Sassaquin Pond
Baseline Assessment Report

Draft FINAL REPORT
April 2015

for the

City of New Bedford

Prepared by:

Coastal Systems Program
School for Marine Science and Technology
University of Massachusetts Dartmouth
706 South Rodney French Blvd.
New Bedford, MA 02744-1221

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Department of Public Infrastructure

and

Sassaquin Pond Betterment Alliance

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Cover photo: Sassaquin Pond (October 28, 2014)

Acknowledgements

The authors acknowledge the contributions of the many residents of the Sassaquin Pond community and the staff of the City of New Bedford that led to the completion of this report. The authors specifically recognize and applaud the generosity of time and effort spent by Sassaquin Pond Betterment Alliance members. Among this group particular thanks go to Dennis Audette and Marie Pepin, Jeff and Liz Miller, and Michael Frye. These individuals gave their assistance to the support collection of water quality information, which made the development and implementation of this project possible. Special acknowledgement is also deserved for Dennis Audette and Marie Pepin for their generosity and assistance with logistical support for the project. The authors also specifically thank City of New Bedford staff David Fredette from Department of Public Infrastructure and Sarah Porter from the Office of Environmental Stewardship for their generous assistance and technical support that allowed the completion of this project. The authors also acknowledge the assistance of technical and project support from David White, Sara Sampieri, Jennifer Benson, Amber Unruh and others at the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth.

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Executive Summary

Sassaquin Pond, New Bedford MA
Baseline Assessment Report
Final Report
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Sassaquin Pond is a 38-acre pond located near the northern edge of New Bedford, Massachusetts. Water quality in the pond has become a significant concern to residents and New Bedford officials, particularly given documented algal blooms and bacterial contamination. In response, the City of New Bedford has begun plans to update the stormwater system currently discharging into the pond. Area pond users have also formed a citizen advocacy group, Sassaquin Pond Betterment Alliance, concerned about regular recreational use and long-term ecological health of the pond.

At the request of the City of New Bedford, the Coastal Systems Program at the School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) was asked to complete a baseline assessment of Sassaquin Pond in order to document future improvements from the upgraded stormwater system and any other management actions. Baseline conditions were established by measuring water quality in the pond, assessing the pond sediments as a nutrient source, updating the pond bathymetry and volume, and measuring flows and nutrient loads from the stormwater system that discharges to the pond.

Water quality samples were collected on 10 dates between April and November 2014. Samples were collected each meter (typically 7 samples per profile) and analyzed at the SMAST Coastal Systems Analytical Facility using standard procedures that have been approved by the Massachusetts Department of Environmental Protection (MassDEP) and USEPA. Dissolved oxygen and temperature profiles and water clarity readings were also collected on each date.

Review of the water quality results shows that Sassaquin Pond is impaired by high nutrient levels. One consequence is that the pond regularly has dissolved oxygen concentrations that are less than Massachusetts regulatory minimums. Phosphorus, nitrogen, and chlorophyll concentrations also exceed their respective ecoregion guidance concentrations. Clarity is regularly limited. The reduced clarity and high chlorophyll a concentrations are the direct result of phytoplankton blooms supported by the high nutrient conditions. Review of nitrogen and phosphorus concentrations show that management of phosphorus levels is needed to restore the water and habitat quality within the pond.

Stormwater runoff measurements and water quality samples were collected during six storm events. Samples and readings were collected from two outfall pipes that represent greater than half of the overall stormwater system that discharges into Sassaquin Pond. Discharge volumes from the two outfall pipes generally behaved similarly and carried dissolved and particulate constituents consistent with the type of land use within the stormwater watersheds. Larger storms generated greater discharge with an overall range of runoff from 6% to 61% of measured precipitation. Measurements of contaminants in runoff showed variable relationships between runoff amounts, the amount of contaminants, and which outfall was being measured. Runoff samples were analyzed at the SMAST Coastal Systems Analytical Facility using standard procedures. Contaminants measured included nitrogen, phosphorus, and total suspended solids. Most contaminants increased with increased runoff flow, but selected contaminants (ortho-phosphate, ammonium-nitrogen, and TSS) had poor relationships for one or both of the outfall pipes. Resolution of these differences would require more refined evaluations of the outfall pipe watersheds/collection areas. It should also be noted that the estimated annual loads of nitrogen, phosphorus, and TSS based on the stormwater runoff measurements are significantly less than those previously estimated in previous investigations, due in large part to assumed concentrations that were significantly higher than any of the measured 2014 concentrations.

The bathymetric survey conducted by CSP-SMAST staff was significantly more refined than previous evaluations and results showed that the pond volume was 19% smaller than previous estimates. Review of past pond watershed delineations also noted an inconsistency with recently derived watershed delineation information from the Massachusetts Estuaries Project (MEP). MEP delineations of Slocums River, Westport River, and Apponagansett Bay estuarine systems show that Sassaquin Pond is located in an area between the northern edges of these watersheds. These delineations suggest that Sassaquin Pond is part of the Taunton River watershed and the pond watershed should include areas that have not been included in previous assessments. Resolution of this issue, along with the impacts of the refined bathymetry, is outside of the scope of the current project, but would be useful to inform nutrient management strategies for the pond. A smaller volume and a larger watershed would alter a number of aspects of the system characterization, including interpretation of water quality data and the water budget.

Sediment cores collected and incubated under *in situ* conditions showed storage of significant nutrients that could be released with changes in dissolved oxygen conditions. In general, the sediments collected phosphorus during aerobic conditions, which always occurred in the shallower areas (≤ 3 m depth) during the 2014 baseline sampling, but these sediments then released phosphorus as dissolved oxygen concentrations declined. Potential phosphorus release was large for the initial phase of anoxia, but substantially more would be released with prolonged anoxia. Water quality readings suggest that the sediments in the deep basins had accelerated phosphorus release in July and sustained these conditions through November. Nitrogen more readily exchanged with the sediments due to its greater availability, but cores showed significant mass stored in shallower sediments. Anaerobic sediment conditions appeared to cross a nitrogen release threshold in August and September, due to lower coupled nitrification-denitrification in the sediments (from lack of oxygen for nitrification). As a result, during this period the mass of nitrogen in the pond water column nearly doubled.

Based on the baseline characterization of Sassaquin Pond, CSP/SMAST staff also listed some recommendations for the City to evaluate if additional pond management activities are considered. These recommendations include: a) an updated watershed delineation, b) a submerged aquatic plant and phytoplankton survey, c) development of updated nutrient and water budgets, d) a bacterial assessment (re: TMDL), e) continuing assessment of water quality as stormwater improvements are implemented and f) a comprehensive pond management plan. The rationale for these recommendations is included in this baseline assessment.

CSP/SMAST staff is available to discuss and refine any evaluations and conclusions in this report.

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I. Introduction

Sassaquin Pond is a 38-acre pond located near the northern edge of New Bedford, Massachusetts (**Figure I-1**). Water quality in the pond has become a significant concern with regular algal blooms (**Figure I-2**) and bacterial concerns. In response, the City of New Bedford has begun plans to update the stormwater system that currently discharges into the pond. Area pond users have also formed a citizen advocacy group, Sassaquin Pond Betterment Alliance, concerned about regular recreational use and long-term ecological health of the pond. At the request of the City of New Bedford, the Coastal Systems Program at the School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) was asked to complete a baseline assessment of the pond. This assessment was tasked with measuring water quality within the pond and determining the stormwater flows and contaminant loads discharging into the pond, updating the pond bathymetry, and determining role of the pond sediments as a nutrient source/sink for the pond waters. This report documents these results and provides context for future water quality management planning.

II. Sassaquin Pond History

Land use near the pond has undergone a series of changes over the past few decades. The nearby neighborhood was originally summer houses with septic systems, but by the mid-1970's many of the houses were year-round residences and the City began connecting the houses to the municipal sewer system to address water quality problems in the pond.[1] Because of this land use development history, most of the parcels in the area around the pond are residential and most are less than 10,000 sq ft (see **Figure I-1**).

The dense development also included a stormwater drainage system that collected runoff and discharged it into the pond through a series of pipes. This system, which had initial construction during the 1960's, includes 12 pipes and three drainage swales that discharge stormwater runoff into the pond from catch basins throughout its watershed (**Figure II-1**). In 2013, it was proposed to the City that the stormwater system be updated to include 60 tree box filters to remove nutrients and suspended solids from the runoff prior to discharge into the pond.[2]

The pond ecosystem has also been extensively managed. In 1962, a fisheries survey was completed, a pesticide was used to remove the existing fish population, and the pond was stocked with largemouth bass.[3] Herbicides were used to reduce white and yellow water lilies in the late 1960's/early 1970's and a ban on gasoline-powered boat engines was implemented in the 1970's.

Various water quality monitoring efforts have been undertaken in Sassaquin Pond, however many of the efforts have been limited in scope and naturally led to additional questions. A 1987 preliminary evaluation included collection and analysis of

[1] Nitsch Engineering. 2013. Sassaquin Pond Watershed Restoration Study. Boston, MA.
[2] *Ibid*.
[3] Baystate Environmental Consultants, Inc. 1987. A Preliminary Evaluation of Sassaquin Pond and its Watershed. East Longmeadow, MA.

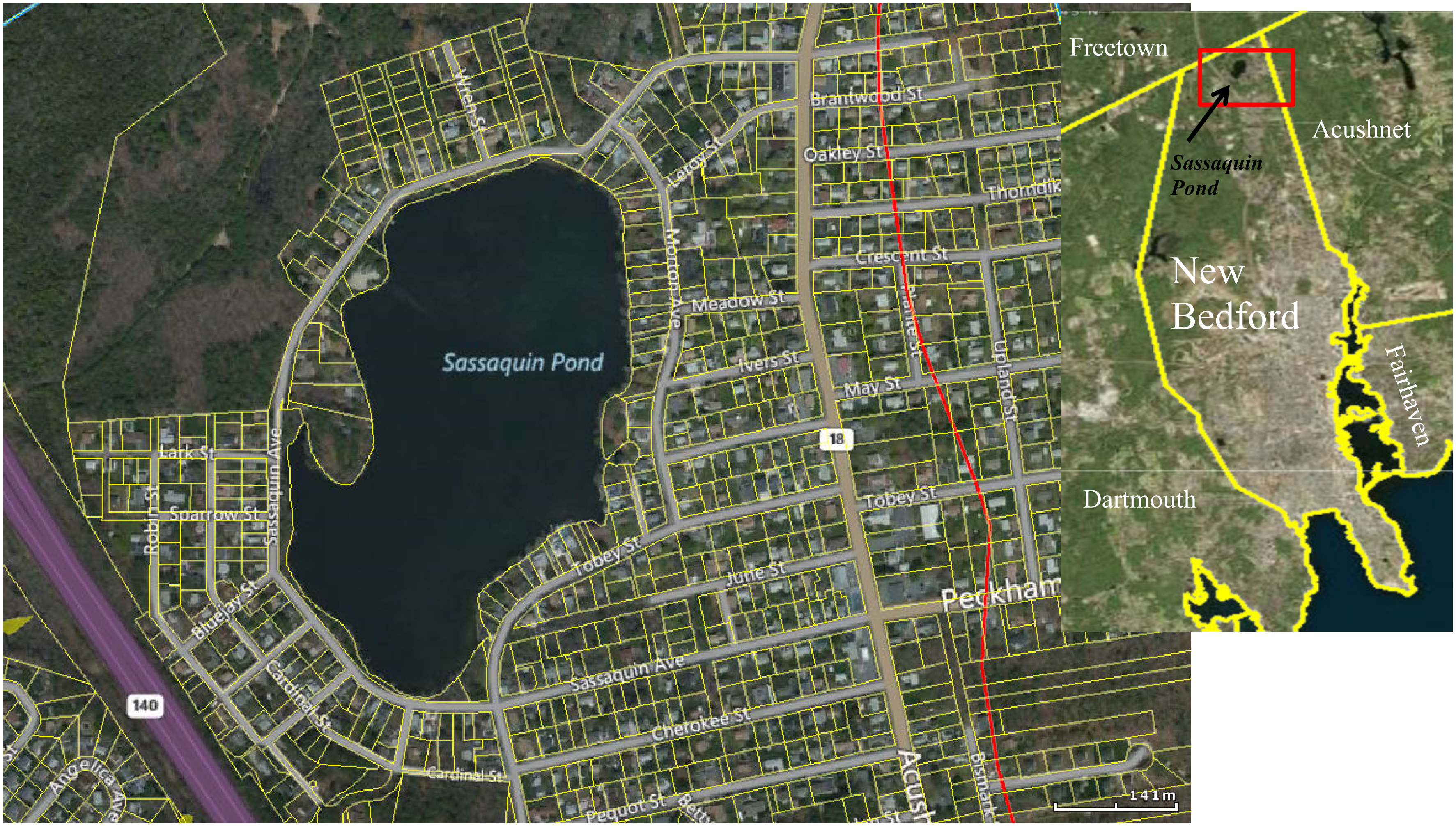

Figure I-1. Sassaquin Pond Locus Area. Sassaquin Pond is a 38 acre pond, located in the northern portion of the City of New Bedford, east of Route 140 and west of Route 18. Yellow lines indicate Level 3 2012 City of New Bedford assessor's parcels available from MassGIS. Red line is the Massachusetts Estuaries Project watershed to New Bedford Harbor.

Figure I-2. 2013 Algal Bloom Impacts in Sassaquin Pond. Upper picture appears to show a mix of green and blue-green algae on August 15, while the lower picture shows algal breakdown products ("whitening") on September 8. Photos courtesy of Dennis Audette and Liz Miller, SPBA.

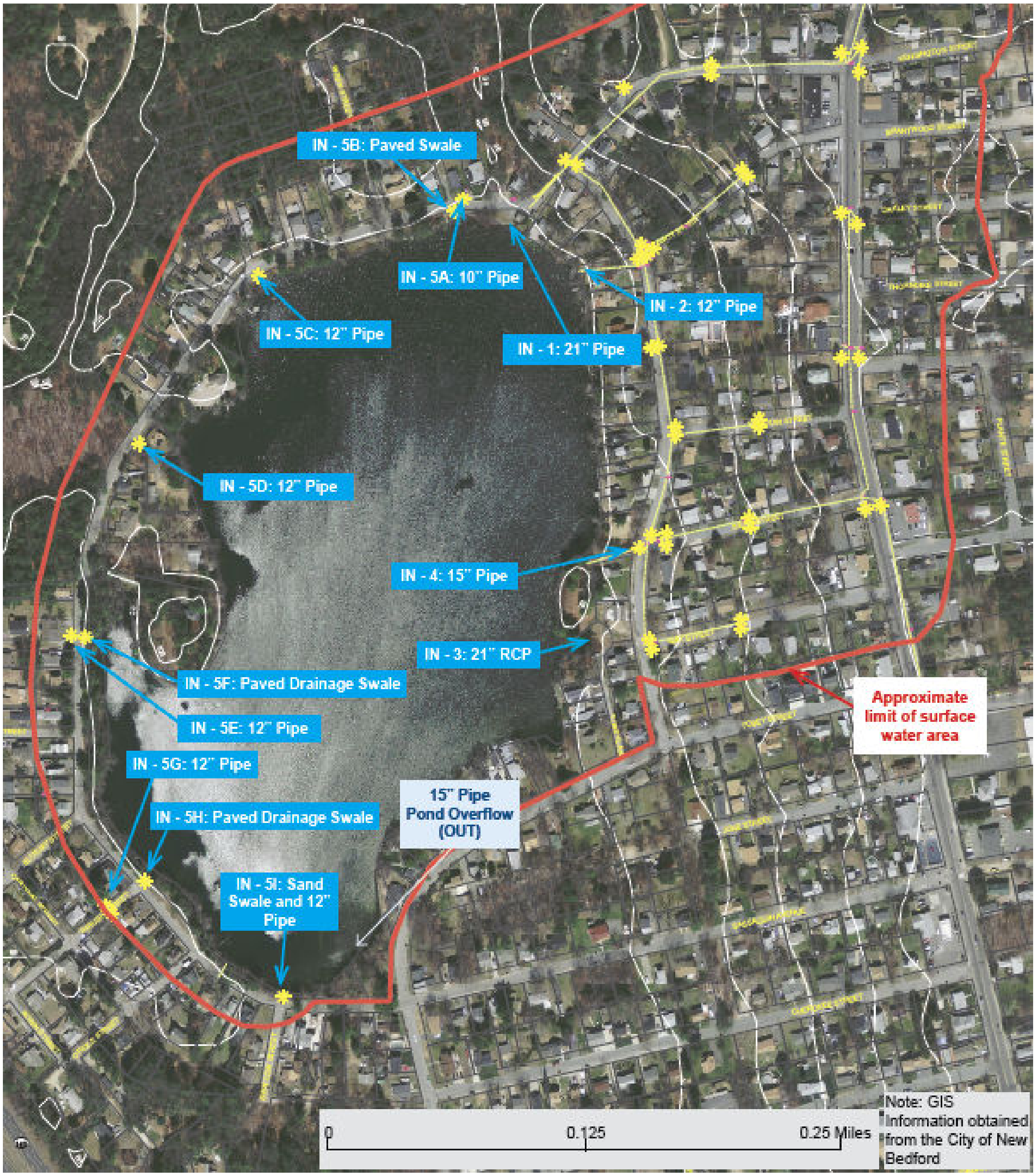

Figure II-1. Sassaquin Pond Stormwater Discharges and Collection System. The estimated watershed to Sassaquin Pond has a series of stormwater catch basins (indicated by yellow symbols) that collect stormwater into a series of pipes that discharge into the pond. Modified from Map 4 in Nitsch Engineering Sassaquin Pond Watershed Restoration Study (2013).

individual stormwater samples from 2 of the 12 pipes on September 9, one snapshot of dissolved oxygen and temperature profiles on September 8, and installation of 6 groundwater wells and 24 seepage meters to try to refine the characterization of the watershed and residence time of the pond.[4] Based on a review of available reports, no other stormwater monitoring has occurred at Sassaquin Pond. The recommendations of the 1987 evaluation included establishing a water quality monitoring program, completing a more comprehensive evaluation of the contributing area to the pond, and diverting some of the stormwater runoff outside of the existing collection system area. In 2013, dissolved oxygen and temperature profiles and total phosphorus samples were collected monthly at two depths.[5] The recommendations from this effort included implementation of a stormwater monitoring program and a concurrent, more intensive in-lake sampling program. There have also been a regular bacterial sampling between 1996 and 2001, a couple of single time snapshots of bacterial sampling (4/18/12, 5/10/12), toxin testing during an August 2010 algal bloom, and speciation of phytoplankton during a December 2012 algal bloom.

