.71 kg. This load is also the total estimated release for 2009 (April 2 to December 31)(Table IV-3).
2) Releases in 2010. Three minor rain-related releases occurred during 2010: the last week of March 2010 (1 acre ft), last week of April 2010 (1 acre ft), and May 19, 2010 (0.5 acre ft). Total TP in those releases was 0.24 kg.
3) Release in 2011. The only measured release to the pond in calendar 2011 occurred on August 15 following a 5-inch rain event (2 pumps to the upland were already running and could not keep up). That water (2.8 acre ft) was pumped out to the pond and contained 0.25 kg TP. This load is also the total estimated release for 2011.

Water and phosphorus releases to White Island Pond from FF bogs are summarized in Table IV-3, while water and phosphorus releases from ADM bogs are summarized in Table IV-4. Water flows are discussed in Section II.4.

Table IV-3. Summary of water and phosphorus releases to White Island Pond from FF bog	
2009 (began 5/20)	
Discharges to pond?	Estimated 10 acre ft released after major rain on Sept. 12, some seepage drainage for 2 weeks post-harvest. All harvest water pumped to upland; winter flood in place at year end
Sample locations	WIP edge; pipe discharging to upland
2010	
Discharges to pond?	winter flood (Jan-Mar); spring; winter flood (Dec.)
Sample locations	WIP edge; pipe discharging to upland; discharge to pond
2011	
Discharges to pond?	No winter flood after December 2010 release; snow melt not sampled or quantified; one release of excess rainfall Aug. 15-16
Sample locations	WIP edge; pipe discharging to upland; discharge to pond

Details of FF bog releases to White Island Pond			
2009	volume (acre feet)	TP conc (ppm)	TP released (kg)
September 12	10	0.220	2.71
2 weeks of post-harvest seepage not quantified or sampled			
2010	volume (acre feet)	TP conc (ppm)	TP released (kg)
January 4	36	0.127[a]	5.64
February 10	33.6	0.315[b]	13.06
March 13[c]	32.1	0.054	2.14
March 31[d]	1	0.062	0.08
April 26 (week)	1	0.043	0.05
May 19	0.5	0.175	0.11
December 30	10	0.019	0.23
TOTAL	114.2		21.3 (net 9.7)[e]
2010 notes: [a] Based on sample collected 11/23/09 (none on this date) [b] The TP concentration in the 2/10 sample was exceptionally high. This sample was collected at the very end of the release. In comparison, the 3/13 release has a similar volume, but a TP concentration <20% of the 2/10 release. Winter flood releases in a 2008-2010 study of 6 sites had TP in the range of 0.05-0.16 ppm, which matches the measured range here without the 2/10 sample. [c] sample collected this date - release of this volume occurred Mar 13-15 [d] sample collected this date – release of this volume discharge occurred over several days (including Mar 29-30) [e] if TP added to bog from imported pond water is balanced, the net TP addition to the pond is 9.7 kg			
2011	volume (acre feet)	TP conc (ppm)	TP released (kg)
winter snow melt not quantified or sampled			
August 15	2.8	0.073	0.25

Table IV-4. Summary of water and phosphorus releases to White Island Pond from ADM bog	
2009 (began 4/2)	
Discharges to pond?	no
Sample locations	WIP edge; holding pond; canal to holding pond; samples coming through an imbrium test filter
2010	
Discharges to pond?	spring only, annual total 6.9 kg TP
Sample locations	WIP edge; holding pond; canal to holding pond; samples at discharge flume to pond
2011	
Discharges to pond?	no
Sample locations	WIP edge; holding pond

Details of 2010 ADM bog releases to White Island Pond			
date	volume (acre feet)	TP conc (ppm)*	TP released (kg)
March 18, 2010	27.39	0.07	2.365
May 3-4, 2010	41.25	0.089[a]	4.53
TOTAL	68.64		6.89

Notes:
1) *Sample taken from holding pond (this water was then released to the pond)
2) [a]The May load is based on average of concentrations measured at the beginning and end of the overall input event

At ADM, the April 27 sample taken prior to the May 3 second release at the ADM bog showed 0.054 ppm TP, while the sample collected at the flume to the pond at the tail end of the release had a concentration of 0.142 ppm TP. One can presume that the integrated value during the release is somewhere between these concentrations. Review of the ortho-phosphorus concentrations shows that samples on April 27 at the flume and holding pond were 0.027 ppm and 0.029 ppm, respectively, while the May 3 flume ortho-phosphorus concentration was virtually the same (0.028 ppm). Conversely, the respective total phosphorus concentrations were 0.054, 0.071, and 0.142 ppm.

The substantial jump for the May 3 flume sample taken at the tail end of the release event suggests that higher concentrations of organic phosphorus associated with bottom waters of the ADM holding pond were being mobilized. This explanation also makes sense since the May release volume (41.25 ac-ft) is so much larger than the March release volume (27.39 ac-ft) and that larger volume would be more likely to access near-sediment waters. In order to reasonably balance the concentrations, while still remaining conservative, the average of the April 27 and May 3 flume and holding pond TP concentrations were used to calculate the TP load associated with the May 2010 release event. The March release event had a TP release of 2.4 kg, while the May release event had a TP release of 4.5 kg (see Table IV-4). As a result, the total 2010 ADM release of phosphorus to the White Island Pond is 6.9 kg. No releases of phosphorus from the ADM bogs to the pond occurred in 2009 or 2011.

The impact of pump withdrawal of sediment laden water also appears to occur in the FF monitoring. The particulate P in monitoring at the upland pipe is often quite high and the TP concentrations are often higher than those from measured releases through the bog flume. It is possible that the pump, placed in a shallow water hole within the bog, is pulling up sediment that normally would remain within the bog. This is likely the cause of the exceptionally high TP concentration associated with the February release (0.315 ppm). TP concentrations for all other 2010 releases are between 0.019 and 0.175 ppm with an average of 0.07 ppm. Review of the winter flood releases from six bogs studied by DeMoranville[114] from 2008-2010 reinforces how exceptionally high the February 2010 TP concentration is; the six bogs had winter flood TP concentrations between 0.05-0.16 ppm, which essentially matches the range for FF except for the very high February concentration. Using the TP data presented in Table IV-3, the total, uncorrected load of 21.3 kg TP was released to White Island Pond from the FF bog in the 2010 calendar year.

The 2010-2011 winter saw only one FF flood release to the pond in the final days of 2010 following a large snowfall. That release was estimated at 10 acre feet and contained 0.2 kg TP. The snow cover remained on the bog, functioning to replace a second flood. The flume boards remained out as this snow cover gradually melted. However, given the long time frame of the melt we did not measure the volume or sample the snow melt. The only measured release to the pond in calendar 2011 occurred on August 15 following a 5-inch rain event. Using the TP data presented in Table IV-3, the total, uncorrected load of 0.25 kg TP was released to White Island Pond from the FF bog in the 2011 calendar year.

All of the exports of TP discussed above are not corrected to account for the TP load imported to the bogs from the pond. If loads based on the total phosphorus concentrations in the north basin of White Island Pond at the nearest approximate times of the pond water withdrawals are summed, 11.6 kg of phosphorus was imported to the FF bog between December 2009 and December 2010. Balancing this load with the measured load exported to the pond shows a net load to the pond of +9.7 kg in 2010. This is the highest of the annual FF loads among the three years.

