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Memorandum

To	George Meservey, Director of Planning & Community Development Michael Domenica, PE, Program Manager
CC	Betsy Shreve, AICP, AECOM Project Director Sia Karplus, Science Wares, Inc. Paula Winchell, AECOM
Subject	**Town of Orleans, MA** **Water Quality and Wastewater Planning** **Task 10.2 – Adaptive Management Implementation** **Task Number 10.2.G – Water Quality Remediation and Protection Plans for Priority Freshwater Ponds**
Project Number	60476644
From	Thomas Parece, P.E., AECOM Project Manager
Date	06/25/17

Approvals	Date	Signature / Initials
George Meservey, Orleans, MA Director of Planning & Community Development		
Michael Domenica, PE, Water Resources Associates, Program Manager		

1. Background

The following comments summarize our review of the Draft Final Report prepared by SMAST entitled "Town of Orleans Freshwater Ponds Water Quality Monitoring Database Development and Review", dated May 2017 (Appendix A) and meeting held on June 6, 2017.

2. Data Aggregation and Presentation

After a detailed review of the data set and report, the data from four different sources was accurately combined and these data are organized and presented appropriately in both tabular and graphic format. The aggregated data set is available in Excel format. The format for the data set and report are organized in a way that can be readily used for pond-specific evaluations. For example, the figures for dissolved oxygen (DO) present the percent saturation as well as concentrations. In addition, observed data gaps are listed for each pond.

3. Specific Comments/Considerations

These additions could be included to enhance the data presentation:

- In Table II-1, the title of headings could be changed to clarify that the source for April/May data is also SMAST;
- In each Table III, in addition to providing the number of samples, it would be helpful to provide the percent of samples that do not meet the threshold listed;
- In each Table III, average data across different seasons for some parameters is presented. This was discussed, and although some averages do not make analytical sense (e.g. temperature), SMAST prefers inclusion for consistency of structure;
- While it may not make sense given the range in data, it is difficult to compare the same parameter between different ponds (e.g. total nitrogen) because the scales used on the vertical axis of the figures in Appendix B are not uniform. If possible it would be better to keep the scale of each parameter consistent across ponds; and
- The data trends for each pond are described in the text but the analysis is not shown on the figures for each pond in Appendix B or in the tables. We recommend that where trends (increasing/decreasing) are noted, these should be shown in the figures, with the confidence interval. For example, there are trends in Secchi depths identified for Baker's Pond, Crystal Lake, Gould Pond, Icehouse Pond, Meadow Bog Pond, Pilgrim Lake, Shoal Pond, Twining's Pond, Uncle Israel's Pond and Uncle Seth's Pond. Trends for DO, nutrients and the nitrogen/phosphorus ratios are also noted.

Appendix A

Town of Orleans Freshwater Ponds
Water Quality Monitoring Database Development and Review
by SMAST dated May 2017

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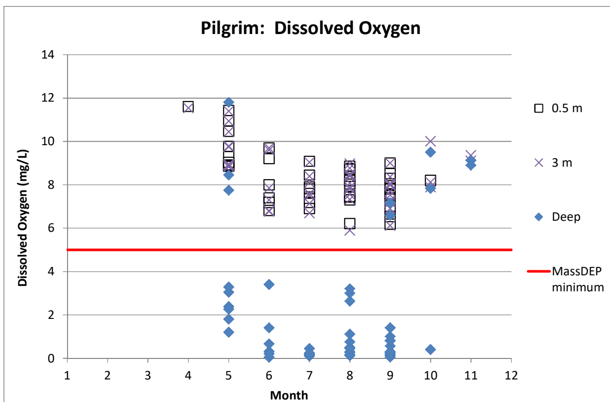
Town of Orleans Freshwater Ponds
Water Quality Monitoring Database Development and Review

Draft FINAL REPORT
May 2017



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Town of Orleans Freshwater Ponds
Water Quality Monitoring Database Development and Review

Draft FINAL REPORT
May 2017

Prepared for

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Acknowledgements:
The authors acknowledge the years of efforts and contributions of the many individuals and boards who have worked for many years for the restoration and protection of the ponds and lakes in the Town of Orleans. Without these pond stewards and their efforts, this project and associated restoration efforts would not be possible.

The authors also specifically recognize and applaud the generosity of time and effort spent by past and present members of the Orleans Marine and Fresh Water Quality Task Force (soon to become a Town Committee), members of the Orleans Water Quality Advisory Panel, the Orleans Ponds Working Group, and pond monitoring volunteers. Among these groups, particular thanks go to Judy Scanlon, Carolyn Kennedy, and Judith Bruce for their many years of monitoring and supporting monitors. Extra special thanks also go to Carolyn Kennedy, who is current chair of the Task Force and tracked down missing field data during the development of the town pond water quality database.

In addition to these contributions, project support has been freely and graciously provided by Alan McClennen and Mike Domineca. Special thanks also to the staff at the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth for the hours of laboratory analysis and logistics support during the Cape Cod PALS Snapshots that provided the majority of the data in the Town of Orleans ponds water quality database.

Cover photos (clockwise from lower left): pond volunteers collecting samples, Pilgrim Lake dissolved oxygen readings by month, dissolved oxygen meter, and Uncle Harveys Pond milfoil and algal bloom

Recommended Citation
Eichner, E and B. Howes. 2017. Town of Orleans Freshwater Ponds: Water Quality Monitoring Database Development and Review. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 217 pp.

EXECUTIVE SUMMARY

The Town of Orleans has 63 ponds covering a total area of 220 acres (Eichner and others, 2003).[1] These ponds and lakes are scattered throughout the town, in a variety of land use settings from relatively undeveloped areas to highly developed areas, included downtown. They are located in the major estuary watersheds and the Town Watershed. They have a large range in size, with 25 greater than one acre and three greater than 10 acres.[2] They also have a variety of regulatory settings, including those located within the Pleasant Bay Areas of Critical Environmental Concern and the town's Zone II, wellhead protection areas.

One of the things that most of the ponds have in common is that prior to 2000 they had not had a water quality sample collected from them and little was known about the status of their ecosystems. Volunteer citizen water quality monitoring began for Orleans ponds in 2000 and has continued for 17 years. During this time, 18 ponds have been sampled on a regular basis with some periods of more extensive sampling, a variety of labs for sample analysis, and limited organization and review of the data.

In 2015, the Town, through the Water Quality Advisory Panel, began the process of integrating pond management into an overall strategy to comprehensively address water quality management throughout the town. As part of this process, the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) was asked to organize and review available pond water quality data and provide the Town with guidance about how this data can be used for prioritizing individual pond management efforts.

CSP/SMAST staff collected available water quality data for Orleans ponds and lakes. The primary source of pond sampling data was the Pond and Lakes Stewardship (PALS) Snapshots, which were initiated in 2001 by CSP/SMAST and the Cape Cod Commission and have continued every year since. The PALS Snapshots were designed to provide an initial survey of pond water quality in the anticipated worst time of the year (mid-August to the end of September). PALS samples[3] were the first ever collected on many ponds and project designers thought that continued annual Snapshots over a number of years would provide a good sense of the variability of water column conditions in each pond at relatively low cost. It was also anticipated that data would eventually be useful in pond assessments and development of pond management plans.

Aside from PALS, other pond data was also collected with varying frequency, but sampling procedures generally followed PALS protocols so varying data sources could be compared. During 2003-2005, volunteers collected samples throughout the summer for many of the ponds under a grant from Cape Cod National Seashore (CCNS/NPS). In 2007, available pond data was organized and reviewed in the Orleans Ponds Report and it was recommended that the town collect April samples to provide better context for the PALS results each year.[4] Following the

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[1] Review of water quality data completed during this project has confirmed that a number of the ponds originally identified are brackish or have become more saline during the course of citizen monitoring since 2000.

[2] Baker Pond, Crystal Lake and Pilgrim Lake. Ponds greater than 10 acres are classified as Great Ponds under Massachusetts law and are generally subject to state regulatory requirements.

[3] All PALS Snapshot samples from 2001 to 2016 have been assayed at the CSP/SMAST Analytical Facility without cost to the Town to support local efforts at environmental management on Cape Cod.

[4] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. Cape Cod Commission. Barnstable, MA. 80 pp.

conclusion of the CCNS/NPS grant, town volunteers have collected both spring and late summer samples each year for selected ponds.

CSP/SMAST staff collected all available pond water quality data, including lab assay results from CSP/SMAST, CCNS/NPS, Center for Coastal Studies, and Barnstable County Department of Health and the Environment and results from available pre-PALS pond studies. This data was reviewed for the laboratory methods used, including detection limits and the reporting units (*e.g.*, milligram per liter versus micromolar concentrations). Accompanying field data was also collected. All data was organized and placed in a common format.

Once all data was organized, CSP/SMAST staff reviewed the data. Mean average concentrations for the various parameters were determined at shallow and deep depths with interim depths if these were available. Averages were also determined for spring (April to May 15) and summer (August to September) timeframes. At the same time as averages were developed, data was analyzed to remove statistical outliers. Data was also used to determine the frequency of results compared to Massachusetts Department of Environmental Protection surface water regulatory limits[5] (*e.g.*, dissolved oxygen concentrations, pH readings) and compared to Cape Cod Ecoregion thresholds (*e.g.*, total phosphorus, total nitrogen, chlorophyll, etc.). Statistical analysis was completed to determine if the average means by depth and season were significantly different. Trend analysis was also completed to determine if there were any statistically significant trends in the data between 2000 and 2016. The results of these analyses and their potential implication for pond functions are presented for each of the 18 ponds reviewed. Project staff also used this analysis to make recommendations for each individual pond regarding data gaps that should be addressed in order to formulate reliable management strategies.

In general, the data review led to some general conclusions about the water quality status and characteristics of Orleans ponds:

a. All of the monitored ponds are impaired based on their comparisons to the state regulatory standards and the Cape Cod Ecoregion thresholds.
b. Each pond is unique based a host of factors, including the water quality results, their relationship to the standards and thresholds, watershed setting, hydrology, surrounding development, area, volume, and depth.
c. Each pond has similar data gaps. The reviews in this report are focused on the water column measurements and samples collected by volunteers. These help to provide insights into the biological functions within each pond ecosystem, but further context is necessary to understand which management tools are most appropriate and how best to apply them.. This further context should be addressed through data gap surveys primarily focused on sediment core collection and incubation, continuous recording of water quality parameters, characterization of the plant community in the pond (both phytoplankton and rooted plants) and stormwater flows and nutrient loads.
d. Pond water quality management will require a pond-by-pond approach. The unique nature of each pond will mean the set of management options to address pond impairments will vary based on the individual characteristics of the pond, its structure, hydrology and watershed.

Recommendations regarding future pond water quality monitoring are also included.

[5] 314 CMR 4.00 (CMR = Code of Massachusetts Regulations)

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Appendices

Town of Orleans Freshwater Ponds
Water Quality Monitoring Database Development and Review

APPENDIX A: Water Quality Laboratory Information: Information on detection limits for the four laboratories with data in the Orleans Ponds Water Quality Database

APPENDIX B: Pond Water Quality Graphs: Graphs of Orleans Ponds Water Quality Database compared to MassDEP regulatory limits and Cape Cod Ecoregion thresholds.

I. Introduction

The Town of Orleans has numerous ponds and lakes scattered throughout the town. According to the Cape Cod Pond and Lake Atlas, Orleans has 63 ponds covering a total area of 220 acres (Eichner and others, 2003).[6] Of these ponds, 25 are greater than one acre and three are greater than 10 acres.[7] Since citizen water quality monitoring was initiated in Orleans in 2000, local advocacy for pond water quality has grown and volunteer monitoring has been sustained with many ponds having more than 15 years' worth of water quality data. As this data has been collected, local concerns about algal blooms, fish kills, and impacts of changing land uses have all been raised and nascent discussions have begun about how to develop pond management strategies. In 2015, the Town began the process of integrating pond management into an overall strategy to comprehensively address water quality management throughout the town. This report summarizes the results of organizing available pond water quality data and how this data can be used as guidance for prioritizing individual pond management efforts and as part of individual pond assessments.

Assessment and management of Cape Cod pond resources has evolved slowly, but has recently become more focused as federal, state, and local water quality protection interests have begun to converge. Any ponds greater than 10 acres are classified as "Great Ponds" under Massachusetts law and are publicly-owned waters.[8] This concept was developed prior to the creation of the United States, during the governance of the Massachusetts Bay Colony.[9] Federal laws protecting surface water quality were reaffirmed and strengthened in 1972 with the passage of the Clean Water Act.[10] The Clean Water Act created provisions linking state laws and regulations with water quality assessments. A key provision in the Act was the concept of determining acceptable contaminant loads, otherwise known as Total Maximum Daily Loads (TMDLs), for surface waters that are not attaining state water quality standards. The Act states that these waters shall be classified as "impaired" and all impaired water bodies must have a TMDL for each contaminant causing impairment.

In 1988, residents of all 15 towns on Cape Cod approved the creation of the Cape Cod Commission, which eventually led to the creation of a regional integrated water quality management strategy that included all water resources including fresh ponds and lakes.[11] In 2000, Cape Cod pond resources moved closer to a regionally-coordinated assessment and management approach with the creation of the Cape Cod Pond and Lake Stewards (PALS) program. PALS activities included the production of the Cape Cod Pond and Lake Atlas, which contained the first complete list of all ponds on Cape Cod (nearly 1,000 ponds), and the first PALS water quality snapshot.[12] The first PALS snapshot included volunteers from all 15 Cape

[6] Review of water quality data completed during this project has confirmed that a number of the ponds originally identified are brackish or have become more saline during the course of citizen monitoring since 2000.

[7] Baker Pond, Crystal Lake and Pilgrim Lake

[8] MGL c. 91 § 35

[9] Heather J. Wilson, The Public Trust Doctrine in Massachusetts Land Law, 11 B.C. Envtl. Aff. L. Rev. 839 (1984), http://lawdigitalcommons.bc.edu/ealr/vol11/iss4/6

[10] 33 U.S.C. §1251 *et seq*.

[11] Eichner, EM. 1993. Watershed protection: A Cape Cod perspective on national efforts. *Environmental Science and Technology* 27, no. 9: 1736—1740.

[12] 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.

Cod towns and the collection of over 400 water quality samples from more than 190 ponds. The Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) provided logistical, laboratory analysis and project management services at no cost to the towns or volunteers and the results were used in the Cape Cod Pond and Lake Atlas to complete a regional overview of pond and lake water quality. For most of these ponds and lakes, this was the first water quality measurements ever collected. CSP/SMAST has continued the PALS Program to date and has provided the needed services for every PALS Snapshot since 2001 (over 15 years). Many of the Cape towns, including Orleans, have used this data and the volunteer network to begin to look at the water quality in their ponds, including securing funding to review the data and provide the town and volunteers with feedback on the results and, in some cases, used the data to identify data gaps that need to be filled in order to fully understand the pond health and functioning (*e.g.*, watershed delineations, sediment measurements, plant surveys, etc.) and provide a reliable basis for the development and implementation of water quality management strategies for individual ponds.

The Town of Orleans last completed a review of town-wide pond water quality nearly 10 years ago.[13] Aside from reviewing 2001-2005 data for all the ponds, this 2007 Orleans Ponds Report also included more refined data review and synthesis, identification of data gaps, and potential management steps for five ponds selected by the Town from among the 18 ponds with monitoring data. The more refined data reviews completed for the five selected ponds included delineation of watersheds, development of water budgets, and phosphorus budgets. These preliminary steps toward development of management strategies provided analysis of the conditions of the ponds and which data gaps were major roadblocks for development of management strategies and goals.

The 2007 Ponds Report also included Town-wide recommendations to adjust monitoring strategies (*e.g.*, include an early spring sampling paired with continued August/September PALS snapshots) and noted that targeted data surveys were likely to be necessary to complete reliable management strategies. Among the targeted data surveys identified at the time were understanding sediment nutrient concentrations, stormwater nutrient loads, and stream inputs and outputs for ponds with these features.

This current report expands on the 2007 report and documents the collection, organization, and review of all the available Orleans Ponds water quality data collected between 2001 and 2016. All PALS Snapshot results and any available supplementary data were synthesized, including all data collected since the 2007 Ponds Report. This current review has allowed CSP/SMAST project team to prepare a unified database of all the available pond data and use this database to provide a better understanding of functions within the 18 ponds regularly monitored, whether the data indicates any significant trends, and how the data should be supplemented and used to develop future management strategies.

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[13] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. Cape Cod Commission. Barnstable, MA. 80 pp.

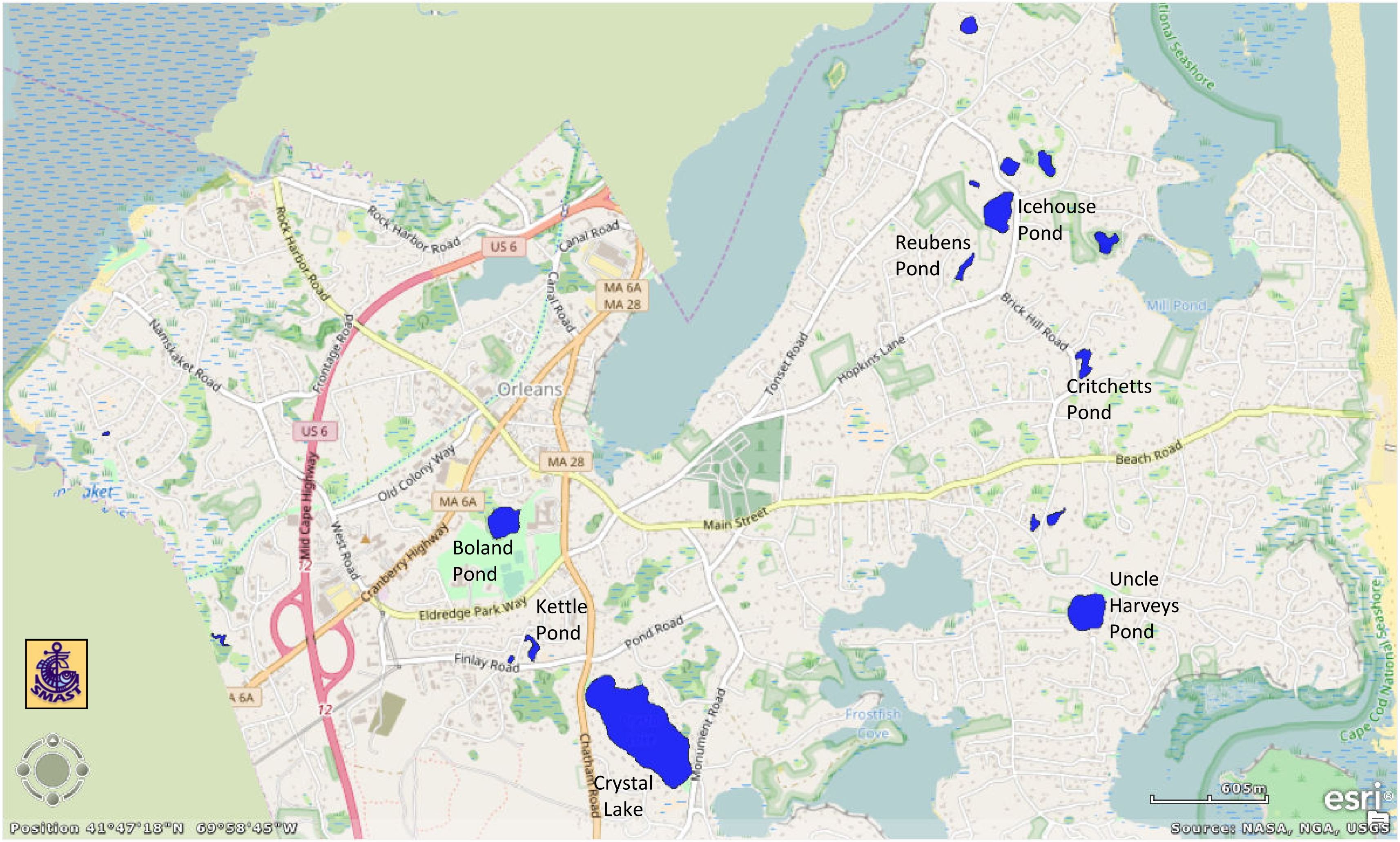

Figure I-1 (north). Orleans Ponds reviewed from water quality database

Data from 2000 to 2016 was reviewed for 18 ponds. Orleans has a total of 63 ponds, most of which are small, within the town boundaries. Ponds regularly monitored with data reviewed in this report are named above. Pond delineations based on MassDEP 1: 12000 wetland coverage (http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/depwetlands112000.html).

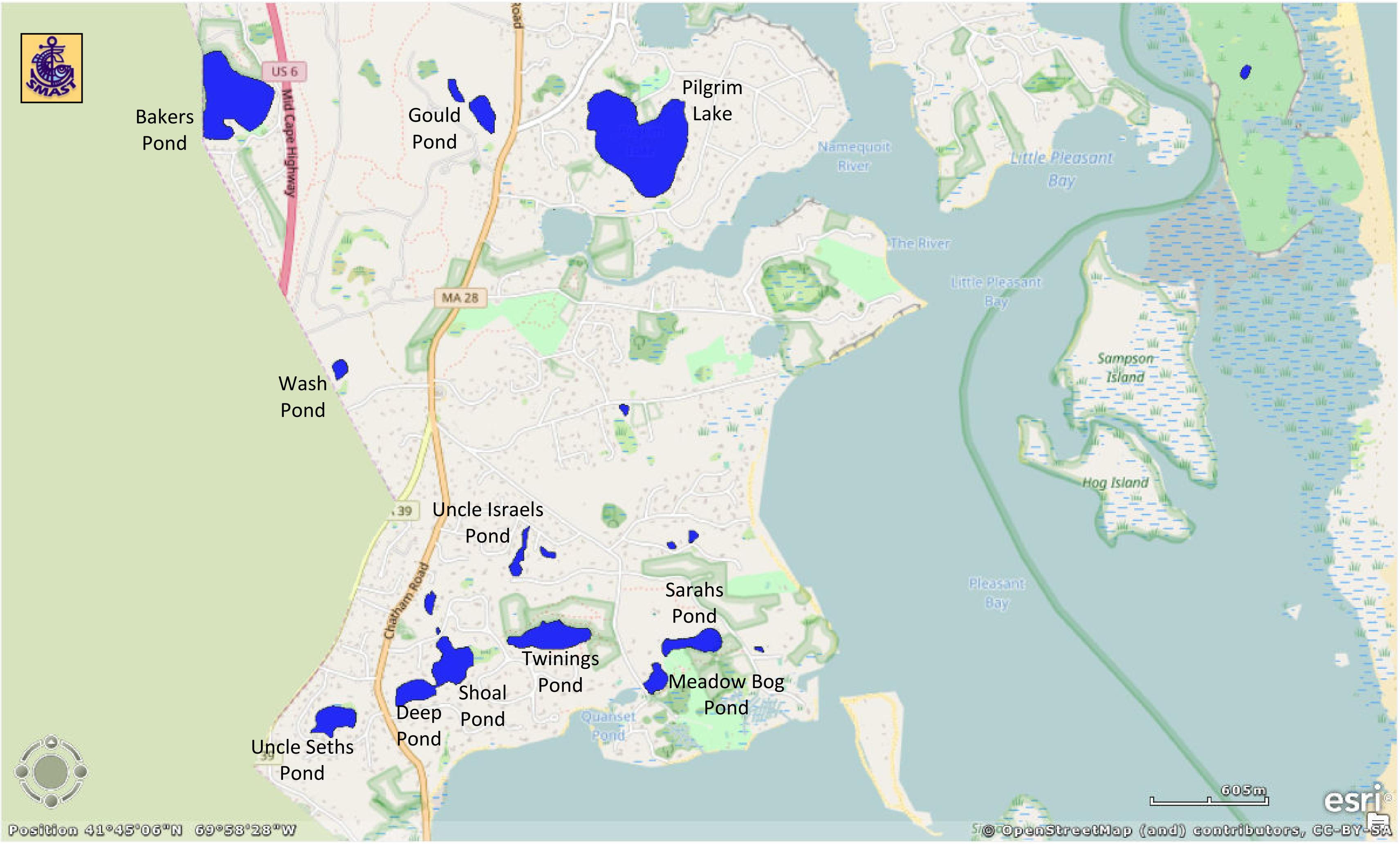

Figure I-1 (south). Orleans Ponds reviewed from water quality database
Data from 2000 to 2016 was reviewed for 18 ponds. Orleans has a total of 63 ponds, most of which are small, within the town boundaries. Ponds regularly monitored with data reviewed in this report are named above. Pond delineations based on MassDEP 1: 12000 wetland coverage (http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/depwetlands112000.html).