III. Regulatory Setting and Water Quality Standards

Sassaquin Pond has a surface area of 38 acres. Since this area is greater than 10 acres, it is classified as a Great Pond, which is a publicly owned "water of the Commonwealth" under Massachusetts law[6] and is one of two Great Ponds in the City of New Bedford (Turner Pond is the other Great Pond). Massachusetts maintains regulatory standards for all of its surface waters.[7] These regulations include descriptive water quality standards for various classes of waters based largely on how waters are used and the ecosystems they support plus an accompanying set of four numeric standards for each class for the following factors: dissolved oxygen, pH, temperature, and bacteria. For example, Class A waters are used as a drinking water source and "are designated as excellent habitat for fish, other aquatic life and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation, even if not allowed. These waters shall have excellent aesthetic value."[8] Further distinctions are made between warm and cold water fisheries.

Under these state regulations, Sassaquin Pond would be classified as a Class B water. Review of the historic temperature profile data suggests that the pond might be able sustain a cold water fishery (waters at 6 m and deeper generally remain below 20°C throughout the year). As such, the following numeric standards would apply: a) dissolved oxygen shall not be less than 6.0 mg/L, b) temperature shall not exceed 68°F (20°C) in the cold fishery, c) pH shall be in the range of 6.5 to 8.3, and d) no single sample for bacteria shall exceed 235 colonies per 100 ml at bathing beaches (with variations available for multiple samples). If temperature readings indicated that deep waters exceed the 20°C threshold, the pond would be classified as a warm water fishery. In this case, the temperature limit would rise to 83°F (28.3°C) and the dissolved oxygen minimum would decrease to 5.0 mg/L. All other numeric standards would remain the same. The descriptive standards for Class B waters are:

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[4] *Ibid.*

[5] Normandeau Environmental Consultants. May, 2014. Sassaquin Pond Total Phosphorus Study. Completed for City of New Bedford. 9 pp.

[6] Massachusetts General Law, Ch. 131, sec. 1 specifies all ponds greater than 10 acres are "Great Ponds" and all Great Ponds are "waters of the Commonwealth" and, as such, are publicly owned.

[7] 314 CMR 4.00 (CMR = Code of Massachusetts Regulations)

[8] 314 CMR 4.05(3)(a)

> "designated as a habitat for fish, other aquatic life, and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. Where designated in 314 CMR 4.06, they shall be suitable as a source of public water supply with appropriate treatment ("Treated Water Supply"). Class B waters shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. These waters shall have consistently good aesthetic value."[9]

Under the federal Clean Water Act, surface waters failing to attain state surface water standards are considered "impaired." Impaired waters are required under the Clean Water Act to have a maximum concentration or load limit defined for the contaminant causing the impairment.[10] This limit is labeled as a Total Maximum Daily Load or TMDL. States are required to list all waters that are impaired as part of an Integrated List of Waters, which must be submitted and approved by the Environmental Protection Agency (EPA) ever two years. This list includes a listing of all waters in the state and their status, including whether their water quality has been assessed and whether it has been judged impaired.

The latest final approved integrated list from Massachusetts was the 2012 list.[11] Sassaquin Pond is listed as a Category 5 (Impaired) water in this list based on the following causes: a) Excess Algal Growth, b) Fecal Coliform, and c) Taste and Odor. These causes were the same in 2010 and in 2008, while in the 2006 list, the impairments were for "pathogens" and "noxious aquatic plants." The 2006 listing is the first appearance of Sassaquin Pond on the Massachusetts Integrated List and it is not clear what prompted the initial listing based on a search of the EPA TMDL website. Based on these listings, Sassaquin Pond is required to have TMDLs developed for each of the impairments. TMDLs are generally developed by a refined assessment of the water body, followed by a public process involving a draft proposed TMDL, a public hearing, and a final TMDL that is submitted by MassDEP to EPA for approval.

IV. Pond Assessment and Findings

Under the current project CSP-SMAST was charged with developing a baseline assessment of Sassaquin Pond composed of the following tasks: a) updating the pond bathymetry, b) determining the stormwater flows and contaminant loads discharging into the pond, c) measuring nutrient water quality within the pond and d) determining nutrient concentrations in the pond sediments. Each of these tasks and their associated findings are discussed below.

IV.A. Sassaquin Pond Bathymetry

On June 9, 2014, CSP-SMAST staff conducted a bathymetric survey of Sassaquin Pond. A fathometer[12] and RTK GPS unit[13] collected simultaneous readings as a shallow draft vessel followed a pre-established 35 m interval grid of survey lines (**Figure IV-1**). All depth and

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[9] 314 CMR 4.05(3)(b)

[10] 40 CFR 130.7 (CFR = Code of Federal Regulations)

[11] Massachusetts Department of Environmental Protection. March, 2013. Massachusetts Year 2012 Integrated List of Waters, Final Listing of the Condition of Massachusetts' Waters Pursuant to Sections 305(b), 314 and 303(d) of the Clean Water Act. MassDEP, Division of Watershed Management, Watershed Planning Program. Worcester, MA.

[12] Odom Hydrotrac single beam precision fathometer, 0.01 meter resolution

[13] Leica Real Time Kinetic GNSS/GPS with an accuracy of +/- 0.05m

position data were recorded into a laptop computer using hydrographic software (HYPACK) integrating the DGPS position and depth measurement into a single data set.

Based on the bathymetric data collected from the survey, the total volume of Sassaquin Pond was calculated to be 513,663 cubic meters (m^3) (**Table IV-1**). In general, the pond has a relatively circular, central basin with ~16% slope from the shoreline to the 8.1 m deep center (**Figure IV-2**). The southern portion of the pond juts off this basin at the 4 m contour and has a ~8% slope along its eastern side. At the time of the survey the water surface elevation was 28.5 m NAVD88.

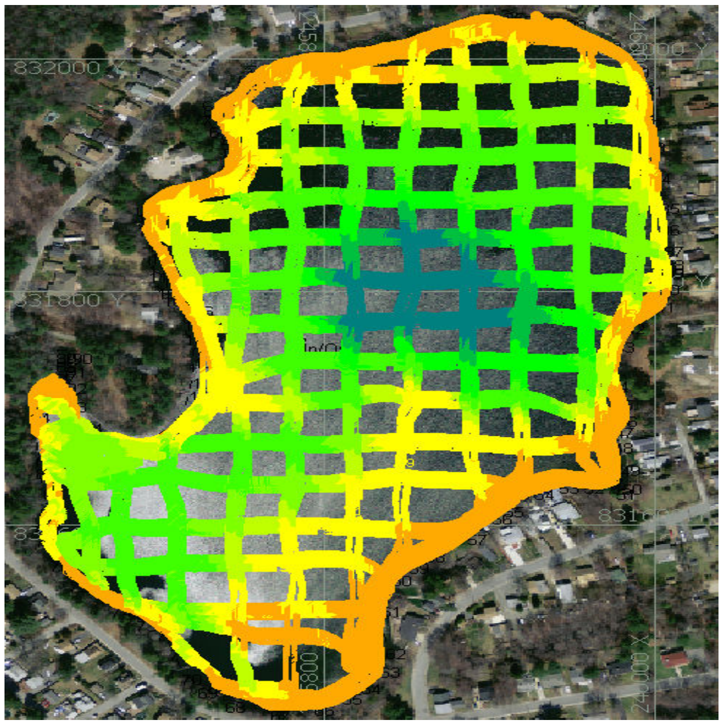

Figure IV-1. Bathymetric survey grid of Sassaquin Pond. 35 meter spacing between survey lines was used.

Table IV-1. Sassaquin Pond volume by depth interval. Based on bathymetry readings collected on June 9, 2014.

Depth Interval (m)	Volume (cubic meters)	Surface Area (square meters)
0-1	141,482	5,497
1-2	118,830	29,589
2-3	91,550	20,162
3-4	74,239	17,345
4-5	47,829	35,015
5-6	21,922	14,470
6-7	12,254	6,303
7-8	5,558	9,404
TOTAL	513,664	137,785

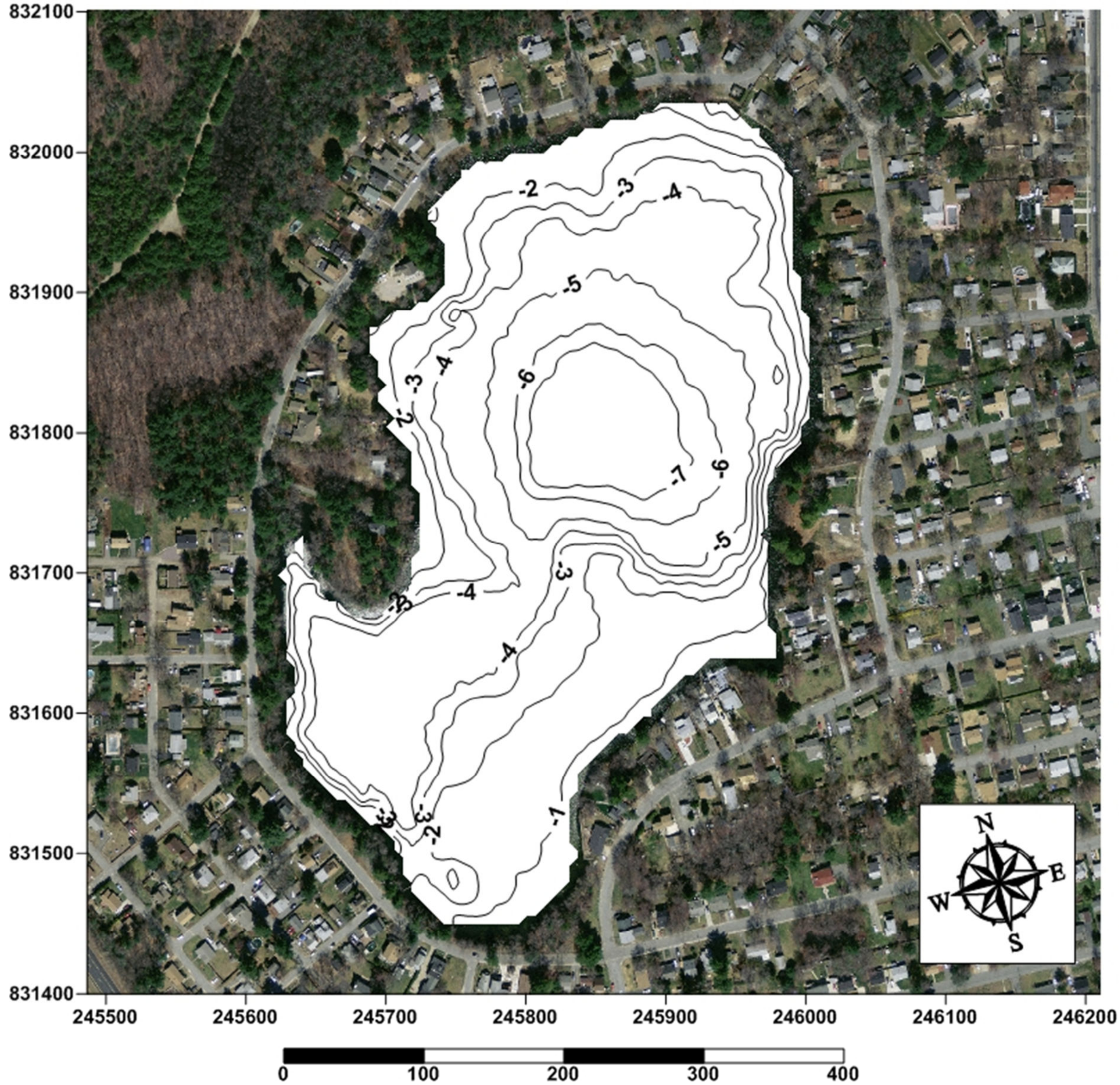

Figure IV-2. Bathymetric map of Sassaquin Pond. Contour intervals are 1 m increments. The deepest point in the pond (8 m) is indicated. The water surface of the pond was 28.4 m NAVD88 at the time of the bathymetric survey (June 9, 2014).

The detailed bathymetric information collected by CSP/SMAST changes some of the past details about Sassaquin Pond. The bathymetric information in the BEC (1987) report showed relatively steep slope ringing the pond with consistent, less steep slopes toward the deep basin in waters deeper than 3 m (**Figure IV-3**). Using this bathymetry, BEC calculated a pond volume of 636,400 m^3, which is 19% greater than the CSP/SMAST volume. A smaller volume based on the CSP/SMAST refined assessment changes a number of aspects of the system characterization, including interpretation of water quality data and a water budget.

Review of the watershed delineation in the BEC (1987) report also raises some watershed characterization issues. BEC delineated a watershed to Sassaquin Pond based on review of the

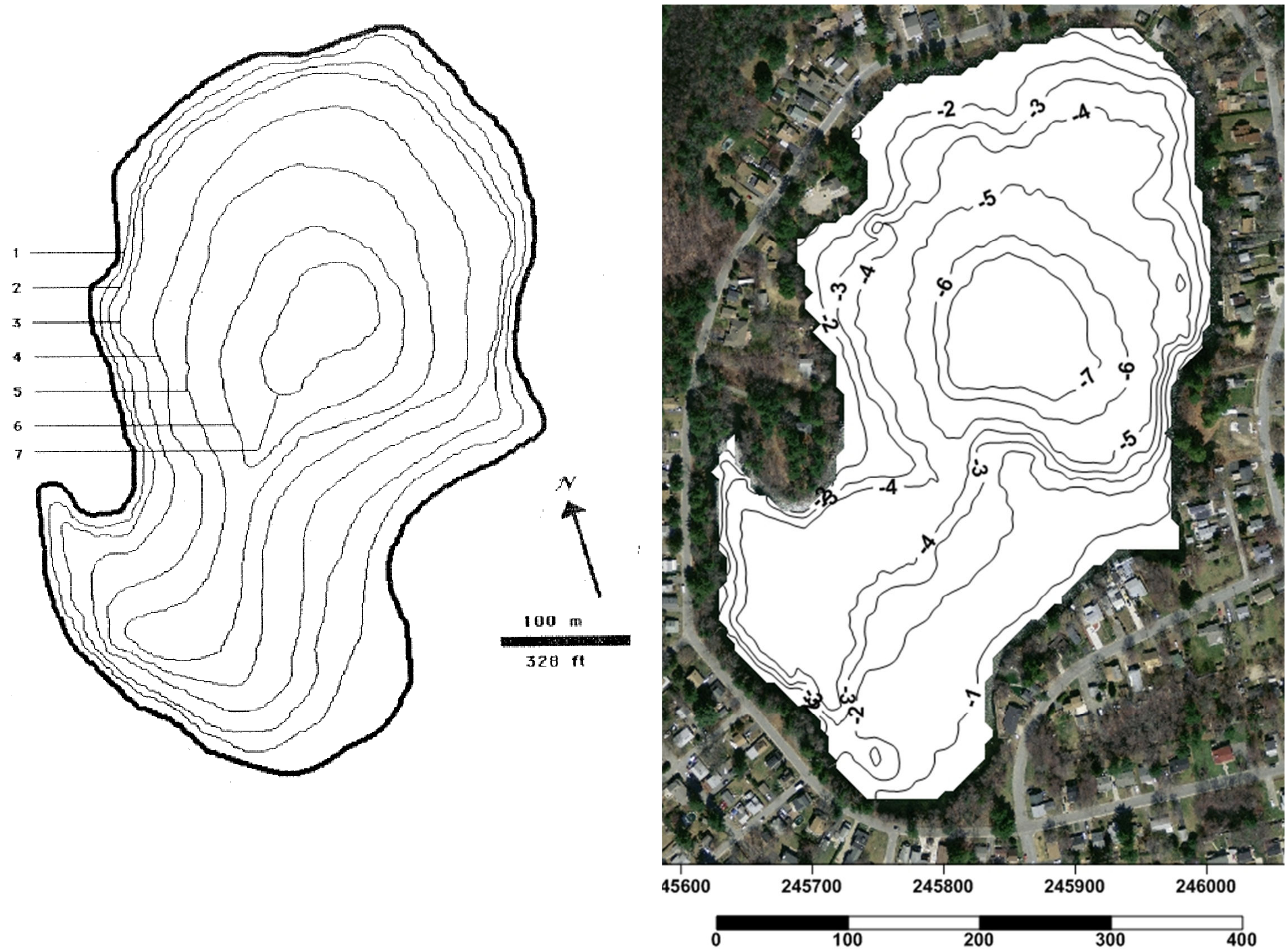

Figure IV-3. Comparison of CSP/SMAST and BEC (1987) Bathymetry for Sassaquin Pond. CSP/SMAST developed bathymetry under the current project based on integrated GPS and sonar fathometer data collection. The resulting CSP/SMAST pond volume is 19% less than the BEC pond volume. BEC bathymetry is Figure 2 in 1987 report.

stormwater collection system and installation of some groundwater wells and seepage meters around the edge of the pond. The seepage meters showed flow into the pond from all sides, while the groundwater elevations from the wells suggested flow out of the pond to the north toward the Taunton River. Based on their interpretation of the information, BEC delineated the watershed shown in **Figure IV-4**.