It is also worth noting that the releases of water from the bogs to the pond generally occur during periods when the pond ecosystem is less active and less responsive to nutrient additions. If May through September is conservatively defined as the active pond ecosystem period, measured releases during this period from the FF bog totaled 2.71 kg in 2009, 0.11 kg in 2010, and 0.25 kg in 2011, while ADM releases totaled 0 kg in 2009, 4.53 kg in 2010, and 0 kg in 2011. Timing of bog releases should be considered in the development of the water quality management strategies for White Island Pond.

Overall, FF meets the TMDL TP allocation in all three years. During the December 2009 to December 2010 period, 21.3 kg of TP was contained in the water released to the pond from the FF bogs, 11.6 kg of TP was imported to the bogs from the pond and 78.2 kg was discharged to the upland. The TP balance between the imported TP from the pond and the TP exported from the bog is less than the TP allocation to FF in the TMDL. The three winter floods in 2009-

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[114] DeMoranville, Carolyn J., "Nutrient Management" (2011). Cranberry Station Extension meetings. Paper 108. http://scholarworks.umass.edu/cranberry_extension/108 lists the 2009 data; 2010 data is not yet published.

2010 accounted for >95% of the total release of the FF bogs to the pond. In winters like 2010-2011 where a sequence of only two floods (or fewer) is required, the TP released to the pond is significantly reduced. The few emergency, in-season releases accounted for 2.71 kg TP in 2009, less than 1 kg TP in 2010 and 0.25 kg TP in 2011. If we look at the January and March flood releases (leaving out the February, suspected to be a false high reading), the two floods averaged 3.9 kg TP released, indicating that two such floods could easily meet the 10 kg TP TMDL limit. When weather conditions dictated a third flood, meeting the TMDL could be more of a problem.

The apparent impact of sampling point locations and likely sediment contributions raise a number of issues related to TMDL compliance and long-term performance of the MOA-specified management measures. If a large proportion of sediments are being mobilized at the FF bog during pumping to the upland, as the comparison of FF2 (bog collection) and FF3 (pump discharge) concentrations suggest, these sediments may function to slowly reduce the infiltration capacity of the FF discharge area. In addition, if a large proportion of the TP discharged to the pond is in particulate forms as suggested by the differences in the ADM7 (pump) and ADM4 (holding pond) monitoring, much of the phosphorus may not be biologically active especially if the forms are only suspended as a result of the pumping programs. These heavier particles would tend to settle quickly after discharge into the pond and would likely remain largely biological unavailable in the oxic pond sediments. The lack of availability of this phosphorus might be one of the reasons that no significant water quality improvements were noted following the adoption of the MOA-specified management measures.

Groundwater levels and precipitation were exceptionally high during the months when discharge occurred from the bogs to the pond (see Figures II-3 and II-4 for groundwater levels); precipitation during March 2010 was 13.52 inches, which is 56% higher than the next highest month during the two year period (see Figure II-10). FF discharged a total of 129,762 m3 between January 3 and May 18 with the 97% of the flow discharged on January 3, February 9 and March 12. TP samples taken on these three days show that a total of 21.1 kg of phosphorus was discharged from the FF bogs to the pond. ADM discharged a total of 84,666 m3 on March 17 and between May 3 and 4. TP samples taken on the day of these discharges show that a total of 5.1 kg of phosphorus was discharged from the ADM bogs to the pond. The total phosphorus load from both bogs to White Island Pond is 26 kg/yr. Based on water quality monitoring from the bogs, both bogs add approximately 60% additional P to the incoming White Island Pond water, therefore approximately 40% of the loads discharged from the bogs are returned pond phosphorus or approximately 15.6 kg/yr.

One other cranberry bog loading issue to try to evaluate from the available data is what the historic addition of phosphorus to the pond might have been prior to the implementation of the phosphorus management restrictions by the bog owners. Based on current practices, the bog owners likely withdrew irrigation and flood waters from the pond. The phosphorus in this pond water would have been subject to higher fertilizer phosphorus additions, but the harvest yields would likely have been similar to what occurs today (Table IV-5). Harvest and flood water plus any groundwater discharge and recharge water to the bogs would likely have been allowed to travel through the bog ditches for most of the year unless water was needed for flood events.

<table>
<tr><th colspan="8">Table IV-5 Cranberry Bog Fertilizer Application Rates and Yield (2005-2011): Federal Furnace Cranberry Company (FF) and A.D. Makepeace Company (ADM) Bogs at White Island Pond</th></tr>
<tr><td colspan="4">ADM</td><td colspan="4">FF</td></tr>
<tr><td rowspan="2">Year</td><td>P rate</td><td>tissue P</td><td>Yield</td><td rowspan="2">Year</td><td>P rate</td><td>tissue P</td><td>Yield</td></tr>
<tr><td>lbs/acre</td><td>% dry weight</td><td>barrels/ acre</td><td>lbs/acre</td><td>% dry weight</td><td>barrels/ acre</td></tr>
<tr><td>2005</td><td>9.6</td><td></td><td>118</td><td>2005</td><td>27.5</td><td></td><td>208</td></tr>
<tr><td>2006</td><td>17.5</td><td></td><td>138</td><td>2006</td><td>32.5</td><td></td><td>184</td></tr>
<tr><td>2007</td><td>15.6</td><td></td><td>91</td><td>2007</td><td>25.8</td><td></td><td>195</td></tr>
<tr><td>2008</td><td>7.3</td><td>0.13</td><td>165</td><td>2008</td><td>7.8</td><td>0.15</td><td>240</td></tr>
<tr><td>2009</td><td>0.6</td><td>0.15</td><td>94</td><td>2009</td><td>3.7</td><td>0.16</td><td>158</td></tr>
<tr><td>2010</td><td>0.8</td><td>0.11</td><td>123</td><td>2010</td><td>9.1</td><td>0.13</td><td>215</td></tr>
<tr><td>2011</td><td>0.7</td><td>0.15</td><td>133</td><td>2011</td><td>4.4</td><td>0.16</td><td>222</td></tr>
<tr><td colspan="8">Note: Federal Furnace Cranberry Company (FF) and A.D. Makepeace Company (ADM) operate cranberry bogs north and upgradient of the North basin of White Island Pond. Both companies began reducing phosphorus fertilizer additions to their bogs in 2008. ADM average phosphorus application rate between 2005 and 2007 is 14.2 lb/ac, while FF is 28.6 lb/ac. FF has reduced their average application rate between 2008 and 2011 by 78% to 6.2 lb/ac, while ADM has reduced their average application rate during the same period by 83% to 2.4 lb/ac. Average yields in the pre- and post-P application reduction have increased in both bogs: +27% at the ADM bog and +4% at the FF bog.</td></tr>
</table>

Comparison of bog fertilizer practices shows that phosphorus application rates have decreased significantly. ADM phosphorus applications during 2005 to 2007 averaged 6.1 times the average in 2008 to 2011, while at the FF bog 2005 to 2007 phosphorus applications were 4.6 times the average applications in 2008 to 2011 (see Table IV-4). If the average application rates in 2004 to 2007 are used for ADM and FF bog surfaces and the flooded bog at ADM is included in the area calculations, the historic annual phosphorus fertilizer additions at the two bogs are 648 kg at FF and 245 kg at ADM. If one then compares the average application rates from 2008 to 2011, the annual average phosphorus fertilizer additions are 142 kg at FF and 40 kg at ADM. Based on these calculations, the maximum estimated load to the pond would be the difference between the higher application rate period and the lower application rate period or 506 kg at FF and 205 kg at ADM. Given that the yields are similar in the same periods, these load would be the maximum additions to the pond even with the correction for the bog harvests.