II. Pond Data Sources

Project staff have collected and organized available pond water quality data (Table II-1). Available datasets included PALS Snapshot data from 2001 to 2015[14], pre-PALS pond data from studies completed on Baker, Crystal and Pilgrim, selected profile data from 1948, and data from town-funded collection of April/May water quality samples. The available data includes results from four different laboratories: 1) CSP/SMAST Analytical Facility, 2) Barnstable County Department of Health and the Environment Laboratory (BCHDE), 3) National Park Service North Atlantic Coastal Laboratory at Cape Cod National Seashore (CCNS/NPS), and 4) Center for Coastal Studies laboratory (CCS). Sampling protocols since the creation of PALS in 2001 have generally followed PALS protocols regardless of the lab utilized for analysis of water quality samples.

All PALS Snapshot samples between 2001 and 2015 were assayed at the CSP/SMAST Analytical Facility using the same procedures each year. April/May samples were assayed at the CCNS/NPS lab between 2005 and 2011[15] and were assayed at the CCS lab from 2013 to 2016 (samples were not assayed in 2012). There is also a dataset of samples that were generally collected between May and October for selected ponds during the years 2002 and 2003; these were assayed at the CCNS/NPS lab under grant funding. Samples were also collected from Baker, Crystal and Pilgrim in 2000 and 2001 under grant projects and were generally assayed at the BCDHE lab.

Table II-1. Available Orleans Pond data included in 2016 CSP/SMAST database development.

year	Separate studies	PALS	April/May	CCNSS
1948	X			
1980	X			
2000	X			
2001	X	X		
2002		X		X
2003		X		X
2004		X		
2005		X	X	
2006		X	X	
2007		X	X	
2008		X	X	
2009		X	X	
2010		X	X	
2011		X	X	
2012		X	X	
2013		X	X	
2014		X	X	
2015		X	X	
2016		X	X	

Notes: April/May samples were assayed at CCNSS/NPS until 2011 and then at CCS from 2013 to present. All PALS samples were assayed at CSP/SMAST.

Water quality samples analyzed at the CSP/SMAST Analytical Facility used analysis and sampling procedures in the MassDEP-approved SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (2003). These procedures utilized consistent detection limits, have been used for all 16 years of PALS Snapshot samples, and include analysis of the following parameters: total nitrogen, total phosphorus,

[14] 2016 PALS water samples were collected, but assay results were not available. Field data (e.g. profiles and transparency) are included in the unified database.

[15] Selected ponds had spring samples in 2003, but none in 2004.

chlorophyll-*a*, pH, and alkalinity. CSP/SMAST Detection limits and methods are listed in **Appendix A**.

BCDHE assays were completed in 2000 and 2001 for MassDEM-funded studies of Baker Pond[16] and Baker Pond, Crystal Lake and Pilgrim Lake (the 3 Pond Study),[17] as well as 1981/1982 samples for a limited study of algal blooms in Crystal Lake.[18] The initial assays completed in the 3 Pond Study utilized total phosphorus detection limits that were much too high for pond analyses (50 µg/L TP) and laboratory adjustments were completed during the Baker Pond assays (TP detection limit reduced to 5 µg/L). Pond water quality assays completed by BCDHE generally had the following parameters: pH, chloride, ortho-phosphorus, total phosphorus, sulfate, ammonium, nitrate-nitrogen, total Kjeldahl nitrogen, calcium, magnesium, potassium, sodium, and total organic carbon. The BCDHE laboratory is state-certified to test drinking water, bacterial analytes for bathing beaches, groundwater and wastewater (no separate state-certification exists for surface water assays). Laboratory assays followed USEPA, MassDEP and APHA/AWWA/WEF[19] standard methods; BCHDE detection limits and methods used in the Orleans Ponds dataset are listed in **Appendix A**.

As mentioned, CCNS/NPS completed assays for samples collected during April/May until 2011, but also completed analyses during 2001 for the Baker Pond study and the 3 Pond study. Assays completed during the two 2001 studies and for the town in 2003 and 2005 included some summer samples collected on the same day as PALS samples that were analyzed at the CSP/SMAST Analytical Facility. Spring pond water quality assays completed by CCNS/NPS generally had the following parameters: ortho-phosphorus, total phosphorus, ammonium, nitrate-nitrogen, and total nitrogen, while chlorophyll was occasionally included and the 2001 study assays included other parameters in the BCDHE list. The CCNS/NPS lab is largely dedicated to assessments completed by CCNS staff and visiting researchers. CCNS/NPS laboratory assay methods and detection limits used in the Orleans Ponds dataset are listed in **Appendix A**.

CCS completed assays on April/May samples from Orleans Ponds beginning in 2013. CCS has not completed analysis of any pond samples during other portions of the year. Spring pond water quality assays completed by CCS had the following parameters: ortho-phosphorus, total phosphorus, ammonium, nitrate-nitrogen, and total nitrogen. CCS laboratory assay methods and detection limits used in the Orleans Ponds dataset are listed in **Appendix A**.

In assembling the pond water quality database, project staff reviewed the various laboratory methods used and associated detection limits and whether duplicate field samples were collected. Standard practice in reviewing water quality data is to assign results that are below detection limits half of the detection limit value. Since detection limits are largely determined by the lab

[16] Eichner, E.M., J. Scanlon, G. Heufelder, and J. Wood. 2001. Baker Pond Water Quality Assessment. Prepared for Town of Orleans and Massachusetts Department of Environmental Protection. Cape Cod Commission. Barnstable, MA.

[17] Scanlon, J. and G. Meservey. 2001. 3 Ponds Study, Orleans, MA. Crystal Lake, Pilgrim Lake, Baker's Pond.

[18] Mello, M.J. 1982. Investigation of Bloom Conditions of *Aphanizomenon flos-aquae* in Crystal Lake with Recommendations for its Prevention. Provincetown Center for Coastal Studies.

[19] American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Environment Federation (WEF) jointly publish a list of water and wastewater analysis techniques called *Standard Methods for the Examination of Water and Wastewater.*

methods used for assays, an understanding of laboratory procedures are important for understanding the resulting water quality reporting. Duplicate field samples are a standard quality assurance/quality control (QA/QC) procedure to review field variability; the PALS Snapshot sampling procedures have duplicate collection built into the overall approach: all ponds less than a meter deep are supposed to have two samples collected just below the surface. Sampling procedures were never put in place for direct comparison of results between laboratories (*e.g.*, split samples).

Duplicate samples sample analysis was available for samples assayed by CSP/SMAST, BCDHE, and CCNS/NPS. Because duplicate samples are built into the PALS procedures, duplicate comparisons are most extensively available for CSP/SMAST assays (n=61 to 64 depending on the parameter). BCDHE duplicates are limited to samples collected during 2000-2001 (n=14 to 28 depending on the parameter) and CCNS/NPS assays are limited to four duplicate samples. No duplicates are available for the CCS assays. CSP/SMAST duplicate comparisons generally had excellent agreement among duplicates for all parameters (*i.e.*, correlation coefficients >90%) except phaeophytin (chlorophyll and phaeophytin assays tend to be more variable). BCDHE only had sufficient assay results for comparison of pH, sulfate and chloride; pH and sulfate had correlation coefficients >90%, while chloride was 39%. Reliable comparisons of various BCDHE nitrogen and phosphorus results were not possible because most of the analyses were below detection limits. Duplicate comparisons of CCNS/NPS samples were not completed because of the limited number of duplicates.

Organization of the available data found that the variety of datasets needed to be brought into a consistent format in a number of ways. Among the predominant issues addressed were: a) column order was often different from year to year (even at the same lab), b) reporting units for the same parameter differed between the labs, c) non-PALS datasets stored profile and lab results separately, and d) pond names often differed from year to year (*e.g.*, “Uncle Harvey’s Pond” vs. “Uncle Harvey’s” vs. “Uncle Harveys” vs. “'UncHrvy's”). In addition, during the assembly of the unified database, some data input errors were found and corrected, including: data transpositions (*e.g.*, dissolved oxygen and temperature profiles transposed) and incorrect input values (these were corrected from original datasheets). Additional corrections were found during the statistical reviews of the data and incorporated into the unified database. All available data was brought into a consistent format for later review and analysis.

Collection, handling and transport of samples generally followed PALS Snapshot protocols. PALS protocols call for collection of samples based on the depth of the pond at the sampling station. PALS protocols require each pond to have a minimum of two samples collected. Shallow ponds less than 1.5 m deep have two samples collected just below the surface (0.5 m depth). Ponds up to 9 m deep have a shallow sample collected at 0.5 m depth and a deep sample 1 m above the bottom. Ponds greater than 10 m deep have four samples collected: 0.5 m, 3 m, 9 m, and one meter above the bottom. Water samples are collected as whole water, stored at 4°C, and transferred to the CSP/SMAST lab and processed within 24 hours.[20] In addition to the collection of water samples, measurements of dissolved oxygen (DO), temperature, clarity/Secchi depth, and station depth are recorded. Temperature and DO profiles are generally recorded at 1 m increments after the 0.5 m measurement (*i.e.*, recorded at 0.5 m, 1 m, 2 m, etc.).

[20] Some of the CCNS/NPS and CCS sampling involved freezing of samples.

Profile recordings in ponds shallower than 3 m are recommended at 0.5 m increments. Volunteers are trained/briefed by local PALS "captains" that have been trained in sampling techniques and have PALS Snapshot experience. These PALS captains organize the town volunteers, oversee sharing of equipment, ensure timely transfer of samples, etc.; in Orleans, the Marine and Fresh Water Quality Task Force worked to ensure volunteers followed PALS sampling protocols.

The PALS Snapshot was designed to collect samples during the period when water quality is likely to be at its worst (*i.e.*, between August 15 and the end of September). This period was initially targeted as a way to find out which of the ponds were most likely to have impaired water quality and use that information to guide collection of more refined supplementary data and prioritize the development of management options. The PALS field sampling strategies have been used by Orleans volunteers and those in other towns to conduct sampling outside of the PALS Snapshot period to develop expanded summer-long results or sampling during April/May to evaluate seasonal changes. The April/May sampling was recommended in the 2007 Orleans Pond Report as a next step in volunteer pond monitoring to provide a better context for the late summer PALS sampling results and, over time, a sense whether conditions during the PALS Snapshots occur throughout the summer or develop later. Use of consistent PALS sampling protocols throughout all these samplings has allowed all the data to be compared regardless of the season when it was collected.

III. Review of Individual Ponds

CSP/SMAST staff was also tasked with reviewing the gathered pond data once it was all organized in the water quality database. The review was to focus on comparison of the data to available MassDEP regulatory surface water standards[21] (*e.g.*, the state regulatory basis for whether a water body is classified as impaired) and ecoregion guidance levels established for Cape Cod ponds.[22] Staff was also asked to evaluate any trends in the gathered data to see if factors had significantly changed over the past 15-17 years.

In order to complete these comparisons, staff reviewed the datasets to identify any potential data outliers. Outliers were identified as sample results two standard deviations greater than or less than the mean average. Outliers were generally infrequent with one or two samples identified per dataset/analyte. These exceptionally high or exceptionally low results could be due to a number of sampling[23] or ecosystem[24] conditions and could be included in future standard deviation ranges as more data is collected. Staff reviews included determination of mean averages by season (*e.g.*, Spring vs. Summer) and depth (*e.g.*, shallow vs. deep). Data from all labs were included in these reviews, though in all cases PALS August/September data tended to be the predominant source for the overall dataset. During the course of the outlier review, additional mistakes in underlying dataset were found and corrected.

Statistical comparisons (t-tests) of shallow and deep mean averages and seasonal mean averages (April/May/Spring and August/September/Summer) were completed. Datapoints identified as

[21] 314 CMR 4.00 (CMR = Code of Massachusetts Regulations)

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

[23] *e.g.*, inadvertent collection of suspended sediments after tapping the bottom in a deep sample

[24] *e.g.*, algal bloom

outliers in seasonal or depth analyses were retained in calculations if other seasons or different groupings of similar data (*e.g*., all shallow data vs. shallow summer data) showed the datapoint was not an outlier. This relatively inclusive approach was retained in order to maximize power for the statistical and trend analyses. T-test comparisons of averages were identified as significantly different at the $\rho<0.05$ level (*i.e.*, there is a less than 5% chance that the averages of the two datasets are the same).

Trend analysis was also completed based on the 2001-2016 dataset for each pond. Trend analysis generally was based on linear analysis of trends, although if indicated, some trend analyses were also completed based on seasonal (*e.g.*, summer only) or specific depth (*e.g.*, only surface readings) groups. Trend analysis was generally initiated only for those r-squared relationships greater than 20% ($r^2>0.20$ means that the change of time explains more than 20% of the variation in the water quality parameter). Statistically significant trends were identified if a F-statistic had a significance level of $\rho<0.05$ (*i.e.*, there is a less than 5% chance that the parameter is not increasing or decreasing with time).

Review of the individual pond datasets also included comparisons to available numeric Massachusetts Department of Environmental Protection (MassDEP) surface water regulatory standards and Cape Cod-specific ecoregion guidelines previously developed from PALS data.[25] Graphs of dissolved oxygen, temperature, chlorophyll, total phosphorus, and total nitrogen at shallow and deep depths are included in **Appendix B** for each pond. Discussion of the data results also includes recommendations for subsequent targeted data collection to support management decisions and develop pond-specific management strategies.

Massachusetts maintains regulatory standards for all of its surface waters.[26] These regulations include numeric standards for dissolved oxygen, pH, temperature, and bacteria, as well as descriptive standards for various classes of waters that largely depend on their use. For example, Class A waters are used for drinking water 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."[27] Further distinctions are made between warm and cold water fisheries.

Class B waters, which are generally freshwater ponds that are not used for drinking water supplies, must meet the following numeric standards:

a) dissolved oxygen shall not be less than 5.0 mg/L (6.0 mg/L minimum in cold water fisheries),
b) temperature shall not exceed 83°F (28.3°C) (20°C maximum for cold water fisheries),
c) pH shall be in the range of 6.5 to 8.3, and
d) *E. coli* bacteria shall not exceed 235 colonies per 100 ml at bathing beaches (with variations available for multiple samples).

[25] Cape Cod-specific pond water quality guideline concentrations were developed using the results of the first PALS Snapshot and are included in the Cape Cod Pond and Lake Atlas (Eichner and others, 2003).
[26] 314 CMR 4.00 (CMR = Code of Massachusetts Regulations)
[27] 314 CMR 4.05(3)(a)

The descriptive standards for Class B waters are "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."[28] Measurements outside of these ranges may be acceptable if it is adequately documented that the measurements are "natural."

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.[29] 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 updated and approved by the Environmental Protection Agency (EPA) ever two years. This Integrated List is supposed to list all waters in the state and their status, including whether their water quality has been assessed and whether they have been judged impaired. The latest list from Massachusetts was the 2014 list and it included the listing of all three Orleans Great Ponds (Baker, Crystal, and Pilgrim), but none of the other smaller ponds.[30] Crystal Lake is the only one of the ponds listed on MassDEP's list that is currently required to have a TMDL; Baker Pond is classified as having a TMDL completed for mercury in fish tissue and Pilgrim Lake is classified as having "no uses assessed."

Since low dissolved oxygen conditions are more of a terminal impairment (*i.e.*, reflective of many years of excessive nutrient inputs), scientists and water quality managers have been focusing for a number of years on defining acceptable pond and lake nutrient and other water quality thresholds that would prevent ponds from attaining low dissolved oxygen impairments. During the preparation of the Cape Cod Pond and Lake Atlas, project staff utilized the 2001 PALS results to begin this process for Cape Cod ponds and lakes. Project staff used the PALS results to determine ecoregion-specific thresholds for total phosphorus, total nitrogen, chlorophyll and pH.[31] At the time, 2001 PALS database was the most comprehensive Cape Cod pond water quality database and included water quality data from 195 Cape Cod ponds and lakes. Using this database, project staff determined the following ecoregion-specific pond water quality thresholds: a) total phosphorus 10 µg/L, b) total nitrogen 0.31 mg/L, c) chlorophyll 1.7 µg/L, and pH 5.62. For the purposes of reviewing Orleans pond and lake water quality data, project staff noted the number of readings exceeding these Cape Cod-specific factors for TP, TN, and chlorophyll (pH was not used since MassDEP regulatory limits have a pH limit). Project staff also reviewed the number of readings less than MassDEP regulatory limits for dissolved oxygen and pH.

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[28] 314 CMR 4.05(3)(b)

[29] 40 CFR 130.7 (CFR = Code of Federal Regulations)

[30] Massachusetts Department of Environmental Protection. December 2015. Massachusetts Year 2014 Integrated List of Waters, Final Listing.

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

III.A. Bakers Pond

Bakers Pond (PALS# OR-167) is a 28-acre pond that is mostly in Orleans, but straddles the town line between Orleans and Brewster (see **Figure I-1**). It is the deepest of the Orleans fresh ponds and lakes. Review of historic 1943 and the current USGS quad maps do not show any hydroconnections to adjacent ponds or wetlands, including a small pond to the west, one to the east, and a fairly large wetland approximately 100 m to the north.. It is just west of Route 6 and approximately 0.8 km south of Route 6A. It is shared between the Town Cove and Pleasant Bay MEP[32] estuary watersheds, is also located within a designated Massachusetts Natural Heritage Priority Habitat, and the Town of Orleans Water Department Zone II (*e.g.*, wellhead protection area). Given that it has a surface area greater than 10 acres, it is classified as a Great Pond and is included in the most recent final MassDEP Integrated List.[33] This list classifies Bakers Pond as having a TMDL completed (for mercury in fish tissue), but does not list any other impairments.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling between 2002 and 2016, but regular spring sampling since 2013. Bakers was selected for additional assessment in the 2007 Orleans Ponds Report[34] and this assessment included a watershed delineation, determination of water and nutrient budgets, and a more detailed review of the available water quality data. It was noted in the 2007 report that there were 11 single family residences adjacent and upgradient of the pond and that the pond water residence time was just over 1 year. It was also noted that Bakers used to receive stormwater runoff from a significant portion of Route 6 with flow across the beach off Bakers Pond Road. Discussions with town volunteers have indicated that this flow has been eliminated; although the sediment delta is still evident in aerial photos. The Ponds Report also noted that pond water quality was largely determined by phosphorus inputs, that the pond thermally stratified during the summer, and that it had relatively healthy conditions, but also noted some water quality concerns that should be monitored, including occasional bottom anoxia.

Data in the Orleans Pond and Lake unified database found that the average depth at the Bakers Pond sampling station was 17.85 m (n=73), which was the deepest among the monitored ponds. Mean average Secchi transparency depth was 7.17 m (n=96) and 43% (n=72) of the total depth. Average total depth was significantly lower in the summer compared to the spring, but average seasonal Secchi depths were not significantly different. The station total depth had a significant increasing trend between 2001 and 2016, increasing +0.04 m per year. Secchi transparency also had a significant increasing trend over the same period with a higher rate (+0.15 m per year). Most of the increasing Secchi transparency trend was due to August Secchi readings, which are the most frequent Secchi readings (n=21) in the dataset, and these readings had a significant increasing trend of +0.27 m per year. September Secchi readings do not have a significant trend and other months readings are too sporadic for trend analysis. Combined April/May Secchi readings do not have a significant trend.

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[32] Massachusetts Estuaries Project (MEP) is a partnership project between towns, MassDEP and CSP/SMAST to assess the health of southeastern Massachusetts estuaries and set restoration targets for impaired basins and provide the foundation for MassDEP/USEPA TMDL development. To date 70 estuaries have been evaluated.

[33] Massachusetts Department of Environmental Protection. December 2015. Massachusetts Year 2014 Integrated List of Waters, Final Listing.

[34] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. pp. 36-42.

Comparison of data to MassDEP numeric standards show that deep summer conditions are generally impaired, the pond is naturally acidic, and it should be regarded as a cold water habitat for the purposes of the MassDEP regulations. Review of temperature readings showed that waters 10 m and deeper generally constitute a cold water habitat in Bakers Pond according to MassDEP temperature maximum (20°C[35]). Average dissolved oxygen concentrations throughout the water column are generally above the MassDEP cold water minimum of 6 mg/L except for deep waters (nearest the sediments) during the summer, which averaged 0.8 mg/L; all 41 summer deep concentration readings were below 6 mg/L (**Table III-1**). The shallowest DO reading less than 6 mg/L was at 10 m. In spring, 3 of the 20 recorded deep DO concentrations (15%) were less than 6 mg/L. Warmer summer conditions generally create lower DO concentrations: summer average DO concentrations at the surface, 3 m, 9 m, and deep were significantly lower than spring averages, while corresponding summer average temperatures were all significantly higher. All but 4 of the 118 pH readings (97%) are less than the MassDEP minimum of 6.5.

Based on previous bathymetry, the waters 10 m and deeper were approximately 11% of the total pond volume. Review of DO concentrations show that 71% of the cold water habitat summer readings were less than the MassDEP minimum. Review of individual DO profiles showed that there was generally a pronounced "bulge" of higher DO waters around 9 to 10 m depth; lower concentrations are generally measured above and below this depth. This type of mid-depth maxima generally occurs when phytoplankton congregate near a thermal transition layer where higher nutrient concentration exists below the layer due to sediment regeneration.

Review of DO readings showed increasing trends between 2000 and 2016. Surface, 3 m, 9 m and deep DO readings have significant increasing trends: annual average increases of +0.07 mg/L, +0.06 mg/L, +0.11 mg/L, and +0.20 mg/L, respectively. Review of temperature readings do not show any significant trends, but % saturation DO also showed significant increasing trends at similar depths, except for 3 m. The lack of significant temperature changes accompanying the DO increases suggest that there was a significant increase in photosynthesis in the water column, but additional data would be necessary to discern whether this is due to rooted plants or phytoplankton.

Review of nutrient data showed evidence of sediment nutrient regeneration, TP and TN trends, and more sensitivity to impairment by phosphorus than nitrogen. Overall mean average shallow TP concentrations and averages during both spring and summer were below the 10 µg/L Cape Cod Ecoregion threshold with occasional readings (10-20% of all readings) above the threshold. Shallow TN concentrations followed a similar pattern. Both TP and TN did not have significant differences in mean average concentrations at shallow, 3 m, or 9 m depths and there were no significant seasonal differences among these. The deepest mean averages, however, were significantly higher than the shallower mean averages during the summer, but not during the spring. Deep summer TP readings averaged 28.9 µg/L (76% of readings above the ecoregion threshold), while deep summer TN readings averaged 0.63 mg/L (90% of readings above the ecoregion threshold). Both summer deep mean averages were also significantly higher than spring deep averages. These summer increases indicate substantial sediment regeneration of

[35] MassDEP standards require a 7 day average of less than 20°C (314CMR4.05(b)2.), but that would require more refined monitoring than has been completed to date.

both nutrients, but also show that the increase tends to have an impact only in the cold water habitat.

N:P ratios showed water quality in Bakers Pond was controlled by phosphorus. Average overall ratios were approximately 7X the Redfield ratio threshold at all depths. Ratios were lower during the summer, which would be consistent with more phosphorus in the pond, but they were not significantly different from spring ratio mean averages. Trends for deep and 3 m N:P ratios both showed significant decreases, but ratios for surface and 9 m results did not have significant trends. Deep ratios had a decreasing trend of -12.8 per year, which would be consistent with the significant increase in deep TP concentrations (+1.26 µg/L per year). Shallow and 9 m TP concentrations did not have significant trends, but 3 m TP concentrations had a significant increasing trend (+0.66 µg/L per year). TN concentrations had a different trend pattern: shallow and deep concentrations had significant decreasing trends (-0.009 mg/L per year and -0.017 mg/L), but concentrations at 3 m and 9 m did not have significant trends. Further analysis of the data and insights from sediment core incubation and continuous water quality monitoring would help to clarify the likely sources of these trends and their implications for water quality management.