Since the completion of the BEC report, the Massachusetts Estuaries Project has completed watershed delineations for the Slocums River,[14] Westport River,[15] and Apponagansett Bay estuarine systems. Sassaquin Pond is located in an area between the northern edges of these watersheds, which were confirmed by annual continuous flow measurements in their respective main branch rivers (see **Figure IV-4**). These watershed delineations seem to suggest that Sassaquin Pond's watershed flow includes an area to south that is not traditionally included in the Pond's watershed and that groundwater and topographic flows out of the pond should be toward the north and into the wetland system that eventually drains into the Taunton River. Resolution of this issue, along the impacts of the revision of the bathymetry, is outside of the scope of the current project, but would inform nutrient management strategies for the pond.

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[14] Howes B.L., N.P. Millham, S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner (2012). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Slocum's and Little River Estuaries, Dartmouth, Massachusetts. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

[15] Howes B., E. Eichner, R. Acker, R. Samimy, J. Ramsey, and D. Schlezinger (2012). Massachusetts Estuaries Project Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Westport River Embayment System, Town of Westport, MA, Massachusetts Department of Environmental Protection. Boston, MA.

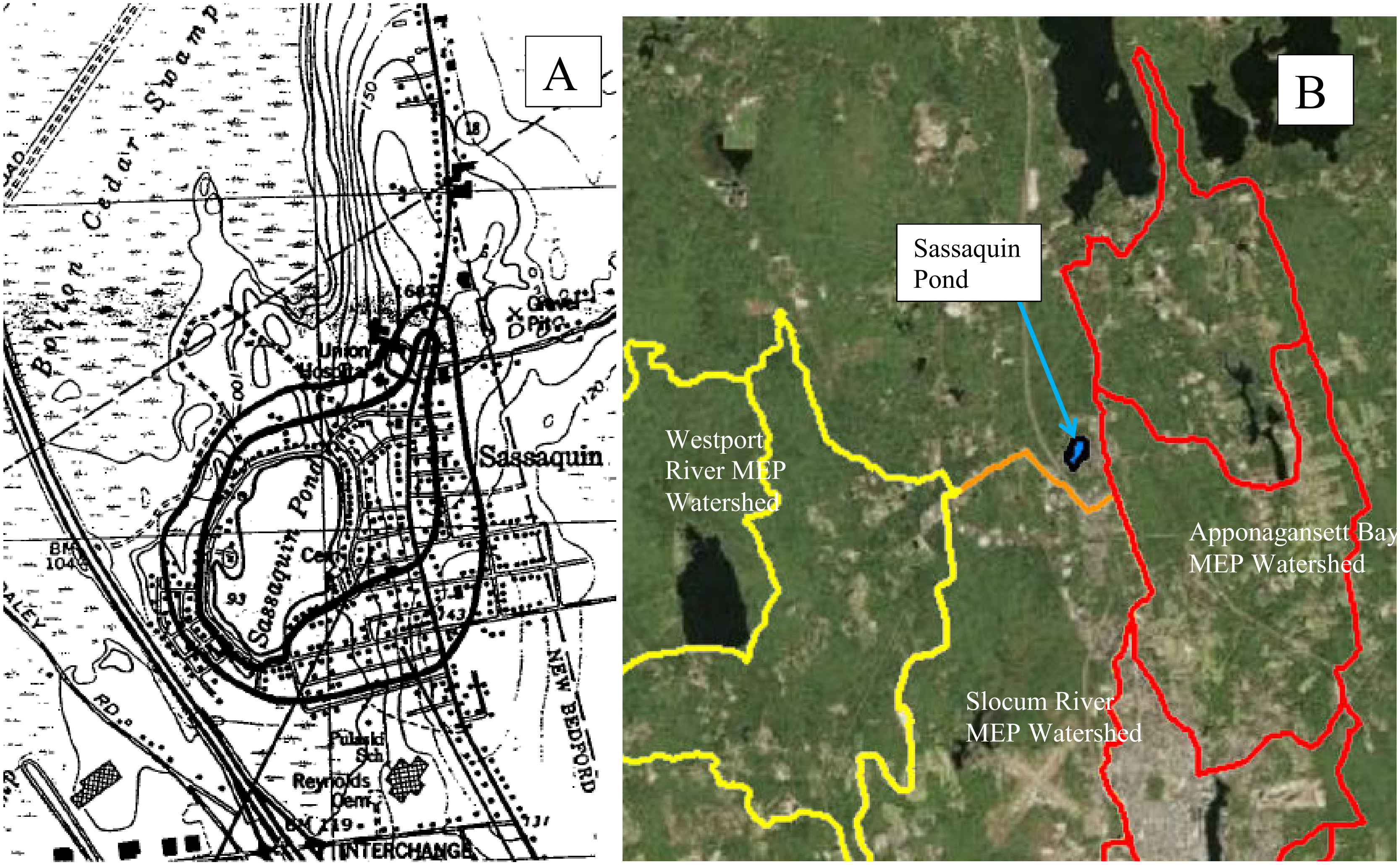

Figure IV-4. Differences in Sassaquin Pond Watershed Delineation. "A" shows Sassaquin Pond watershed delineation completed by BEC (1987). This delineation shows flow into the pond from all sides. "B" shows watershed delineations surrounding Sassaquin Pond completed by the Massachusetts Estuaries Project. These watershed delineations suggest that Sassaquin Pond has a different delineation than suggested by BEC with flow out of the pond toward the north as part of the Taunton River watershed.

IV.B. Sassaquin Pond Stormwater Inputs

As noted above, there is an extensive stormwater collection system throughout the watershed area to Sassaquin Pond (see **Figure II-2**). In order to measure the constituent loading from the stormwater system, CSP-SMAST staff conducted sampling and flow measurements at specific discharge locations along the perimeter of Sassaquin Pond.

The Nitsch Engineering stormwater system assessment determined that a total 16 sites discharge into the pond during storm events.[16] The sites range from swales to pipes, collecting stormwater from a variety of different size areas surrounding the pond, and extending into the estimated watershed and along Acushnet Avenue (**Figure IV-5**). Based on subsequent discussions with City of New Bedford engineers, three discharge locations were initially selected as being the most representative for a stormwater monitoring effort. CSP-SMAST staff completed a field site visit to assess the feasibility of regular sampling at these locations and found that two of the sites were suitable, but the third discharge pipe was submerged and, therefore, unsuitable for routine monitoring. Based on this initial site visit, project sampling efforts focused on outfall pipes STW1 (Sassaquin Ave Pump Station) and STW9 (May St.)(see **Figure IV-3**).

STW1 and STW9 collect a combined 52% of the 75.4 acre stormwater collection area and represent the two largest stormwater collection areas which discharge to Sassaquin Pond. STW1 collects stormwater from approximately 19 acres of mostly residential land use. Stormwater runoff is collected in 19 catch basins that are located along the roadway gutters and discharged to the Sassaquin Pond with minimal treatment through an existing 21 inch outfall pipe.[17] Similarly, STW9 collects stormwater from approximately 20 acres of mostly residential land use withrunoff collected in 22 catch basins and discharged with minimal treatment through a 21 inch outfall pipe located on a drainage easement between 1441 and 1453 Morton Avenue.[18]

In order to complete the baseline stormwater sampling, CSP-SMAST staff collected samples during 6 storm events between September, 2013 and October, 2014. Staff also installed a continuous water level recorder to measure the fluctuations of the pond water level during storms (measured every 10 minutes), as well as overall level changes during the project period. Sampling generally targeted storm events with more than 0.25 inches of rainfall to ensure measureable runoff. Discharge pipe sampling during individual storms included measurement of pipe flows and collection of water samples for constituent analysis. Sampling began with the first flush sample (T0) within two hours of when precipitation began, followed by sequential samples (T1, T2, T3, T4, T5, etc.) designed to characterize the whole storm. Flow measurements were recorded using a flowmeter (Marsh McBirney Flo-Mate 2000). Water quality samples were collected directly from the discharge pipes into acid washed bottles. Nutrient samples were placed on ice and transported to the Coastal Systems Analytical Facility at SMAST under QA/QC procedures approved by MassDEP and USEPA. Water quality samples were analyzed for nitrogen forms (NH4, NO3/NO2, DON, PON, TN), phosphorus (PO4 and TP), Particulate Organic Carbon and Nitrogen (POC), and Total Suspended Solids (TSS).

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[16] Nitsch Engineering. 2013. Sassaquin Pond Watershed Restoration Study.

[17] *Ibid*, p. 24.

[18] *Ibid*, p. 26.

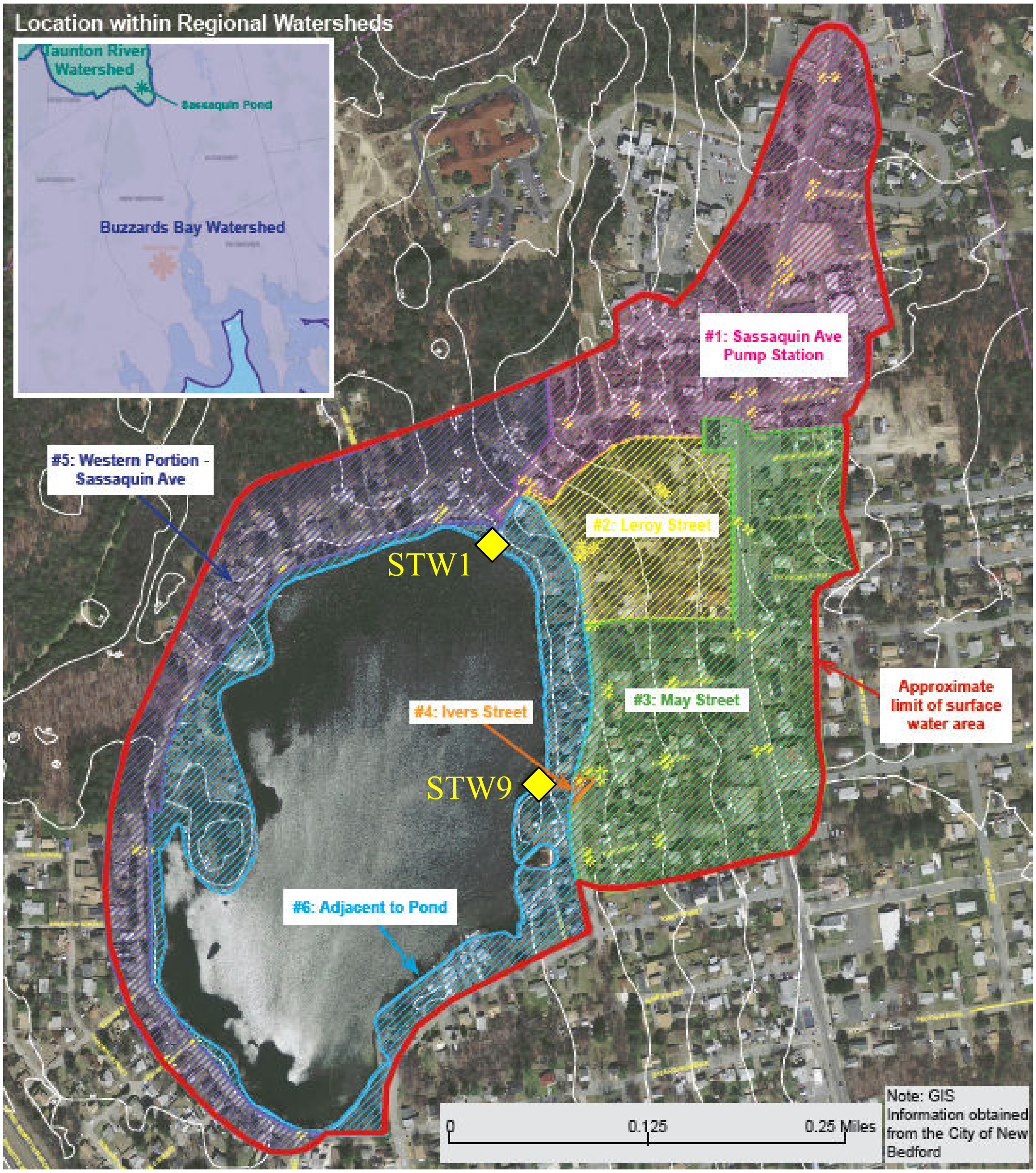

Figure IV-5. Sassaquin Pond Stormwater Collection System Subwatersheds. CSP-SMAST stormwater monitoring focused on Sassaquin Avenue Pump Station outfall (STW1), which collects stormwater from subwatershed #1, and May Street outfall (STW9), which collects stormwater from subwatershed #3. Modified from Map 5 in Nitsch Engineering Sassaquin Pond Watershed Restoration Study (2013).

IV.B.1. Stormwater Runoff Flows

Discharge volumes from the two outfall pipes had similar discharge characteristics and were a reasonable reflection of the type of land use within the stormwater watersheds. Stormwater discharge volumes were measured six times (**Table IV-2**). Daily rainfall amounts during the sampling period were taken from a nearby weather station 2.2 km south of Sassaquin Pond.

Review of the storm flows suggest that like other stormwater systems there is a threshold precipitation amount that is sufficient to create runoff and hence discharge to Sassaquin Pond. Comparison of flow volumes and precipitation suggest that this threshold is at approximately 2.5 mm (0.1 inches) (**Figure IV-6**). Based on this review rain events of less than 2.5 mm would be insufficient to create runoff and discharge into Sassaquin Pond. During 2014, the annual precipitation at New Bedford Airport was 50.3 inches.[19] Review of the daily precipitation amounts show that 47.9 inches of the annual rate (or 95% of the annual amount) were generated by storms greater than 0.1 inches.

Comparison of the storm flows and the amount of precipitation within the collection system subwatersheds allowed refinement of the estimate of annual flow. For the one storm, near the 2.5 mm runoff threshold, the two pipes discharged 6% and 8% of the total precipitation within their respective collection system subwatersheds, while during larger storms, the percentage of precipitation arriving at the outfall as runoff increased to as high as 61% of the precipitation volume. A 61% runoff rate would match the design rate generally used for residential areas with 0.25 acre lots in sandy soils.[20] Runoff rates for the two outfall pipe subwatersheds are similar although there tends to be a higher runoff percentage from the May Street subwatershed.

The strong positive relationship (r^2 = 0.94) between the pipe discharges and precipitation suggests that runoff from the two pipes into Sassaquin Pond is almost exclusively based on rainfall. The strength of the relationships suggests that no additional water inputs (*e.g.*, groundwater or wastewater) are influencing runoff rates.