If one then evaluates the range of discharges that occurred in recent three years of bog discharge monitoring, the potential load from the bogs to the pond has even greater variability. As shown in Table IV-3, in 2009, 10 ac-ft of water and 2.7 kg of phosphorus was discharged to the pond from FF without any use of the upland discharge site. In 2010, 114 ac-ft of water and 21 kg of phosphorus was discharged to the pond and 78 kg of phosphorus was discharged to the upland site. In 2011, 2.8 ac-ft of water and 0.25 kg of phosphorus was discharged to the pond and none was discharged to the upland site. Under a fertilizer regime where an average of 142 kg of phosphorus is applied to the FF bogs, the amount of phosphorus released from the bogs varies in 2009, 2010, and 2011 from 2.7 kg, 99 kg, and 0.25 kg, respectively. These loads represent 2%, 70%, and 0.2% of the phosphorus applied, respectively. If the range of these percentages is applied to the older historic application rates, the estimated loads from the bogs are 1.3 kg to 454 kg from FF and 0.5 kg to 172 kg for ADM or a total annual range of 1.8 to 626 kg.

At the low end of the range, the additions of phosphorus from the bogs to the pond would have been negligible and phosphorus concentrations in the pond would have been determined by other factors (*e.g.*, watershed and sediment inputs, precipitation, outflow, temperatures, etc.). At the high end of the range, the timing of the loading would be key. During 2010, winter flood waters at FF were generally released in January through March and this is 89% of the water released from the bogs to the pond that year. If this situation occurred at the highest loading rate, 557 of the 626 kg would be released to the pond while the plants in the pond are largely dormant; the net addition during the summer period would be 69 kg, which is less than the peak addition measured in summer 2010 (see Figure IV-1). If this load were added on top of the peak addition measured in summer 2010, the surface TP concentrations would be twice as high as any measured during 2009 or 2010 and 75% higher than any of the readings recorded by MassDEP. These calculations suggest that bog loads of phosphorus to the pond have generally followed the current practices with most of the loading occuring during the colder months.

IV.7. Pond Sediment Loading

The rate of phosphorus release from pond sediments into the water column is dependent on a number of factors including the available mass, the temperature, the area of sediments, and the loading to the sediments. Deeper portions of ponds tend to function as settling basins with winnowing of near shore sediments toward the deep points, so greater sediment accretion is generally greater in the deepest basin with thinning towards the shoreline. During aerobic or oxic conditions, sediment release of inorganic phosphorus is variably balanced by settling of particulate organic phosphorus (including phytoplankton) in overlying waters depending on temperature and circulation patterns. In warmer, summer water conditions, anaerobic sediment conditions can move closer to the sediment/water interface and cause phosphorus release through the interface boundary even when the overlying water is generally well-oxygenated. If sediment oxygen demand is sufficient enough to create low oxygen or anaerobic conditions in the overlying water, sediments will shift to anaerobic processes and phosphorus will be released from the sediment at rates that are generally at 5 to 10 times the aerobic rates.

In White Island Pond, sediments were sampled as described in Section III.4. During this sampling, the sediments were collected at various depths in each of the basins and sediment characteristics were noted (*e.g.*, sand, cobbles and/or mud). Water quality conditions overlying the sediments at the time of core collection were generally oxic, although depressed dissolved oxygen concentrations were recorded in the Middle Basin on August 19, 2009. Based on the core incubations and after accounting for the location and depth of the cores and the bathymetry of the basins, the following gross aerobic phosphorus daily regeneration rates for the basins were determined: 1.6 kg in the North basin, 2.7 kg in the Middle basin, and 1.7 kg in the West basin. These rates include corrections for phosphorus settling from the water column, but do not account for phosphorus that is released and chemically re-precipitated and returned to the sediments. Assuming a standard portion of water column phosphorus settles, the net result of the core incubations suggest that on average 45% of the phosphorus that settles on the sediments is regenerated in the North basin, 19% is regenerated in the Middle basin and 29% is regenerated in the West basin. The mass settling in the Middle basin is high compared to either of the other basins: 3.5 kg in the North basin, 5.8 kg in the West basin, and 14.4 in the Middle basin. These findings confirm the Middle Basin is the primary depository of phosphorus retained by the Eastern portion of the pond and is the also the primary source for any regenerated phosphorus.

Comparison of the sediment data to the measured water quality data shows that the regeneration rates should be adjusted with measured settling data in the pond (settling was not part of the data collection). Total phosphorus mass in the water column in the West basin average 52 kg between July 2009 and November 2010 with an exceptional peak of 117 kg in August 2010 (see Figure IV-1). The watershed phosphorus loading estimates are 46 to 64 kg/yr. Adjusting the watershed load and sediment loads to account for the 578 day residence time, the estimated steady state mass in the pond would be 1035 to 1063 kg. This analysis suggests that West basin sediments are on average accreting over 90% of the phosphorus added to the basin. This retention rate is high, but common for ponds with long residence times (*e.g.*, Brett and Benjamin, 2008). Similar review of the East basin shows a retention rate of 77%. This review reinforces the role of seasonal fluctuations in sediment conditions are a key for water quality conditions in White Island Pond.

Review of the statistical analysis of the water quality data shows the control that sediments have over the water quality conditions in the Eastern basin; near sediment phosphorus concentrations explain 80% of the variability in the water column phosphorus mass measured in the East basin. In the West basin, sediments play less of a role; near sediment phosphorus concentrations explain 50% of the variability in the water column phosphorus mass measured in the West basin.

IV.8. Phosphorus Management Model/Budget Discussion

Review of the water quality data in White Island Pond clearly indicates that the phosphorus mass in the pond fluctuates throughout the year (see Figure IV-1). It is also clear that the fluctuations appear to be more significantly impacted by sediment interactions than watershed inputs given that watershed additions from residential development should be relatively constant due to aquifer groundwater flow and phosphorus retention and that most of the bog additions occur, during the years they do occur, in between times when the spikes in pond phosphorus mass are measured.

The phosphorus mass in White Island Pond fluctuates but shows a baseline of 70 and 100 kg in the Eastern basin and approximately 50 kg in the Western basin (see beginning of this section). During the summer, the phosphorus mass in the pond increases and peaks in August. Phosphorus mass in the East basin averaged 162 kg in summer 2009 and 151 kg in summer 2010; the average of both summers is 156 kg. August peaks in the East basin are: 200 kg on 8/19/09 and 254 kg on 8/27/10. Both peaks correspond to the year’s temperature maximums. West basin masses are smaller with a summer peak occurring only in August 2010. If the August 2010 peak is excluded, the average mass in the West Basin in the summer and throughout the year are essentially the same (49 and 47 kg, respectively). This similarity suggests that sediments are not as important for determining water quality in the West basin as they are in the East basin.