Chlorophyll and pH readings were generally only collected during the summer season through PALS snapshots, so seasonal comparisons were not available. As mentioned above, almost all (97%) the pH readings were below the MassDEP minimum of 6.5; mean average of all shallow readings was 6.23. These readings are consistent with most Cape Cod ponds and lakes, which tend to be acidic due to the general lack of carbonate aquifer materials. The mean average pH reading at 3 m was not statistically different from the shallow mean, but 9 m and deep mean averages were significantly lower than the shallower averages. This is also generally consistent with other Cape Cod ponds and lakes, where photosynthesis of both phytoplankton and rooted plants in the upper portions of the water column tend to raise shallower pH readings. Among the mean average chlorophyll concentrations, the highest mean was at 9 m (1.46 µg/L; n=22), which was near where the DO bulge generally occurred; this mean average concentration was significantly higher than the shallow mean average (0.77 µg/L; n=28). Overall, only 14% (13 of 94) of the individual chlorophyll concentrations exceeded the Cape Cod Ecoregion threshold of 1.7 µg/L.

Overall Assessment and Identified Data Gaps:

Bakers Pond is a Great Pond and, as such, its management will need to address both the Town's specific uses and resource quality objectives and those of MassDEP, including any regulatory requirements. Surface water quality conditions generally show low impacts with average concentrations below Cape Cod Ecoregion thresholds, but deeper waters show signs of excessive nutrients and impairment of cold water habitat dissolved oxygen concentrations especially during summer months. Based on the extent of these impairments, Bakers Pond will eventually require a TMDL for low dissolved concentrations and development of management options to reduce phosphorus regeneration from the sediments. These efforts can be addressed through the development of a Bakers Pond Management Plan.

Preparation of a management plan will require addressing data gaps in order to provide proper context for the available water quality data and to prepare reliable management options.

Currently identified data gaps include continuous monitoring using an automated device to evaluate conditions that create the DO bulge around 9 m and the deep hypoxic conditions, collection and incubation of sediment cores to determine both potential nutrient regeneration and conditions that trigger regeneration, a survey of plant communities (both rooted macrophytes and phytoplankton) to determine the extent of their role in creating the measured water quality data, stormwater monitoring of any direct discharges to measure their contribution to the overall nutrient loading, and a freshwater mussel survey given the endangered species classification of some mussels and how their sediment habitat is likely to be a crucial management area in an overall water quality management plan. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or nearby residents. Once data gaps are adequately addressed, the Town should consider development of a Bakers Pond Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating effectiveness of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Bakers Pond because the impairments measured in the pond occur in the summer. Sampling in Bakers Pond in April and August/September should continue to follow PALS protocols.

Table III-1. Bakers Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	17.85			18.07		17.78		<	
N	73			16		32			
Max	18.60			18.60		18.30			
Min	16.83			17.28		16.88			
Secchi Depth									
Average (m)	7.17			7.25		7.12			
N	96			19		38			
Max	10.43			10.39		9.92			
Min	3.27			3.30		3.27			
Temperature: MassDEP Cold Water Maximum = 20°C									
Average (°C)	15.27	20.42	8.97	14.86	7.62	24.01	9.33	>	>
N	1696	95	108	19	20	37	41		
Max	27.00	27.00	14.44	20.50	11.87	27.00	10.60		
Min	4.43	8.80	4.43	10.60	6.10	19.80	8.20		
Dissolved Oxygen: MassDEP Regulatory Minimum = 6 mg/L									
Average (mg/L)	7.88	8.83	3.41	10.53	8.80	7.87	0.80	<	<
N	1690	95	108	19	20	37	41		
Max	14.05	11.75	11.87	11.75	11.87	9.81	4.13		
Min	0.05	6.90	0.07	9.08	2.13	6.92	0.08		
N < 6 mg/L DO	339	0	78	0	3	0	41		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.12	6.23	5.98	6.34	5.86	6.19	5.99		
N	118	35	31	1	1	25	23		
N < 6.5 pH	114	32	31	1	1	25	23		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	1.04	0.77	0.79	0.53		0.87	0.79		
N	94	28	19	2	0	21	19		
Max	10.60	2.28	10.60	1.05		2.28	10.60		
Min	0.00	0.00	0.03	0.01		0.00	0.03		
N > 1.7 µg/L	13	2	2	0		2	2		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	10.21	6.49	18.85	7.72	11.05	5.60	28.90		>
N	230	61	60	12	12	28	59		
Max	70.92	41.20	70.92	41.20	41.40	15.99	70.92		
Min	0.50	0.50	0.50	2.50	4.94	0.77	2.50		
N > 10 µg/L	66	13	32	2	3	4	22		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.31	0.25	0.51	0.22	0.28	0.25	0.63		>
N	225	62	58	11	11	30	30		
Max	1.26	0.68	1.26	0.67	0.81	0.61	1.26		
Min	0.03	0.06	0.07	0.06	0.07	0.12	0.29		
N > 0.32 mg/L	63	10	41	2	3	3	27		

III.B. Boland Pond

Boland Pond (PALS# OR-136) is a relatively small pond that is located to the east of Route 6A, south of Route 28 and north of Eldridge Parkway (see **Figure I-1**). Nauset Middle School is directly to the east of the pond with ballfields of Orleans Elementary School to the south and within its watershed. It is within the Town Cove portion of the MEP Nauset estuary watershed. Review of both a historic 1944 and the current USGS quad maps show no hydroconnections to nearby ponds or Town Cove. Review of historic aerial photos showed that the pond surface area has varied between approximately 5 and 8 acres depending on the elevation of surrounding groundwater.[36] Given that its area is less than 10 acres, it is not considered a public pond under Massachusetts law and is not included in the latest MassDEP Integrated List.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling between 2002 and 2016. Boland was selected for additional assessment in the 2007 Orleans Ponds Report.[37] The additional assessment in 2007 included a watershed delineation, determination of water and nutrient budgets, and a more detailed review of the available water quality data. The report noted a large commercial septic system and only one house upgradient and within 300 ft of the pond. The water residence time was estimated at approximately 4 months. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including total phosphorus concentrations more than three times the Cape Cod Ecoregion threshold and anoxia in its deeper waters. The report also noted a number of data gaps, including stormwater runoff, and suggested that the town consider development of a management plan to evaluate options to address the impairments.

Data in the Orleans Pond and Lake database completed for this project found that the average depth at the Boland Pond sampling station was 5.71 m (n=51). Mean average Secchi transparency depth was 1.52 m (n=49) and 27% (n=52) of the total depth. Mean average total depth was significantly lower in the summer (5.55 m; n=21) compared to the spring (5.95 m; n=13), but mean average seasonal Secchi depths and % Secchi readings were not significantly different. No significant trends were noted in Secchi depth, total depth or % Secchi depth readings between 2001 and 2016.

Review of temperature data in Boland Pond show that the temperature regime is somewhat novel for a shallow pond. Typically shallow ponds have only a slight decrease in temperature with increasing depth; this temperature regime allow the entire water column to be regularly mixed by the typical winds seen on Cape Cod. Deep water in Boland Pond (3.5 to 5 m deep) during both spring and summer had mean average temperatures more than 10°C colder (and statistically colder) than corresponding surface mean averages (**Table III-2**). The summer mean average was 9.36°C (n=21), which is less than the MassDEP cold water fishery regulatory maximum of 20°C. Since this temperature regime appears to be regularly sustained, Boland Pond monitoring results were compared to the MassDEP cold water fishery standards.

Comparison of data to MassDEP numeric standards show that deep DO conditions were consistently impaired and the pond is naturally acidic. Mean average deep DO concentrations

[36] Based on a review of available Google Earth aerial photographs.

[37] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. pp. 36-42.

during both the summer and the spring were less than the MassDEP cold water minimum with the summer average (0.20 mg/L; n=21) significantly less than the spring mean average (3.26 mg/L; n=15). Shallow DO concentrations were consistently above the MassDEP minimum (only 3 of 53 shallow readings were less than 6 mg/L) and had significantly higher mean averages than deep means during both spring and summer. Percent saturation (% Sat) readings, which remove temperature impacts on DO, had similar relationships; mean average deep summer % Sat was only 2% of atmospheric equilibrium. Mean average pH readings at both shallow and deep depths were less than the MassDEP minimum of 6.5; only 1 of 34 readings (3%) was above 6.5. No significant trends were found for DO, temperature, or pH.

Review of nutrient data showed excessive nutrient concentrations, evidence of sediment nutrient regeneration and enhancement of regeneration during the summer. Mean average shallow TP concentrations during both spring and summer were well above the 10 µg/L Cape Cod Ecoregion threshold with averages of 31.6 µg/L (n=10) and 37.2 µg/L (n=23), respectively, but they were not significantly different. Deep readings, however, showed the significant impact of summer sediment regeneration; mean average spring deep TP concentration was 64.8 µg/L (n=10), while the corresponding summer mean average was 196.8 µg/L (n=20). Mean average TN concentrations also showed significant summer deep TN increases (spring 0.62 mg/L; summer 1.12 mg/L), but also had a significant shallow increase between spring and summer mean averages (spring 0.49 mg/L; summer 0.74 mg/L). These differences suggest that sediment regeneration is important in determining water column nutrient concentrations, but the increase in TN, but not TP, during the summer suggests there is also a change in watershed inputs. More refined and updated evaluation of potential watershed sources should be considered as a data gap to be addressed if the Town choses to pursue development of a Boland Pond Management Plan. The nutrient data also reinforces that collection and incubation of sediment cores with associated continuous monitoring of dissolved oxygen and temperature should also be a data gap that is addressed to provide additional context for how low oxygen conditions develop, are sustained, and what conditions lead to regeneration of nutrients and measure the maximum potential nutrient releases. No significant trends were noted in the TP and TN concentrations between 2001 and 2016.

N:P ratios showed that the pond is most sensitive to phosphorus additions, but sediment regeneration has created lower ratios in the deepest waters. Shallow N:P ratios were generally 3X the Redfield threshold, which is generally consistent with shallow Cape Cod ponds; mean average shallow ratio was 48.7 (n=42). However, the sediment TP regeneration resulted in a significantly lower deep mean average ratio (23.2; n=38). Spring and summer shallow and deep mean average ratios were not significantly different, but the deep summer mean average was at the Redfield threshold (16.6 mean, n=21). This analysis reinforces the need to better characterize the sediments and conditions that lead to nutrient regeneration. No significant trends were noted in the N:P ratios data between 2001 and 2016.

Chlorophyll and pH readings were only collected during the summer; so seasonal comparisons to spring data were not available. As mentioned above, almost all (97%) the pH readings were below the MassDEP minimum of 6.5; mean average of all shallow readings was 6.26. The deep average was significantly lower at 6.15. These naturally acidic readings were consistent with most Cape Cod ponds. Deep chlorophyll mean average concentration was significantly higher than surface average [47.7 µg/L (n = 18) and 10.2 µg/L (n=26), respectively]. This difference suggests an active summer phytoplankton community that is part of the regular nutrient recycling in the pond. Average mean deep phaeophytin pigment concentration (part of the regular PALS analytes and a daughter of degrading chlorophyll) was significantly higher (~10X higher) than the surface mean, which would be consistent with degrading phytoplankton settling to the sediments and becoming part of the high deep TP concentrations and sediment regeneration cycle. Overall, 93% of the chlorophyll concentrations exceeded the Cape Cod Ecoregion threshold of 1.7 µg/L. As part of developing a management plan, it would provide better context for this data, if a phytoplankton and rooted plant survey was completed. Measurement of the phytoplankton community and how it changes throughout the summer and as sediment nutrient regeneration increases would help to clarify how the water column measurements develop and provide better insights into management strategies to address the identified impairments. No significant trends were found for chlorophyll or pH readings.

Overall Assessment and Identified Data Gaps:

Boland Pond water quality conditions generally show profound impairments compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. Nutrient and resulting chlorophyll concentrations were very high. Management of the water quality in the pond should focus on phosphorus management. Given that Boland Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context. The primary data gaps appear to be information about the: a) characterization of available sediment nutrients, including core collection and incubation, b) characterization of phytoplankton population dynamics throughout an extended summer (April to October) with accompanying continuous monitoring to assess DO, temperature, pH, and chlorophyll, c) extent of rooted plants and their impact on nutrient cycling in the pond, d) a hydrologic assessment to determine the cause of the unique temperature structure of the pond and its relationship to observed impairments, and e) assessment of the presence of freshwater mussels if sediment management is considered. Additional work is also recommended for measurement of stormwater. Boland Pond recently had a volunteer stormwater project focused on three discharge locations around the pond, but limitations within the data collection will require additional stormwater monitoring in order to adequately address this issue. It is also anticipated that access to the pond and the desired amount of rooted plants will also be significant issues to address in a management plan. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or nearby residents. Once data gaps are adequately addressed, the Town should consider development of a Boland Pond Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Boland Pond because of the increase in impairments measured in the pond during the summer. Sampling in Boland Pond in April and August/September should continue to follow PALS protocols.

Table III-2. Boland Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal diff	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	5.71			5.95		5.55		<	
N	51			13		21			
Max	6.60			6.60		5.94			
Min	4.64			4.70		4.64			
Secchi Depth									
Average (m)	1.52			1.57		1.59			
N	49			12		21			
Max	2.40			1.93		2.40			
Min	0.73			1.27		0.90			
Temperature: MassDEP Cold Water Maximum = 20°C									
Average (°C)	14.94	20.60	8.38	16.93	6.89	23.22	9.36	>	>
N	316	53	56	13	15	22	21		
Max	28.00	28.00	12.70	23.40	10.00	27.00	12.70		
Min	4.90	7.80	4.90	12.50	4.90	18.90	7.30		
Dissolved Oxygen: MassDEP Regulatory Minimum = 6 mg/L									
Average (mg/L)	4.36	7.96	1.31	8.99	3.26	7.32	0.20	<	<
N	315	53	56	13	15	22	21		
Max	11.10	11.10	7.19	10.61	7.19	9.68	0.80		
Min	0.04	4.50	0.04	7.20	0.23	4.50	0.07		
N < 6 mg/L DO	184	3	52	0	11	2	21		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.20	6.26	6.15	-	-	6.26	6.15		
N	35	18	15	0	0	18	15		
N < 6.5 pH	34	17	15	-	-	17	15		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	26.58	10.17	47.69	-	-	10.91	49.89		
N	46	26	18	0	0	21	17		
Max	98.16	42.83	98.16	-	-	42.83	98.16		
Min	0.59	0.59	10.22	-	-	0.59	16.21		
N > 1.7 µg/L	43	23	18	-	-	18	17		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	84.36	34.31	141.76	31.63	64.75	37.22	196.76		>
N	84	43	38	10	10	24	20		
Max	574.00	64.96	574.00	54.70	129.19	64.96	574.0		
Min	3.10	7.15	3.10	12.70	23.63	7.15	3.10		
N > 10 µg/L	82	42	37	10	10	23	19		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.77	0.66	0.90	0.49	0.62	0.74	1.12	>	>
N	84	43	38	10	10	24	20		
Max	2.88	1.38	2.88	0.71	1.16	1.38	2.88		
Min	0.32	0.41	0.32	0.41	0.32	0.46	0.44		
N > 0.32 mg/L	84	43	38	10	10	24	20		

III.C. Critchetts Pond

Critchetts Pond (PALS# OR-129) is a 1.9-acre, very shallow pond that is located off Brick Hill Road, north of Dunlukin Lane and south of Harbor View Lane, and approximately 300 m from the Mill Pond portion of the Town Cove/Nauset Estuary watershed. Review of historic 1943 and the current USGS quad maps do not show any hydroconnections to adjacent ponds or wetlands. Review of available historic aerial photos show extensive rooted plants often covering most of the pond surface. These rooted plants are submerged during some periods (presumably high groundwater periods) and then emergent and covering the pond area during other periods (presumably low groundwater periods). Critchetts Pond is within Town Cove/Nauset Harbor MEP estuary watershed. Given that its area is less than 10 acres, it is not considered a public pond under Massachusetts law and is not included in the latest MassDEP Integrated List.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2004 and 2016, but limited sampling outside of the PALS sampling period between 2004 and 2016. Mean average shallow depth (0.65 m; n=19) and mean average Secchi transparency (0.64 m; n=19) were nearly equal. Since these are nearly equal, on average, light can reach the bottom of the pond and, therefore, plants can grow throughout its entire bottom. Mean average total depth was significantly lower in the summer (0.57 m; n=14) compared to the spring (0.87 m; n=4) and mean average Secchi readings had similar depths. No significant trends were noted in Secchi or total depth readings between 2004 and 2016.

Since Critchetts Pond is so shallow, volunteers tended to collect temperature and dissolved oxygen readings at one depth. On the few occasions where these readings were collected at two depths, both readings tended to be similar, as would be expected in a very shallow pond where the water column can be easily mixed by winds blowing across the surface. Temperature readings were higher in the summer, but the summer mean average (22.4°C; n=15) was not significantly different from the spring mean (19.3°C; n=5). The mean summer dissolved oxygen concentration (5.14 mg/L; n=14) was significantly lower than the mean spring reading (8.33 mg/L; n=5), which is partially due to lower capacity of warmer waters to hold dissolved oxygen, but also likely due to sediment oxygen demand. This characteristic was largely confirmed by comparison of the spring and summer percent saturation dissolved oxygen readings; spring readings had a mean average of 91%, which is generally in equilibrium with atmospheric oxygen, while the summer readings had significantly lower mean average of 57%. Since percent saturation removes temperature impacts, this difference means that factors other than temperature (*i.e.*, sediment oxygen demand) are lowering the water column dissolved oxygen. Overall, 6 of the 14 (43%) summer dissolved oxygen readings were less than the MassDEP 5 mg/L minimum (**Table III-3**). Review of pH, the other MassDEP numeric standard, showed that the most of the pH readings (12 of 14) were less than the 6.5 minimum, indicating that the pond is naturally acidic. No significant trends were found for DO, temperature, or pH.

Review of nutrient and chlorophyll data showed excessive nutrient and chlorophyll concentrations, which would both be consistent with a large phytoplankton population. All of the individual TP and TN concentrations were above the respective Cape Cod Ecoregion thresholds (10 µg/L TP and 0.32 mg/L TN, respectively) and 92% (12 of 13) of the chlorophyll readings were above its ecoregion threshold (1.7 µg/L chlorophyll). Comparison of spring and summer mean average TP and TN concentrations showed evidence of sediment regeneration;

summer TP and TN mean average concentrations (61.7 µg/L TP and 0.97 mg/L TN, respectively) were significantly higher than spring mean averages. Chlorophyll and pH readings were only assayed in the summer, so a similar comparison was not available for these parameters. No significant trends were found for TP, TN, chlorophyll or pH readings.

N:P ratios showed that Critchetts Pond is most sensitive to phosphorus additions, but the ratio was lower than usually encountered in Cape Cod ponds and may lead to management of both phosphorus and nitrogen. N:P ratios had a mean average of 38 (n=18), which is approximately 2X the Redfield threshold of 16. Most freshwater ponds on Cape Cod have N:P ratios that are 3 to 4 times higher than the Redfield threshold, although lower ratios are often encountered in ponds with significant sediment phosphorus regeneration. Even though Critchetts Pond is very shallow, the low ratio would be consistent with either regular high sediment regeneration of phosphorus or high retention of phosphorus. Given the extensive plant coverage, TP retention would be consistent, although the plant coverage may also mask TP regeneration during the significantly lower summer DO concentrations. The mean average N:P ratios had no seasonal difference, which may indicate that the summer sediments are regenerating TP and TN at ratios similar to those that exist in the water column in the spring. Clarification of the nutrient relationships and better context for the measure water column data could be resolved by collection and incubation of sediment cores with accompanying continuous DO, temperature, and chlorophyll concentrations. These data gap surveys could be completed during the development of a pond management plan. No significant trends were noted in the N:P ratios data between 2001 and 2016.

Overall Assessment and Identified Data Gaps:
Critchetts Pond is a shallow pond with water quality generally indicating impaired conditions compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. Nutrient and resulting chlorophyll concentrations were very high. Management of the water quality in the pond should focus on phosphorus management, but adequate data gap analysis may lead to consideration of management of both phosphorus and nitrogen. Given that Critchetts Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context and to provide a solid basis for the preparation of water quality management options. The initial primary data gaps appear to be: a) extent of rooted plants and their relationship to phytoplankton population dynamics, b) contributions and available mass of nutrients in the sediments and triggers for regeneration, and c) presence of freshwater mussels since sediment management will likely play a large role in overall pond water quality management. In addition, it is recommended that the plant and sediment surveys include the installation of continuous monitoring devices to evaluate and measure conditions that create the deep low oxygen conditions. Development of a data gap scope should also consider whether there are direct stormwater discharges to the pond and, if so, measurement of nutrient loads should also be included. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of a Critchetts Pond Management

Plan. It is anticipated that access, the role of the adjacent pond, and the role of legacy land uses will also be significant issues in the Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Critchetts Pond because of the increase in impairments measured in the pond during the summer. Sampling in Critchetts Pond in April and August/September should continue to follow PALS protocols.

Table III-3. Critchetts Pond Water Quality Summary. Most collected data was from one depth, so shallow and deep readings are too limited for statistical review. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal diff	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	0.65			0.87		0.57		<	
N	19			4		14			
Max	0.99			0.99		0.78			
Min	0.33			0.79		0.33			
Secchi Depth									
Average (m)	0.64			0.85		0.56		<	
N	19			4		14			
Max	0.99			0.99		0.70			
Min	0.33			0.75		0.33			
Temperature: MassDEP Warm Water Maximum = 28.3°C									
Average (°C)	21.65			19.32		22.42			
N	21			5		15			
Max	28.70			24.20		28.70			
Min	16.10			16.10		17.20			
Dissolved Oxygen: MassDEP Regulatory Minimum 5 mg/L									
Average (mg/L)	5.94			8.33		5.14		<	
N	20			5		14			
Max	10.27			10.27		7.54			
Min	2.50			6.83		2.50			
N < 5 mg/L DO	6			0		6			
pH: MassDEP Regulatory Minimum 6.5									
Average (stnd)	6.18			-		6.18			
N	14			0		14			
N < 6.5 pH	12			-		12			
Chlorophyll: Cape Cod Ecoregion Threshold 1.7 µg/L									
Average (µg/L)	10.06			-		10.06			
N	13			0		13			
Max	28.68			-		28.68			
Min	1.63			-		1.63			
N > 1.7 µg/L	12			-		12			
Total Phosphorus: Cape Cod Ecoregion Threshold 10 µg/L									
Average (µg/L)	53.98			37.69		61.70		>	
N	19			4		14			
Max	117.25			44.63		117.25			
Min	11.03			30.30		37.26			
N > 10 µg/L	19			4		14			
Total Nitrogen: Cape Cod Ecoregion Threshold 0.31 mg/L									
Average (mg/L)	0.88			0.63		0.97		>	
N	19			4		14			
Max	1.22			0.70		1.22			
Min	0.59			0.59		0.62			
N > 0.32 mg/L	19			4		14			

III.D. Crystal Lake

Crystal Lake (PALS# OR-153) is a 38-acre pond that is the second largest pond in the Town of Orleans after Pilgrim Lake. It is located between Route 28 and Monument Road and to the northwest of Kescayogansett/Lonnies Pond estuary (see **Figure I-1**). It is the second deepest of the ponds in the Town after Bakers Pond with a maximum depth of 49 ft and its deepest basin closest to Monument Road. It has a public swimming beach, a boat ramp, and a surface water connection to Lonnies Pond through an adjacent cranberry bog. The 1944 historic USGS quad map also shows it had a hydroconnection to a cranberry bog along its northeast side. Review of a 1996 aerial photographs appears to show that the bog had not been in use for some time, while it is hard to discern in more recent aerial photographs. Crystal Lake is within the Pleasant Bay watershed, Pleasant Bay Area of Critical Environmental Concern, and is a designated Massachusetts Natural Heritage Priority Habitat. Given that it has a surface area greater than 10 acres, it is classified as a Great Pond and is included in the most recent final MassDEP Integrated List.[38] This list classifies Crystal Lake as impaired due to low dissolved oxygen conditions and, as an impaired water, will eventually require preparation of a TMDL to satisfy the requirements under the Clean Water Act.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling between 2001 and 2016. Crystal Lake was also sampled in 2000 and 2001 as part of a Town-sponsored project[39] and a snapshot sampling was completed by the state once in 1948.[40] Crystal Lake was also selected for additional assessment in the 2007 Orleans Ponds Report, which included a watershed delineation, determination of water and nutrient budgets, and a more detailed review of the available water quality data.[41] It was noted in this report that there were 17 upgradient single family residences, four multifamily residences, municipal land, and road areas upgradient of the pond and that the water residence time was estimated at just over 1 year. It was also noted that Crystal received stormwater runoff discharge from a significant portion of Route 28; a subsequent Town stormwater infrastructure survey has identified two additional runoff discharges, both collect stormwater from Monument Road.[42] Other additional potential management issues identified since the Ponds Report include quantifying the surface outflow from the pond to the adjacent cranberry bog located off Monument Road. The 2007 Ponds Report noted that pond water quality was very unstable and given to large fluctuations in conditions and that management of phosphorus inputs, both internal and external, were the key to managing its overall water quality.