[19] Annual average precipitation reported at New Bedford Airport by NOAA was 50.77 in/yr between 1971 and 2000, which suggests that 2014 precipitation approximates average conditions.

[20] *i.e.*, SCS runoff curve number for 1⁄4 acre residential lots in Type A soils.

Table IV-2. Stormwater discharge volumes from two outfall pipes to Sassaquin Pond. Individual storm precipitation was measured at a station 2.2 km (coordinates: 41.712 -70.946) from Sassaquin Pond. The 4/30 storm extended over two days.

Storm date	Total Precipitation	STW1		STW9		Total Discharge STW1 & STW9
		Discharge	Runoff	Discharge	Runoff	
	Mm	m3	% of precip	m3	% of precip	m3
9/22/13	9.1	142	20%	131	17%	273
11/7/13	10.9	105	13%	159	18%	264
4/30/14	24.9	1,015	54%	1,244	61%	2,259
6/4/14	2.8	13	6%	18	8%	31
6/5/14	15.0	293	26%	366	30%	660
10/16/14	21.6	232	14%	386	22%	618
TOTAL	84.3	1,800		2,305		4,105

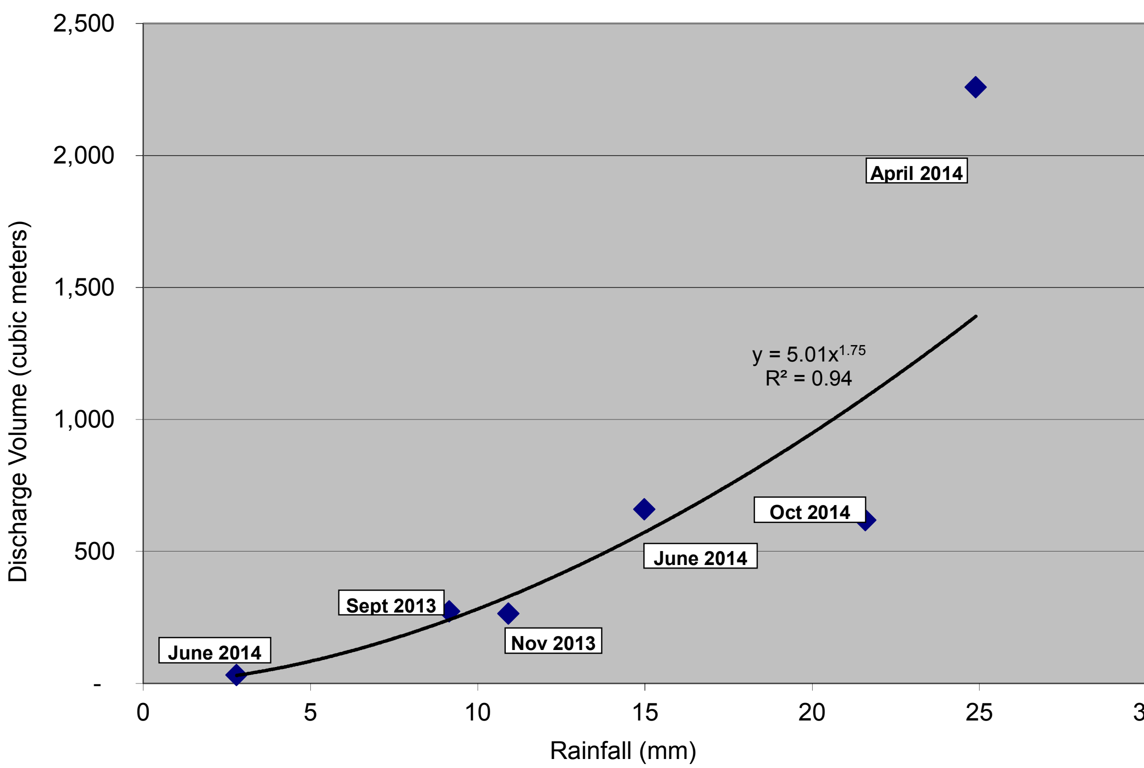

Figure IV-6. Stormwater discharge to Sassaquin Pond based on rainfall amount. Total flow from outfall pipes STW1 and STW9 (52% of total stormwater) is compared to precipitation on the day of the storm events. Measurements suggest a rainfall threshold of approximately 2.5 mm below needed to generate runoff. Precipitation accounts for 94% of the variability in outfall flows, which suggests that measured runoff volumes are composed of only precipitation.

Readings from the continuous data logger provides an estimate of the impact of water levels in the pond due to each of the measured storms. The logger was programmed to record water levels every hour and was installed on March 21, 2014 and removed on November 18, 2014. The logger experienced some recording difficulties at the end of the recording period, so analysis focused on readings through August 7. Of the 3,335 readings during this 139 day period, the average pond water surface elevation was 28.46 m NAVD88 with a range between maximum and minimum elevations of 0.5 m (**Figure IV-7**).

The water level of the pond generally fell throughout the recording period. Water levels were at their highest in March and fell ~0.2 m throughout the summer and into the fall. Comparison of the pond water levels to groundwater levels at the nearest long-term monitoring location show that this falling trend generally followed regional groundwater levels.[21] As noted in Figure IV-5, individual storms caused transitory increases in the pond water elevation. Without accounting for temperature and evapotranspiration impacts, precipitation amounts during individual storms explained 60% of the variability in water surface elevation changes.

[21] US Geological Survey groundwater elevation well NGW116 is located at New Bedford Airport, ~6.5 km SSW from Sassaquin Pond (http://nwis.waterdata.usgs.gov/usa/nwis/gwlevels/?site_no=414025070572801)

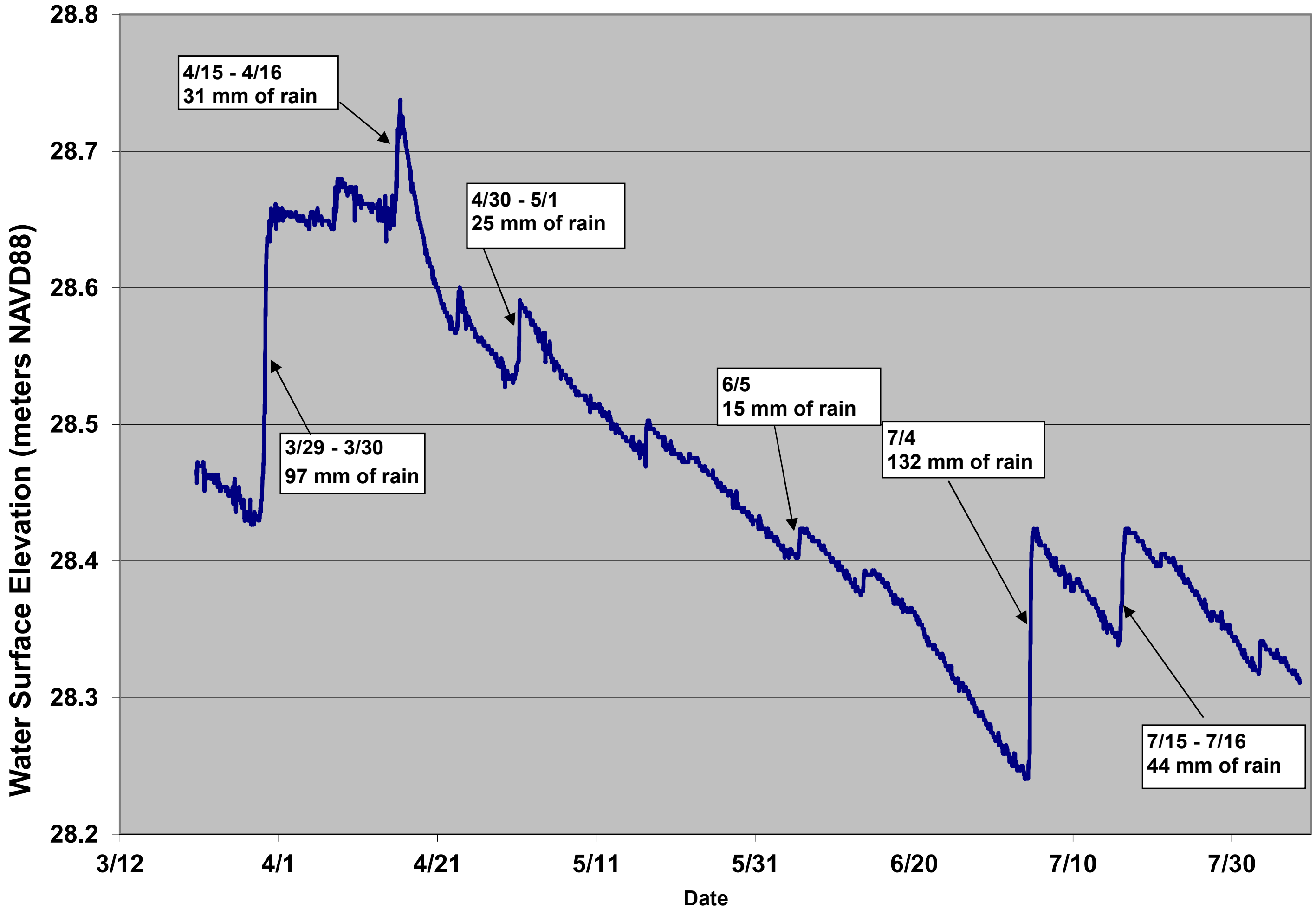

Figure IV-7. Sassaquin Pond Water Level (March to August 2014). Water level recorded every 10 minutes by an automated device. Water levels generally fell during the recording period with transitory increases due to storm precipitation and associated runoff. Average elevation was 28.46 m with a range between maximum and minimum elevations of 0.5 m.

IV.B.2. Stormwater Runoff Loads

During the course of each storm event, an accompanying water quality sample was collected with each runoff flow measurement. As mentioned, these samples were analyzed at the Coastal Systems Analytical Facility at SMAST for a number of constituents, mostly focused on the nutrients phosphorus and nitrogen. The concentrations determined from these samples were combined with the runoff flow volumes to calculate a mass load for each constituent and the sum of all these incremental mass loads provided the constituent load to Sassaquin Pond for each pipe during each storm event. **Table IV-3** shows the total mass of each constituent from both pipes for each of the six monitored storms, as well as estimates of total annual load to the pond based on the measured data and the estimated percentage of annual flow captured by the storms (7%). Stormwater constituent estimates calculated by Nitsch Engineering are also shown.[22]

In general, the constituent masses discharged to Sassaquin Pond are directly related to the runoff flow with greater mass discharge associated with greater runoff flow. However, there are some differences for individual constituents and between the mass discharges from the two outfall pipe watersheds. While runoff flow explains 90% or more of the variability in most of the constituent mass transfers (*i.e.*, $R^2 > 0.9$), ortho-phosphorus mass discharge is only somewhat linked to runoff flow. Measured runoff flow explained 61% of the variability in discharge of ortho-P from the Sassaquin Avenue Pump Station subwatershed (STW1), but only 11% of ortho-P variability from the May Street subwatershed (STW3). Fertilizers tend to be the primary source of ortho-P and fertilizers tend to be added to lawns only during lawn growing seasons, so this lack of consistent availability may be the cause of the poor relationship with runoff flow. Ammonium-N and PON, which are also usually associated with fertilizers, particularly slow release fertilizers, also had moderately good relationships with runoff flow ($R^2 = 0.67$ and $R^2 = 0.73$, respectively) in the May Street subwatershed, but were better in the Sassaquin Avenue Pump Station subwatershed ($R^2 = 0.9$ and $R^2 = 0.97$, respectively). Total Suspended Solids (TSS) mass, on the other hand, had a poor relationship in the Sassaquin Avenue Pump Station subwatershed ($R^2 = 0.46$), but strong link to runoff flow ($R^2 = 0.9$) from the May Street subwatershed. Review of the Sassaquin Avenue Pump Station subwatershed data shows that TSS mobilization tends to occur at low runoff rates and increase rapidly with small runoff increases, but exceptionally high storm runoff (≥ 25 mm precipitation) did not always mobilize more TSS than a smaller storm. Further evaluations of the STW1 and STW9 watersheds may help to clarify these relationships.

It should also be noted that the estimated annual loads of nitrogen, phosphorus, and TSS based on the stormwater runoff measurements are significantly less than those estimated by Nitsch Engineering. Nitsch Engineering used a flow and load estimate method developed by the New Hampshire Department of Environmental Services (NHDES).[23] This method results in runoff volumes that reasonably approximated the annual estimated measured volumes, but in the absence of actual measurements, the method-assigned average TP, TN, and TSS concentrations that exceeded all of the directly measured concentrations of 2014. These estimated average concentrations result in annual loads that exceed the annual loads based on the measured concentrations and reinforce the benefits of measuring, rather than estimating, water quality contaminants.

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[22] Nitsch Engineering. 2013. Sassaquin Pond Watershed Restoration Study. Table 4, p. 12.

[23] NHDES. 2010. Guidance for Estimating Pre- and Post-Development Stormwater Pollutant Loads. Available at: http://des.nh.gov/organization/commissioner/pip/publications/wd/documents/wd-10-11.pdf

Table IV-3. Stormwater Runoff at Sassaquin Pond (Mass Flux and Discharge Volumes). Runoff volumes and mass loads are totals for each listed storm. These totals are based on incremental measurements throughout each storm event. Annual estimates are based on extrapolating the flow and mass discharges to reflect precipitation measured throughout 2014 (50.3 inches at New Bedford Airport) and pond-wide estimates assume runoff discharges around the pond are comparable to measurements at STW1 and STW9. Nitsch Engineering annual estimates of mass discharges were reported in Table 4 of the 2013 Nitsch Engineering Sassaquin Pond Watershed Restoration Study; these estimates were based on standard engineering estimates.

	Discharge	Total Mass Flux								
		PO4	**TP**	**NH4**	**NOx**	**DON**	**PON**	**TN**	**POC**	**TSS**
Date	**m3**	**g**	**g**	**g**	**g**	**g**	**g**	**G**	**g**	**g**
STW1 Sassaquin Avenue Pump Station Outfall										
9/22/13	142	20	37	26	35	95	34	190	430	4,402
11/7/13	105	17	24	15	20	42	32	109	543	1,746
4/30/14	1,015	33	140	117	157	222	256	752	3,269	6,480
6/4/14	13	2	4	8	7	11	7	33	83	282
6/5/14	293	7	25	58	75	101	117	352	1,531	5,586
10/16/14	232	9	24	9	18	57	64	148	1,066	5,858
STW1 TOTAL	1,800	87	253	234	314	528	508	1,584	6,921	24,353
Annual Estimate	27,275	1,321	3,835	3,539	4,756	8,005	7,705	24,005	104,881	369,041
Nitsch Engineering Annual Estimate			17,418					172,637		2,346,431
STW9 May Street Outfall										
9/22/13	131	23	30	29	32	75	23	159	317	1,584
11/7/13	159	47	66	19	28	104	73	225	1,156	3,110
4/30/14	1,244	33	109	127	183	292	235	837	3,679	18,586
6/4/14	18	6	9	16	12	29	9	66	161	550
6/5/14	366	27	55	101	86	153	193	534	2,160	7,383
10/16/14	386	26	46	18	26	114	99	256	1,606	11,288
STW9 TOTAL	2,305	162	315	311	366	766	633	2,076	9,079	42,502
Annual Estimate	34,927	2,453	4,779	4,713	5,548	11,614	9,588	31,463	137,572	644,063
Nitsch Engineering Annual Estimate			18,824					186,381		2,533,629
Pond-wide Annual Total										
	m3	kg	kg	kg	kg	kg	kg	kg	kg	kg
Annual Estimate	119,951	7	17	16	20	38	33	107	468	1,954
Nitsch Engineering Annual Estimate			70					692		9,411

IV.C. Sassaquin Pond Water Quality

Sassaquin Pond was sampled by CSP/SMAST staff approximately monthly on 10 dates between April and November 2014. Samples were collected at three stations: SAS1 is located in the southern portion of the pond with a depth of ~4.5 m, SAS2 is located over the central, deepest basin of the lake with a depth of ~7.2 m, and SAS3 is located just to the north of the central basin with a depth of ~4.4 m (**Figure IV-8**). Water quality samples and dissolved oxygen and temperature readings were collected at the Pond surface and every meter of depth at each station. Secchi clarity and station depth readings were also collected during each sampling run. Samples were collected, stored, and transported using standard procedures, including collection of field duplicates. Collected water samples were transported to the SMAST Coastal Systems Analytical Facility in New Bedford. The SMAST lab analysis protocols and sample handling procedures are described in the SMAST Coastal Systems Analytical Facility Quality Assurance Plan (2003), which was approved by the Massachusetts Department of Environmental Protection (MassDEP).