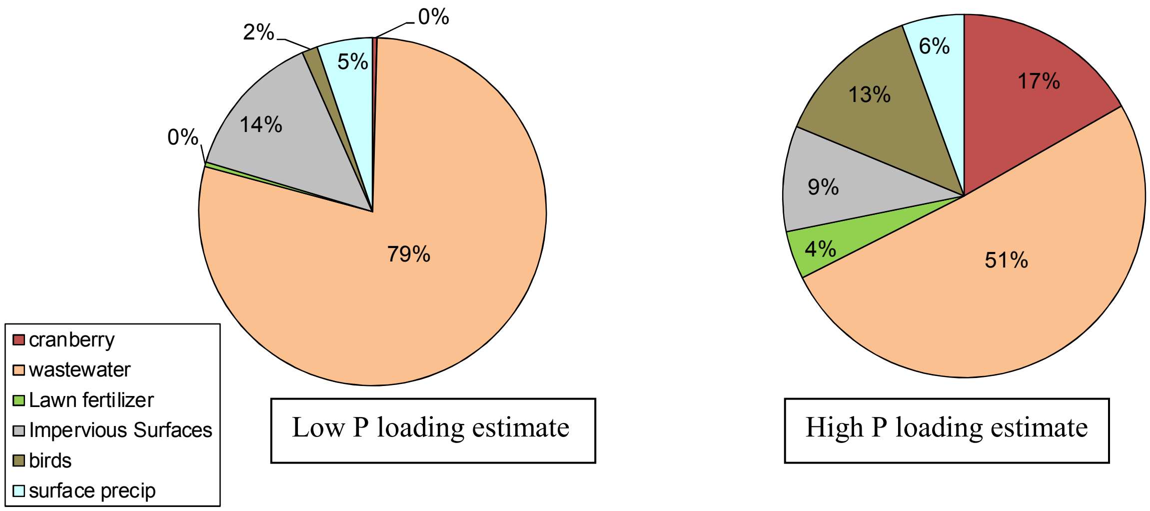
Using the phosphorus loading factors discussed above, the estimated annual load to the East basin without including the cranberry bogs is between 61 and 82 kg, while the West basin is between 46 and 64 kg. In both basins, wastewater is the largest component of the watershed load. Both of these estimates tend to match well with the measured mass in the pond attributed to the watershed after accounting for the measured loads from the cranberry bogs.

Based on the measured discharge and water quality data, the two cranberry bogs would add varying annual phosphorus masses to the East basin of the pond: 2.7 kg in 2009, 16.6 kg in 2010, and 0.25 kg in 2011. As a result of these additions, the total estimated annual watershed loading ranges to the East basin would be: 64 to 85 kg phosphorus in 2009, 78 to 99 kg in 2010, and 61 to 82 kg in 2011. The maximum of these annual loading ranges including the maximum cranberry bog addition fits within the estimated baseline watershed load based on the measured mass of phosphorus in the pond.

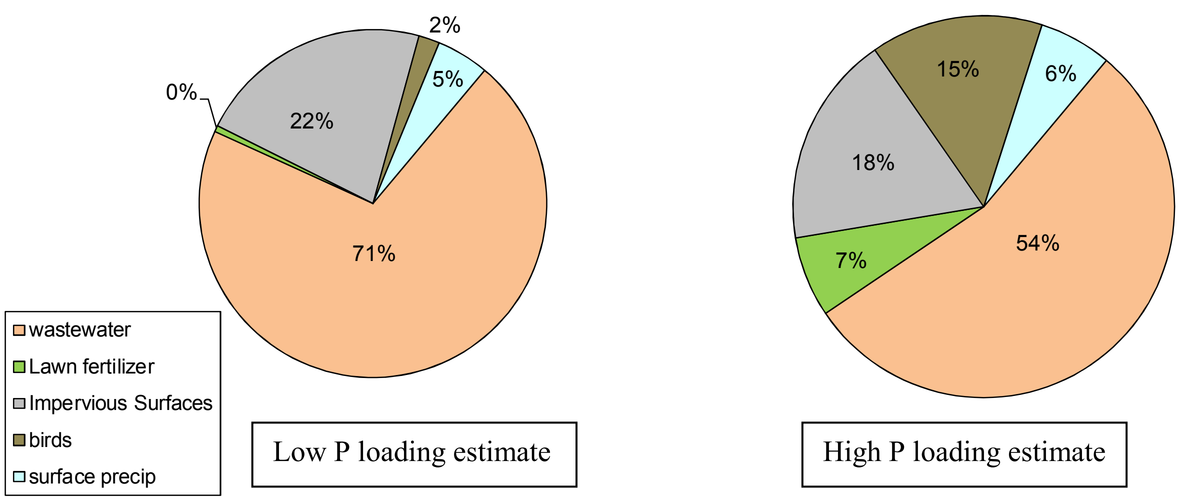
Since the measured data and the estimated watershed loading data generally agree, staff determined the range of phosphorus additions associated with the various watershed sources. Based on this assessment, wastewater is the largest source of annual watershed phosphorus loads to White Island Pond varying between 51% and 79% of the high and low watershed estimates to the East basin and between 54% and 71% to the West basin (Figure IV-6). Based on the 2009 to 2011 monitoring data, the two cranberry bogs add between 0.4% and 17% of the annual East basin watershed load. Other East basin sources are: impervious surfaces, 9 - 14%; lawns, 0.4 - 4%; birds, 2 – 13%, and direct precipitation, 5 – 6%. Other West basin sources are: impervious surfaces, 18 - 22%; lawns, 0.6 - 7%; birds, 2 – 15%, and direct precipitation, 5 – 6%.

Another factor to consider in the discussion of the phosphorus mass in the water column is the phosphorus load from sediment regeneration. If one looks at the summer watershed load to the East basin during its average 157 day residence time, the summer phosphorus watershed loading would be 26 to 35 kg. In order to achieve the average summer mass of 156 kg, the sediments would contribute the difference or 120 to 129 kg (Figure IV-7). This sediment load is roughly an order of magnitude greater than the aerobic regeneration and suggests that the bottom sediments in the East basin become anaerobic, even though the overlying water does not, and these conditions cause releases from the large pool of sediment phosphorus that is only mobilized under anaerobic conditons. The corresponding sediment regeneration rate to attain this release is 0.79 to 0.85 kg/d.

In the West basin, the residence time is significantly longer (578 days) and would extend over two summers; the average summer mass in the West basin is 59 kg. This mass is only slightly larger than the May to October average mass of 46 kg and fits within the estimated 14 kg P/month associated with the net aerobic sediment phosphorus regeneration for the West basin (see Section III.4). Since the length of the residence time in this basin extends over more than a year and a half, water column phosphorus masses will potentially reflect sediment conditions of two summers. If loads from one East basin residence time (157 days) are considered, the estimated summer load from the sediments varies between 0.2 and 0.25 kg/d, which is reasonably consistent with the sediment sampling data, but may suggest less phosphorus regeneration and more retention by the sediments. This basin also shows the impact of likely anaerobic sediment condition in August 2010, when the mass in the West basin increased



A. East Basin



B. West Basin

Figure IV-6. Annual Watershed Phosphorus Loading Estimates for the East and West basins of White Island Pond. Annual phosphorus loading estimates and resulting percentages by source within each of the basin subwatersheds are displayed; wastewater is the major source to both basins. Loads are based on low and high estimates of all input factors as described in the text. Cranberry bog additions to the East basin are based on measured discharges in 2009, 2010, and 2011 from the ADM and FF bogs.