Data in the Orleans Pond and Lake unified database found that the mean average depth at the Crystal Lake sampling station was 13.61 m (n=57). Mean average Secchi transparency depth was 4.65 m (n=68) and 32% (n=56) of the total depth. Average total depth was significantly lower in the summer (13.47 m; n=25) compared to the spring (14.03 m; n=11), but average summer Secchi depths were significantly greater (**Table III-4**). Over the data record between

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[38] Massachusetts Department of Environmental Protection. December 2015. Massachusetts Year 2014 Integrated List of Waters, Final Listing.

[39] Scanlon, J. and G. Meservey. 2001. 3 Ponds Study, Orleans, MA. Crystal Lake, Pilgrim Lake, Baker's Pond.

[40] Massachusetts Division of Fisheries and Game

[41] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. pp. 36-42.

[42] GHD, Inc. 2013. Stormwater Sampling Plan, Town of Orleans, MA. Hyannis, MA. 120 pp.

2000 and 2016, Secchi depths had a significant decreasing trend (-0.15 m per year) with no significant trend in overall station depth. Decreasing Secchi transparency is usually due to increasing phytoplankton populations, especially in Cape Cod ponds, where other factors influencing transparency (*e.g.*, suspended solids) tend to be minimal.

Comparison of data to MassDEP numeric standards show that deeper summer conditions are generally impaired and the pond is naturally acidic. Mean average dissolved oxygen concentrations at the shallow and 3 m depths were generally above the MassDEP cold water minimum of 6 mg/L during both during the spring and the late summer. Spring 9 m and deep mean average DO concentrations were also above the MassDEP minimum, but summer mean averages were well below the minimum (1.45 mg/L and 0.59 mg/L DO, respectively). All 37 individual deep summer DO readings were less than 6 mg/L, while 5 of 13 available spring deep readings were less than the MassDEP minimum. Summer mean average DO concentrations at the shallow, 3 m, 9 m, and deep depths were significantly lower than the corresponding spring mean averages. Overall records of surface, 3 m, 9 m and deep DO readings had no significant trends from 2000 to 2016. Most (83%) of the individual pH readings were less than the MassDEP minimum of 6.5 and mean average pH readings at all depths were also less than the minimum; this is consistent with natural acidic conditions in most Cape Cod ponds and lakes.

Review of temperature readings show that 7 m and deeper generally constitutes a cold water habitat in Crystal Lake (20°C or less[43]). Average mean temperature readings at shallow and 3 m depths were not significantly different during either the spring or summer, but during both seasons, average mean temperatures at 9 m and deeper were significantly colder (both seasons had average mean temperatures less than 10°C). Closer review of the individual profiles showed that some readings at 6 m exceeded the 20°C cold water threshold, but none of the 7 m or deeper readings did. Review of temperature trends found that surface and 3 m temperatures did not have significant trends, but 9 m and deep temperature both had significant decreasing trends (-0.16°C/yr and -0.12°C/yr, respectively). Since the surface water did not have significant trends, the deeper trends, which are roughly the same, suggest that this impact may be due to the timing of thermal stratification in the lake. Earlier stratification, which would correspond to warmer temperatures earlier in the year, would cause colder waters than normal to be isolated in the deeper waters. Review of the relatively limited May shallower temperatures seem to confirm this hypothesis; May shallow and 3 m temperature readings both showed a significant increasing trend (+0.4 to 0.5°C/yr). Tracking this impact would be important for the long term management of Crystal Lake.

Comparison of the DO and temperature data showed that the temperature-defined deep water habitat (7 m and deeper) was generally impaired, especially during the summer. Of the total combined 29 summer readings at 7 m during August and September, 19 (65%) were less than the MassDEP minimum. Waters 7 m and deeper are 24% of the total pond volume. Additional review of individual summer DO profiles showed that there occasionally was a pronounced "bulge" of higher DO waters around 6 m depth; lower concentrations are generally measured above and below this depth. This type of mid-depth maxima generally occurs when phytoplankton congregate near a thermal transition layer where higher nutrient concentration

[43] MassDEP standards require a 7 day average of less than 20°C (314CMR4.05(b)2.), but that would require more refined monitoring than has been completed to date.

exists below the layer due to sediment regeneration. Installation of continuous recording equipment would provide better context for the development of this bulge and the factors that sustain it.

Review of nutrient data showed evidence of sediment nutrient regeneration and complex nutrient trends. Spring TN and TP had no significant difference among mean average concentrations at the shallow, 3 m, 9 m, and deep sampling depths. During the summer, mean average TN and TP concentrations had a different pattern. Mean average TN concentrations at shallow, 3 m, and 9 m depths were no significantly different, but the deep mean average was significantly higher (0.60 mg/L TN; n=26). Mean average TP concentrations were not significantly different at shallow and 3 m depths, but the 9 m mean average was significantly higher than the 3 m mean and the deep mean average was significantly higher than all of the shallower depths. This pattern is consistent with sediment nutrient regeneration and how phosphorus regeneration is generally more rapid than nitrogen release in low oxygen conditions. Trend analysis showed no significant TP trends, but did show small (+0.009 mg/L), but significant, increasing trends in TN concentrations at 3 m and 9 m. Increasing trends shallower than the typical stratification depth suggests that the increasing TN at 3 m may be due to increasing watershed inputs. More refined data collection (*e.g.*, continuous monitors) and review of watershed changes would help to clarify DO and nutrient relations and further analysis of the data during development of a pond management plan may offer additional clarification of some of the relationships.

N:P ratios showed more sensitivity to phosphorus than nitrogen; average overall ratios were 3X to 4X the Redfield ratio at all depths. Mean average ratios were not significantly different during the spring and summer, but ratio higher in the water column (shallow and 3 m) were lower during the spring, while deeper mean average ratios (9 m and deep) were higher during the spring. The deep summer decrease in the mean ratios is consistent with increased TP sediment regeneration, while the increased shallow ratios during the summer suggest preferential removal of TP in the water column (perhaps by rooted plants). This summer decrease in TP was measured in the mean average 3 m concentration, but not at the shallow depth. This review showed the complexities of these relationships and how additional information about the pond (*e.g.*, extent of rooted plants and measurement of sediment core nutrient releases) could clarify what the water column results mean about the nutrient interactions in the pond. No significant trends in N:P ratios were noted except for a decreasing trend at 3 m (-3.5 per year), which would be consistent with the noted small significant increasing trend in TN concentrations at the same depth. It is recommended that further clarification of these relationships and their implications for water quality management options be evaluated when a Crystal Lake Management Plan is developed.

Chlorophyll and pH readings were only collected during the summer (*i.e.*, through the PALS Snapshots), so seasonal comparisons were not available. As mentioned above, the pond was naturally acidic with most (83%) of the pH readings were below the MassDEP minimum of 6.5; mean average of all shallow readings was 6.36. Readings at 3 m were not statistically different, but 9 m and deep averages were significantly lower than the shallower averages. Photosynthesis tends to raise pH, so the shallower areas in most Cape Cod ponds tend to have higher pH due to the presence of more plants (both phytoplankton and rooted plants) than deeper areas. Mean average chlorophyll concentrations were highest at 9 m (2.56 µg/L) near where the occasional

DO bulge generally occurred; this concentration was not significantly higher than the shallow average (2.46 µg/L). Overall, more than half (54%) of the chlorophyll concentrations exceeded the Cape Cod Ecoregion threshold of 1.7 µg/L. No significant chlorophyll trends were noted at any of sample depths analyzed. Surface and deep pH readings had small, but significant, increasing trends (+0.03 per year and +0.02 per year, respectively), but the causes of these increases are likely different. The surface increase is likely due to photosynthesis, but likely rooted plants rather than phytoplankton given the lack of significant chlorophyll trends, while the deep rise is likely due to increased bacterial activity (*i.e.*, breakdown of organic materials tends to increase hydrogen ion concentrations).

Overall Assessment and Identified Data Gaps:

Crystal Lake is a Great Pond and, as such, its management will need to address both the Town's specific uses and resource quality objectives and those of MassDEP, including any regulatory requirements as a result of it having been designated as an impaired water body. Given the MassDEP designation, Crystal Lake will eventually need to have a TMDL prepared. Development of a Crystal Lake Management Plan could address both development of a TMDL and management strategies to restore the pond and resolve the impairment.

Preparation of a management plan will require addressing data gaps in order to provide proper context for the available water quality data and to prepare reliable management options. Currently identified data gaps include a) stormwater monitoring of the identified and any other direct discharges, b) collection and incubation of sediment cores to measure both potential nutrient regeneration and conditions that trigger regeneration, c) a survey of plant communities (both rooted macrophytes and phytoplankton) to determine the extent of their role in creating the measured water quality data, d) measurement of surface water flow and associated nutrient load into and out of the pond to the active cranberry bog and perhaps the historic, abandoned bog, e) a freshwater mussel survey given that sediment treatment is likely to be a management strategy to be considered, the endangered species designation of certain freshwater mussels, and how a survey can be accomplished at the same time as a plant survey is completed, and f) installation of a number of continuous recording devices to evaluate conditions that create the occasional DO bulge and the deep hypoxic conditions, as well as relationships to plant community findings. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or nearby residents.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Crystal Lake because the impairments measured in the pond occur in the summer. Sampling in Crystal Lake in April and August/September should continue to follow PALS protocols.

Table III-4. Crystal Lake Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	13.61			14.03		13.47		<	
N	57			11		25			
Max	15.00			15.00		14.50			
Min	12.00			13.00		12.00			
Secchi Depth									
Average (m)	4.65			3.65		4.89		>	
N	68			13		27			
Max	8.08			5.38		7.61			
Min	1.82			2.75		3.25			
Temperature: MassDEP Cold Water Maximum = 20°C									
Average (°C)	14.31	21.01	8.36	17.11	7.39	23.51	8.36	>	>
N	965	70	79	13	13	28	37		
Max	26.90	26.90	11.11	22.10	9.50	26.90	11.11		
Min	6.10	8.30	6.10	10.20	6.10	19.10	6.70		
Dissolved Oxygen: MassDEP Regulatory Minimum = 6 mg/L									
Average (mg/L)	6.28	8.57	2.33	10.04	6.06	7.87	0.59	<	<
N	956	70	79	13	13	28	37		
Max	13.10	12.03	10.78	11.90	10.78	9.93	2.30		
Min	0.04	5.71	0.04	8.50	0.36	5.71	0.07		
N < 6 mg/L DO	347	1	64	0	5	1	37		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.19	6.36	6.10	-	-	6.35	6.13		
N	104	32	30	0	0	24	22		
N < 6.5 pH	86	22	29	-	-	16	22		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	2.28	2.46	1.89	-	-	2.64	1.57		
N	89	24	18	0	0	21	17		
Max	7.40	4.67	7.40	-	-	4.67	7.40		
Min	0.01	0.32	0.03	-	-	1.04	0.03		
N > 1.7 µg/L	48	17	6	-	-	16	5		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	19.28	17.15	30.95	15.52	23.33	18.50	46.02		>
N	216	58	57	8	7	29	28		
Max	295.00	295.00	155.00	42.50	62.00	15.99	155.00		
Min	0.50	0.50	0.50	3.54	3.79	0.77	0.50		
N > 10 µg/L	109	24	39	5	5	4	22		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.35	0.30	0.49	0.32	0.44	0.31	0.60		
N	195	53	52	8	7	29	27		
Max	1.00	0.52	1.00	0.50	0.95	0.52	1.00		
Min	0.11	0.11	0.19	0.17	0.22	0.16	0.28		
N > 0.31 mg/L	94	19	38	3	5	13	26		

III.E. Deep Pond

Deep Pond (PALS# OR-262) is a 4.7 acre pond in southern Orleans and located just to the east of Route 28 and north of Towhee Lane (see **Figure I-1**). It is part of a complex of ponds, which includes Uncle Seths Pond, Shoal Pond, and Twinings Pond, that is oriented in an east/west line and parallel to the shore of Pleasant Bay. It has a surface water connection to Shoal Pond (that was not shown on the historic 1943 USGS quad map), is within the Pleasant Bay watershed, and within a Massachusetts Natural Heritage Priority Habitat. Given that its area is less than 10 acres, it is not considered a public pond under Massachusetts law.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling between 2002 and 2016. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including an average deep DO concentration less than the MassDEP minimum. Deep Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Deep Pond sampling station was 5.62 m (n=49). Mean average Secchi transparency depth was 1.92 m (n=49) and 34% (n=49) of the total depth. Average total depth was significantly lower in the summer (5.53 m; n=23) compared to the spring (5.79 m; n=12). Summer average Secchi depth was lower than the spring average, but not significantly different (**Table III-5**). Trends in overall station depth or Secchi depth were not significant.

Comparison of data to MassDEP numeric standards shows that deeper conditions (both summer and spring) are generally impaired and the pond is naturally acidic. All shallow dissolved oxygen concentrations were above the MassDEP warm water minimum of 5 mg/L. Most (90%) of the deep DO concentrations, including spring (92%) and summer (100%) readings, were below the MassDEP minimum. DO readings less than the MassDEP limit were recorded at 2 m and deeper. Shallow and deep averages are significantly different during both the spring and the summer. The summer shallow DO average was significantly less than the spring average, but deep seasonal averages are not significantly different. No significant trends were found in the overall DO datasets, but August DO readings showed a significant decreasing trend (-0.1 mg/L DO per year) between 2001 and 2016. Overall average pH readings were naturally acidic. The shallow mean average pH was just above the MassDEP minimum of 6.5 (6.63; n=18), while the deep mean average was 6.20 (n=17).

Review of temperature readings show that deeper waters were consistently colder, but definitely warmed during the summer. Mean average spring surface temperature was 16.56°C (n=11) with a significantly lower deep mean average of 8.39°C (n=12). Corresponding summer mean temperatures also showed significantly warmer shallow waters, but were significantly higher than the spring mean average (24.32°C and 13.73°C, respectively). These readings indicate regular separation of shallow and deep waters, but review of individual temperature profiles also suggest that there are regular thermal mixing events. Installation of continuous temperature recorders would help to clarify how often these mixing events occur and how they develop. No significant temperature trends were noted.

Review of nutrient data showed evidence of sediment nutrient regeneration that was enhanced during the summer. Spring TN and TP had no significant difference among average mean concentrations at the shallow and deep sampling depths, but deep TN and TP summer mean averages were significantly higher than shallow TN and TP summer means. Cross-comparison of the seasonal mean averages showed TP means at both depths were not significantly different in spring and summer, but shallow summer TN mean average was significantly higher than the spring mean. The deep summer and spring TN mean averages were not significantly different. This pattern is consistent with the persistent sediment regeneration of nutrients during both spring and summer, while the increase in shallow TN during the summer suggests increased watershed inputs. Evaluation of potential seasonal watershed changes during the development of a management plan could help to clarify these water column measurements. The majority of both spring and summer TP readings exceeded the 10 µg/L TP Cape Cod Ecoregion threshold, while 90% of the 86 TN readings were above the 0.31 mg/L TN ecoregion threshold. No significant trends were noted in the overall TN or TP concentrations between 2001 and 2016.

N:P ratios showed the pond had more sensitivity to phosphorus than nitrogen; average overall ratios were 5X the Redfield ratio at both shallow and deep depths. Mean average ratios were generally lower at both depths during the spring [shallow mean = 59.7 (n=9), deep mean = 58.2 (n=9)], but not significantly different from the summer [shallow mean = 88.7 (n=24), deep mean = 84.0 (n=23)]. These differences and the TN data showed that more TN was added to the water column during the summer, but the significant increase in the shallow TN mean average suggests that a watershed addition was more prominent than sediment regeneration. Actual measurement of sediment regeneration rates from collection and incubation of sediment cores would help to further understand the water column data. No significant trends were noted in the overall shallow or deep N:P ratios between 2001 and 2016.

Chlorophyll and pH readings were only collected during the summer season, so seasonal comparisons were not available. The majority (66%) of the pH readings were below the MassDEP minimum of 6.5 with higher shallow mean averages. Photosynthesis tends to raise pH, so the shallower areas, which tend to have more plants (both phytoplankton and rooted plants), will also tend to have higher pH. Deep chlorophyll mean average concentration (36.89 µg/L; n=20) was significantly higher than the corresponding shallow mean average (8.71 µg/L; n=23). Further data review could clarify this difference, but typically higher deep chlorophyll concentrations are due to an active phytoplankton population with regular and extensive settling of decaying phytoplankton. Collection of spring chlorophyll samples could provide comparison with summer readings and clarify whether these conditions also exist during the spring. In addition, it would also be useful for developing management strategies to understand the extent of rooted plants and how phytoplankton populations change throughout the summer. No significant chlorophyll trends were noted.

<u>Overall Assessment and Identified Data Gaps:</u>
Deep Pond water quality conditions generally show impaired conditions compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. Nutrient and resulting chlorophyll concentrations were very high, and bottom waters were hypoxic. Management of the water quality in the pond should focus on phosphorus management. Given that Deep Pond is

not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context and provide a reliable basis for development of management options. The primary data gaps appear to be information about the: a) characterization of available sediment nutrient inputs to summer water column measurements, including core collection and incubation, b) characterization of phytoplankton population dynamics throughout an extended summer (April to October) with accompanying continuous monitoring to assess DO, temperature, pH, and chlorophyll, c) extent of rooted plants and their impact on nutrient cycling in the pond, d) assessment of the presence of freshwater mussels if sediment management is considered and e) measurement of direct stormwater inputs, if any are identified as a potentially significant phosphorus source with clear management options. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or nearby residents. Once data gaps are adequately addressed, the Town should consider development of a Deep Pond Management Plan. Based on the review of water quality, it is anticipated that access and the desired amount of rooted plants will be significant management issues for consideration in the management plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this latter issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Deep Pond because of the increase in impairments measured in the pond during the summer. Sampling in Deep Pond in April and August/September should continue to follow PALS protocols.

Table III-5. Deep Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	Deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	5.62			5.79		5.53		<	
N	49			12		23			
Max	6.17			6.17		5.95			
Min	4.94			4.95		4.94			
Secchi Depth									
Average (m)	1.92			2.10		1.86			
N	49			11		23			
Max	3.11			2.90		3.11			
Min	0.80			1.21		0.80			
Temperature: MassDEP Warm Water Maximum = 28.3°C									
Average (°C)	17.49	21.90	11.85	16.56	8.39	24.32	13.73	>	>
N	315	49	52	11	12	23	25		
Max	27.70	27.70	20.30	24.20	12.80	27.30	20.30		
Min	5.30	10.20	5.30	10.20	6.20	19.70	5.30		
Dissolved Oxygen: MassDEP Regulatory Minimum = 5 mg/L									
Average (mg/L)	5.79	7.99	1.66	9.43	2.20	7.36	0.87	<	
N	315	49	52	11	12	23	25		
Max	12.05	10.60	10.40	10.42	8.58	9.49	3.10		
Min	0.05	5.34	0.05	8.10	0.23	5.34	0.05		
N < 5 mg/L DO	112	0	47	0	11	0	25		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.42	6.63	6.20	-	-	6.63	6.20		
N	35	18	17	0	0	18	17		
N < 6.5 pH	23	6	17	-	-	6	17		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	21.46	8.71	36.89	-	-	9.53	39.19		
N	45	23	20	0	0	20	18		
Max	81.67	32.36	81.67	-	-	32.36	81.67		
Min	0.36	0.36	9.79	-	-	1.00	9.79		
N > 1.7 µg/L	43	21	20	-	-	19	18		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	19.44	16.23	22.07	18.64	22.36	17.27	25.45		
N	86	43	42	9	9	24	24		
Max	49.60	42.55	49.60	42.50	49.00	42.55	49.60		
Min	3.25	4.79	3.25	4.79	11.53	4.98	3.25		
N > 10 µg/L	63	28	34	6	9	16	20		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.32 mg/L									
Average (mg/L)	0.57	0.48	0.66	0.37	0.54	0.54	0.73	>	
N	86	43	42	9	9	24	23		
Max	1.65	0.86	1.65	0.56	0.99	0.86	1.65		
Min	0.24	0.24	0.25	0.24	0.25	0.31	0.41		
N > 0.32 mg/L	77	36	40	5	8	24	23		

III.F. Gould Pond

Gould Pond (PALS# OR-174) is a 4 acre pond located just within the Orleans Watershed land, to the west of Route 28, and to the north of Lisa's Way (see **Figure I-1**). A small (1.3 acre) unnamed pond nearby looks like it may occasionally have a surface water connection to Gould Pond. The first (1893) USGS topographic map of the area does not include the smaller pond, but the more detailed 1944 map shows Gould Pond with a stream connection to the smaller pond, two connected cranberry bogs, and a stream connection to Arey's Pond.[44] Gould Pond is within the Pleasant Bay watershed and Pleasant Bay Area of Critical Environmental Concern (ACEC), the Town of Orleans Water Department Zone II (*e.g.*, wellhead protection area), and a Massachusetts Natural Heritage Priority Habitat. Given that its area is less than 10 acres, it is not considered a public pond under Massachusetts law.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling between 2002 and 2016. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including an average deep DO concentration less than the MassDEP minimum. Gould Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Gould Pond sampling station was 3.99 m (n=37). Mean average Secchi transparency depth was 2.87 m (n=36) and 73% (n=36) of the total depth (**Table III-6**). Average total depth was significantly lower in the summer (3.72 m; n=20) compared to the spring (4.29 m; n=11). Summer mean average Secchi depth (2.75 m; n=20) was also significantly less than the spring mean average (3.42 m; n=11). Secchi depth had a significantly increasing trend (+0.06 m/yr) between 2001 and 2016; total depth did not have a significant trend.

Comparison of water quality data to MassDEP numeric standards show that summer conditions generally created water quality impairments and that the pond was naturally acidic. All but 1 of the 37 shallow dissolved oxygen concentrations were above the MassDEP warm water minimum of 5 mg/L. In contrast, the majority (65%) of the 37 recorded deep DO concentrations were below the MassDEP minimum; most of the deep DO readings less than the MassDEP minimum were recorded during the summer. Shallow and deep mean DO averages were significantly different during both the spring and the summer. The summer shallow and deep DO mean averages were significantly less than the corresponding spring mean averages; the deep summer mean DO average (2.91 mg/L) was also less than the MassDEP minimum. No significant trends were noted in the overall DO datasets. All 35 pH readings were below 7 and below the MassDEP 6.5 minimum reading.

Review of temperature readings show that Gould Pond generally had significantly colder deep waters and this persisted during both spring and summer. Summer warming would place the pond in MassDEP's warm water category; both shallow and deep summer maximum temperatures were above the MassDEP 20°C cold water fisheries upper limit. Average mean

[44] University of New Hampshire, Historic USGS Maps Collection. http://docs.unh.edu/nhtopos/MassachusettsList.htm (accessed 4/6/17)

spring shallow temperature was 17.59°C (n=11) with a significantly lower deep mean average of 13.45°C (n=11). Both summer average mean temperatures were significantly higher than the corresponding spring reading (25.00°C and 22.56°C, respectively) and shallow and deep mean averages were also significantly different. These readings indicate regular separation of shallow and deep waters, but review of individual temperature profiles suggest that there are regular thermal mixing events. Installation of continuous temperature recorders would help to clarify how often these circumstances occur and how they develop and further review of resistance to mixing would clarify how often mixing could have occurred in the individual profiles. No significant temperature trends were noted.