IV.C.1. Dissolved Oxygen, Temperature, Clarity

In ponds with depth and bathymetry like Sassaquin Pond, wind energy typically keeps the whole water column vertically mixed with temperature and dissolved oxygen readings being similar throughout the water column. In a pond of this depth, it would be reasonable to assume that water clarity would generally allow the bottom to be seen from most of the surface.

Temperature readings collected in 2014 from Sassaquin Pond generally showed well-mixed conditions down to a depth of 4 m with some thermal layering/density differences in the main basin below 5 m during the summer months (**Figure IV-9**). The shallower depths at the north (SAS3) and south (SAS1) stations showed uniform temperature readings throughout the monitoring period. At the deep basin/central station (SAS2), there was some slight layering (stratification) at 5 m early in the monitoring period, but by mid-July waters at this depth had mixed downward and 5 m temperatures matched surface temperatures. Water at depths of 6 m and 7 m generally had cooler temperatures that were distinct from surface temperatures from May until the end of September when the whole water column had similar temperatures.

The maximum temperatures generally show that Sassaquin Pond should be classified as a warm water fishery for the purposes of the Massachusetts Surface Water Regulations.[24] The maximum temperature recorded among the ten sampling dates was a surface reading of 26.6°C.[25] The deepest waters (7 m) in the main basin (SAS2) averaged less than the regulatory cold water threshold of 20°C, but the water at this depth and deeper is only 1% of the total pond volume. All temperatures were less than the 28.3°C regulatory maximum for warm water fisheries.

Dissolved oxygen (DO) readings show the impact of sediment oxygen demand throughout the summer, as well as the impact of phytoplankton growth in the late summer (**Figure IV-10**). In the main basin (SAS2), the first DO profile in April shows consistent concentrations throughout the water column with dissolved oxygen levels in equilibrium with the atmosphere (*e.g.*, 100% saturation). The next profile in May shows DO concentrations at 5 m and deeper have dropped

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[24] 314 CMR 4.05

[25] SAS3 on July 14.

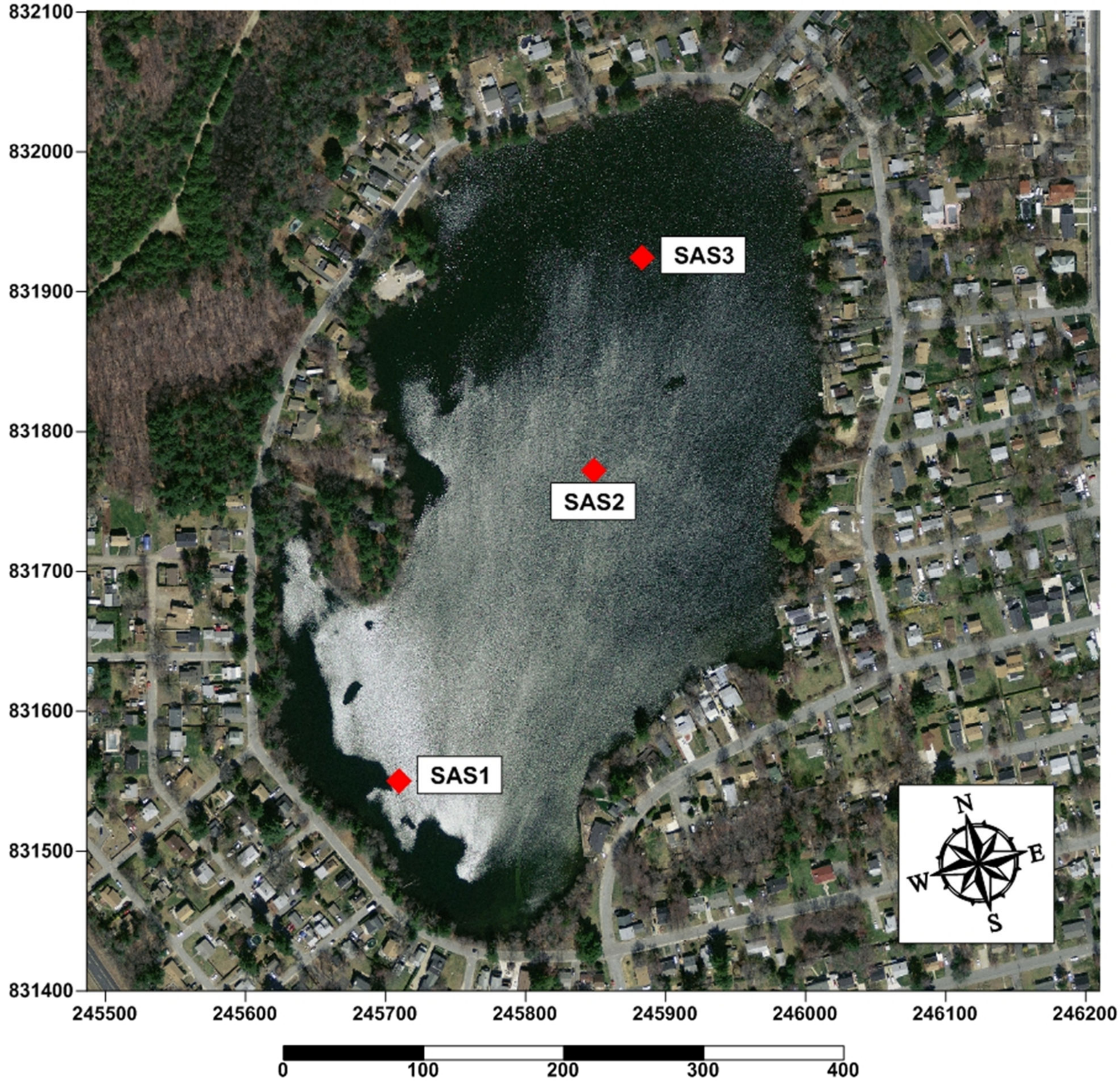

Figure IV-8. Sassaquin Pond 2014 Water Quality Sampling Sites. SAS1 is located over a depth of 4.4 m. SAS2 is located in the central main basin over a depth of 7.2 m. SAS3 is located just to the north of the main basin over a depth of 4.4 m.

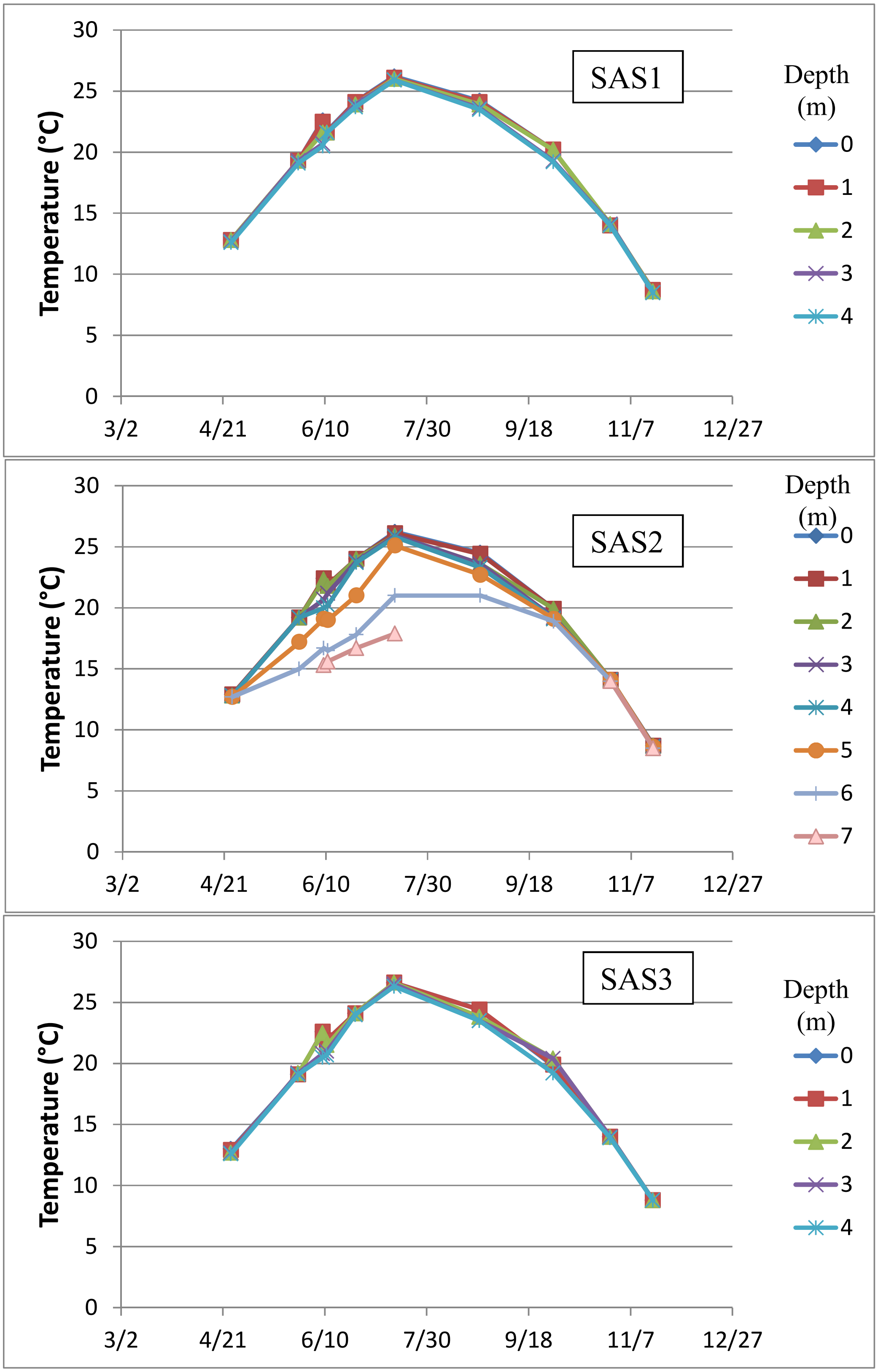

Figure IV-9. Sassaquin Pond 2014 Temperature Readings. Temperature readings were generally the same throughout the water column except for some slightly cooler waters at 5 m and deeper in the main basin (SAS2) that developed in May and were sustained until the end of September.

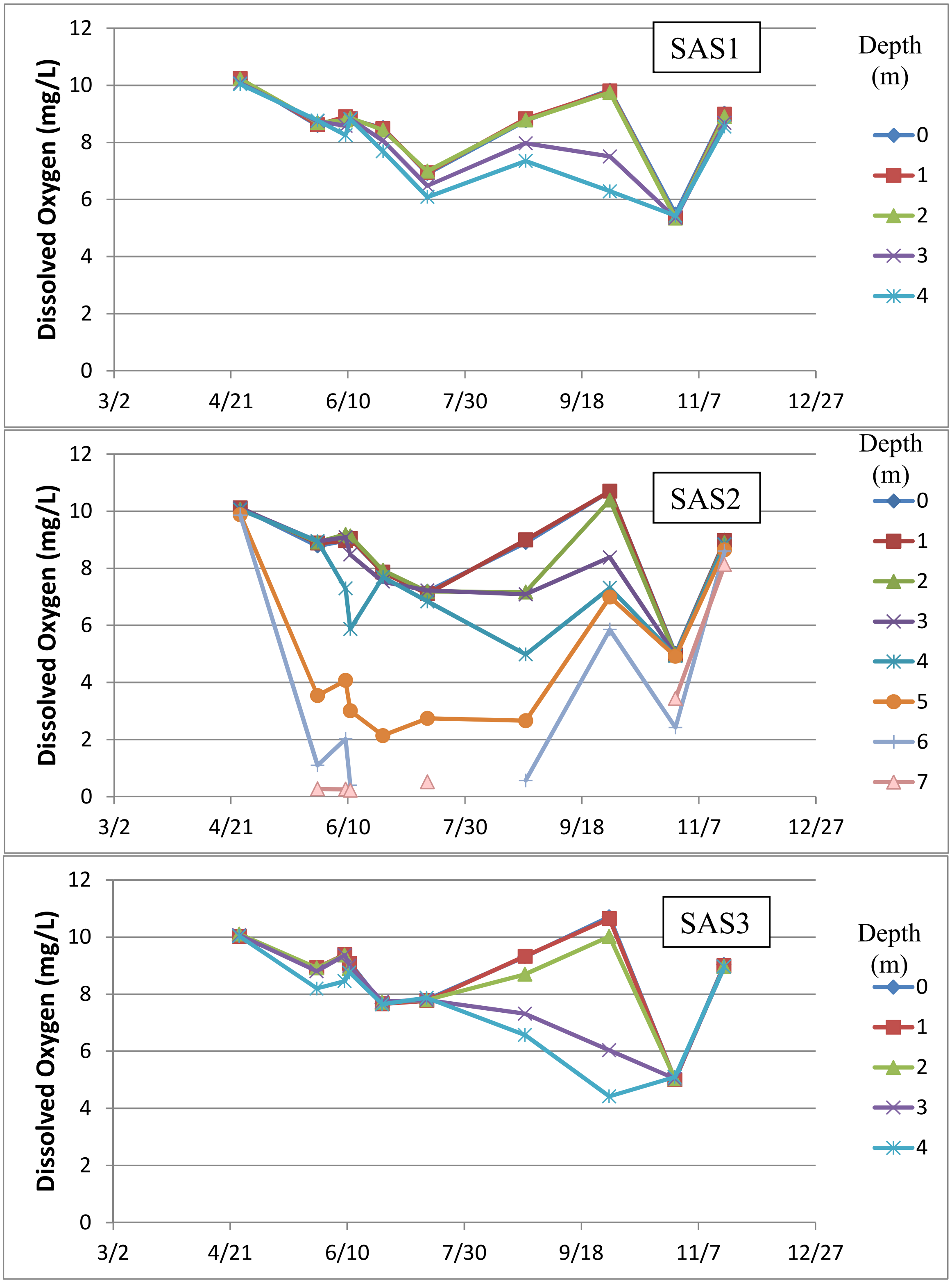

Figure IV-10. Sassaquin Pond 2014 Dissolved Oxygen Readings. Sediment oxygen demand in the main basin (SAS2) caused reduced DO readings at 5 m and deeper beginning in May and sustained through October. Similar reductions were not measured at the shallower stations until August. Concentrations below the state regulatory minimum (5 mg/L) occurred at both SAS2 and SAS3.

below the 5 mg/L state regulatory minimum for warm water fisheries.[26] These deep waters remain below 5 mg/L until the September 30 profile. Reduced DO conditions reach up to 3 m during the course of the summer, but the waters above 5 m depth at SAS2 generally remain greater than the state minimum concentration. Concentrations at the two shallower stations (SAS1 and SAS3) also show reduced DO concentrations in their deeper waters (3 and 4 m), but minimum concentrations are always above 5 mg/L standard.

Since the deeper waters of Sassaquin Pond had regular DO concentrations below the 5 mg/L warm water fishery minimum in the Massachusetts Surface Water Regulations, Sassaquin Pond should be classified as an impaired water for dissolved oxygen. Sassaquin Pond is already on the most recent final Massachusetts Integrated List as being an impaired water for: i) excess algal growth, ii) fecal coliform, and iii) taste and odor.[27] Addressing dissolved oxygen would almost certainly be addressed through remediation activities that target "excess algal growth."

All three stations also show an increase in DO percent saturation levels well above atmospheric equilibrium in the late summer profiles (August 25 and September 30) (**Figure IV-11**). These kinds of DO conditions typically occur when a phytoplankton population is actively growing and their resulting photosynthesis is producing oxygen at a rate that is greater than it is being released to the atmosphere. Phytoplankton populations only produce these conditions when there are excessive nutrients available. Surface saturation levels reached maximums of 108%, 118%, and 117% at SAS1, SAS2, and SAS3, respectively.

On October 28, the water column at all three stations completely mixed again with generally the same temperatures throughout the water column. The mixing of low oxygen waters and oxygen demand due to high phytoplankton caused reduced dissolved oxygen concentrations at all depths. In the main basin (SAS2), where the sediment oxygen demand was the greatest, the DO concentrations throughout the whole, well-mixed water column dropped just below the 5 mg/L regulatory minimum. By the next reading date (November 18), the water temperatures remained the same throughout the water column and DO concentrations had recovered somewhat to concentrations above the regulatory minimum, but still were notably below saturation (*i.e.*, all stations had DO saturation levels of ~80%).

Secchi clarity readings appear to confirm a substantial increase of the phytoplankton population in late summer. Clarity readings at all three stations average ~3.6 m through the July 14 sampling with 75-80% of the water column visible at the two shallow stations (SAS1 and SAS3) and 48% of the water column visible at the deepest station (SAS2) (**Figure IV-12**). For the next four samplings, Secchi clarity is significantly reduced with an average depth 1.2 m and only 27% of the water column visible at the two shallow stations and 17% at the deepest station. Clarity minimums were recorded at all stations in August and September with some recovery in the October and November readings, but not back to spring/early summer levels. This pattern suggests that the large phytoplankton population, though not as active in the last sampling runs, was present in the water column through at least the last sampling run in November.