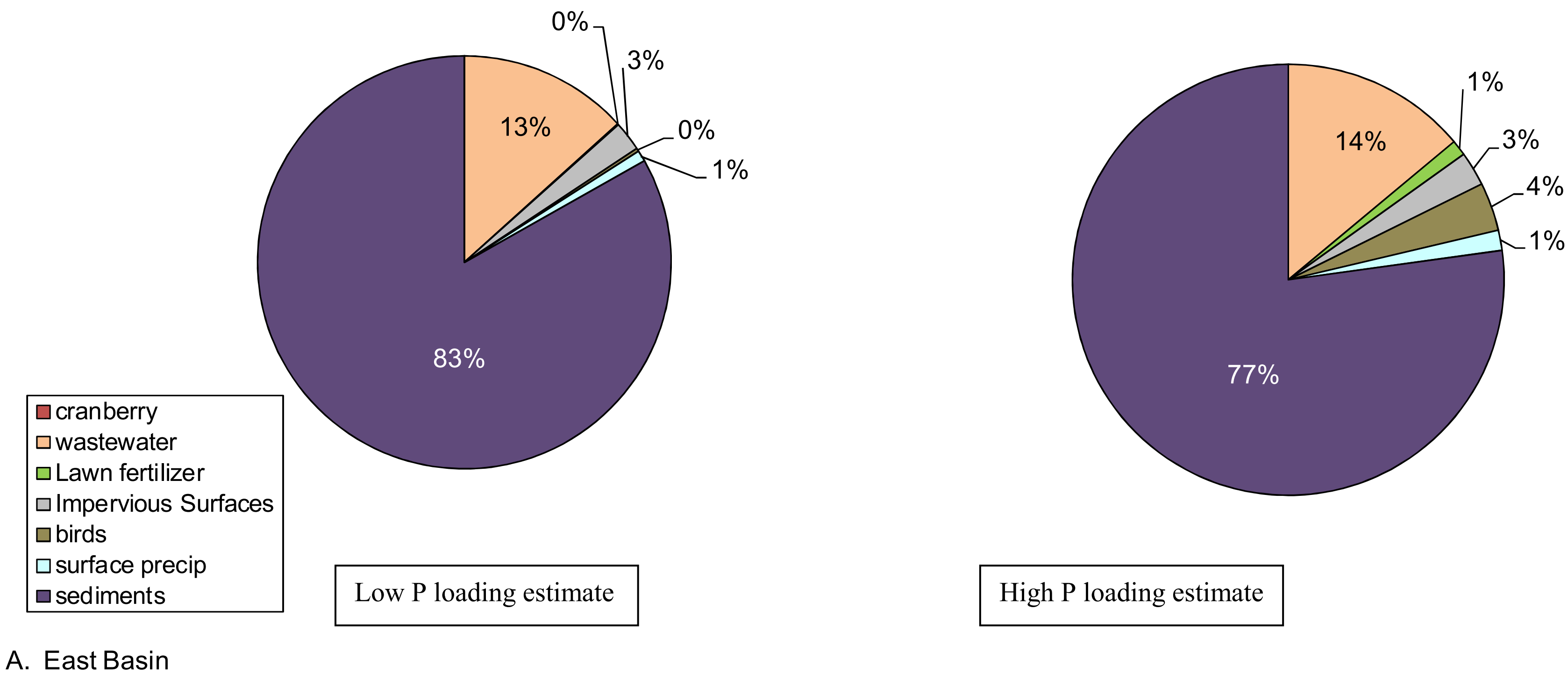


Figure IV-7. Average summer phosphorus budget for East Basin of White Island Pond. Average total mass in the East basin of White Island Pond during the summer (June to September) of 2009 and 2010 is 156 kg. The above pie charts are based on the low and high estimates of basin watershed inputs during the residence times of each basin plus the necessary sediment input to achieve the average summer total masses. No cranberry load is included in the East basin load because the bogs do not discharge to the basin during the summer. As indicated in the figure, sediment loads during the summer are the predominant source of phosphorus in the East basin.

to 117 kg. The peak releases in both basins in August 2010 are statistical outliers; phosphorus mass in August 2010 is more than 50 kg greater than the next highest mass in both basins.

Seasonality factors are also important in understanding the impact of the cranberry bogs on the total phosphorus concentrations in the pond. While the maximum annual load to the pond from the bogs was in 2010, the bogs had minimal discharges to the pond during 2009 and 2011 (see Tables IV-3 and IV-4). Most of the phosphorus loads from the bogs to the pond occurred while the pond ecosystem was inhibited by colder temperatures. In 2010, the two bogs had a cumulative load of 16.6 kg (FF had a net load of 9.7 kg, while ADM had a load of 6.9 kg), but none of this load occurred during the primary productive period of June to September. Cumulatively across three monitoring years (2009-2011), only 3 kg of phosphorus were added to the pond during this active growing period.

The seasonal timing of outflows is also something to consider in developing an understanding of the White Island Pond system and the potential impact of phosphorus additions during varying parts of the year. As indicated in Figure II-8, flow out of the pond was very high during the early months of 2010 and then declined significantly during the summer. Comparison of the total phosphorus mass in the pond to the flow at Outlet2 shows that higher mass in the pond is measured when flows are lower. Since flows are lowest during the summer, phosphorus additions, regardless of their source, will have the greatest impact during this period. Conversely, this also suggests that additions during the more dormant ecosystem period, such as those from the cranberry bogs, are less important for determining water quality conditions in White Island Pond.

The watershed loads other than the cranberry bogs are subject to the same issues of timing, but are more likely to be delivered to the pond throughout the year. Wastewater from year-round residences will discharge phosphorus throughout the year, while seasonal residences will only discharge during times of occupancy. Seasonally-occupied, summer homes often have higher occupancy than year-round homes, so wastewater phosphorus loading to the groundwater are intensive, but are limited to the season and may not reach the pond within the season the loading occurs depending on the distance of septic system leachfields to the pond and the amount of wastewater generated. Similar starts and stops in loading likely occur with stormwater on impervious surfaces (most precipitation generally occurs during the non-summer months) and lawn fertilizers (mostly during the summer). The additions of these loads to the aquifer will become mixed as groundwater moves them closer to discharge at the pond shoreline; differing time periods and additions will be blended together near the discharge interface to produce a relatively stable year-round load.

It is also notable that the water quality data indicates that average summer surface concentrations of total phosphorus have not significantly changed over the 2007, 2009, and 2010 samplings (see Figure III-4) even though the fertilizer phosphorus application rates in 2007 were much greater (see Table IV-5). Since 2007 was also prior to the implementation of the MOA changes at FF and ADM, it seems to indicate that the likely winter additions of water and phosphorus from the bogs in 2007 did not have a significant impact on water quality conditions, in much the same way that the 2009-2010 additions do not appear to have significant impact.

V. Phosphorus Management Options: White Island Pond

Assessment of the water quality in White Island Pond shows that it is impaired by excessive nutrients in both basins and that these impairments are expressed in growth of phytoplankton and decreased water clarity. Water quality data shows that the East basin is more impaired than the West basin and that the primary nutrient controlling water quality conditions in both basins is phosphorus. Review of the sources of phosphorus shows that the primary source of phosphorus to the East basin is internal sediments and the primary source to the West basin is watershed wastewater. The sediments are a net source of phosphorus to the East basin and a net sink for phosphorus going into the West basin.