Review of nutrient data showed evidence of sediment nutrient regeneration that was enhanced during the summer. Spring TN and TP average mean concentrations had no significant difference between the shallow and deep sampling depths, but deep summer TN and TP mean averages were significantly higher than shallow summer means. Shallow summer mean TP and TN averages were also significantly higher than the spring mean averages. Deep summer TN mean average was also significantly higher than the spring mean average, but the deep summer TP mean average was not significantly different from the spring mean TP average. This pattern is generally consistent with the summer deep low DO conditions enhancing sediment nutrient regeneration, but the lack of difference between the spring and summer TP deep mean averages suggest that sediment/water column interactions are complex and likely strongly influenced by water column mixing and/or inputs from the small pond to the northwest. The majority of deep TP concentrations during both the spring and summer exceeded the 10 µg/L ecoregion threshold, while the majority of deep TN concentrations were only greater than the 0.31 mg/L threshold during the summer. The majority of shallow summer TP readings exceeded the ecoregion threshold, but none of the spring shallow readings exceeded the threshold. Only 2 of the 14 spring TN concentrations were greater than the ecoregion threshold. These differences reinforce the changes in seasonal conditions and would benefit from the installation of a continuous recording device as discussed above. No significant trends were noted in the overall TN or TP concentrations between 2001 and 2016.

N:P ratios showed more sensitivity to phosphorus than nitrogen; average overall ratios were 3X the Redfield ratio threshold at both shallow and deep depths. Spring mean average ratios were generally higher at both depths (shallow mean = 63.7, deep mean = 49.1) than those during the summer (shallow mean = 53.3, deep mean = 54.1), but the differences were not significant. These differences are consistent with the sediment regeneration of TP suggested by the comparison of shallow and deep TP data. Actual measurement of sediment regeneration rates from collection and incubation of sediment cores would help to further understand the water column data. No significant trends were noted in the overall shallow or deep N:P ratios between 2001 and 2016.

Chlorophyll and pH readings were only collected during the summer season, so seasonal comparisons were not available. As mentioned above, all of the pH readings were below the MassDEP minimum of 6.5. The mean average deep pH reading (5.84; n=15) was significantly less than the shallow average mean (5.98; n=17). Photosynthesis tends to raise pH, so shallower areas, where light is more readily available, tend to have higher pH. Although the deep chlorophyll mean average concentration (16.81 µg/L; n=14) was greater than the corresponding shallow mean average (5.48 µg/L; n=19), they means were not significantly different largely due to the high variability of the readings. Further data review could clarify the causes of this variability, but typically higher deep chlorophyll concentrations are due to an active phytoplankton population with regular and extensive settling of decaying phytoplankton and chlorophyll concentrations in shallow ponds tend to be more variable due to the ease of water column mixing. Addition of a chlorophyll sensor to a continuous recording device could clarify factors influencing chlorophyll concentrations. In addition, collection of spring chlorophyll samples could provide comparison with summer readings and clarify whether the summer conditions also exist during the spring. No significant chlorophyll or pH trends were noted.

Overall Assessment and Identified Data Gaps:

Gould Pond water quality conditions generally show impaired conditions compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. Management of the water quality in the pond should focus on phosphorus management and summer conditions. Since Gould Pond is within the Orleans Watershed, most of the impairments are likely due to legacy impacts from past land uses. Given that Deep Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context and provide a reliable basis for development of management options. The primary data gaps appear to be information about the: a) characterization of available sediment nutrients and their role in summer blooms, including core collection and incubation, b) characterization of phytoplankton population dynamics throughout an extended summer (April to October) with accompanying continuous monitoring to assess DO, temperature, pH, and chlorophyll, c) extent of rooted plants and their impact on nutrient cycling in the pond, d) assessment of the presence of freshwater mussels if sediment management is considered and e) measurement of direct stormwater inputs, if any are identified as a potentially significant phosphorus source with clear management options. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or nearby residents. Once data gaps are adequately addressed, the Town should consider development of a Gould Pond Management Plan. Based on the review of water quality, it is anticipated that access, the desired amount of rooted plants, and the role of legacy land uses will be significant management issues for consideration in the management plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Gould Pond because of the increase in impairments measured in the pond during the summer. Sampling in Gould Pond in April and August/September should continue to follow PALS protocols.

Table III-6. Gould Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	3.99			4.29		3.72		<	
N	37			11		20			
Max	4.58			4.55		4.35			
Min	3.18			3.77		3.18			
Secchi Depth									
Average (m)	2.87			3.42		2.75		<	
N	36			11		20			
Max	4.20			4.20		3.80			
Min	1.49			2.44		1.49			
Temperature: MassDEP Warm Water Maximum = 28.3°C									
Average (°C)	20.97	22.80	18.78	17.59	13.45	25.00	22.56	>	>
N	175	37	37	11	11	20	20		
Max	29.90	27.50	29.90	23.80	16.70	27.50	29.90		
Min	10.60	13.40	10.60	13.40	10.60	19.10	14.50		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	6.43	7.60	3.92	9.60	7.16	6.58	2.91	<	<
N	175	37	37	11	11	20	20		
Max	11.85	11.39	11.00	11.39	11.00	8.01	6.56		
Min	0.11	4.55	0.11	8.06	1.74	4.55	0.11		
N < 5 mg/L DO	44	1	24	0	3	1	15		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	5.92	5.98	5.84	-	-	5.98	5.84		
N	35	17	15	0	0	17	15		
N < 6.5 pH	35	17	15	-	-	17	15		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	10.15	5.48	16.81	-	-	5.48	16.81		
N	37	19	14	0	0	19	14		
Max	100.34	22.11	100.34	-	-	22.11	100.3		
Min	1.49	1.49	2.46	-	-	1.49	2.46		
N > 1.7 µg/L	37	16	14	-	-	16	14		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	14.85	11.82	17.66	7.56	16.42	13.35	19.79	>	
N	60	28	26	6	7	21	16		
Max	41.60	23.45	41.60	9.38	41.60	23.45	40.47		
Min	2.64	3.10	2.64	4.90	6.03	3.10	2.64		
N > 10 µg/L	39	15	20	0	5	15	14		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.31	0.29	0.33	0.22	0.25	0.32	0.38	>	>
N	61	30	26	7	7	21	16		
Max	0.73	0.48	0.73	0.36	0.43	0.48	0.73		
Min	0.09	0.09	0.12	0.09	0.12	0.22	0.22		
N > 0.32 mg/L	27	11	14	1	1	9	12		

III.G. Icehouse Pond

Icehouse Pond (PALS# OR-113) is a 5.6 acre pond located just to the west of Brick Hill Roads and to the northeast of Reubens Pond (see **Figure I-1**). Based on insights from the Freshwater Ponds Work Group, the pond has small hydroconnections to Town Cove and has freshwater mussels. Review of 1944 USGS quad map does not show this connection. Review of historic aerial photographs suggests that rooted plants may be a management issue, especially in the northern portion of the pond. Icehouse Pond is within the MEP Town Cove watershed of the larger Nauset Marsh Estuary watershed. Given that its area is less than 10 acres, it is not considered a public pond under Massachusetts law.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2015 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling between 2002 and 2016. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including average deep summer DO concentrations less than the MassDEP regulatory minimum. Icehouse Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Icehouse Pond sampling station was 6.0 m (n=45). Mean average Secchi transparency depth was 4.15 m (n=48) and 70% (n=47) of the total depth (**Table III-7**). Average mean summer total depth was less than mean spring depth, but not significantly different. Summer mean Secchi depth, on the other hand, was significantly less (3.62 m; n=21) than the spring mean depth (4.53 m; n=13). Both total depth and Secchi depth records had significantly decreasing trends (-0.038 m/yr and -0.055 m/yr, respectively) between 2001 and 2016. August Secchi depth had a slightly greater, significant decreasing trend (-0.073 m/yr).

Comparisons of data to MassDEP numeric standards show that summer conditions generally create water quality impairments and that the pond is naturally acidic. All of the shallow dissolved oxygen concentrations were above the MassDEP warm water minimum of 5 mg/L. The majority (55%) of the recorded deep DO concentrations were below the MassDEP minimum and most of these low DO concentrations were recorded during the summer. During the spring, mean average DO readings were not significantly different (9.40 mg/L and 7.86 mg/L, respectively), but during the summer, the deep mean average was significantly less than the surface mean average (7.15 mg/L and 2.40 mg/L, respectively). Spring shallow and deep mean average DO concentrations were significantly greater than the corresponding summer mean averages. No significant trends were noted in the overall DO datasets except for deep DO (+0.26 mg/L per year); review of the data frequency suggest that this may be due to greater frequency of snapshots in the 2001 to 2005 period increasing the chance of detecting low oxygen event, continuous recording of DO concentrations could help to resolve this issue. Most of the pH readings (76%) were naturally less than the MassDEP minimum of 6.5 with the overall mean average of 6.34 (n=34).

Review of temperature readings show that the water column of Icehouse Pond generally has significantly colder deep waters, during both spring and summer, but maximum summer readings at both depths place the pond in MassDEP's warm water category. Mean average spring shallow temperature was 15.62°C (n=13) with a significantly lower deep mean average of 12.45°C (n=13). Summer average mean temperatures at both depths were significantly higher (23.81°C and 20.93°C, respectively) and the shallow summer mean was significantly higher than the deep summer mean average. These readings indicate regular separation of shallow and deep waters, but review of individual temperature profiles also suggest that there are regular thermal mixing events. Installation of continuous temperature recorders and review of resistance to thermal mixing in individual profiles would help to clarify how often these circumstances occur and how they develop. Ponds with periodic summer water column mixing present different challenges for management than ponds with more static water columns. No significant temperature trends were noted.

Review of nutrient data showed significant changes in seasonal TN concentrations, but no significant changes in seasonal TP concentrations. Spring and summer TN and TP average mean concentrations had no significant difference between the shallow and deep sampling depths. However, summer TN mean averages at both shallow and deep depths were significantly greater than the spring mean averages; given the lack of significant deep TP increases, this suggests that the increase was likely due to watershed/external inputs of nitrogen. These finding also suggest that although deep average mean summer DO concentrations were low and sufficient to effect fish and benthic organisms, the concentrations were not low enough or prolonged enough to trigger a significant pulse in sediment regeneration of TP. This pattern is somewhat complex and further clarification would require more frequent/continuous monitoring of DO and temperature conditions to look at water column mixing and frequency of hypoxic conditions. Snapshot profiles had low enough DO concentrations to trigger TP sediment regeneration, but perhaps these concentrations were not of sufficient duration. Another possibility would be that there is little TP available for regeneration in the sediments; collection and incubation of sediment cores with continuous recording of DO concentrations would clarify these results and the associated implications for management. The majority of deep TP concentrations during both the spring and summer exceeded the 10 µg/L ecoregion threshold. The majority of shallow TP readings exceeded the ecoregion threshold, but none of the spring shallow readings exceeded the threshold. No significant trends were noted in the overall TN or TP concentrations between 2001 and 2016.

N:P ratios showed more sensitivity to phosphorus than nitrogen; average overall ratios were 4X the Redfield ratio threshold at both shallow and deep depths. No significant differences were noted in the ratios by depth or by season. This lack of significant differences is consistent with the lack of significant TP concentration differences; TP variance usually is the primary driver of N:P ratio variability in freshwater ponds. No significant trends were noted in the overall shallow or deep N:P ratios between 2001 and 2016.

Chlorophyll and pH readings were only collected during the summer season[45], so seasonal comparisons were not possible. Average mean pH readings by depth were below the MassDEP minimum of 6.5 with significantly higher shallow (6.42; n=17) than deep mean (6.25; n=16) average. Photosynthesis tends to raise pH, so shallower areas, where light is more readily available, tend to have higher pH. Most of the chlorophyll concentrations (83%) were above the Cape Cod Ecoregion threshold of 1.7 µg/L. The deep chlorophyll mean average concentration

[45] PALS Snapshots are the only source of pH data for Icehouse Pond.

(27.58 µg/L; n=18) was significantly greater than the shallow mean average (4.23 µg/L; n=21). Typically higher deep chlorophyll concentrations, especially in shallow ponds, are due to an active phytoplankton population with regular and extensive settling of decaying phytoplankton. Collection of spring chlorophyll samples could provide comparison with summer readings and clarify whether these conditions also exist during the spring. No significant pH or chlorophyll trends were noted.

Overall Assessment and Identified Data Gaps:
Icehouse Pond water quality conditions generally show impaired conditions compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. Management of the water quality in the pond should focus on phosphorus management to manage summer blooms and hypoxia of bottom waters. Given that Icehouse Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context and provide a reliable basis for development of management options. The primary data gaps appear to be information about the: a) characterization of available sediment nutrients, including core collection and incubation, b) the persistence of low dissolved oxygen conditions near the sediments through the installation of a continuous recording device, c) survey of phytoplankton population dynamics and rooted plant coverage now and in the past, d) characterization of the hydroconnection to Town Cove (*e.g.*, water flow and nutrient mass leaving the pond), e) assessment of the presence of freshwater mussels if sediment management is considered and f) measurement of direct stormwater inputs, if any are identified, as a potentially significant phosphorus source with clear management options. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of an Icehouse Pond Management Plan. It is anticipated that access, the role of the adjacent pond, and the role of legacy land uses will also be significant issues in the Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Icehouse Pond because of the increase in impairments measured in the pond during the summer. Sampling in Icehouse Pond in April and August/September should continue to follow PALS protocols.

Table III-7. Icehouse Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	6.00			6.10		5.89			
N	45			12		19			
Max	6.54			6.54		6.25			
Min	5.10			5.60		5.10			
Secchi Depth									
Average (m)	4.15			4.53		3.62		<	
N	48			13		21			
Max	5.80			5.80		4.92			
Min	2.64			3.35		2.64			
Temperature: MassDEP Warm Water Maximum = 28.3°C									
Average (°C)	19.69	21.00	17.56	15.62	12.45	23.81	20.93	>	>
N	293	47	52	13	13	21	27		
Max	28.20	28.20	26.10	23.00	15.80	26.90	26.10		
Min	10.10	11.80	10.10	11.80	10.10	19.20	16.10		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	6.96	8.06	4.20	9.40	7.86	7.15	2.40	<	<
N	300	48	53	13	13	21	27		
Max	10.99	10.60	10.82	10.60	10.82	8.60	6.65		
Min	0.12	6.13	0.12	7.25	0.33	6.13	0.14		
N < 5 mg/L DO	42	0	29	0	2	0	21		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.34	6.42	6.25	-	-	6.42	6.25		
N	34	17	16	0	0	17	16		
N < 6.5 pH	26	11	15	-	-	11	15		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	14.37	4.23	27.58	-	-	4.36	27.58		
N	41	21	18	0	0	20	18		
Max	159.67	13.90	159.67	-	-	13.90	159.67		
Min	0.91	1.11	0.91	-	-	1.11	0.91		
N > 1.7 µg/L	34	16	17	-	-	15	17		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	15.16	13.67	16.76	15.36	18.27	14.15	17.54		
N	77	39	36	10	9	22	20		
Max	73.41	45.40	73.41	45.40	47.50	41.13	73.41		
Min	3.77	3.77	4.90	4.45	4.90	3.77	5.00		
N > 10 µg/L	56	26	28	6	7	17	16		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.45	0.41	0.49	0.36	0.39	0.44	0.55	>	>
N	77	39	36	9	9	23	20		
Max	1.31	0.62	1.31	0.43	0.58	0.62	1.31		
Min	0.23	0.23	0.27	0.29	0.28	0.24	0.27		
N > 0.31 mg/L	68	34	32	7	7	22	19		

III.H. Kettle Pond

Kettle Pond (PALS# OR-147) is a 1.2 acre pond located just to the east of Kettle Pond Way and north of Finlay Road (see **Figure I-1**). Review of historic aerial photographs show that a cranberry bog was located approximately 30 m to its southeast, but has since grown in. The 1944 USGS quadrangle shows a hydroconnection to the bog and another hydroconnection to the wetland system south of Finlay Road. Kettle Pond is within the Town Cove watershed of the larger Nauset Marsh Estuary watershed. Given that its area is less than 10 acres, it is not considered a public pond under Massachusetts law.

Water quality data in the pond was generally collected in the PALS Snapshots between 2002 and 2014 (missed in 2012) and was not sampled in 2015 or 2016. Other summer monitoring has been limited to a few snapshots in couple of years and spring sampling occurred in 2007, 2008, 2010, and 2011. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including average summer anoxia at 1 m. Kettle Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Kettle Pond sampling station was 1.97 m (n=17). Mean average Secchi transparency depth was 0.32 m (n=18) and 17% (n=18) of the total depth (**Table III-8**). Average mean summer total depth and Secchi depth were less than corresponding mean spring depths, but not significantly different. No significant trends were noted in total depth, Secchi depth, or % Secchi depth.

Comparison of data to MassDEP numeric standards showed that impaired dissolved oxygen conditions generally persist from May through September and that the pond was naturally acidic. All but 2 of the 40 dissolved oxygen concentrations were less than the MassDEP warm water minimum of 5 mg/L. Shallow readings had a mean average DO concentration of 3.11 mg/L (n=17), while deep readings (average depth of 1.2 m) had a mean average of 1.22 mg/L (n=20). Seasonal deep mean average concentrations were significantly less than surface means during both the spring and summer, but spring mean averages at both shallow and deep depths were not significantly different than corresponding summer mean averages. No significant DO trends were noted. All of the pH readings (n=23) were naturally acidic and less than the MassDEP minimum of 6.5 with the overall mean average of 5.11.

Review of temperature readings in Kettle Pond show that it was generally colder than expected for such a shallow pond. Mean average deep water temperatures during both the spring and summer were significantly less than shallow mean average temperatures and the majority of all readings (80%) in the pond were less than the MassDEP cold water category limit (20°C). Summer shallow and deep mean average temperatures were significantly higher (19.51°C and 17.61°C, respectively) than corresponding spring mean temperatures (15.93°C and 11.73°C, respectively). It should be noted, however, that spring readings were fairly limited (n=4). These colder than expected temperatures are somewhat similar, though not as extreme, as those measured in Boland Pond, which is approximately 500 m to the northwest and approximately 3 m deeper. It raises a question of whether similar hydrogeologic controls are regularly bringing cooler groundwater from deeper flow paths into these ponds. Installation of continuous temperature recorders from spring to summer would help to clarify how stable these conditions are and how often water column mixing events occur. No significant temperature trends were noted.

Review of nutrient data showed very high concentrations, evidence of summer sediment nutrient regeneration, and some alteration in the relationship between phosphorus and nitrogen. Shallow and deep mean average total phosphorus (TP) and total nitrogen (TN) were not significantly different during the spring, summer, or overall. However, summer TP and TN mean average concentrations were significantly higher than corresponding spring mean averages. Summer shallow and deep TP mean average concentrations were 201 µg/L (n=15) and 214 µg/L (n=11), respectively, while the corresponding spring mean average concentrations were 63 µg/L (n=4) and 60 µg/L (n=2), respectively. TN means averages had a similar pattern. It should be noted that spring mean averages are based on a small number of samples (n<5). These differences indicate significant sediment regeneration appears to be influence more significantly by increased summer warmth than low DO concentrations, since low DO was pervasive in both spring and summer readings. More extensive spring DO readings and/or continuous DO recording may show that changes in DO concentrations also play a role. All available TP and TN concentrations were above their respective Cape Cod Ecoregion thresholds. No significant trends were noted in the overall TN or TP concentration datasets.

Although there were no statistically significant trends in the TP or TN concentration, their comparison, N:P ratios, showed a significantly decreasing trend in shallow waters. Overall, N:P ratios averaged just above the Redfield ratio threshold; mean average shallow N:P ratio was 23.2 (n=20), while the deep mean average was 19.1 (n=13). The surface ratio had a significant decrease of -1.08 per year, while the deep ratio had no significant trend. As noted, neither TN or TP had significant trends over the whole dataset, but further exploration of just the August/September readings TP readings showed a significant increasing trend (+9.6 µg/L) over the period of record, while corresponding TN concentrations showed no trend. This increase in TP concentrations, which occurs extensively in the summer, appears to be pushing the N:P ratios closer to the Redfield ratio threshold. Since the ratio in Kettle Pond was so close to the Redfield ratio threshold, strategies for management of water quality should address both TP and TN sources.

Chlorophyll and pH readings were only collected during the summer season, so seasonal comparisons were not available. As mentioned above, all of the pH readings were below the MassDEP minimum of 6.5, which would generally be expected in most naturally acidic Cape Cod ponds. Mean shallow and deep pH readings were not significantly different. With the high measured nutrient concentrations, it would be expected that chlorophyll concentrations would be very high and most (83%) of the individual chlorophyll concentrations were higher than the 1.7 µg/L Cape Cod Ecoregion threshold. Shallow and deep mean chlorophyll concentrations were not significantly different (10.69 µg/L; n=14 and 8.67 µg/L; n=10, respectively). No significant pH or chlorophyll trends were noted in summer only readings (Kettle Pond pH and chlorophyll readings are only available through August and September PALS Snapshots).

<u>Overall Assessment and Identified Data Gaps:</u>
Kettle Pond water quality conditions generally show impaired conditions due to nutrient over-enrichment compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds.

Management of the water quality in the pond should focus on both phosphorus and nitrogen management. Given that Kettle Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context and provide a reliable basis for development of management options. The primary data gaps appear to be information about the: a) characterization of available sediment nutrients, including core collection and incubation, b) triggers for sediment nutrient regeneration through measurement of continuous DO and temperature, c) if hydroconnections still exist, continuous measurement of flow with accompanying monthly sampling of water quality to determine export of water and mass of nutrients and its role in the nutrient and hydrologic budgets, c) a survey of plant communities (both rooted macrophytes and phytoplankton) to determine the extent of their role in creating the measured water quality data, d) survey for the presence of freshwater mussels given the role sediments seem to play in nutrient loads and e) measurement of direct stormwater inputs, if any are identified, as a potentially significant phosphorus source with clear management options. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of an Kettle Pond Management Plan. It is anticipated that access, the role of the adjacent pond, and the role of legacy land uses will also be significant issues in the Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Kettle Pond because of the increase in impairments measured in the pond during the summer. Sampling in Kettle Pond in April and August/September should continue to follow PALS protocols.

Table III-8. Kettle Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	1.97			2.41		1.84			
N	17			4		13			
Max	2.80			2.80		2.30			
Min	1.37			1.80		1.37			
Secchi Depth									
Average (m)	0.32			0.46		0.28			
N	18			4		14			
Max	0.75			0.75		0.40			
Min	0.18			0.30		0.18			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	17.22	18.66	16.44	15.93	11.73	19.51	17.61	>	>
N	40	17	20	4	4	13	16		
Max	20.70	20.70	20.10	16.50	13.80	20.70	20.10		
Min	9.70	15.00	9.70	15.00	9.70	17.30	12.20		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	2.09	3.11	1.22	4.44	1.08	2.70	1.26		
N	40	17	20	4	4	13	16		
Max	6.14	6.14	3.78	6.14	2.98	4.35	3.78		
Min	0.07	1.22	0.07	2.22	0.24	1.22	0.07		
N < 5 mg/L DO	38	15	20	2	4	13	16		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	5.11	5.13	5.08	-	-	5.13	5.08		
N	23	13	10	0	0	13	10		
N < 6.5 pH	23	13	10	-	-	13	10		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	9.85	10.69	8.67	-	-	10.69	8.67		
N	24	14	10	0	0	14	10		
Max	44.50	44.50	41.57	-	-	44.50	41.57		
Min	0.03	0.88	0.03	-	-	0.88	0.03		
N > 1.7 µg/L	20	13	7	-	-	13	7		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	172.04	165.33	181.61	63.03	60.09	201.30	214.64	>	>
N	34	20	14	4	2	15	11		
Max	314.52	294.64	314.52	74.13	62.95	296.64	314.52		
Min	35.11	35.11	57.23	56.12	57.23	100.00	89.82		
N > 10 µg/L	34	20	14	4	2	15	11		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	1.69	1.62	1.80	0.66	0.61	1.89	2.00	>	>
N	35	20	15	4	2	15	12		
Max	2.81	2.29	2.81	0.81	0.76	2.29	2.81		
Min	0.45	0.53	0.45	0.53	0.45	1.36	1.29		
N > 0.31 mg/L	35	20	15	4	2	15	12		

III.I. Meadow Bog Pond

Meadow Bog Pond (PALS# OR-256) is a 2.9 acre pond located just to the east of Quanset Road and south of Sarahs Pond (see **Figure I-1**). It has a hydroconnection via a culvert under Quanset Road to a salt pond, Quanset Pond, which is part of the Pleasant Bay estuary. Review of historic aerial photographs suggest an intermittent hydroconnection to Sarahs Pond, but further field visits in a variety of high and low groundwater conditions would be necessary to further evaluate this connection. The historic 1944 USGS quadrangle does not show a connection between Meadow Bog Pond and either Sarahs Pond or the Quanset Pond estuary. Limited salinity data from selected water quality snapshots showed occasional salinity (maximum = 4 ppt) at the culvert with most readings having no salinity (<0.1 ppt), so there is likely occasional limited tidal connection. Meadow Bog Pond is within Pleasant Bay MEP watershed, the Pleasant Bay ACEC, and is a designated Massachusetts Natural Heritage Priority Habitat. Given that its area is less than 10 acres, it is not considered a public pond under Massachusetts law.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling between 2003 and 2016. Review of collected data in the 2007 Orleans Ponds Report showed that the pond regularly had impaired conditions, including shallow DO concentrations well above atmospheric equilibrium (>114%) and a mean average deep DO concentration less than the MassDEP minimum. Meadow Bog Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Meadow Bog Pond sampling station was 1.52 m (n=50). Mean average Secchi transparency depth was 1.03 m (n=48) and 69% (n=49) of the total depth (**Table III-9**). Mean average total depth did not vary with season, but mean average Secchi depth and % Secchi depth were both significantly lower in the summer than in the spring. No significant trends were noted in total depth, but Secchi depth and % Secchi depth had significant increasing trends (+0.03 m/yr and +2% per year, respectively) between 2001 and 2016.