[26] 314 CMR 4.05(b)1

[27] MassDEP. March, 2013. Massachusetts Year 2012 Integrated List of Waters, Final Listing.

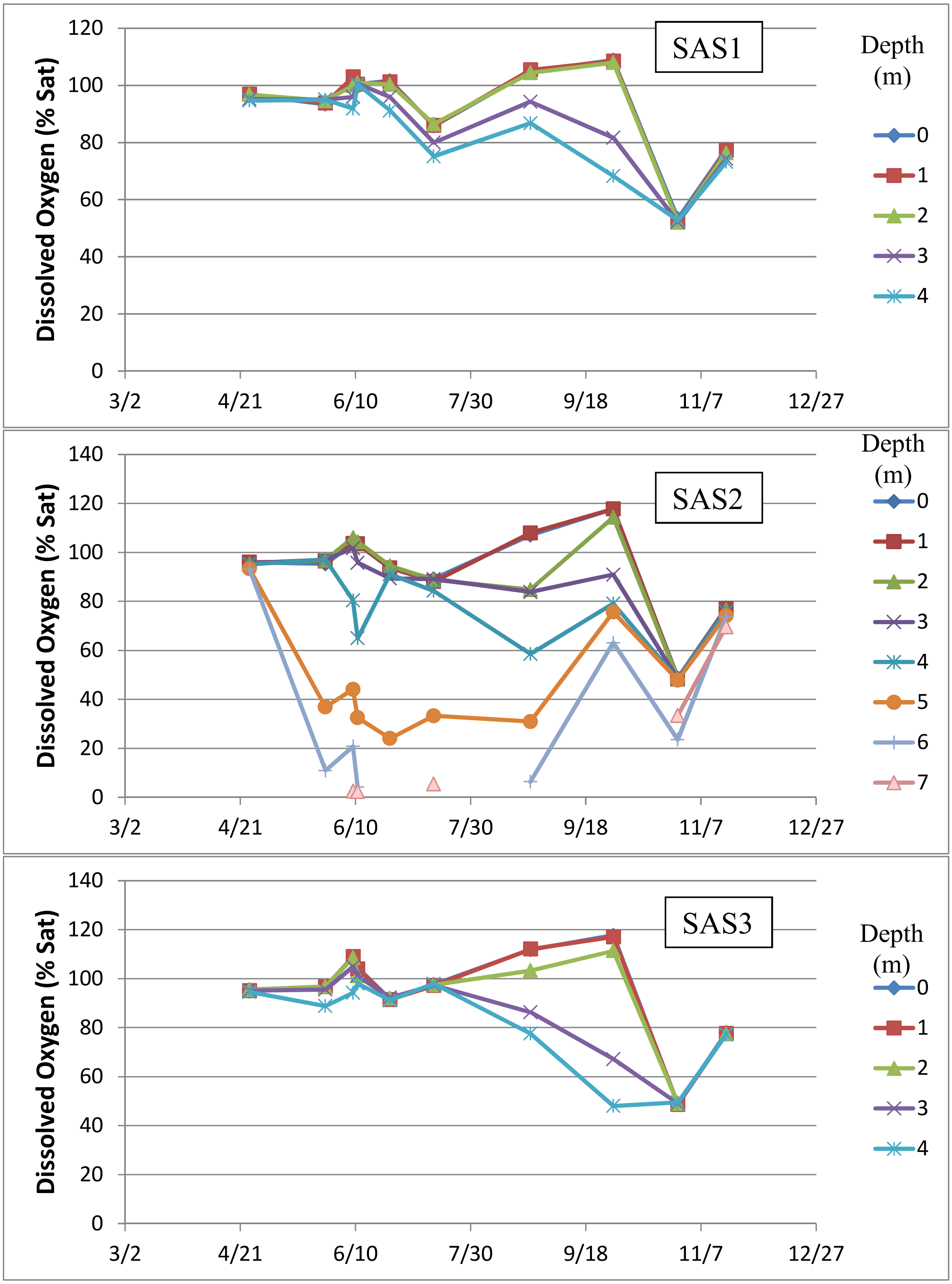

Figure IV-11. Sassaquin Pond 2014 Dissolved Oxygen Saturation Readings. Surface DO % saturation levels generally are in balance with atmospheric readings (100% saturation) for the readings until August when active phytoplankton photosynthesis raise levels above 100%. This condition is sustained into September. % saturation levels drop throughout the water column in October when the deeper reduced oxygen waters are mixed throughout the pond.

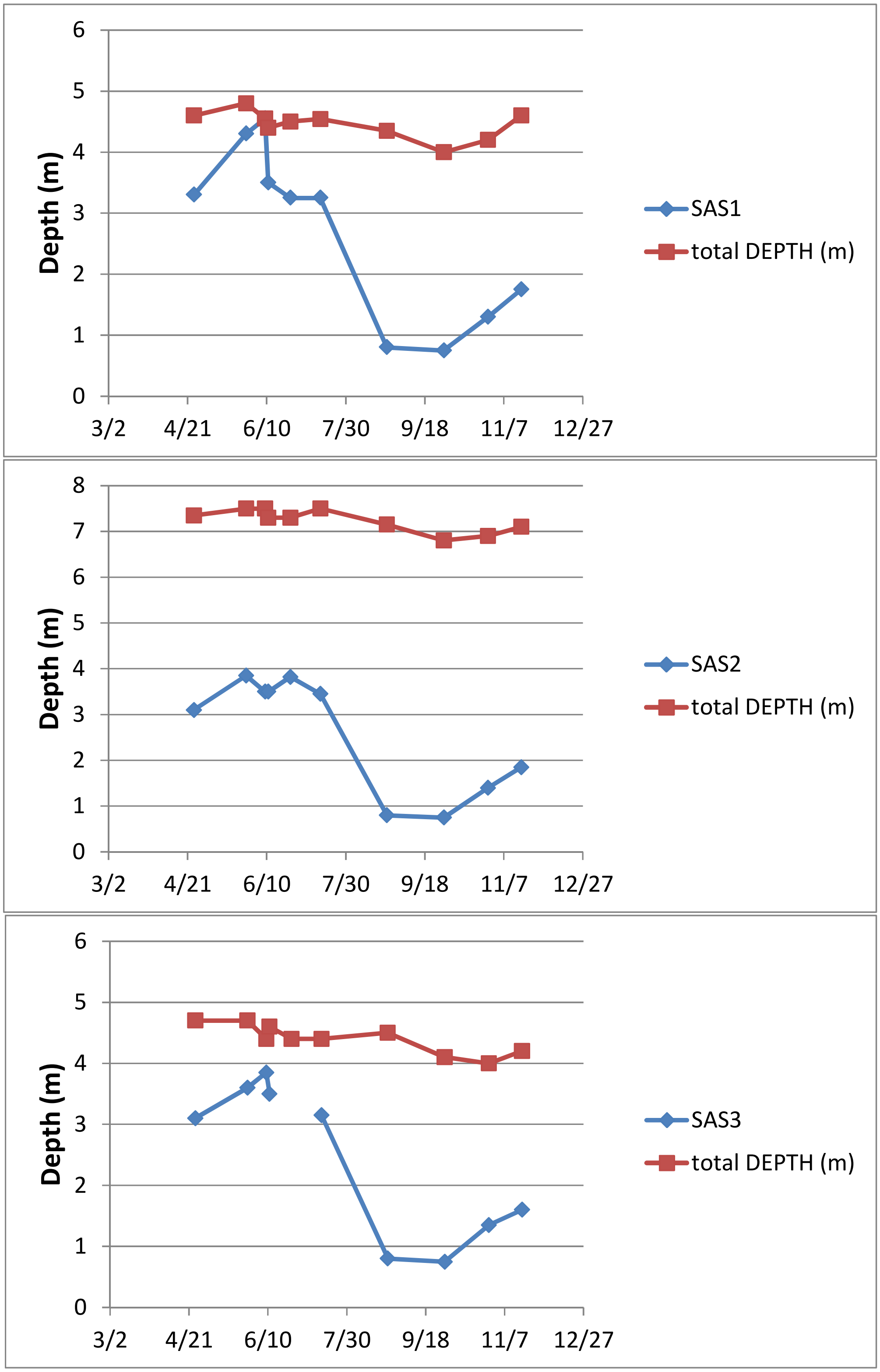

Figure IV-12. Sassaquin Pond 2014 Secchi/Clarity Readings. Clarity readings at all three stations average ~3.6 m April thru July 14 and then 1.2 m into November. Lowest clarity was in August and September improving in October and November, but not to levels measured in the early part of the year. Clarity is mainly controlled by phytoplankton in the watercolumn.

IV.C.2. Nutrients, Phytoplankton Pigments, and pH

As part of the baseline sampling, CSP/SMAST staff also collected water samples on 10 dates within 2014. Samples were collected at three stations at the surface and 1 m depth increments. This protocol allowed water quality sample results and field measurements of dissolved oxygen and temperature to be collected at the same depths. Water quality results are available for: pH, alkalinity, ortho-phosphate, dissolved organic phosphorus, total dissolved phosphorus, total phosphorus, ammonium-nitrogen, nitrate+nitrite nitrogen, dissolved organic nitrogen, particulate organic carbon, particulate organic nitrogen, total nitrogen, chlorophyll-a, and pheophytin-a. Complete sampling results were given to the City of New Bedford in an electronic file. All laboratory analyses were completed at the SMAST Coastal Systems Analytical Facility using standard procedures documented in SMAST Coastal Systems Analytical Facility Quality Assurance Plan (2003), which was approved by the Massachusetts Department of Environmental Protection (MassDEP).

Plant growth in ecosystems is typically governed by availability of nutrients and light. In freshwater systems, phosphorus is usually the nutrient that determines the amount of growth and this is confirmed by comparing nitrogen and phosphorus concentrations. 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 and should be the nutrient that is managed to maintain or restore water quality. Phosphorus-limited pond systems generally have N to P ratios that are 2-5 times the Redfield ratio of 16. Review of Sassaquin Pond N to P ratios show that average ratios are clearly phosphorus limited; the overall average was 55, while the surface average was 63. Deeper waters, especially those in the deep basin (SAS2), have lower averages due to phosphorus being released from the sediments by hypoxic conditions; the 7 m average N to P ratio at SAS2 was 23. These results support the focus on phosphorus as the nutrient to target for management of Sassaquin Pond.

Table IV-4 shows the average, maximum, and minimum concentrations for key nutrients and other watercolumn parameters. Review of the data shows that nitrogen concentrations, in general were not statistically different ($\rho<0.05$) among the stations at the same depths and among the depths at each station. This finding is not surprising given that nitrogen is available in abundance when compared to phosphorus. Some of the deeper dissolved organic nitrogen (DON) concentrations were statistically higher than surface concentrations, which suggest some regular sediment release from decay processes.

Review of phosphorus concentrations show a number of facets to how this nutrient is being used within Sassaquin Pond. Total phosphorus (TP) concentrations were statistically different between surface and deep concentrations only at station SAS2; there was no statistically significant difference among concentrations at any depth at SAS1 or SAS3. At SAS2, TP concentrations at almost every depth were statistically lower than concentrations at 6 and 7 m (average concentrations of 38 µg/L and 75 µg/L, respectively). This finding indicates the significant release of sediment phosphorus in the deep basin, but not at the two shallower stations. TP concentrations were statistically different, but concentrations of ortho-phosphate and dissolved organic phosphorus were not statistically different. This finding suggests that most of the difference in the TP concentrations is due to particulate phosphorus, which would be phosphorus bound to organic materials, such as incorporated into phytoplankton. This lack of

Table IV-4. Sassaquin Pond: 2014 Summary of Select Water Quality Parameters. Average, standard deviation, maximum, minimum and count of samples collected at each of the three sampling stations and the associated depths. Data is presented for total phosphorus (TP), ortho-phosphate (ortho-P), total nitrogen (TN), dissolved inorganic nitrogen (DIN), chlorophyll-a, total pigments, and pH.

Station	Depth	TP (µg/L)					ortho-P (µg/L)					TN (mg/L)					DIN (mg/L)				
	m	Avg	Stdev	Max	Min	N	Avg	Stdev	Max	Min	N	Avg	Stdev	Max	Min	N	Avg	Stdev	Max	Min	N
SAS1	1	20.98	5.36	30.42	13.67	10	4.08	0.24	7.28	1.55	9	0.56	0.23	1.09	0.35	10	0.02	0.02	0.06	0.01	10
	2	21.62	6.03	32.59	12.62	10	4.88	5.94	18.96	1.55	8	0.52	0.14	0.79	0.34	10	0.01	0.02	0.06	0.00	10
	3	24.33	11.06	48.89	11.57	10	4.01	2.20	8.52	1.55	10	0.52	0.14	0.80	0.37	10	0.01	0.02	0.06	0.00	10
	4	24.71	10.82	41.61	11.57	8	7.60	9.68	29.40	2.82	7	0.62	0.18	1.03	0.44	8	0.02	0.02	0.05	0.00	8
SAS2	1	18.31	6.56	28.25	9.47	10	3.44	2.03	6.97	1.55	10	0.56	0.25	0.95	0.34	10	0.02	0.03	0.09	0.00	10
	2	21.83	6.38	30.42	11.72	10	3.80	4.60	16.74	1.55	10	0.51	0.17	0.85	0.34	10	0.01	0.02	0.06	0.00	10
	3	21.83	5.88	29.24	11.72	10	2.53	1.14	4.65	1.55	9	0.56	0.17	0.90	0.39	10	0.01	0.02	0.06	0.00	10
	4	25.03	7.36	39.47	14.78	10	3.77	3.59	13.16	1.55	10	0.51	0.12	0.71	0.34	10	0.02	0.02	0.06	0.00	10
	5	31.38	16.07	74.31	16.83	10	5.53	5.36	15.49	1.55	9	0.61	0.18	1.01	0.45	10	0.02	0.02	0.06	0.01	10
	6	38.18	15.49	69.53	24.74	10	6.44	6.64	24.08	1.55	10	0.61	0.19	1.01	0.40	10	0.05	0.07	0.22	0.00	10
	7	74.87	19.22	102.61	57.35	5	5.69	4.19	12.57	1.55	5	0.79	0.25	1.12	0.54	5	0.03	0.03	0.08	0.01	5
SAS3	1	21.67	6.79	28.25	8.42	10	2.98	2.01	7.74	1.55	10	0.53	0.31	1.29	0.33	10	0.02	0.01	0.05	0.00	10
	2	22.01	5.81	32.61	13.73	10	3.33	2.34	7.74	1.55	9	0.50	0.21	1.03	0.36	10	0.01	0.02	0.06	0.00	10
	3	25.05	14.19	63.28	14.44	10	4.15	2.83	10.07	1.55	10	0.58	0.24	1.05	0.35	10	0.02	0.02	0.06	0.00	10
	4	26.61	12.13	47.23	15.78	10	2.82	1.24	4.65	1.55	7	0.46	0.09	0.63	0.32	10	0.01	0.01	0.03	0.00	7

Station	Depth	Chlorophyll-a (µg/L)					Total Pigments (µg/L)					pH				
	m	Avg	Stdev	Max	Min	N	Avg	Stdev	Max	Min	N	Avg	Stdev	Max	Min	N
SAS1	1	7.3	9.5	29.4	1.1	10	9.9	11.8	39.4	1.5	10	7.0	0.8	9.0	6.3	10
	2	9.2	10.6	33.0	1.1	10	12.1	13.3	44.4	1.8	10	7.0	0.8	9.1	6.3	10
	3	10.6	14.0	43.7	1.1	10	13.0	19.3	61.8	1.8	10	6.8	0.2	7.0	6.4	10
	4	7.5	7.9	26.3	1.5	8	7.9	7.8	26.3	1.8	8	6.6	0.2	6.9	6.4	8
SAS2	1	6.0	7.2	24.6	0.7	10	8.2	10.2	35.4	1.0	10	7.1	0.9	9.3	6.3	10
	2	9.1	10.5	34.2	1.0	10	11.7	13.5	46.5	1.2	10	7.0	0.7	8.9	6.3	10
	3	9.2	11.8	40.0	1.1	10	12.4	17.0	59.1	2.2	10	6.8	0.2	7.0	6.3	10
	4	7.6	10.9	37.0	1.2	10	10.7	15.7	54.0	1.7	10	6.7	0.2	6.8	6.3	10
	5	7.9	9.7	32.4	0.9	10	11.9	15.9	53.2	1.2	10	6.4	0.2	6.8	6.2	10
	6	6.9	7.3	24.3	1.1	10	14.3	15.4	53.2	2.0	10	6.4	0.2	6.6	6.1	10
	7	14.5	11.5	30.4	2.3	5	23.2	15.8	40.5	3.7	5	6.3	0.1	6.5	6.1	5
SAS3	1	8.5	10.3	32.2	1.0	10	12.7	18.1	61.0	1.3	10	7.2	0.8	8.8	6.6	10
	2	10.9	13.1	41.4	1.0	10	13.5	16.7	56.2	1.5	10	7.0	0.5	8.2	6.5	10
	3	7.4	11.0	34.9	0.8	10	15.0	19.2	52.6	2.0	10	6.7	0.1	6.9	6.5	10
	4	4.5	4.9	15.1	0.9	10	5.0	5.5	17.0	1.2	7	6.8	0.1	7.0	6.6	10

availability of dissolved forms would be consistent with its role as a limited, controlling nutrient with inorganic forms rapidly incorporated into plant materials.