V.1. Phosphorus Management Options: East Basin

V.1.1. Implemented Cranberry Bog Phosphorus Reductions

The two cranberry bog operators along the north side of the East basin have: a) reduced their phosphorus fertilizer applications, b) removed one bog cell from production, and c) managed water flows within the bogs to recirculate flows prior to discharge to the pond. These activities have reduced annual phosphorus inputs from the bogs 86% to 97% (from an estimated 1.8 to 626 kg/y prior to 2007 to measured 0.25 to 16.59 kg/yr in 2009, 2010 and 2011).

Review of the implemented steps show that the reduction in phosphorus fertilizer applications have had the greatest impact. The combined average annual fertilizer application for the two bogs in 2005 to 2007 was 893 kg. In 2009 to 2011, the annual fertilizer applications averaged 142 kg or a reduction of 84%. The conversion of a portion of the ADM bog to a permanently flooded bog has also removed its potential fertilizer application (5.4 kg) from potentially discharge to the pond. Since monitoring of bog discharges was not completed prior to the implementation of the MOA actions, it is not possible to compare phosphorus discharges from the bogs prior to MOA actions.

Given the residence time of water in the East basin and since bog discharges tend to occur during non-summer months, these reductions may reduce sediment regeneration over the long-term, but is not likely to have significant impact on summer conditions. Comparison of 2007 MassDEP data to 2009/2010 data in this report do not show significant summer water quality differences. Due to the relatively rapid residence time, late spring discharges from the bogs will have diminishing impacts as the summer progresses.

V.1.2. Potential Sediment Phosphorus Reductions

Given the large role that the sediments play in the water quality in White Island Pond, project staff reviewed options to address the sediments. Practical options to reduce the impact of sediment phosphorus regeneration in the East basin are largely confined to some type of phosphorus precipitation/inactivation or dredging of the sediments. Given the infrequent nature of anoxic conditions in the sediments and the generally well-oxygenated water column, staff do not think oxygen introduction strategies are efficacious.

Typical phosphorus inactivation in southeastern Massachusetts has been through “alum” treatments (*e.g.*, a mix of aluminum sulfate and sodium aluminate). Treatments have been completed on Ashumet Pond in Falmouth, Long Pond in Harwich/Brewster, and Hamblin and Mystic Ponds in Barnstable. Issues to be addressed during the planning and permitting of these applications have included: 1) achieving the right mix of aluminum salts to avoid any swings in pH that might be lethal to fish, 2) incorporating acceptable endangered species protections (*e.g.*,. endangered freshwater mussels were identified in two of these applications), and 3) maintaining long-term monitoring to ensure that the inactivation is sustained (monitoring on Ashumet Pond showed the need for another application, while monitoring at Hamblin Pond has shown that the benefits have been sustained for at least 10 years[118]). Sediment dredging has not been pursued in any of these cases, largely based on the comparative costs to alum treatments, but also because of the permitting uncertainties.

In order to meet the TMDL concentration of 19 µg/l, the phosphorus mass in the East basin would need to be 42 kg or less. The comparable annual phosphorus load to meet this mass/TMDL limit is 98 kg because the residence time of the East basin is less than a year (157 days). The current annual watershed load range to the East basin including the measured cranberry bog additions in 2009 – 2011 is 61 to 99 kg. This finding suggests that if sediment treatment is successful, further reductions in the watershed are not warranted and that some relaxation of phosphorus restrictions on the bogs could be considered.

Alum treatments have a range of efficacy.[119,120] If it is conservatively assumed that 90% of the sediment phosphorus regeneration is removed by an alum treatment or an alternative treatment, the remaining phosphorus mass in the pond would effectively be reduced to the watershed load. Summer peaks of phosphorus additions would also be eliminated. The lowest measured phosphorus mass in the East basin during October to May, when sediment regeneration is reduced, is 67 kg. This mass is equivalent to an annual load of 156 kg, which is higher than the watershed estimates of 61 to 99 kg/yr. This comparison suggests that winter mass in the pond includes sediment regeneration of between 32 and 41 kg. If these sediment regeneration masses are reduced by 90%, the average total phosphorus concentration in the East basin would be between 14 and 17 µg/l. This concentration range is less than the TMDL limit.

V.1.3. Potential Watershed Phosphorus Reductions

If it was decided that a sediment phosphorus reduction would not be pursued in the East basin, another potential reduction source would be within the watershed. As documented above, the cranberry bogs have reduced their inputs by 86% to 97%. Current East basin watershed loading estimates range from 61 to 99 kg with wastewater as the largest component (51 to 79%) (see Section IV.8). Since the sediments are estimated to add between 120 and 129 kg during the summer and the watershed adds only 26 to 35 kg, complete removal of watershed phosphorus additions would be insufficient on their own to meet the TMDL limit.

However, it may be worthwhile to evaluate potential watershed phosphorus reductions as part of an adapative management strategy. Potential options could include retrofitting of current stormwater treatment, shoreline buffer management, lawn size reductions or fertilizer

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[118] Eichner, E.M., T.C. Cambareri, and S. Michaud. 2006. First Order Assessment of the Indian Ponds: Mystic Lake, Middle Pond, and Hamblin Pond. Completed for Indian Ponds Association and the Town of Barnstable. Cape Cod Commission. Barnstable, MA. 71 pp.
[119] Reitzel, K., J. Hansen, F.O. Andersen, K.S. Hansen and H.S. Jensen. 2005. Lake Restoration by Dosing Aluminium Relative to Mobile Phosphorus in the Sediment. *Environ. Sci. Technol.* 39: 4134-4140.
[120] de Vicente, I., P. Huang†, F.O. Andersen, and H.S. Jensen. 2008. Phosphate Adsorption by Fresh and Aged Aluminum Hydroxide. Consequences for Lake Restoration. *Environ. Sci. Technol.* 42(17): 6650–6655.

phosphorus elimination, septic system leachfield setback requirements, and future development limits. Restricting lawn fertilizer applications has been discussed in a number of southeastern Massachusetts towns. Most of the discussed strategies include development of an educational program. Programs like these generally achieve 80-90% compliance; further discussions should occur if regulatory mechanisms are also considered for this approach.

V.2. Phosphorus Management Options: West Basin

Average summer TP concentrations in the West basin averaged 28 and 32 µg/l in 2009 and 2010, respectively (see Figure III-4). In order to attain the TMDL 19 µg/l concentration, the phosphorus mass in the West basin would need to be no more than 32 kg and the annual watershed load could be no more than 20 kg. Based on the 2009-2010 monitoring data, the average October to May phosphorus mass in the West basin is 46 kg with a range of 33 to 62 kg. Annual watershed phosphorus loading rate is 46 to 64 kg.

Since the residence time of the West basin (578 days) extends over more than 1.5 years, the mass of phosphorus in the pond is directly influenced by watershed and sediment additions during the previous year. Because temperature influences would cause the sediments to move through a cycle of acting as both a source of phosphorus (regeneration; summer) and as a sink (accretion; winter) during residence time cycle, the management of the West basin is different than in the East basin.

Comparison of the water quality data and the net sediment suggest that there might be less regeneration of phosphorus from the sediments during the summer or, given the long residence time, more accretion of phosphorus during the winter. Review of the sediment data also shows that West basin sediments are regenerating significantly less inorganic phosophorus than the East basin, which further suggests that the majority of the regenerated West basin phosphorus is not as bioactive as the regenerated phosphorus in the East basin. All of these considerations would tend to reduce the annual sediment load compared to the summer rates (see Table III-2).