Comparison of data to MassDEP numeric standards show significant sediment oxygen demand and high saturation levels, as well as unusually high pH readings. Shallow dissolved oxygen concentrations were generally above the MassDEP minimum, but the majority (52%) of deep summer DO concentrations were less than the MassDEP minimum. Although shallow readings were above the MassDEP minimum, a high percentage (29%) of the DO % saturation levels were above 120% of atmospheric equilibrium. DO saturation levels above 120% are usually associated with an extensive plant population (phytoplankton and/or rooted plants) regularly adding more DO via photosynthesis than can be vented to the atmosphere. These high saturation levels are typically a sign of impaired conditions. Not surprisingly, the shallow summer average mean DO concentration was significantly greater than the deep mean average concentration. All of the pH readings (mean 7.72; n=32) were greater than the MassDEP minimum of 6.5, which is unlike most of the other ponds on Cape Cod. No significant DO trends were noted.

Review of temperature readings in Meadow Bog Pond showed a well-mixed water column with significantly higher temperatures in summer compared to spring. Shallow and deep mean averages temperatures during spring and summer were not significantly different, but comparison between seasons showed summer shallow and deep mean temperatures were significantly higher [24.10°C (n=23) and 24.03°C (n=23), respectively] than corresponding spring mean temperatures [18.20°C (n=12) and 17.92°C (n=10), respectively]. Although these readings indicate similar temperatures throughout the water column on average, occasional profiles showed warmer temperatures in the deeper waters. This condition is likely related to high tides allowing warmer high salinity estuary waters to flow into the pond. Because of the greater density of saline waters, these waters would settle to the bottom of the pond and their relatively warmer temperatures result in a bit of a temperature inversion. Since the average temperatures showed similar readings throughout the water column, these temperature inversions generally appear to be temporary. Continuous recording of temperatures would help to clarify the frequency and impact of these saline additions. No significant temperature trends were noted.

Review of nutrient data showed very high concentrations and some evidence of year-round sediment nutrient regeneration. All of the TP concentrations and most (92%) of the TN concentrations exceeded their respective Cape Cod Ecoregion thresholds. Deep average mean TP and TN concentrations were generally higher than shallow average means, but not significantly. Shallow summer mean TP and TN concentrations were significantly higher than the corresponding spring shallow means averages, but seasonal deep readings were not significantly different. The higher shallow summer concentrations may be due to increased watershed inputs or may be an artifact of the higher number of summer readings (n=20) vs the limited number of spring readings (n=7). Further resolution of these differences would require either additional spring readings over a number of years or more intensive monitoring during one or two years. No significant trends were noted in the overall shallow or deep TN or TP concentrations.

Review of N:P ratios suggested that while phosphorus was the key nutrient for managing water quality, management of nitrogen should also be a concern. The overall N:P ratio mean average was 31, which is slightly less than 2X the Redfield ratio threshold. Typically freshwater ponds have ratios that are 3X-6X the Redfield threshold, so this lower average may be due to the occasional inputs of saline water. Estuarine waters from Pleasant Bay would be relatively phosphorus-enriched compared to a freshwater pond and have N:P ratios below the Redfield threshold. Mean average N:P ratios in Meadow Bog Pond were not significant different with depth or with season and no significant trends were noted. Management discussions should clarify whether these occasional saline inputs are desired; if the current configuration is maintained, management of Meadow Bog Pond should include reductions in both nitrogen and phosphorus.

Chlorophyll and pH readings were only collected during the summer season, so seasonal comparisons were not available. As mentioned above, all of the pH readings were above the MassDEP minimum of 6.5 and most (75%) were above 7. Most Cape Cod ponds are naturally acidic; a freshwater pond with a basic pH is relatively novel. There was no significant difference in shallow and deep mean averages. High photosynthesis activity usually results in increased pH and the chlorophyll readings tend to very high. Almost all (95%) of all chlorophyll concentrations were higher than the 1.7 µg/L Cape Cod Ecoregion threshold. As with pH readings, only summer chlorophyll readings were available (i.e., PALS Snapshot only), so comparison to spring conditions is not available. Shallow and deep mean summer chlorophyll concentrations were not significantly different (38.88 µg/L; n=19 and 39.85 µg/L; n=14, respectively), which again suggests a well-mixed water column. No significant chlorophyll or pH trends were noted.

Overall Assessment and Identified Data Gaps:

Meadow Bog Pond water quality conditions generally show impaired conditions from excess nutrients compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. Management of the water quality in the pond should focus on both phosphorus and nitrogen management to manage current phytoplankton blooms and bottom water hypoxia in this shallow pond. Given that Meadow Bog Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context. The primary data gaps appear to be information about the: a) measurement of sediment contributions of nutrients, including core collection and incubation, b) characterization and measurement of flows and nutrient loads of connections to both Sarahs Pond and the Quanset Pond estuary, c) triggers for sediment nutrient regeneration through measurement of continuous DO and temperature (devices should also measure salinity and chlorophyll), d) a survey of plant communities (both rooted macrophytes and phytoplankton) to determine the extent of their role in creating the measured water quality data, e) assessment of the presence of freshwater mussels given the role sediments seem to play in nutrient loads and f) measurement of direct stormwater inputs, if any are identified, as a potentially significant phosphorus source with clear management options. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of a Meadow Bog Pond Management Plan. It is anticipated that the height of the bottom of the culvert under Quanset Road will also present significant issues in the Management Plan, so it is important that the flow through this culvert be characterized.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Meadow Bog Pond because of the increase in impairments measured in the pond during the summer. Sampling in Meadow Bog Pond in April and August/September should continue to follow PALS protocols.

Table III-9. Meadow Bog Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	1.52			1.49		1.53			
N	50			10		23			
Max	1.96			1.95		1.96			
Min	0.99			0.99		1.05			
Secchi Depth									
Average (m)	1.03			1.23		0.94		<	
N	48			10		22			
Max	1.83			1.75		1.83			
Min	0.23			0.80		0.29			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	22.79	22.40	22.42	18.20	17.92	24.10	24.03	>	>
N	134	52	51	12	10	23	23		
Max	32.20	28.50	32.20	21.10	25.20	28.50	30.00		
Min	11.80	12.30	11.80	14.80	11.80	18.40	19.40		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	7.92	9.30	6.81	10.08	10.44	8.02	5.36	<	<
N	133	53	49	13	9	23	23		
Max	15.45	15.30	15.45	13.48	15.13	15.30	13.00		
Min	0.10	2.91	0.10	8.17	0.38	2.91	0.10		
N < 5 mg/L DO	28	2	19	0	1	2	12		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	7.72	7.84	7.74	-	-	7.84	7.74		
N	32	16	13	0	0	16	13		
N < 6.5 pH	0	0	0	-	-	0	0		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	38.12	34.63	40.40	-	-	38.88	39.85		
N	41	23	15	0	0	19	14		
Max	155.07	155.07	96.25	-	-	155.07	96.25		
Min	0.01	0.01	1.42	-	-	2.90	1.42		
N > 1.7 µg/L	39	22	14	-	-	19	13		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	67.14	58.07	85.79	36.72	131.83	70.10	81.89	>	
N	63	31	24	7	3	20	15		
Max	341.03	164.33	341.03	49.87	341.03	164.33	162.75		
Min	11.46	12.03	14.97	17.39	26.73	20.47	31.05		
N > 10 µg/L	63	31	24	7	3	20	15		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.85	0.77	0.95	0.46	0.97	0.96	1.11	>	
N	64	31	25	7	3	20	16		
Max	2.23	1.97	2.23	0.62	2.18	1.97	2.23		
Min	0.01	0.28	0.01	0.28	0.36	0.55	0.66		
N > 0.31 mg/L	59	28	23	6	3	20	16		

III.J. Pilgrim Lake

Pilgrim Lake is a 46-acre pond located west of Arey's Land and east of Monument Road (see **Figure I-1**). It has a fairly complex bathymetry with an island in the middle, and four relatively deep basins: two deeper than 9 m, another at least 7.5 m deep, and another at least 6 m deep.[46] It has a herring run connected to Lonnie's (Kescayogansett) Pond, which was monitored for flow and water quality in 2002-2003 as part of the Pleasant Bay MEP assessment and is currently being monitored as part of the Enhanced Aquaculture demonstration project in Lonnie's Pond. The historic 1944 USGS quadrangle also shows this connection. Pilgrim Lake is within Pleasant Bay MEP watershed and the Pleasant Bay ACEC. As a surface water body with an area greater than 10 acres, it considered a public Great Pond under Massachusetts law and is listed in the most recent version of the MassDEP Integrated List as a Category 3 water ("no uses assessed").[47] If water quality in Pilgrim Lake was classified as impaired, a TMDL would be required under the federal Clean Water Act to determine an appropriate level of pollutant(s) to remove the impairment.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling. Pilgrim was also part of town-supported summer-long sampling in 2001 and was selected for additional assessment in the 2007 Orleans Ponds Report.[48] The additional assessment in 2007 included a watershed delineation, determination of water and nutrient budgets, and a more detailed review of the available water quality data. It was noted in this report that there were 17 single family residences upgradient of the pond and that the water residence time was approximately 6 months. The Ponds Report also noted that pond water quality was largely determined by phosphorus inputs, the pond thermally stratified without well-defined hypolimnion during the summer, and anoxic conditions regularly occurred below 5 m depth. It was also noted that the thin hypolimnion created only a very small cold water habitat; the review compared DO concentrations to both warm water or cold water MassDEP minimum DO concentrations.

Data in the Orleans Pond and Lake unified database found that the average depth at the Pilgrim Lake sampling station was 8.65 m (n=36). Mean average Secchi transparency depth was 3.92 m (n=50) and 43% (n=36) of the total depth (**Table III-10**). Mean average total depth, Secchi depth, and % Secchi depth were not significantly different in spring and summer. No significant trends were noted in the overall dataset for these measures, but there was a significant decreasing trend in September Secchi readings (-0.13 m per year; n=13). August Secchi readings did not have a significant trend.

Comparison of data to MassDEP numeric standards show that deep conditions during both spring and summer were generally impaired and the pond was naturally acidic. All DO concentrations in the upper portions of the water column were above the MassDEP warm water minimum of 5 mg/L; overall mean average shallow and 3 m DO concentrations were 8.37 mg/L and 8.31 mg/L, respectively. The mean average deep DO concentration was 2.20 mg/L (n=54) with 83% of all deep readings below the MassDEP minimum. The spring deep mean average

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[46] See bathymetric map in Orleans Ponds report

[47] Massachusetts Department of Environmental Protection. December 2015. Massachusetts Year 2014 Integrated List of Waters.

[48] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. pp. 36-42.

(4.66 mg/L DO; n=9) was significantly higher than the summer deep mean average DO concentration (1.25 mg/L DO; n=27). Both spring and summer deep mean averages were significantly lower than corresponding shallow or 3 m mean averages and all spring mean averages (shallow, 3 m, and deep) were significantly higher than the corresponding summer mean averages. Most of the pH readings (84%) were above the MassDEP minimum of 6.5 and more than half (59%) were less than 7. No significant trends were noted in DO.

Review of temperature readings show that waters 7 m and deeper generally meet the MassDEP cold water habitat criteria (20°C or less[49]), but given the complexity of the bottom, it is unclear whether this characteristic occurs in all three of the deepest basins. Spring and summer deep mean average temperatures were less than 20°C: 11.2°C (n=9) and 15.4°C (n=27), respectively. Summer surface, 3 m, and deep mean average temperatures were significantly higher than the corresponding spring mean averages. Deep temperatures have a significant increasing trend (+0.19°C per year) between 2001 and 2016. This trend is likely due to warmer spring temperatures and/or later stratification; further data review of individual temperature profiles and continuous recording of temperature at various depths from the spring to summer could clarify how temperature stratification sets up and is maintained. These data gap surveys could be completed during development of a Pilgrim Lake management plan. Shallow temperatures did not have a notable trend between 2001 and 2016.

Review of nutrient data showed concentrations above Cape Cod thresholds and evidence of summer sediment nutrient regeneration. Overall mean average shallow TP concentrations and mean averages during both spring and summer were above the 10 µg/L Cape Cod Ecoregion threshold. Spring shallow and deep mean average TP concentrations were not significantly different (n=8), but the summer deep mean average was significantly greater (37.4 µg/L; n=21) than mean averages at shallow and 3 m depths (14.6 µg/L and 14.32 µg/L, respectively) indicating sediment regeneration. Among all the shallow TP concentrations, 60% (27 of 45) exceeded the ecoregion threshold. Mean TN averages had a similar pattern with deep summer concentrations significantly higher than shallow concentrations and no significant differences between mean average spring concentrations. Trend analysis of nutrient concentrations indicated both increasing and decreasing trends. Shallow TN concentrations had no notable trend, but deep TN concentrations had a significant decreasing trend (-0.07 mg/L per year) between 2001 and 2016. This decreasing trend may be due to increasing denitrification related to the deep temperature rise noted above; further exploration of this could occur during sediment data collection for a pond management plan. Shallow TP, on the other hand, had a significant increasing trend (+0.7 µg/L per year). Further review of the data noted that this may be an artifact of extremely low concentrations reported from the NPS lab during 2001/2002. Analysis of surface TP data from 2002 to 2016 showed no significant trend. In any event, review of the nutrient data clearly indicated the role of sediment regeneration in Pilgrim Lake.

Review of N:P ratios showed that water quality in Pilgrim Lake was determined more by phosphorus than nitrogen; average surface ratios were 5X to 6X the Redfield ratio. Mean average deep ratios were lower than surface ratios during both the spring and summer, but generally not significantly different. Summer mean average surface ratios were greater than spring ratios at shallow and 3 m depths, but again, not significantly different. Summer deep

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[49] MassDEP standards require a 7 day average of less than 20°C (314CMR4.05(b)2.), but that would require more refined monitoring than has been completed to date.

mean average ratio was lower than the spring deep mean average due to the increased summer TP sediment regeneration. No significant trends were noted in the N:P ratio data.

Chlorophyll and pH readings were generally only collected during the summer season, so seasonal comparisons were not available. As mentioned above, only 16% of the pH readings were below the MassDEP minimum of 6.5 with most of the readings below 6.5 in the deep waters. The deep summer mean average pH reading was 6.58 (n=19) and this was significantly less than the shallow summer mean average (6.99; n=20). These pH readings are higher than those measured in most Cape Cod ponds and are likely due to high photosynthesis activity, which causes pH to rise. Mean average summer surface chlorophyll concentration was >3X the 1.7 µg/L Cape Cod Ecoregion threshold indicating a significant phytoplankton population. Mean average deep summer chlorophyll concentration was >11X the threshold and significantly greater than the surface mean average concentrations indicating significant settling of degrading phytoplankton and likely regeneration of associated nutrients. Collection of phytoplankton throughout the summer with accompanying chlorophyll monitoring would help clarify population dynamics and how this might impact management strategies. No significant chlorophyll or pH trends were noted. Clarification of the role of plants (both phytoplankton and rooted plants) in determining measured water quality should be determined in development of a Pilgrim Lake management plan.

<u>Overall Assessment and Identified Data Gaps:</u>
Pilgrim Lake is a Great Pond with no uses assessed by MassDEP. Based on the data reviewed in this report, the lake is a Great Pond that is not meeting MassDEP minimum standards. As such, Pilgrim Lake will eventually need to have a TMDL prepared due to its nutrient enriched condition and bottom water hypoxia. Development of a Pilgrim Lake Management Plan could address both development of a TMDL and management strategies to restore the pond and resolve the indicated impairments.

Preparation of a management plan will require addressing data gaps in order to provide proper context for the available water quality data and to prepare reliable management options. Pilgrim Lake was prioritized by the Town Pond Working Group to address data gaps in FY2018 (June 2017 to June 2018). CSP/SMAST was asked to prepare a scope of work to address sediment, plant, and water quality data gaps and the funding article passed in the May 2017 Town Meeting. Data gap activities are proposed to include a) collection and incubation of sediment cores to measure both potential nutrient regeneration and conditions that trigger regeneration, b) a survey of plant communities (both rooted macrophytes and phytoplankton) to determine the extent of their role in creating the measured water quality data, c) a freshwater mussel survey given the likely role of sediment in determining water quality conditions and its management being a likely component of an overall water quality management plan, and d) continuous monitoring using an automated device to evaluate conditions that lead to deep hypoxia and their persistence. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or nearby residents.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluation of the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Pilgrim Lake because the impairments measured in the pond have been intensified during the summer. Sampling in Pilgrim Lake in April and August/September should continue to follow PALS protocols.

Table III-10. Pilgrim Lake Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.								
	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	Dee p
Total Depth									
Average (m)	8.65			8.39		8.53			
N	36			8		18			
Max	10.00			9.30		10.00			
Min	6.45			7.55		6.45			
Secchi Depth									
Average (m)	3.92			3.73		3.78			
N	50			10		23			
Max	6.00			5.60		5.58			
Min	1.76			2.15		1.76			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	18.55	21.02	13.61	16.24	11.21	23.31	15.44	>	>
N	453	51	53	10	9	23	27		
Max	26.40	26.40	22.60	21.90	13.20	26.10	22.60		
Min	9.40	10.40	9.40	10.70	9.40	18.80	10.40		
Dissolved Oxygen: MassDEP Regulatory Minimum = 5 mg/L									
Average (mg/L)	6.55	8.37	2.20	9.92	4.66	7.78	1.25	<	<
N	451	50	54	10	9	23	27		
Max	11.80	11.61	11.80	11.61	11.80	9.00	7.17		
Min	0.04	6.18	0.04	8.85	1.20	6.18	0.05		
N < 5 mg/L DO	111	0	45	0	6	0	25		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.87	7.02	6.59	6.84	6.43	6.99	6.58		
N	70	25	24	1	1	20	19		
N < 6.5 pH	11	2	9	0	1	2	7		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	10.23	5.44	18.73	4.69	-	5.76	19.68		
N	62	25	17	1	0	21	16		
Max	78.76	15.17	78.76	-	-	15.17	78.76		
Min	0.01	0.01	3.56	-	-	0.01	4.01		
N > 1.7 µg/L	58	22	17	1	-	19	16		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	17.63	12.50	25.40	14.03	16.42	14.56	37.36		
N	127	45	42	8	8	24	21		
Max	223.32	46.60	223.32	46.60	45.20	44.93	223.32		
Min	0.50	0.50	0.50	4.02	5.25	0.50	0.50		
N > 10 µg/L	80	27	26	4	5	17	15		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.60	0.46	0.88	0.37	0.43	0.45	1.15		>
N	106	37	35	7	7	21	19		
Max	3.79	1.22	3.79	0.51	0.56	0.57	3.79		
Min	0.23	0.23	0.28	0.23	0.28	0.32	0.34		
N > 0.31 mg/L	100	35	34	6	6	21	19		

III.K. Reubens Pond

Reubens Pond (PALS# OR-123) is a 1.1 acre pond located southwest of Icehouse Pond, north of Hopkins Lane, and east of Captain Curtis Way (see **Figure I-1**). The historic 1944 USGS quadrangle shows the pond without any hydroconnections, but surrounded by a number of smaller ponds and wetlands. Review of historic aerial photographs often showed emergent plants on its surface and variable surface area, likely due to fluctuations in groundwater levels. Reubens Pond is within Town Cove MEP watershed. Given that its area is less than 10 acres, it is not considered a public pond under Massachusetts law and is not listed in the most recent MassDEP Integrated List.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2002 and 2016 with intermittent spring sampling since 2007. Review of collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including very high nutrient and chlorophyll concentrations. Reubens Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Reubens Pond sampling station was 1.02 m (n=20). Mean average Secchi transparency depth was very poor, 0.37 m (n=22) and 36% (n=20) of the total depth (**Table III-11**), due to the very high phytoplankton biomass in the water column. Mean average total depth and Secchi depth were significantly higher in the spring than in the summer. However, the summer and spring mean average % Secchi depth were not significantly different, indicating that Secchi depth and total depth tended to decrease at roughly the same rate. No significant trends were noted in total depth, Secchi depth or % Secchi depth between 2002 and 2016.

Comparison of data to MassDEP numeric standards shows acceptable DO concentrations with DO % saturation levels indicating impacts of sediment oxygen demand and naturally acidic pH readings. Given the shallow depth of Reubens Pond, only one or two temperature and DO readings were usually collected. The shallow depth means DO concentrations should be above the MassDEP minimum (5 mg/L) with % saturation levels near equilibrium with the atmosphere (~100% saturation). DO concentrations average 7.33 mg/L with no significant difference between spring and summer, but review of % saturation levels show they average 80%, which suggests sediment oxygen demand is reducing DO concentrations throughout the water column. All pH readings were less than the MassDEP minimum (6.5) with readings only collected during the PALS snapshots in August and September; the average mean pH reading was 5.86. No significant DO trends were noted.

Review of temperature readings in Reubens Pond showed a significant warming of the pond in summer. This warming should reduce % saturation DO levels, but the lack significant difference suggests that photosynthesis from rooted plant or phytoplankton community was boosting summer DO concentrations. Temperature readings would classify the pond as a warm-water system under MassDEP regulatory definitions. No significant temperature trends were noted.

Review of nutrient data showed very high concentrations and evidence of a summer increase in sediment nutrient regeneration. All of the TP and TN concentrations exceeded their respective Cape Cod Ecoregion thresholds. Summer TP and TN mean average concentrations were significantly greater than spring mean averages and approximately double the spring averages.

Summer TP mean average concentration (208 µg/L; n=18) was 20X the Cape Cod Ecoregion threshold, while summer TN mean average concentration (2.34 mg/L; n=19) was 7.5X its threshold. These summer increases suggest greater sediment regeneration and would generally be consistent with the depressed % saturation DO levels. More refined, continuous monitoring in the water column would be necessary to measure how near-sediment conditions change and encourage nutrient regeneration as the pond warms during the summer. No significant trends were noted in the overall TN or TP concentrations, but August/September TN concentrations showed a significant decreasing trend (-0.08 mg/L per year) between 2002 and 2016. This decrease may be due to decreased inputs or more denitrification due to slightly increasing (but not significantly) August/September temperatures.

Review of N:P ratios suggested that while phosphorus was the key nutrient for managing water quality, management of nitrogen should also be a concern. The overall N:P ratio mean average was 26.2, which only slightly greater than the Redfield ratio threshold. Typically freshwater ponds have ratios that are 3X-6X the Redfield threshold, so this lower average is likely due to the high phosphorus concentrations. Spring and summer mean average ratios were not significantly different, but the summer mean (24.8; n=19) was lower than the spring mean (33.1; n=4) which would be consistent with preferential TP sediment release during the summer.[50] The N:P ratios and high concentrations of both TP and TN suggest that management of Reubens Pond should include reductions in both nitrogen and phosphorus.