Among the chemical constituents tested, Massachusetts only has regulatory numeric standards for pH.[28] Regulations require pH to be within a 6.5 to 8.3 range, but do allow readings outside of this range if these are natural conditions. Average pH readings in Sassaquin Pond generally are within this range except for depths at 5 m and deeper at SAS2 (see **Table IV-4**). Readings in groundwater fed, outwash plain soils do not tend to have significant carbonate materials to balance the natural acidity of rainwater.[29] Increases in pH for ponds in these types of soils typically are from photosynthesis; when aquatic plants photosynthesize they take carbon dioxide and hydrogen ions out of the water causing pH to increase. The readings in Sassaquin Pond suggest that the low pH readings at depth were more reflective of natural pH, while the higher pH readings measured in the shallower depths at all the stations likely reflect the significant amount of phytoplankton photosynthesis.

The other average concentrations in Sassaquin Pond also suggest a nutrient rich, impaired system. While there are only limited MassDEP regulatory numeric thresholds, the Massachusetts Surface Water Regulations indirectly suggest consideration of nutrient and phytoplankton concentrations to address the descriptive ecosystem goals/standards stated in the regulations. EPA has developed an approach to provide guidance for appropriate nutrient and chlorophyll concentrations based on evaluation of available water quality data from ponds and lakes in similar settings. EPA has divided the United States into various "ecoregions" that share similar geology, soils, and precipitation regimes. Based on EPA's divisions, New Bedford is located within the Northeastern Coastal Zone Ecoregion (*i.e.*, Level III Ecoregion 59), which EPA characterizes as having "relatively nutrient-poor soils."[30] This ecoregion includes all of eastern Massachusetts except for Cape Cod and the Islands (**Figure IV-13**). Within these larger ecoregions are further subdivisions called Level IV ecoregions; New Bedford and Sassaquin Pond are in the Narragansett/Bristol Lowland Level IV ecoregion. The EPA approach for providing ecoregion-specific concentrations relies on review of existing data within the same ecoregion. Using the available data from the ecoregion that includes New Bedford and Sassaquin Pond, the TP threshold would be 8 µg/L, while the TN and pH thresholds would be 0.32 mg/L and 6.51, respectively (**Table IV-5**).[31] Using these ecoregion thresholds, Sassaquin Pond would be considered impaired by excessive nutrients. Based on the 2014 monitoring, average TP, TN, and pH readings in Sassaquin Pond at all three stations and at all monitored depths exceeded the respective ecoregion thresholds. These ecoregion thresholds could serve as potential water goals for Sassaquin Pond as the City of New Bedford considers future restoration activities.

[28] Bacteria and pH are the only other numeric standards in the Massachusetts Surface Water Regulations; bacteria testing was not part of this project.

[29] pH of natural rainwater in balance with carbon dioxide in the atmosphere is 5.65. Average pH of 193 ponds sampled on Cape Cod, which is mostly outwash plain, in 2001 was 6.16 (Eichner, *et al.*, 2003).

[30] U.S. Environmental Protection Agency. 2001. Ambient Water Quality Criteria Recommendations. Information Supporting the Development of State and Tribal Nutrient Criteria for Lakes and Reservoirs in Nutrient Ecoregion XIV. EPA 822-B-01-011. US Environmental Protection Agency, Office of Water, Office of Science and Technology, Health and Ecological Criteria Division. Washington, DC.

[31] *Ibid.*, p. 17, Table 3a.

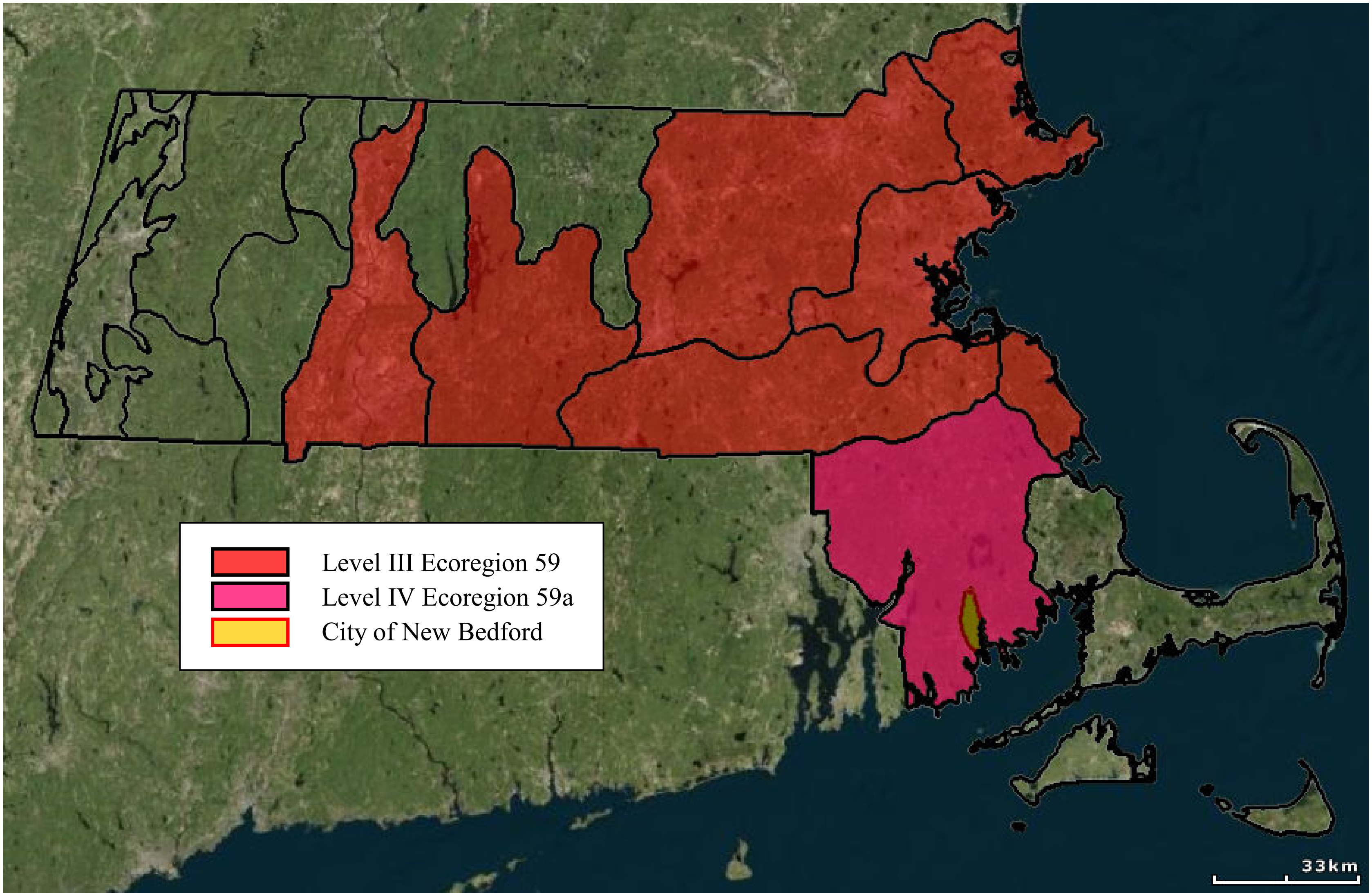

Figure IV-13. US Environmental Protection Agency Northeastern Coastal Zone Ecoregion (Level III Ecoregion 59). New Bedford is located within Ecoregion 59 and the subset Narragansett/Bristol Lowland Ecoregion (Level IV Ecoregion 59a). EPA has developed a strategy for establishing nutrient thresholds for water bodies based on collected data within the same ecoregions.

Table IV-5. USEPA Nutrient Reference Concentrations for Lakes in Ecoregion 59. Ecoregion 59 includes all of Eastern Massachusetts except for Cape Cod and the Islands. Reference concentrations are based on review of available pond and lake water quality in the same ecoregion (USEPA, 2001).			
Parameter	Units	# of lakes	Reference
Total Kjeldahl N	mg/L	30	0.43
Nitrate-N + nitrite-N	mg/L	31	0.05
Total N	mg/L	119	0.32
Total P	µg/L	213	8
pH	std units	310	6.51

The 2014 water quality data can also be used to estimate the mass of nutrients in Sassaquin Pond and how they change with time and are affected by the water budget. Using the concentrations of total phosphorus and the pond volumes from the refined bathymetry, project staff determined the mass of phosphorus in the pond on each of the sampling dates. The phosphorus mass in the pond at the beginning of the sampling season (April 25) was 9.1 kg, rose to 13.6 kg within the initial warming of the pond (May 28), fell as early phytoplankton died and fell to the sediments (throughout June). The total mass of phosphorus then rose again in July and was sustained into October, until dropping slightly in November (**Figure IV-14**). These readings follow a familiar pattern of nutrient mass based largely on seasonal warmth and sediment contributions in ponds with hypoxic conditions. They also seem to suggest that a hypoxic equilibrium in terms of sediment release of phosphorus was attained in July and sustained through November. Review of nitrogen mass shows larger masses and a somewhat different fluctuation pattern, but a pronounced peak in August and September. The timing of this peak suggests that anoxic conditions had been sustained for long enough for denitrification to be impeded and sediment released N to build-up in the watercolumn. Comparison of the phosphorus mass in water column in April, the refined pond volume, and the estimated annual phosphorus stormwater input (17 kg in Table IV-3) also suggests that the pond water residence time is close to 2 years. Consideration of other watershed phosphorus sources would increase the residence time estimate. Similar calculations for nitrogen, which is a more conservative nutrient, would estimate the residence time at 2.7 years assuming stormwater is the only nitrogen source. The BEC (1987) estimated a residence time of 1.22 years. These calculations reinforce that there is some uncertainty regarding the watershed delineation/water budget for Sassaquin Pond (also noted in Section IV.A).

IV.D. Sassaquin Pond Sediments

Review of past Sassaquin Pond monitoring suggested that sediment oxygen demand was a significant issue.[32] In order to help address this issue, as well as measuring potential sediment nutrient regeneration, CSP/SMAST was tasked with collecting a minimum of 5 sediment cores in the pond. Cores would be incubated using standard CSP/SMAST procedures by exposing them to various oxidizing and reducing conditions and directly measuring the amount of nutrient release. This assessment of the sediments can provide insights into the available sediment nutrients, their distribution in the pond, and the conditions under which these nutrients would be released to the water column.

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[32] Normandeau Environmental Consultants. May, 2014. Sassaquin Pond Total Phosphorus Study. Completed for City of New Bedford. 9 pp..

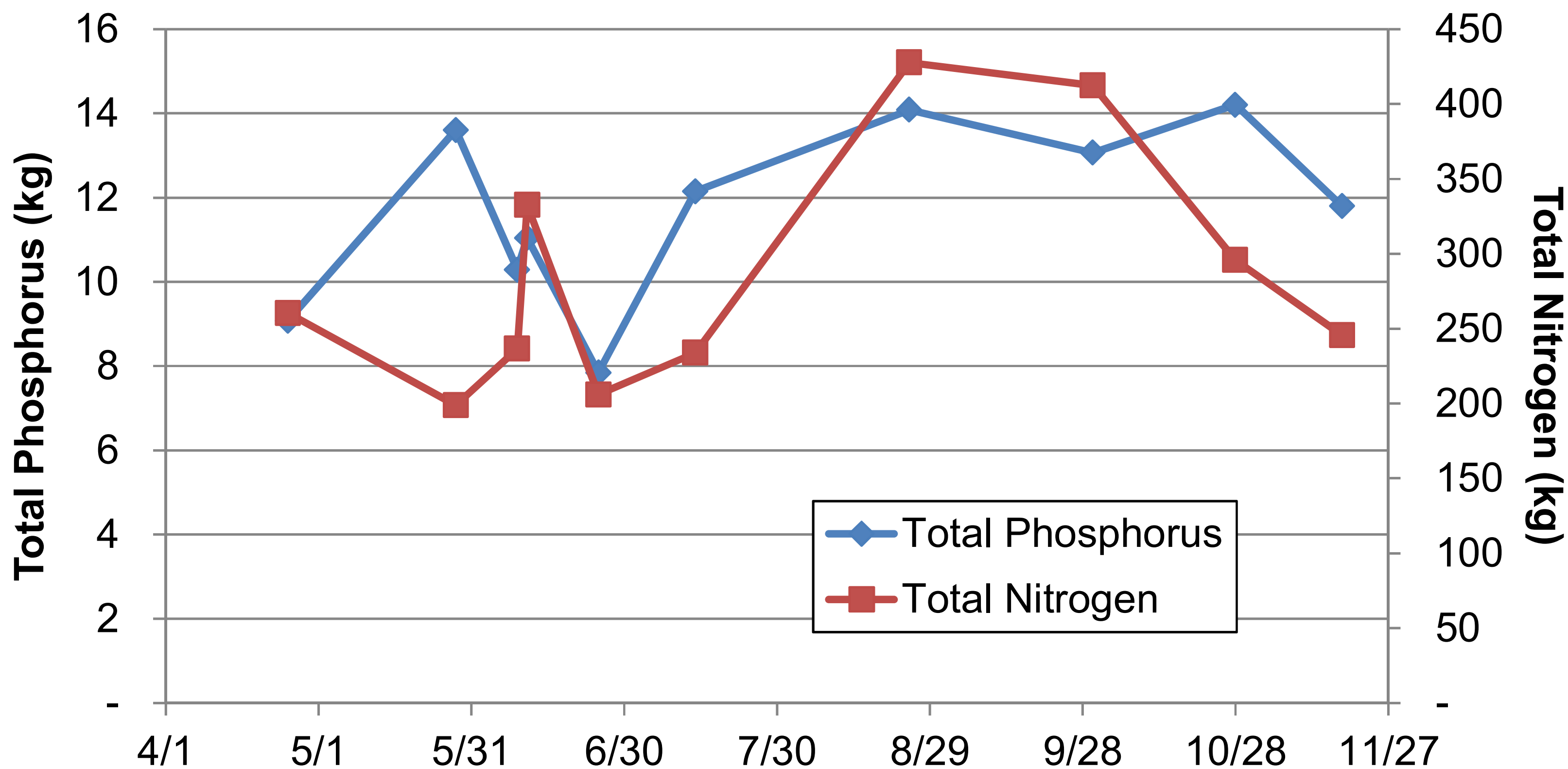

Figure IV-14. Sassaquin Pond: 2014 Water Column Mass of Phosphorus and Nitrogen. Project staff used the bathymetry and water quality concentrations measured at each depth to develop an estimate of phosphorus and nitrogen mass in the water column.

CSP/SMAST staff collected 8 cores on June 11, 2014 at the locations shown in **Figure IV-15.** Core locations were selected based on the bottom topography, spatial coverage, and extent of past hypoxic water column conditions, including preliminary CSP/SMAST water quality data collected in 2013. These undisturbed sediment cores were collected by SCUBA diver and were incubated at in situ temperatures to evaluate nutrient regeneration from the sediments under oxic and anoxic conditions. Sediment cores were not taken from the deepest area of the pond due to anaerobic bottom conditions at the time; anaerobic conditions would have caused the regeneration of sediment nutrients prior to the collection of the sediment cores.

Observations during the collection of the sediment cores noted the presence of submerged aquatic vegetation and sediment characteristics. Extensive submerged aquatic vegetation was observed in the southern portion of the pond (sites C1, C2, C3 and C4) and in the shallower northern areas (sites C6 and C7). Most of the core sites had a layer of soft mud except for the shallowest site (C1), which was fine to medium sand (**Table IV-6**). Soft organic mud was noted at sites C2 and C3, while C4 also had a mud layer but sand was noted underneath during the core collection. Observations at sites C6 and C7 noted coarser sands or gravel underneath a mud layer. At C5, which was the deepest site and is located at a depth that was regularly hypoxic during 2014 sampling, sediments were composed of very soft mud with the presence of a refusal layer below the mud. Site C8, which was located at a slightly shallower depth than C5, also was composed of similar soft mud. Project staff was requested by city staff to measure the depth of the mud layer in the deep basin; a sediment probe used by the staff diver reached a refusal depth between 2.0-2.5 meters within the deepest section of pond. The presence of a surface mud layer a several sites can be a reflection of the only recent eutrophication of the Pond or large storm events resuspending soft muds in the shallow areas and redepositing them in the deeper basins. Further data collection would be needed to determine which of these processes is a work here.