These considerations also then raise the level uncertainty associated with the impact of an alum treatment or similar sediment phosphorus inactivation. Completing an alum treatment would certainly remove a summer peak phosphorus regeneration release, but only one of these occurred during the 2009-2010 monitoring period. If the exceptionally high TP concentraitons on August 27, 2010 are removed from the dataset, the 2009 vs. 2010 averages during the summer, winter, and year-round are virtually the same. The relationships suggest that the water quality in the West basin is largely controlled by watershed loadings.

If watershed loading is the primary controller of water quality conditions in the West basin, watershed phosphorus loading would need to be reduced by 57% to 69%. Since wastewater constitutes 54 to 71% of the watershed phosphorus load (see Figure IV-8), the removing this source would be the most direct way to address the required reduction to meet the TMDL.

Since removing the wastewater loading would require sewering and rough estimated cost of $2 to 4 million, staff are recommending that West basin water quality should be monitored following the implementation of East basin restoration activities. East basin restoration steps are more straightforward and implementation of these steps while monitoring the West basin water quality will clarify the interactions between the basins and the potential improvements that the West basin may derive from the improvements in the East basin. Further monitoring may also clarify that the two basins are different enough to warrant different TMDLs.

VI. Conclusions

White Island Pond is a 291 acre freshwater pond that is considered a Great Pond under Massachusetts law[122] and, as such, is a "water of the Commonwealth" and publicly owned. White Island Pond is listed as an "impaired water" on MassDEP's most recent list of all state surface waters.[123] As a state-listed, impaired water, the federal Clean Water Act requires that it have a Total Maximum Daily Load (TMDL) prepared.[124] TMDLs are pollutant limits or thresholds, which when attained will restore the water quality in the listed waters.

MassDEP proposed a draft TMDL of 19 micrograms per liter (µg/l) total phosphorus for White Island Pond in April 2009. The draft TMDL reviewed available water quality data collected by MassDEP and concluded that the primary cause of the water quality impairments in the pond were due to phosphorus additions from the two upstream cranberry bogs located along the northern edge of the eastern basin. MassDEP forwarded the draft TMDL to USEPA and it was approved by USEPA in January 2010 with a phosphorus loading limit of 147 kg/yr based on a target concentration of 19 µg/l.[125]

During the development of the draft TMDL, the Massachusetts Department of Agricultural Resources, MassDEP, the Cape Cod Cranberry Growers' Association (CCCGA), and the UMASS Cranberry Station (UMASS-CS) signed a Memorandum of Agreement (MOA) to "work cooperatively with certain cranberry growers in Massachusetts to develop and implement practices with the potential for reducing the discharge of nutrients associated with cranberry cultivation in order to meet applicable water quality standards." A.D. Makepeace Company and Federal Furnace Cranberry Company, which operate the two upstream bogs along the northern edge of White Island Pond, agreed to participate in a pilot program to develop and implement best management practices (BMPs) to reduce their impact on White Island Pond and meet the goals of the White Island Pond TMDL.

In order to help realize the MOA objectives for White Island Pond, CCCGA obtained a Section 319 grant from MassDEP. CCCGA has been assisted in the completion of grant activities by both UMASS-CS and staff from the Coastal System Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (SMAST). All grant activities are covered under MassDEP's 319 Programmatic Quality Assurance Project Plan (QAPP) and SMAST's Massachusetts Estuaries Project QAPP. At the same time as the 319 grant tasks were proceeding, the CCCGA also asked SMAST staff to assist with the development of additional information that would help to better define the White Island Pond system, as well as helping to

[122] Massachusetts General Law, Ch. 131, sec. 1

[123] Massachusetts Year 2010 Integrated List of Waters. Massachusetts Department of Environmental Protection

[124] Public Law 92-500. Section 303 (D)(1)(c). Federal Water Pollution Control Act Amendments of 1972.

[125] Final Total Maximum Daily Load of Total Phosphorus for White Island Pond (Report Number MA95166-2009-1; CN 330.2). July 20, 2010. Available at: http://www.epa.gov/ne/eco/tmdl/pdfs/ma/WhiteIslandPond.pdf.

provide a reliable basis for development and evaluation of restoration options for the pond. This report documents tasks completed under both the 319 grant and the CCCGA/SMAST project.

SMAST and UMASS-CS staff worked together to complete monitoring of the ADM and FF bogs, as well as completing an updated assessment of water quality in White Island Pond. SMAST staff developed a new watershed to White Island Pond based on the US Geological Survey work completed for the Massachusetts Estuaries Project (MEP).[126] The new watershed was further modified to provide subwatersheds to the Main/East basin and the West basins of the pond. SMAST staff also used an Automated Underwater Vehicle (AUV) to develop a new bathymetric map and basin volumes for White Island Pond.[127] Using the new watershed and pond volumes, residence times have been developed for each basin: 153 days for the East basin and 578 days for the West basin. The new bathymetric map indicates that the pond volume is 38% larger than the volume used in the MassDEP TMDL calculations.

Data collection in White Island Pond and its nearby areas occurred between July 22, 2009 and November 30, 2010 and included 1) water quality and field data collection at three locations in the pond, 2) sediment cores at 13 locations, 3) streamflow and water quality samples at three downstream/outflow locations, and 4) monitoring of discharges from and internal sites within the cranberry bogs. All water quality samples were analyzed at the SMAST Coastal Systems Program laboratory and sediment cores were incubated by SMAST staff to analyze sediment phosphorus regeneration under varying conditions.

Review of 2009 and 2010 total phosphorus (TP) concentrations shows that the West basin averages 30 µg/l during the summer (June to September), while the Middle and North basins average 59 and 53 µg/l, respectively. Statistical analysis shows that there is no significant difference between the Middle and North basin TP averages or any other of the water quality measures and, for this reason, these data were combined and the combined basins were relabeled as the East basin. East and West basin TP averages are significantly different ($\rho<0.05$) and review of other measures seem to confirm that these basins function somewhat separately. TP concentrations in 2009 and 2010 are generally not significantly different from readings collected by MassDEP during the summers of 2000 and 2007, although the average surface concentration in the East Basin in 2000 is significantly higher and the average surface concentration in the West Basin is significantly lower than the averages in 2009 and 2010. Review of TP and total nitrogen (TN) data also confirm that phosphorus control is the key to water quality management and restoration in White Island Pond.

Dissolved oxygen data show that, on average, both basins of White Island Pond are well oxygenated and sediment testing confirms that sediment oxygen demand is usually fairly low. Dissolved oxygen concentrations in the West and North basins remained above the MassDEP 5 ppm regulatory limit[128] throughout the monitoring period. Middle basin concentrations dipped below the 5 ppm limit in August 2009, but average summer concentrations at all depths in all three basins are better than the regulatory limit. Well oxygenated deep water limits the sediment phosphorus regeneration.

[126] See Figure II-1.
[127] See Figure II-2 and Table II-2.
[128] Massachusetts Surface Water Quality Standards, 314 CMR 4.00, Department of Environmental Protection.