Chlorophyll and pH readings were only collected during the summer season, so seasonal comparisons were not available. As mentioned above, all of the pH readings were naturally below the MassDEP minimum of 6.5. With the high nutrient concentrations, it would be expected that chlorophyll concentrations would be very high. The mean average chlorophyll concentration (124.6 µg/L; n=16) was >70X the 1.7 µg/L Cape Cod Ecoregion threshold and all readings were above the threshold concentration. Since spring concentrations were not available, it is unclear whether these high chlorophyll concentrations are a summer occurrence or are sustained throughout the spring and summer. No significant chlorophyll trends were noted. There was a significant increasing trend in pH readings (+0.03 units per year), which usually is associated with increasing photosynthetic activity, but may be due to other changes since there was no chlorophyll trend. Collection of spring chlorophyll and pH readings and continuous measurements throughout a summer would help to provide better context for the water column data.

Overall Assessment and Identified Data Gaps:

Reubens Pond water quality conditions generally show impaired conditions compared to Cape Cod Ecoregion thresholds, but not MassDEP regulatory standards. Nutrient and resulting chlorophyll concentrations were exceptional high. Management of the water quality in the pond should focus on both phosphorus and nitrogen management to lower phytoplankton levels. Given that Reubens Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

[50] Phosphorus is typically regenerated from sediments at less prolonged hypoxia than nitrogen. It is also notable that the number of spring readings was small and results may vary as more data is collected

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context. The primary data gaps appear to be information about the: a) measurement of sediment contributions of nutrients, including core collection and incubation, b) potential role and extent of both phytoplankton and rooted plants completed by surveying rooted plants, phytoplankton changes throughout the summer, and continuous recording of chlorophyll, c) triggers for sediment nutrient regeneration through measurement of continuous DO, temperature, and water level at two depths, d) assessment of the presence of freshwater mussels given the role sediments seem to play in nutrient loads and e) measurement of direct stormwater inputs, if any are identified, as a potentially significant phosphorus source with clear management options. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of a Reubens Pond Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Reubens Pond because of the increase in impairments measured in the pond during the summer. Sampling in Reubens Pond in April and August/September should continue to follow PALS protocols.

Table III-11. Reubens Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	1.02			1.17		0.99		<	
N	20			4		16			
Max	1.20			1.20		1.15			
Min	0.80			1.12		0.80			
Secchi Depth									
Average (m)	0.37			0.53		0.32		<	
N	22			5		17			
Max	0.65			0.65		0.45			
Min	0.18			0.33		0.18			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	20.22			17.20		21.02		>	
N	24			5		19			
Max	24.20			19.00		24.20			
Min	14.90			14.90		18.30			
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	7.33			7.56		7.26		<	
N	24			5		19			
Max	10.03			9.96		10.03			
Min	5.68			6.25		5.68			
N < 5 mg/L DO	0			0		0			
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	5.86			-		5.86			
N	15			0		15			
N < 6.5 pH	15			-		15			
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	124.55			-		124.55			
N	16			0		16			
Max	276.74			-		276.74			
Min	10.68			-		10.68			
N > 1.7 µg/L	16			-		16			
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	178.28			79.17		208.53		>	
N	23			4		18			
Max	324.61			99.60		324.61			
Min	30.16			70.68		106.43			
N > 10 µg/L	23			4		18			
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	2.11			1.16		2.34		>	
N	24			4		19			
Max	3.70			1.58		3.70			
Min	0.84			0.84		1.13			
N > 0.31 mg/L	24			4		19			

III.L. Sarahs Pond

Sarahs Pond (PALS# OR-249) is a 5.8 acre pond located just to the east of Quanset Road, west of Davis Road and to the northeast of Meadow Bog Pond (see **Figure I-1**). It is the easternmost pond of an east/west line of shallow, small ponds in South Orleans that includes Twinings, Shoal, Deep and Uncle Seths. Review of historic 1943 quad map does not show any hydroconnections to adjacent ponds or wetlands, but review of historic aerial photographs suggests that during periods of high groundwater conditions, it may occasionally have a connection to Meadow Bog Pond. The aerial photos do not show extensive emergent rooted plants, but do show periods when the surface of the lake had apparent algal blooms. Sarahs Pond is within the Pleasant Bay MEP estuary watershed, the Pleasant Bay Area of Critical Environmental Concern (ACEC), and a designated Massachusetts Natural Heritage Priority Habitat. Given that its area is less than 10 acres, it is not considered a Great Pond under Massachusetts law and is not included in the latest MassDEP Integrated List.

Water quality data in Sarahs Pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2006 and intermittent spring sampling between 2003 and 2016. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including average deep summer DO concentrations less than the MassDEP regulatory minimum. Sarahs Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Sarahs Pond sampling station was 5.28 m (n=46). Mean average Secchi transparency depth was 2.75 m (n=49) and 52% (n=48) of the total depth (**Table III-12**). Average mean summer total depth was less than mean spring depth, but not significantly different. Summer mean Secchi depth, on the other hand, was significantly less (1.97 m; n=23) than the spring mean depth (3.89 m; n=11). The overall datasets for total depth, Secchi depth, and % Secchi depth had no significant trends between 2001 and 2016.

Comparison of data to MassDEP numeric standards show that deep water quality conditions in the pond were often impaired with more consistent summer impairments and that the pond is naturally acidic, but generally above the MassDEP minimum. All of the shallow dissolved oxygen concentrations were above the MassDEP warm water minimum of 5 mg/L with a mean average % saturation at atmospheric equilibrium (96%). However, most (77%) of the recorded deep DO concentrations were below the MassDEP minimum with an mean average deep summer DO concentration of 1.46 mg/L (n=22). Shallow and deep summer mean average DO concentrations were significantly less than spring averages and deep mean average concentrations were significant lower than shallow means during both spring and summer. Most of the pH readings (77%) were greater than the MassDEP minimum of 6.5 with the overall mean average of 6.79 (n=35). No significant trends were noted in the overall DO dataset.

Review of temperature readings show that the water column of Sarahs Pond generally has significantly colder deep waters, but deep waters were warm enough to place the pond in MassDEP's warm water category. Mean average spring shallow temperatures were significantly higher (17.17°C; n=11) than the deep mean average (12.68°C; n=12). Summer mean average temperatures were also significantly different and significantly higher than their corresponding spring mean averages (summer shallow = 25.06°C; n=22, summer deep = 19.80°C; n=21). Overall, 17 of the 47 deep temperature readings were above the MassDEP cold water maximum (20°C) and all of these readings occurred during the summer. The significant difference between shallow and deep mean averages suggest regular separation of shallow and deep waters, but review of individual temperature profiles also suggest that there are regular thermal mixing events. Installation of continuous temperature recorders would help to clarify how often these circumstances occur, how they develop, and how strong the resistance to thermal mixing is. No significant temperature trends were noted in the data between 2001 and 2016.

Review of nutrient data showed strong evidence of summer sediment nutrient regeneration with most individual readings above respective Cape Cod Ecoregion thresholds. Spring shallow and deep TN and TP mean average concentrations had no significant difference, but summer deep mean averages were significantly higher than summer shallow mean averages. Summer mean average shallow TP concentration was 22.7 µg/L (more than 2X the ecoregion threshold), while the summer mean average deep TP concentration was 59.2 µg/L. Summer mean average TN concentrations followed a similar pattern with the shallow mean average concentration (0.49 mg/L; n=40) half of the deep mean average concentration (0.99 mg/L; n=37). Overall, most of the recorded TP and TN concentrations during both the spring and the summer were above their respective Cape Cod Ecoregion thresholds. The only significant trend in the overall TN and TP datasets was a decreasing trend in deep TN concentrations (-0.07 mg/L per year). The cause of this trend is not readily discernable from the existing water quality data and would require some additional understanding of the sediments and their interaction with the deep waters to clarify.

N:P ratios showed water quality in Sarahs Pond was controlled by phosphorus. Average overall ratios were approximately 4X the Redfield ratio threshold at both shallow and deep depths; the shallow mean average N:P ratio was 60.5 (n=40). No significant differences were noted in the ratios by depth or by season. This lack of significant differences is consistent with the mean TP and TN concentrations which showed similar proportional increases with both depth and season. No significant trends were noted in the overall shallow or deep N:P ratios between 2001 and 2016.

Chlorophyll and pH readings were only collected during the summer season, so seasonal comparisons were not available. Most of the pH readings were above the MassDEP minimum of 6.5 with significantly higher shallow mean average than deep mean average. Photosynthesis tends to raise pH, so shallower areas, where light is more readily available, tend to have higher pH. The deep chlorophyll mean average concentration (50.35 µg/L; n=20) was significantly greater than the shallow mean average (18.73 µg/L; n=23) and 91% of all shallow chlorophyll concentrations were above the Cape Cod Ecoregion threshold (1.7 µg/L). Typically higher deep chlorophyll concentrations, especially in shallow ponds, are due to an active phytoplankton population with regular and extensive settling of decaying phytoplankton. Collection of spring chlorophyll samples could provide comparison with summer readings and clarify whether these conditions also exist during the spring. No significant chlorophyll or pH trends were noted.

Overall Assessment and Identified Data Gaps:

Sarahs Pond water quality conditions generally show impaired conditions due to nutrient enrichment compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. Nutrient and resulting chlorophyll concentrations were very high with resulting bottom water hypoxia. Management of the water quality in the pond should focus on phosphorus management. Given that Sarahs Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context. The primary data gaps appear to be information about the: a) measurement of sediment contributions of nutrients, including core collection and incubation, b) triggers for sediment nutrient regeneration through measurement of continuous DO, temperature and water level at two or more depths, c) characterization of the potential hydroconnection to Meadow Bog Pond and measurement of water and nutrient load if extensive, d) potential role and extent of both phytoplankton and rooted plants completed by surveying rooted plants, phytoplankton changes throughout the summer, and continuous recording of chlorophyll at the same time, e) assessment of the presence of freshwater mussels given the role sediments seem to play in nutrient loads and f) measurement of direct stormwater inputs, if any are identified, as a potentially significant phosphorus source with clear management options.. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of a Sarahs Pond Management Plan. It is anticipated that access and the role of legacy land uses will also be significant issues in the Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluation of the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Sarahs Pond because of the increase in impairments measured in the pond during the summer. Sampling in Sarahs Pond in April and August/September should continue to follow PALS protocols.

Table III-12. Sarahs Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	5.28			5.30		5.23			
N	46			11		22			
Max	5.70			5.69		5.41			
Min	4.85			4.85		4.85			
Secchi Depth									
Average (m)	2.75			3.89		1.97		<	
N	49			11		23			
Max	5.54			5.54		3.65			
Min	0.57			2.50		0.57			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	20.56	22.72	17.19	17.17	12.68	25.06	19.89	>	>
N	285	48	47	11	12	22	21		
Max	28.50	28.50	23.90	22.60	15.80	28.50	23.90		
Min	9.00	11.20	9.00	11.20	9.00	20.00	13.40		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	6.51	8.25	2.90	9.30	6.46	8.10	1.46	<	<
N	287	48	48	11	12	22	22		
Max	12.53	10.86	11.11	10.86	11.11	9.98	8.05		
Min	0.05	6.08	0.05	7.55	2.15	6.09	0.05		
N < 5 mg/L DO	73	0	37	0	4	0	20		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.79	6.98	6.60	-	-	6.98	6.60		
N	35	17	18	0	0	17	18		
N < 6.5 pH	8	2	6	-	-	2	6		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	34.82	18.73	50.35	-	-	19.29	49.90		
N	45	23	20	0	0	21	18		
Max	127.38	71.46	127.38	-	-	71.46	127.38		
Min	0.01	0.01	0.03	-	-	0.01	0.03		
N > 1.7 µg/L	42	21	19	-	-	19	17		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	40.03	22.68	59.19	15.89	23.09	27.96	81.09		>
N	78	40	37	6	6	24	22		
Max	227.37	73.44	227.37	44.60	57.40	73.44	227.37		
Min	5.24	5.24	6.19	5.24	10.46	6.19	6.19		
N > 10 µg/L	69	32	36	3	6	23	21		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.73	0.49	0.99	0.31	0.36	0.58	1.13	>	>
N	78	40	37	6	6	24	22		
Max	2.49	1.42	2.49	0.47	0.63	1.42	2.49		
Min	0.19	0.19	0.20	0.19	0.25	0.26	0.20		
N > 0.31 mg/L	64	31	32	3	3	22	21		

III.M. Shoal Pond

Shoal Pond (PALS# OR-253) is located just to the east of Route 28, north of Towhee Lane and between Deep Pond and Twinings Pond (see **Figure I-1**). Review of historic aerial photos show an occasional hydroconnection to Deep Pond, but a 1943 USGS quad map does not show any hydroconnections to adjacent ponds or wetlands. The aerial photos also show extensive emergent rooted plant coverage, persistently located in the eastern lobe, but occasionally covering most of the pond surface. Shoal Pond is within Pleasant Bay MEP estuary watershed and a designated Massachusetts Natural Heritage Priority Habitat. Its northern portion is within the Town of Orleans Water Department Zone II (*e.g.*, wellhead protection area).

The question of whether Shoal Pond is a Great Pond is somewhat open to debate because of the variety of ways its area has been delineated. The area of generally open water is approximately 8.5 acres and this is approximately the same area listed for Shoal Pond in the Cape Cod Pond and Lake Atlas, the area delineated in a historic 1943 USGS quad map, and the most recent USGS quad map of the area. However, the basin or depression in the land surface that includes this open water also includes the eastern lobe, which is usually covered with plants, but is often completely enclosed by pond water according to review of available historical aerial photographs. If this area is added to the open water area, the total area of Shoal Pond would be 10.5 acres. If the pond area exceeds 10 acres, Shoal Pond would be considered a public pond under Massachusetts law. Further clarification of this could be resolved by reviewing the plant communities and the substrate that they grow on within the eastern lobe. Shoal Pond is not included in the latest MassDEP Integrated List.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling between 2003 and 2016. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including mean average summer DO concentrations at both shallow and deep depths that were less than the MassDEP regulatory minimum. Shoal Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Shoal Pond sampling station was 1.91 m (n=45). Mean average Secchi transparency depth was 0.88 m (n=47) and 46% (n=46) of the total depth (**Table III-13**). Average mean summer total depth (2.19 m; n=10) was significantly less than mean spring depth (1.82 m; n=21), likely due to regular seasonal water table fluctuations. Summer mean Secchi depth also was significantly less (0.86 m; n=23) than the spring mean depth (1.22 m; n=10), but % Secchi readings were not significantly different suggesting that seasonal changes in Secchi and total depth tended to change by somewhat similar amounts. The overall datasets for total depth, Secchi depth, and % Secchi depth all had significant increasing trends between 2001 and 2016: total depth, +0.02 m per year; Secchi depth, +0.04 m per year; % Secchi, +1% per year. These trends suggest a localized increase in groundwater elevations, but the trend could be due changes in the hydroconnection. More refined review of this issue could occur during the development of a pond management plan.

Comparison of data to MassDEP numeric standards showed that water quality conditions throughout the water column in the pond were often impaired, with more consistent summer impairments, and that the pond was naturally acidic. The majority of shallow and deep DO concentrations were less than the MassDEP warm water minimum of 5 mg/L, though all spring readings were above minimum. The summer shallow mean average DO concentration was 3.63 mg/L (n=23) with a deep mean average concentration of 2.61 mg/L (n=27). Summer mean average concentrations at both depths were significantly less than their corresponding spring mean averages and shallow mean averages during both seasons were significantly greater than the deep mean averages. In the overall dataset, both shallow and deep, 63% of the 135 DO readings were less than the MassDEP minimum concentration. Installation of continuous DO recorders would help to clarify how low concentrations develop in the water column and how they are sustained during the summer. All of the pH readings were less than the MassDEP minimum of 6.5 with the overall mean average of 6.00 (n=31). Both shallow and deep % DO saturation had significant increasing trends between 2001 and 2016: +3% and +2% per year, respectively. Deep DO concentrations also had a significant increasing trend: +0.2 mg/L per year. The increasing trends in DO suggest increasing photosynthesis and plant growth; further clarification could be addressed through a rooted plant survey and measurement of the phytoplankton community throughout a summer with accompanying continuous recording of DO and chlorophyll levels.

Review of temperature readings show that the water column of Shoal Pond was generally well mixed. Surface and deep temperatures during both seasons were not significantly different, but surface temperatures were significantly higher in the overall dataset [shallow mean average temperature = 20.69 (n=47), while deep mean average temperature = 18.63 (n=53)]. Most of the summer shallow and deep temperatures were greater than the MassDEP cold water maximum, which would place the pond in MassDEP's warm water category. Summer shallow and deep mean average temperatures were significantly higher than their corresponding spring mean averages. Overall, temperatures readings showed a slight temperature gradient with depth, but usually insufficient differences to prevent mixing of the water column. Given the low DO concentrations, regular mixing would provide replenishment of oxygen demand. Because this was apparently no occurring, continuous measurement of temperature at a minimum of two depths at the same time as DO and chlorophyll are measured could help provide better context for the water column data and provide a more reliable basis for development of management strategies. No significant temperature trends were noted in the data between 2001 and 2016.

Review of nutrient data showed almost all individual readings above Cape Cod Ecoregion thresholds and some evidence of sediment nutrient regeneration. Spring and summer shallow and deep mean average TN and TP concentrations had no significant differences, but both seasons had higher deep averages for both nutrients with larger differences between shallow and deep TP mean averages. Summer mean averages were generally not significantly different from their spring counterparts except for deep summer TN mean average, which was significantly higher than the spring deep mean average. All TN concentrations (n=71) exceeded the Cape Cod ecoregion threshold of 0.31 mg/L, while 94% (67 of 71) TP concentrations exceeded the respective ecoregion threshold (10 µg/L). Given the general lack of significant nutrient differences and the low DO concentrations from April to September, these readings suggest a relatively consistent source of both nutrients. No significant trends were noted for TN or shallow

TP, but deep TP had a significant increasing trend (+1.5 µg/L per year) between 2001 and 2016. The cause of this trend is not readily discernable from the existing water quality data and would require some additional understanding of the sediments and their interaction with the deeper waters to clarify.

N:P ratios generally showed water quality in Shoal Pond was controlled by phosphorus. Average mean overall ratios were approximately 3X the Redfield ratio threshold at both shallow and deep depths; the shallow mean average N:P ratio was 53.4 (n=36). No significant differences were noted in the ratios by depth or by season. The deep seasonal average means were lower than the corresponding shallow means, which would be consistent with more phosphorus than nitrogen sediment regeneration. The lack of significant depth differences is consistent with the mean average TP and TN concentrations. No significant trends were noted in the overall shallow N:P ratios between 2001 and 2016, but the deep N:P ratios had a significant decreasing trend (-1.7 per year) which would also be consistent with the increasing trend in deep TP concentrations noted above.

Chlorophyll and pH readings were only collected during the summer season, so seasonal comparisons were not available. As mentioned above, all of the pH readings were less than the MassDEP minimum of 6.5, which would consistent with the naturally acidic pH of most of Cape Cod ponds and lakes. No significant difference was noted between the shallow and deep mean average pH readings. Mean average chlorophyll readings were also not significantly different in shallow and deep depths, but deep readings tended to be higher. Higher deep chlorophyll concentrations, especially in shallow ponds, are typically due to an active phytoplankton population with regular and extensive settling of decaying phytoplankton. The overall average mean chlorophyll concentration was 16.90 µg/L and almost all of the chlorophyll readings (35 of 37) were above the Cape Cod Ecoregion threshold of 1.7 µg/L. Collection of spring chlorophyll samples could provide comparison with summer readings and clarify whether these conditions also exist during the spring. No significant chlorophyll trends were noted, but both surface and bottom pH readings had the same significant increasing trends (+0.06 units per year) between 2001 and 2016. Since both pH trends were the same, these trends suggest similar factors throughout the water column creating these conditions and/or a consistently well-mixed water column. Clarification of this characterization could be resolved with the continuous temperature recording discussed above.

Overall Assessment and Identified Data Gaps:

Shoal Pond water quality conditions generally show impaired conditions compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds due to nitrogen and phosphorus levels and bottom water hypoxia. Nutrient and resulting chlorophyll concentrations were very high. Management of the water quality in the pond should focus on phosphorus management. The Great Pond status of Shoal Pond should be clarified: if it is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives; if it is a Great Pond, the Town may have to address additional MassDEP issues.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context. The primary data gaps appear to be information about the: a) measurement of sediment contributions of nutrients, including core collection and incubation, b) triggers for sediment nutrient regeneration through measurement of continuous DO, temperature and water level at two or more depths, c) characterization of the potential hydroconnection to Deep Pond and measurement of water and nutrient load if extensive, d) potential role and extent of both phytoplankton and rooted plants completed by surveying rooted plants, phytoplankton changes throughout the summer, and continuous recording of chlorophyll at the same time, e) assessment of the presence of freshwater mussels given the role sediments seem to play in nutrient loads and f) measurement of direct stormwater inputs, if any are identified, as a potentially significant phosphorus source with clear management options. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of a Shoal Pond Management Plan. It is anticipated that access and the role of legacy land uses will also be significant issues in the Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Shoal Pond because of the increase in impairments measured in the pond during the summer. Sampling in Shoal Pond in April and August/September should continue to follow PALS protocols.

Table III-13. Shoal Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	Deep	shallow	deep
Total Depth									
Average (m)	1.91			2.19		1.82		<	
N	45			10		21			
Max	2.48			2.48		2.15			
Min	1.20			1.80		1.20			
Secchi Depth									
Average (m)	0.88			1.22		0.86		<	
N	47			10		23			
Max	1.70			1.70		1.70			
Min	0.37			0.77		0.42			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	19.58	20.69	18.63	16.57	13.78	22.45	21.40	>	>
N	139	47	53	10	12	23	27		
Max	26.20	26.20	25.80	24.60	21.80	26.20	25.80		
Min	9.70	10.50	9.70	10.50	10.50	17.50	16.90		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	4.59	5.08	3.62	8.93	7.65	3.63	2.61	<	<
N	135	46	52	9	11	23	27		
Max	11.11	10.14	9.52	10.14	9.52	5.65	5.07		
Min	0.05	0.34	0.05	7.35	5.97	0.34	0.18		
N < 5 mg/L DO	85	25	38	0	0	18	26		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.00	6.00	5.99	-	-	6.00	5.99		
N	31	15	16	0	0	15	16		
N < 6.5 pH	31	15	16	-	-	15	16		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	16.90	14.43	20.14	-	-	12.58	20.14		
N	37	21	16	0	0	18	16		
Max	72.74	47.74	72.74	-	-	47.74	72.74		
Min	0.06	0.06	2.59	-	-	0.06	2.59		
N > 1.7 µg/L	35	19	16	-	-	17	16		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	35.08	32.68	37.56	33.51	40.12	35.20	41.37		
N	71	36	35	8	9	19	19		
Max	73.10	65.47	73.10	55.70	69.69	65.47	73.10		
Min	6.16	6.16	7.75	16.14	18.86	14.12	20.97		
N > 10 µg/L	67	34	33	8	9	19	19		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.74	0.74	0.74	0.66	0.60	0.82	0.83		>
N	71	37	34	8	8	20	20		
Max	1.18	1.10	1.18	1.07	0.82	1.10	1.18		
Min	0.37	0.43	0.37	0.45	0.42	0.56	0.47		
N > 0.31 mg/L	71	37	34	8	8	20	20		

III.N. Twinings Pond

Twinings Pond (PALS# OR-247) is located just to the east of Lake Drive, north of Twinings Lane and between Sarahs Pond and Shoal Pond (see **Figure I-1**). Review of historic aerial photos and a 1943 USGS quad map do not show any hydroconnections to nearby ponds. Twinings Pond is within Pleasant Bay MEP estuary watershed and a designated Natural Heritage Priority Habitat.