Table IV-6. Sassaquin Pond Sediment Core Site Observations (June 11, 2014). Cores were collected by SCUBA diver. Observations noted during the collection of cores.

Core site	Latitude	Longitude	Collection Depth (m)	Sediment Description
C1	41 43.973	70 56.987	1.4	Fine-medium sand
C2	41 44.008	70 57.025	4.2	Soft organic mud
C3	41 44.015	70 56.969	2.1	Soft organic mud
C4	41 44.042	70 56.956	3.2	Soft organic mud over sand
C5	41 44.109	70 56.980	5.3	Fluid mud
C6	41 44.140	70 57.007	2.7	Mud over sand with coarse sand/gravel on bottom
C7	41 44.206	70 56.967	1.7	Mud/sand mix with coarse sand below
C8	41 44.180	70 56.924	4.5	Fluid mud

During the collection of sediment cores, standard handling, incubation, and sampling procedures were followed based on the methods of Jorgensen (1977), Klump and Martens (1983), and Howes (1998). During the core incubations, water samples were withdrawn periodically and chemical constituents were assayed. Rates of sediment nutrient release/uptake were determined from linear regression of analyte concentrations through time. Cores are incubated to first sustain aerobic conditions, matching conditions when oxygen conditions are near atmospheric equilibrium throughout the water column. Dissolved oxygen is then removed and sediment conditions move through a redox sequence that begins with chemical release (severing of weak chemical bonds) and ends with anoxia, similar to water column conditions where dissolved

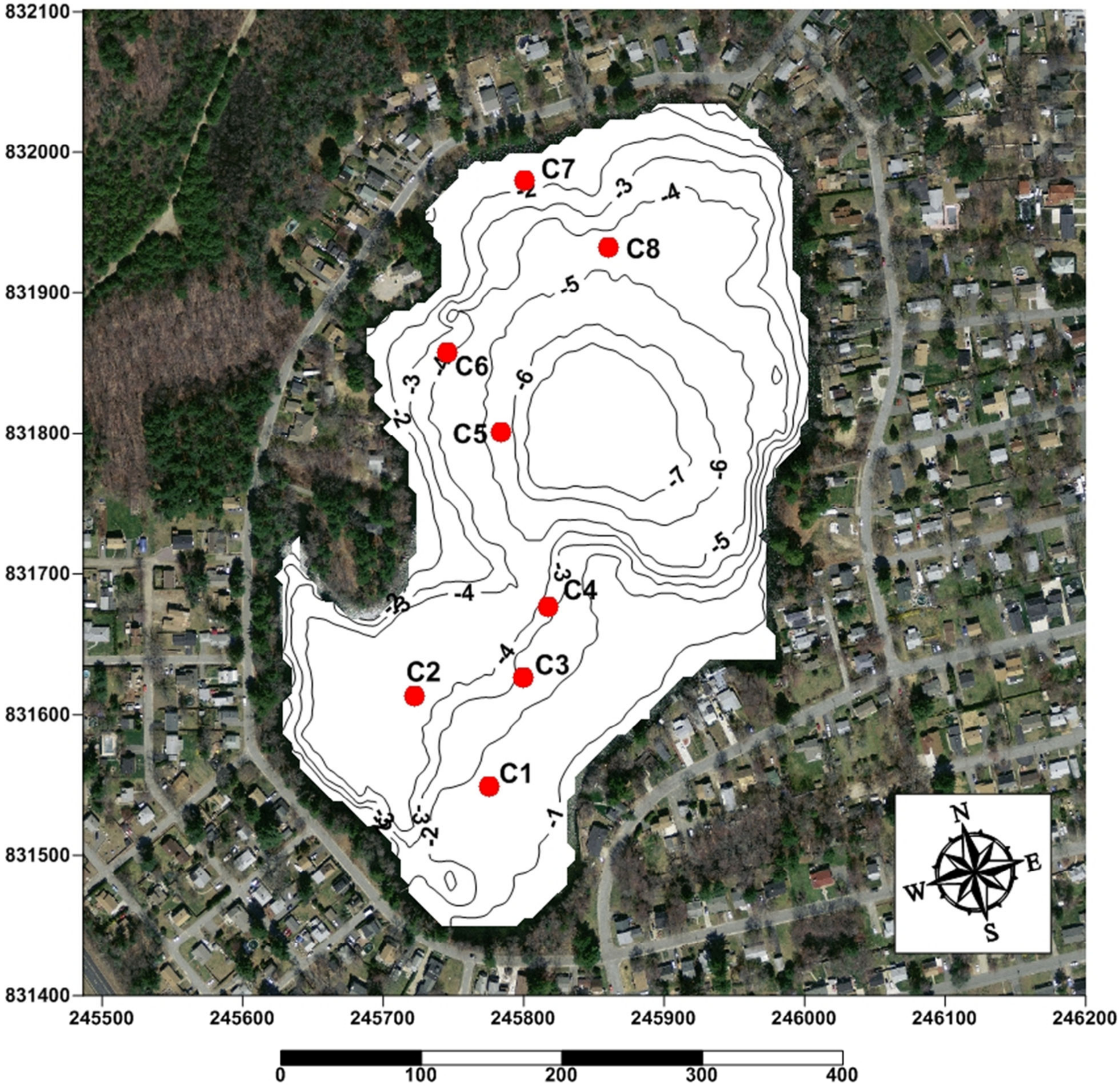

Figure IV-15. Sassaquin Pond Sediment Core Collection Sites. Sediment cores were collected by SCUBA diver on June 11, 2014. Cores were collected at similar depths at various locations both north and south of the main basin. Cores were not collected in the deepest portion of the main basin due to anaerobic bottom conditions, which would have already caused significant nutrient release.

oxygen concentrations drop to less than 1 mg/L. This anaerobic incubation lasted for 35 days. The laboratory followed standard methods for analysis and sediment geochemistry as currently used by the Coastal Systems Analytical Facility at SMAST-UMass Dartmouth. Nutrient release rates are shown in (**Table IV-7**).

The sediment core data was generally comparable to other shallow ponds with excessive nutrients[33] with much of the phosphorus, the key nutrient of concern, is bound in strongly bound, organic forms and chemically sorbed onto iron minerals. Typically, pond sediments retain phosphorus in solid forms under aerobic conditions, but these solids become soluble, and dissolve into the water column, under anaerobic conditions. Anaerobic conditions initially break iron:phosphorus chemical bonds, which generally produce most of the readily available sediment phosphorus release in a relatively rapid (*e.g.*, few days) release. If anaerobic conditions are sustained, bacteria begin to work on phosphorus bound in organic forms (*e.g.*, decomposing plants) and release remaining phosphorus over a long period. In addition, sediment release of nutrients needs to be paired with settling of particles in the water column. Nutrients are being released at the same time as nutrients are being added, so water quality data was collected on the same date as the sediment cores were collected. It is worth noting that under aerobic conditions phosphorus shows a variable release as some is sorbed before it leaves the sediments or phosphorus in the watercolumn is taken up and sorbed by oxidized iron compounds, whereas under anaerobic conditions the flux is consistently into the watercolumn.

In Sassaquin Pond, as in most freshwater ponds, aerobic conditions showed that, on average, sediments were retaining phosphorus in the shallower sediments with the primary release associated with microbial decay of organic matter. However, there was much higher variability in samples collected in the more northern portion of the pond (C7, C6) than in the southern portion (C1, C2, C3). These differences are likely due to the gentler bottom topography in the southern portion of the pond producing more homogenous sediments.

As mentioned, the greatest sediment phosphorus release in most ponds is generally associated with the break of iron:phosphorus bonds at the start of anaerobic conditions. This “chemical release” typically is greater than any subsequent phosphorus release associated with prolonged anaerobic conditions. In Sassaquin Pond, the long-term anaerobic conditions and continuing organic matter decay released more phosphorus than the rapid chemical release phase of the core incubations. This finding suggests that the upper portions of the sediments that are collected in the cores are predominantly from the deposition of phytoplankton that has not been significantly degraded by bacteria. This also suggests that the amount of this deposition is supporting the sediment regeneration of N and P and may be an important source of these nutrients to pond waters to support phytoplankton blooms. This finding is consistent with the high chlorophyll readings and the regularly noted algal blooms. Blooms would concentrate available nutrients in the phytoplankton and then transfer this phosphorus bound in plant material to the sediments to again be recycled.

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[33] *e.g.*, Eichner, E., B. Howes, D. Schlezinger, and M. Bartlett. 2014. Mill Ponds Management Report: Walkers Pond, Upper Mill Pond, and Lower Mill Pond. Brewster, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 125 pp.

Table IV-7. Sassaquin Pond Sediment Core Nutrient Release June 2014.
Sediment cores were collected at eight sites in Sassaquin Pond on June 11, 2014. Cores were incubated at temperatures consistent with water temperatures at the time of core collection. Cores were incubated to measure nutrient release under both aerobic and anaerobic conditions with particular focus on the anaerobic, chemical release phase. Sediment release rates below represent averages of multiple (4-6) samples during each incubation phases. Note that cores were collected at different depths and sites (*i.e.,* are not replicates), which is reflected in the observed rates. Net pond-wide phosphorus sediment transfers, which incorporate settling of measured phosphorus from the 6/11 water column are: -0.39 kg/d under aerobic conditions (negative indicates net retention), +4.93 kg/d at the chemical release phase, and +11.48 kg/d under anaerobic conditions. Anaerobic phosphorus release was essentially exhausted after two weeks, while anaerobic nitrogen release continued until the incubation was stopped after 35 days.

Sediment Sample Site	Water Depth	Sediment Oxygen Demand	Aerobic Flux Rate				Chemical Release	Anaerobic Flux Rate	
			Ammonium	Nitrate	Total Dissolved Nitrogen	Phosphorus	Total P	Nitrogen	Phosphorus
	m	$mM/m^2/d$	all rates in $\mu Moles/m^2/d$				$\mu Moles/m^2/d$	$\mu Moles/m^2/d$	$\mu Moles/m^2/d$
C1	1.4	70	911	1,641	2,737	-65	-14	3,658	101
C2	4.2	53	267	341	685	-45	4	972	57
C3	2.1	75	443	843	725	-31	-11	3,689	152
C4	3.2	62	755	923	2,842	2	0	2,520	101
C5	5.3	82	1,293	499	1,312	-3	70	901	72
C6	2.7	115	1,244	708	1,608	4	3	3,070	107
C7	1.7	125	809	1,794	4,051	10	39	3,722	119
C8	4.5	90	334	492	1,035	-7	-14	771	48

V. Conclusions

CSP/SMAST was tasked with the development of data to establish baseline conditions in Sassaquin Pond in anticipation of stormwater system updates within its watershed. Baseline conditions were established by measuring water quality in the pond, assessing the pond sediments, updating the pond bathymetry and volume, and measuring flows and nutrient loads from the stormwater system that discharges to the pond.

Review of the water quality shows that Sassaquin Pond is impaired. It has dissolved oxygen concentrations that are regularly less than Massachusetts regulatory minimums. Phosphorus, nitrogen, and chlorophyll concentrations all exceed ecoregion guidance concentrations. Clarity is regularly limited. Review of nitrogen and phosphorus concentrations show that management of phosphorus will allow restoration of the water quality in the pond.

Stormwater measurements were collected during six storms from two outfall pipes that represent greater than half of the stormwater systems that discharge into Sassaquin Pond. Discharge volumes from the two outfall pipes generally behaved similarly and were a reasonable reflection of the type of land use within the stormwater watersheds. Larger storms generated greater discharge with an overall range of runoff from 6% to 61% of measured precipitation. Measurements of contaminants in runoff showed variable relationships between runoff amounts, the amount of contaminants, and which outfall was being measured. Contaminants measured included nitrogen, phosphorus, and total suspended solids. Most contaminants increased with increased runoff flows, but selected contaminants (ortho-phosphate, ammonium-nitrogen, and TSS) had poor relationships for one or both of the outfall pipes. Resolution of these differences would require more refined evaluations of the outfall pipe watersheds/collection areas. It should also be noted that the estimated annual loads of nitrogen, phosphorus, and TSS based on the stormwater runoff measurements are significantly less than those previously estimated, due in large part to assume concentrations that were significantly higher than any of the measured concentrations. As such a nutrient budget should be developed to gauge the relative importance of each source to the phytoplankton blooms.

The bathymetric survey conducted by CSP-SMAST staff was significantly more refined than previous evaluations. Survey results showed that the pond volume was 19% smaller than previous estimates. Review of past watershed delineations also noted an inconsistency with recently derived watershed delineation information from the Massachusetts Estuaries Project (MEP). MEP delineations of Slocums River, Westport River, and Apponagansett Bay estuarine systems show that Sassaquin Pond is located in an area between the northern edges of these watersheds. These delineations suggest that Sassaquin Pond is part of the Taunton River watershed and the pond watershed should include areas that have not been included in previous assessments. Resolution of this issue, along the impacts of the revision of the bathymetry, is outside of the scope of the current project, but would inform nutrient management strategies for the pond. A smaller volume and a larger watershed would alter a number of aspects of the system characterization, including interpretation of water quality data and a water budget.

Sediment cores collected and incubated by CSP/SMAST staff showed highly variable conditions and storage of significant nutrients that could be released with changes in dissolved oxygen conditions. In general, the sediments collected phosphorus during aerobic conditions, which always occurred in shallower waters (≤ 3 m) during the 2014 baseline sampling, but released phosphorus as dissolved oxygen declined to <1 mg/L. Potential phosphorus release was large for the initial phase of anoxia, but substantially more would be released with prolonged anoxia. Water quality readings suggest that deep basin sediments were operating under hypoxic/anoxic P release conditions by July and sustained these conditions through November. Nitrogen had higher release rates than P due to its greater availability, but cores showed significant mass stored in shallower sediments. Sediment nitrogen release appeared to increase in August and September, when the mass of nitrogen in the pond water column nearly doubled.

VI. Recommendations

The above review establishes a contemporary baseline for water quality in Sassaquin Pond and will provide a comparison point for anticipated improvements due to the changes in stormwater system that discharges runoff into the pond. Aside from this comparison, the above review also notes some system characterization issues that could be resolved with a more comprehensive assessment of the pond. These issues are listed to assist the City of New Bedford if additional pond management activities are considered:

1. Watershed delineation. Review of the water quality data and the recent MEP watershed mapping show that the delineation of the Sassaquin Pond watershed is different than past delineations suggest. The stormwater collection system is an important consideration for water and nutrient inputs to the pond, but the mapping suggests that the watershed and potential contaminants contributing to Sassaquin Pond is from a larger area.
2. Plant Population. CSP/SMAST divers noted rooted plants during the collection of the sediment cores. The balance between rooted plants and phytoplankton often play a significant role in how nutrients are distributed and express in pond water quality. BEC (1987) noted few aquatic plants, but CSP/SMAST staff noted aquatic plants throughout the southern section of the pond. Establishing distribution and density of rooted plants would help with nutrient budgets to guide management decisions. Also establishing phytoplankton species two or three times during the summer would help to clarify whether blue-green algae, which are toxic, are a significant issue.
3. Nutrient and Water Budgets. Related to the watershed delineation, a water budget would help to establish all the sources of water to the pond, while a nutrient budget would help to establish all the sources of nutrients to the pond. Development and balancing of these budgets would help develop, refine, and estimate costs for addressing the primary sources of each constituent. Most importantly, these budgets are critical to determining additional in pond management options for P.
4. Continued water quality monitoring. Regular monitoring will gauge the level of success of on-going management actions, allow adaptive management and determine when the pond has been restored.
5. Bacterial Assessment. A review of bacterial contamination was not part of this baseline assessment, but Sassaquin Pond was listed on the MassDEP Integrated List of Impaired Waters for fecal coliform contamination. This issue may have been resolved by past management activities, but the City may want to document these activities to avoid any future MassDEP regulatory activities.
6. Pond Management Plan. Water quality was the primary focus of this baseline effort, but it is clear that recreational uses of the pond are also an important consideration. Development of a management plan, including regular water quality monitoring will encourage clear

understanding of expectations and responsibilities. A citizen-based water quality monitoring program (see #4) could keep monitoring costs low and provide an outlet for continued local stewardship. The management plan might also include an education program for pondside homeowners about effective property management that could minimize future management concerns.

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