Average summer water clarity readings in 2009 and 2010 in both portions of the East basin are less than Massachusetts Department of Public Health 4 ft (1.2 m) safe swimming limit (105 CMR 405). West basin readings are significantly ($\rho<0.05$) higher than both the North and Middle basin readings.

Review of watershed phosphorus loading estimates and sediment regeneration reinforce the source of the differences between the East and the West basins. Wastewater is the predominant source of watershed phosphorus loading to both basins; based on 2009 to 2011 monitoring, the bogs contribute 0.4% and 17% of the annual East basin watershed load. The sediments in the East basin also function as a significant phosphorus source; during the summers, the East basin sediments add twice as much phosphorus to the pond as the watershed sources. The West basin sediments generally appear to be in relative equilibrium with the water column phosphorus; only one summer water column reading (August 2010) showed an exceptional spike in total phosphorus mass. The remainder of the West basin average total phosphorus concentrations were the same in 2009, 2010, during the winter, and during summer. Review of sediment core data show that if either basin develops regular low oxygen conditions, there is significant phosphorus in the sediments that could increase sediment release loads more than 100 times over current conditions.

Restoration of water quality in the East basin will require action to address phosphorus regeneration from the sediments. The two cranberry bog operators along the north side of the East basin have implemented a series of management steps to reduce phosphorus additions to the pond: a) reduced their phosphorus fertilizer applications, b) removed one bog cell from production, and c) managed water flows within the bogs to recirculate flows prior to discharge to the pond. These activities have reduced annual phosphorus inputs from the bogs 86% to 97%, but the data review shows meeting the TMDL 19 µg/l TP threshold will require a reduction in sediment phosphorus regeneration. Evaluation of an alum treatment or similar sediment treatment approach that can reduce phosphorus regeneration by 90% would eliminate the summer regeneration peaks and reduce the average total phosphorus concentration in the East basin to between 14 and 17 µg/l. This concentration range is less than the TMDL limit.

Water quality conditions in the West basin are not as impaired as the East basin (*e.g.* Secchi clarity is more than twice as deep, summer average TP concentrations are 40 to 60% less). But the average TP concentrations are greater than the TMDL 19 µg/l TP threshold. Review of the watershed, water quality and sediment data show that the West basin has a residence time that extends over more than 1.5 years, so that the mass of phosphorus in water column is directly influenced by watershed and sediment additions during both the previous and current years. Comparison of the water quality data and the net sediment suggest that there might be less regeneration of phosphorus from the sediments during the summer or, given the long residence time, more accretion of phosphorus during the winter. Because temperature influences would cause the sediments to move through a cycle of acting as both a source of phosphorus (regeneration; summer) and as a sink (accretion; winter) during residence time cycle, the management of the West basin is different than in the East basin.

These considerations also raise the level uncertainty associated with the impact of an alum treatment or similar sediment phosphorus inactivation on the water quality in the West basin. If the single monthly summer peak of sediment regeneration were removed from the dataset, the 2009 vs. 2010 averages during the summer, winter, and year-round are all virtually the same. These relationships suggest that the water quality in the West basin is largely controlled by watershed loadings.

If watershed loading is the primary controller of water quality conditions in the West basin, watershed phosphorus loading would need to be reduced by 57% to 69% to meet the TMDL established for the whole pond. Since wastewater constitutes 54 to 71% of the watershed phosphorus load, removing this source would be the most direct way to address the required reduction to meet the TMDL. Removing the wastewater loading would require sewering and rough estimated cost of $2 to 4 million.

Since this is such a large expenditure, project staff recommend that West basin water quality should be monitored following the implementation of East basin restoration activities. East basin restoration steps are more straightforward and implementation of these steps while continuing to monitor the West basin water quality will clarify the interactions between the basins, as well as clarifying the potential improvements that the West basin may derive from the improvements in the East basin. Further monitoring may also clarify that the two basins are different enough to warrant different TMDLs.

Overall, White Island Pond has impaired water quality caused by excessive phosphorus loads. Water quality in the East basin is more impaired than the West basin and the two basins function mostly separately. Restoration of the water quality in the East basin will require sediment treatment to prevent phosphorus regeneration from the sediments, while West basin restoration strategies should be pursued through an adaptive management approach that uses monitoring results from the implementation of East basin restoration.

VII. Recommendations for Future Activities

Listed below are a summary of recommendations to ensure that water quality in White Island Pond meets state regulatory standards and community goals. Project staff are available to discuss these recommendations with the growers, CCCGA, staff of the involved towns, concerned citizens, and MassDEP and can develop refined cost proposals that will detail the tasks, appropriate schedules and the resulting reports.

VII.1. Develop and Implement an Adaptive Management Plan for White Island Pond

White Island Pond is a dynamic ecosystem subject to fluctuations in a number of factors both natural and induced by those that live and work in its watershed. The data collection documented in this assessment clearly indicates that the overall ecosystem is impaired. MassDEP has selected a target TMDL total phosphorus concentration to remediate the impairments. Because the system is dynamic with multiple controlling factors, efforts to remediate the system have some uncertainty depending on the range of fluctuation in the controlling factors. With this in mind, it is recommended that all involved parties work to develop an adaptive management plan for remediation of White Island Pond.

It is recommended that this plan establish management goals regarding water quality, water levels, use goals, and acceptable land use characteristics. It is clear from the above analysis that sediment treatment to limit phosphorus release is clear, key feature of future management and the plan should incorporate the details of the selected treatment, the follow-up monitoring to assess it efficacy, and criteria and definition of next steps following its completion. The plan should be adaptive to include definitions of what sort of monitoring is necessary to define how the TMDL threshold has been achieved and define the responsibilities of all participants in the regulatory compliance. The plan should also discuss the financial and technical responsibilities to define TMDL compliance. The management plan also offers the opportunity to define community goals regarding use of the lake surface and desired characteristics of the pond.

VII.2. Maintain a Regular Monitoring Program for White Island Pond

Although this assessment includes a detailed and refined monitoring program, it is clear that an regular, on-going monitoring plan of the pond is necessary to: 1) assess fluctuations in the system both before and after implementation of phosphorus reduction strategies, 2) quantify the benefits of any phosphorus reduction strategies, and 3) compare water quality conditions to the TMDL threshold.

Based on the review of the available data, it is recommended that a regular monitoring program be developed for White Island Pond. This program should include the following:

8) Water column profile measurements of dissolved oxygen and temperature and Secchi readings in each of the three basins at the locations sampled during this assessment. There should be a minimum of four sampling events, one each month between June and September.
9) Collection of water samples at each of the three basin locations. At a minimum, samples should be collected at the surface (0.5 m) and one (1) meter off the bottom. Samples should be assayed for at least the following parameters: total phosphorus, total nitrogen, chlorophyll *a*, pH, and alkalinity. Assays should have protocols and detection limits at least as sensitive as those provided by the SMAST-CSP Analytical Facility.
10) Monthly measurement of pond elevation.
11) Regular training for samplers if sample collection is performed by volunteers.
12) Regular technical oversight in order to facilitate the sampling program and provide rapid feedback on monitoring coordination and results interpretation.
13) An annual brief technical memorandum comparing the past summer's sampling results to previous data.
14) A five-year cumulative review assessing trends and progress toward TMDL compliance.

This monitoring plan could be incorporated into the adaptive management plan, so that responsibilities for the monitoring are clearly established and the feedback loops for monitoring findings are incorporated into management activities.

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