The question of whether Twinings Pond is a Great Pond is somewhat open to debate, much as it is for Shoal Pond, because of the variety of ways its area has been delineated. The MassDEP GIS wetlands coverage lists classifies an "open water" polygon of 10.2 acres, which is greater than the Great Pond threshold. The Cape Cod Pond and Lake Atlas excluded the westernmost lobe of the pond, which is often filled with emergent plants in aerial photographs, and stated the area of the pond was 9.1 acres. Review of historical photographs, currently available through Google Earth, show that this westernmost lobe is often inundated with no apparent evidence of emergent plants. The 1943 USGS quad includes this lobe in the area of the pond. If the pond area exceeds 10 acres, Twinings Pond would be considered a Great Pond under Massachusetts law. Further clarification of this could be resolved by reviewing the plant communities and the substrate that they grow on within the western lobe. Twinings Pond is not included in the latest MassDEP Integrated List.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling between 2005 and 2016. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including a deep mean average summer DO concentrations less than the MassDEP regulatory minimum. Twinings Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Twinings Pond sampling station was 3.67 m (n=47). Mean average Secchi transparency depth was 2.82 m (n=45) and 79% (n=46) of the total depth (**Table III-14**). Average mean summer total depth (3.58 m; n=22) was significantly less than mean spring depth (3.85 m; n=11), likely due to regular seasonal water table fluctuations. Summer mean Secchi depth also was significantly less (2.77 m; n=21) than the spring mean depth (3.36 m; n=11) and % Secchi readings were also significantly different. The significant difference in the spring and summer mean average % Secchi readings suggests that on average summer Secchi readings decreased more than the decrease in total depth. The overall datasets for total depth and % Secchi depth did not have significant trends, but Secchi depth had a significant increasing trend (+0.04 m per year) between 2001 and 2016. Since phytoplankton tends to the primary determinant of clarity in Cape Cod ponds, this increasing trend suggests that phytoplankton populations have been decreasing in Twinings Pond. This decrease may be due to increased root plants competing more effectively for available nutrients.

Comparison of data to MassDEP numeric standards show that impaired water quality conditions developed mostly in the summer, especially deep in the pond, and that the pond was naturally acidic. Most of the DO readings in Twinings Pond (87%) were above the MassDEP warm water minimum of 5 mg/L, but summer deep mean average concentration was less than the MassDEP minimum (4.18 mg/L; n=24). All shallow readings were above the regulatory minimum and the summer deep mean average concentration was significantly less than the summer shallow mean. Summer mean average shallow and deep DO concentrations were significantly less than their corresponding spring mean averages. Installation of continuous DO recorders would help to clarify how low DO concentrations develop in the water column during the summer and how long they are maintained. Almost all of the pH readings (94%) were less than the MassDEP minimum of 6.5 with the overall mean average of 6.29 (n=34). No significant trends were noted for DO or % DO saturation between 2001 and 2016.

Review of Twinings Pond temperature readings show that the water column was generally well mixed with significant difference in spring, but not summer, shallow and deep mean average readings. Overall mean average surface and deep temperatures were significantly different: shallow 21.75°C (n=48); deep 19.41°C (n=49). This significant difference also occurred in the spring mean average temperatures, but did not in the summer mean averages. The deep summer mean average (22.3°C; n=23) was greater than MassDEP cold water maximum and would place the pond in MassDEP's warm water category for management purposes. These mean average temperature differences, while statistically different, were generally not sufficiently different to prevent mixing of the water column in Twinings Pond. This finding seems to contradict the significant difference between shallow and deep DO mean concentrations; this reinforces the need to install continuous recording devices to see how low DO readings are sustained in a water column with no apparent resistance to thermal mixing. No significant temperature trends were noted in the data between 2001 and 2016.

Review of nutrient data showed most (>70%) of the individual TP and TN readings above Cape Cod Ecoregion thresholds and evidence of sediment phosphorus regeneration. Deep mean average TP concentrations were significantly greater than shallow mean average TP concentrations during both spring and summer and, while summer means were higher than spring means, they were not significantly different. This finding suggests that sediment phosphorus regeneration greater than water column mixing processes was occurring from April to September. Similar relationships among mean average TN concentrations were not found, which suggests that DO concentrations are generally low enough to cause sediment TP regeneration but not significant TN regeneration. Shallow and deep mean TN averages, during both spring and summer, were not significantly different nor were spring and summer comparisons of shallow and deep mean concentrations. No significant trends were noted for TN or TP, but it is clear that the sediments play a significant role in nutrient concentrations in Twinings Pond. Additional characterization of the sediments and their interaction with the deeper waters is warranted for development of reliable water quality management strategies.

N:P ratios generally showed water quality in Twinings Pond was controlled by phosphorus. Average mean shallow ratios were approximately 4X the Redfield ratio threshold with a decrease to 3X the threshold in the deep, TP-enriched, regeneration-influenced waters. This relationship was reinforced during the summer, where the shallow mean average N:P ratio (65.8; n=24) was significantly higher than the deep mean average (52.4; n=23). The overall shallow mean average N:P ratio was 69.2 (n=41). Comparison of seasonal mean averages had no significant differences. No significant trends were noted in the overall N:P ratios between 2001 and 2016.

Chlorophyll and pH readings were only collected during the summer season, so seasonal comparisons were not available. Almost all of the pH readings (94%) were less than the MassDEP minimum of 6.5, which would consistent with the naturally acidic pH of most of Cape Cod ponds and lakes. No significant difference was noted between the shallow and deep mean average pH readings. Mean average chlorophyll readings were significantly different in shallow and deep depths. Overall shallow readings, across the whole dataset, had a mean average of 3.93 µg/L with 68% of the readings above the Cape Cod Ecoregion threshold of 1.7 µg/L. Overall deep readings had a mean average chlorophyll concentration of 8.08 µg/L. Higher deep chlorophyll concentrations, especially in shallow ponds, are typically due to an active phytoplankton population with regular and extensive settling of decaying phytoplankton. Shallow chlorophyll readings did not have a significant trend, but deep readings had a significant decreasing trend (-0.75 µg/L per year) between 2001 and 2016. No significant trend was noted for shallow pH readings either, but deep pH readings had a significant increasing trend (+0.03 units per year). This decreasing trend appears at first glance to contradict the increasing deep pH trend since pH increases tend to be related to increasing photosynthesis. However, the direction of these trends would be consistent for a pond that was experiencing increasing growth of rooted plants. Further clarification of this should be addressed if the town decides to complete the development of a management plan for Twinings Pond.

<u>Overall Assessment and Identified Data Gaps:</u>
Twinings Pond water quality conditions generally show impaired conditions from nutrient enrichment compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. The majority of nutrient and resulting chlorophyll concentrations were above ecoregion thresholds and deep summer DO concentrations had a mean average below the MassDEP minimum. Management of the water quality in the pond should focus on phosphorus management. The Great Pond status of Twinings Pond needs to be clarified because there are management implications: if it is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives; if it is a Great Pond, the Town may have to address additional MassDEP issues.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context. The primary data gaps appear to be information about the: a) measurement of sediment contributions of nutrients, including core collection and incubation, b) triggers for sediment nutrient regeneration through measurement of continuous DO, temperature and water level at two or more depths, c) potential role and extent of both phytoplankton and rooted plants completed by surveying rooted plants, phytoplankton changes throughout the summer, and continuous recording of chlorophyll at the same time, and d) assessment of the presence of freshwater mussels given the role sediments seem to play in nutrient loads. It does not appear at this time that stormwater inputs are a concern, but this should be clarified when the data gaps and the management plan scope are developed. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of a Twinings Pond Management Plan. It is anticipated that access and the role of legacy land uses will also be significant issues in the Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Twinings Pond because of the increase in impairments measured in the pond during the summer. Sampling in Twinings Pond in April and August/September should continue to follow PALS protocols.

Table III-14. Twinings Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	3.67			3.85		3.58		<	
N	47			11		22			
Max	4.38			4.38		3.88			
Min	3.15			3.60		3.15			
Secchi Depth									
Average (m)	2.82			3.36		2.77		<	
N	45			11		21			
Max	3.85			3.85		3.82			
Min	1.90			2.80		1.90			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	20.68	21.75	19.41	17.68	14.74	23.39	22.30	>	>
N	203	48	49	12	12	22	23		
Max	28.50	28.50	25.90	22.10	19.20	27.10	25.90		
Min	10.80	11.20	10.80	13.50	11.50	19.20	19.00		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	7.05	7.81	5.33	9.20	8.16	6.62	4.18	<	<
N	209	49	50	12	11	22	24		
Max	11.26	10.68	10.72	10.41	10.72	9.17	6.64		
Min	0.08	5.00	0.08	7.56	3.29	5.00	0.17		
N < 5 mg/L DO	27	0	20	0	2	0	12		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.29	6.30	6.28	-	-	6.30	6.28		
N	34	17	17	0	0	17	17		
N < 6.5 pH	32	16	16	-	-	16	16		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	5.76	3.93	8.08	-	-	4.35	8.78		
N	46	22	21	0	0	19	19		
Max	21.69	13.53	21.69	-	-	13.53	21.69		
Min	0.01	0.01	0.01	-	-	0.01	0.19		
N > 1.7 µg/L	36	15	19	-	-	14	18		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	14.38	12.49	16.33	11.25	16.14	14.49	18.57		
N	83	42	41	8	8	24	23		
Max	30.55	25.10	30.55	17.69	21.62	25.10	30.55		
Min	2.87	3.60	2.87	4.67	11.46	4.80	8.67		
N > 10 µg/L	64	28	36	5	8	20	22		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.38	0.37	0.39	0.33	0.36	0.40	0.42		
N	85	43	42	9	9	24	23		
Max	0.68	0.66	0.68	0.66	0.68	0.58	0.67		
Min	0.15	0.15	0.15	0.19	0.15	0.24	0.28		
N > 0.31 mg/L	63	30	33	5	6	20	21		

III.O. Uncle Harveys Pond

Uncle Harveys Pond (PALS# OR-142) is a 7.5 acre pond located just to the south of Pochet Road and east of Barley Neck Road (see **Figure I-1**). Review of historic aerial photos and a 1943 USGS quad map do not show any hydroconnections to nearby ponds, although there is small adjacent wetland area to the west that some locals contend used to be connected to Meetinghouse Pond, a nearby salt pond at the head of Pleasant Bay. Uncle Harveys Pond is within Pleasant Bay MEP estuary watershed. Given that its area is less than 10 acres, it is not considered a Great Pond under Massachusetts law and is not included in the latest MassDEP Integrated List.

Available historic aerial photos do not show extensive emergent rooted plants, but do show periods when the surface of the lake had apparent algal blooms. The Massachusetts Department of Public Health (MassDPH) has issued blue-green algae/cyanobacteria advisories for Uncle Harveys Pond in 2012 and 2015. Advisories are issued by MassDPH when cell counts exceed a 70,000 cells/milliliter threshold and typically include a recommendation to avoid contact with the water. Advisories are usually maintained until cell counts are measured below the advisory threshold. Uncle Harveys Pond is the only pond in the Town where these advisories have been issued.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2005 and intermittent spring sampling between 2005 and 2016. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including a deep mean average summer DO concentrations less than the MassDEP regulatory minimum. Uncle Harveys Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Uncle Harveys Pond sampling station was 5.91 m (n=45). Mean average Secchi transparency depth was 2.97 m (n=46) and 51% (n=46) of the total depth (**Table III-15**). Average mean summer total depth (5.78 m; n=21) was significantly less than mean spring depth (6.16 m; n=11), likely due to regular water table fluctuations. Summer mean Secchi depth also was significantly less (2.40 m; n=21) than the spring mean depth (3.64 m; n=12) and % Secchi readings were also significantly different. The significant difference in the spring and summer mean average % Secchi readings suggests that on average summer Secchi readings decreased more than the decrease in summer total depth. The overall datasets for total depth, Secchi depth, and % Secchi depth did not have significant trends between 2001 and 2016.

Comparison of data to MassDEP numeric standards show that impaired dissolved oxygen conditions existed in the spring and worsened in the summer and that the pond was naturally acidic. Most of the DO readings in Uncle Harveys Pond (77%) were above the MassDEP warm water minimum of 5 mg/L, but most of these readings were in the shallower portions of the water column. Deep spring and deep summer mean average DO concentrations were less than the MassDEP minimum [spring 3.76 mg/L (n=12); summer 1.09 mg/L (n=26)] and were significantly less than the corresponding seasonal surface mean average concentrations. All individual shallow readings were above the regulatory minimum. Summer mean average shallow and deep DO concentrations were significantly less than their corresponding spring mean averages. Installation of continuous DO recorders would help to clarify how low DO concentrations develop and are sustained in the water column during the summer. Most of the pH readings (71%) were greater than the MassDEP minimum of 6.5 with the overall mean average of 6.61 (n=34). Shallow DO concentrations had a significant increasing trend (+0.09 m/L per year) between 2001 and 2016, but no significant trend was noted for deep DO or % saturation at either shallow or deep depths. Increasing shallow DO concentrations would likely be related to greater plant growth, but additional data on rooted plants and phytoplankton would be necessary to clarify the primary source of higher DO.

Review of temperature readings show that the water column of Uncle Harveys Pond generally had some significant differences between shallow and deep mean averages. Both spring and summer shallow mean average temperatures were significantly greater than corresponding deep mean average temperatures. The magnitude of the differences (5-6°C) indicate some thermal layering; review of individual temperature profiles generally show that the upper 4 m tend to be well-mixed with a large decrease at 5 m. Continuous measurements of temperature could clarify whether thermal resistance is generally weak enough to allow mixing and whether temporary layering occurs.[51] The deep summer mean average (18.3°C; n=26) was less than MassDEP cold water maximum, but 8 of the readings were above the threshold and this finding would place the pond in MassDEP's warm water category for management purposes. Summer shallow and deep mean averages were significantly greater than their respective spring mean averages. No significant temperature trends were noted in the data between 2001 and 2016.

Review of nutrient data showed that most (>80%) of the individual readings were above Cape Cod Ecoregion thresholds and evidence of enhanced summer sediment nutrient regeneration. Spring shallow mean average TP and TN concentrations were lower than corresponding deep mean averages, but not significantly different. In contrast, summer deep mean average TP and TN concentrations were significantly higher than the shallow mean averages and the deep summer TP mean average was significantly higher than the deep spring mean average TP concentration. These results show enhanced summer sediment nutrient regeneration with preferential release of TP compared to TN. The results are consistent with the significantly lower deep DO concentrations measured during the summer; the mean average deep summer DO concentration would generally indicate release and regular recycling of any iron-bound phosphorus. Installation of continuous DO recorders and incubation of sediment cores would allow additional quantification of these relationships, including how low DO conditions develop and are sustained. Both shallow and deep TP concentrations had significant increasing trends between 2001 and 2016: +0.75 µg/L per year and +2.4 µg/L per year, respectively. These trends would be consistent with greater recycling of TP and increasing amounts in the water column; the lack of a complementary trend in the deep DO readings may be due to most of the deep DO concentrations being below 1 mg/L in 2001 and throughout the 16 years of additional sampling. Shallow TN concentrations also had a significant increasing trend (+0.02 mg/L per year), but deep TN had no notable trend. This trend would seem to indicate additional watershed N inputs over time, but additional clarification would be necessary to look at changes in the watershed and how sediments may have played a role in raising surface TN concentrations. Overall, the

[51] Continuous temperature measurements in other shallow Cape Cod ponds have shown temporary thermal layering creating conditions favoring sediment TP release and accompanying algal blooms (*e.g.,* CSP/SMAST Technical Memorandum: Lake Wequaquet Dissolved Oxygen Monitoring Program, August – October 2014.)

nutrient concentrations and trends reinforce the need to complete additional characterization of the sediments and their interaction with the deeper waters in order to complete development of reliable water quality management strategies.

N:P ratios generally showed water quality in Uncle Harveys Pond was controlled by phosphorus. Average mean ratios were 3X to 4X the Redfield ratio threshold with higher ratios in surface waters and lower ratios in deep waters. Lower ratios in deep waters were due to enhanced TP sediment regeneration. Seasonal (spring and summer) shallow and deep mean average ratios were not significantly different, but the shallow and deep ratios in the overall dataset, including April through November, were significantly different. The overall shallow mean average N:P ratio was 76.3 (n=41). No significant trends were noted in the overall N:P ratios between 2001 and 2016.

Chlorophyll and pH readings were only collected during the summer season, so seasonal comparisons were not available. As mentioned above, most (71%) of the pH reading were above the MassDEP minimum of 6.5, but most of the readings (88%) were also less than 7, which mean the pond was naturally acidic, as are most of Cape Cod ponds and lakes. The relatively high pH, however, is likely related to phytoplankton photosynthesis. Mean average chlorophyll readings were significantly different in shallow and deep depths, but almost all of the readings (≥94%) were above the Cape Cod Ecoregion threshold of 1.7 µg/L. Overall deep summer chlorophyll readings had a mean average of 24.7 µg/L (n=17), while shallow summer readings had a mean average concentration of 11.2 µg/L (n=21). Higher deep chlorophyll concentrations, especially in shallow ponds, are typically due to an active phytoplankton population with regular and extensive settling of decaying phytoplankton. Shallow readings did not have a significant trend, but deep readings had a significant increasing trend (+2.5 µg/L per year) between 2001 and 2016. This trend would tend to suggest increased phytoplankton settling perhaps due to enhanced competition from blue-green algae. Further clarification of this should be addressed during the development of a management plan for Uncle Harveys Pond and the proposed data gap surveys, including monitoring of the changes in the phytoplankton population throughout the summer.

<u>Overall Assessment and Identified Data Gaps:</u>
Uncle Harveys Pond water quality results showed impaired conditions compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. Most of nutrient and resulting chlorophyll concentrations were above ecoregion thresholds and deep summer and spring DO concentrations had a mean average below the MassDEP minimum. Management of the water quality in the pond should focus on phosphorus management. Management largely depends on the Town's specific uses and resource quality objectives.

The town Freshwater Ponds Management Planning Work Group, formed as part of the work by the Town of Orleans Water Quality Advisory Panel (OWQAP) recently prioritized Uncle Harveys Pond for management activities. As part of that prioritization, the Town asked the Coastal Systems Program from the School for Marine Science and Technology at UMass-Dartmouth (CSP/SMAST) to prepare a scope to develop an Uncle Harvey's Pond Management Plan during FY18 and complete targeted data gap surveys during the summer of 2017.

The CSP/SMAST scope included data gaps surveys of:

a) potential role and extent of both phytoplankton and rooted plants completed by surveying rooted plants, phytoplankton changes throughout the summer (including cyanobacteria), and continuous recording of chlorophyll at the same time,
b) measurement of sediment contributions of nutrients, including core collection and incubation,
c) triggers for sediment nutrient regeneration through measurement of continuous DO, temperature and water level at two or more depths,
d) bathymetry,
e) assessment of the presence of freshwater mussels given the role sediments seem to play in nutrient loads and
f) measurement of direct stormwater inputs as a potentially significant phosphorus source with clear management options.

The details of these planned surveys were developed based on review of available data and field reconnaissance of the pond. These steps included observations of stormwater flows during two storms and discussions with various pond users/monitors. These data gap surveys should create additional information to provide better context for the available water quality data discussed above. This better context will provide a more reliable basis for pond water quality management options and development of a preferred management approach.

Table III-15. Uncle Harveys Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	Deep
Total Depth									
Average (m)	5.91			6.16		5.78		<	
N	45			11		21			
Max	6.65			6.65		6.50			
Min	5.04			5.72		5.04			
Secchi Depth									
Average (m)	2.97			3.64		2.40		<	
N	46			12		21			
Max	4.65			4.65		4.15			
Min	0.40			2.21		0.40			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	19.30	21.47	15.59	16.52	10.65	23.83	18.33	>	>
N	285	46	50	12	11	21	26		
Max	28.10	28.10	23.70	22.70	14.70	27.00	23.70		
Min	7.40	12.20	7.40	12.20	7.40	20.10	14.30		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	6.56	8.30	2.23	9.50	3.76	7.59	1.09	<	<
N	286	46	51	12	12	21	26		
Max	12.80	11.21	12.13	11.21	12.13	9.87	5.91		
Min	0.02	5.95	0.02	7.19	0.24	5.95	0.02		
N < 5 mg/L DO	67	0	41	0	8	0	24		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.61	6.74	6.50	-	-	6.74	6.50		
N	34	16	18	0	0	16	18		
N < 6.5 pH	10	1	9	-	-	1	9		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	16.22	11.01	24.74	-	-	11.21	24.74		
N	45	24	17	0	0	21	17		
Max	74.12	46.61	74.12	-	-	46.61	74.12		
Min	0.34	0.72	0.34	-	-	0.72	0.34		
N > 1.7 µg/L	40	21	16	-	-	20	16		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	24.58	17.52	31.81	17.97	23.88	19.86	38.38		>
N	83	42	41	10	10	24	23		
Max	97.72	45.10	97.72	45.10	43.10	41.15	97.72		
Min	3.95	4.03	3.95	6.83	14.09	6.50	4.00		
N > 10 µg/L	67	32	35	8	10	21	21		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.59	0.49	0.69	0.45	0.56	0.55	0.80		
N	81	39	42	9	10	22	24		
Max	1.48	1.18	1.48	0.60	1.35	1.18	1.48		
Min	0.26	0.26	0.28	0.32	0.31	0.30	0.28		
N > 0.31 mg/L	75	35	40	9	9	21	23		

III.P. Uncle Israels Pond

Uncle Israels Pond (PALS# OR-247) is located just to the south of Uncle Israel's Road, east of Grannys Lane and approximately 280 m north of Twinings Pond (see **Figure I-1**). Review of historic aerial photos and a 1943 USGS quad map do not show any hydroconnections to nearby ponds or wetlands. Aerial photos do show that that the pond area fluctuates and available sources cite the pond area between 1.9 and 2.2 acres. Uncle Israels Pond is within Pleasant Bay MEP estuary watershed, a designated Massachusetts Natural Heritage Priority Habitat, and the Town of Orleans Water Department Zone II (*e.g.*, wellhead protection area). Uncle Israels Pond is not included in the latest MassDEP Integrated List.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 and intermittent spring sampling between 2011 and 2016. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including shallow mean average summer DO concentrations less than the MassDEP regulatory minimum. Uncle Israels Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Uncle Israels Pond sampling station was 0.97 m (n=25). Mean average Secchi transparency depth was 0.58 m (n=25) and 66% (n=25) of the total depth (**Table III-16**). Average mean summer total depth (0.87 m; n=18) was significantly less than mean spring depth (1.36 m; n=5), likely due to regular seasonal water table fluctuations. Summer mean Secchi depth also was less than the spring mean, but they were not significantly different; % Secchi mean averages were also not significantly different. Additional spring readings would be necessary to clarify how important these seasonal differences are. Both total depth and Secchi depth had significant increasing trends between 2001 and 2016 (+0.04 m per year total depth and +0.02 m per year Secchi depth); % Secchi depth did not have a significant trend. These trends suggest a long term rise in the water table, which is also seen in some other ponds, further suggesting localized fluctuations on top of regional aquifer fluctuations. Secchi depth was generally increasing in tandem with the total depth, which is why the % Secchi depth did not have a notable trend. The increased Secchi depth trend in Uncle Israels Pond suggests that the pond has progressively less chlorophyll since phytoplankton tends to the primary determinant of clarity in Cape Cod ponds. This trend may be due to increased rooted plants, but additional information including plant surveys should be developed if the Town pursues a management plan for the pond.

Comparison of data to MassDEP numeric standards show that impaired water quality conditions developed mostly in the summer and that the pond was naturally acidic. The overall mean dissolved oxygen concentration in Uncle Israels Pond (4.42 mg/L; n=49) was less than the MassDEP warm water minimum of 5 mg/L. DO concentrations showed a wide range and a significant difference between mean average shallow and deep concentrations. Typically, very shallow ponds like Uncle Israels Pond have a well-mixed water column and any significant sediment oxygen demand is tempered by mixing in of atmospheric DO contributions. In Uncle Israels Pond, the deep mean average (3.25 mg/L; n=16), which tended to be collected from the lower half of the water column, was significantly less than the shallow mean average (4.98 mg/L; n=27). This difference was seen in the summer, but not the spring, although the number of spring readings was limited (n=4). Overall, 67% of all DO readings were less than the MassDEP minimum. Installation of continuous DO recorders would help to clarify how low DO concentrations develop and whether they are sustained in the water column during the summer. All pH readings were less than the MassDEP minimum of 6.5 with the overall mean average of 5.87 (n=14). No significant trends were noted for DO or % DO saturation between 2001 and 2016.

Review of temperature readings show that the water column of Uncle Israels Pond was generally well mixed with no significant difference in summer or spring shallow and deep mean average readings. The overall mean average temperature was 20.73°C (n=49) with significantly warmer temperatures during the summer compared to the spring [*e.g.*, shallow mean average summer temperature was 22.79°C (n=19), while the shallow mean average spring temperature was 17.47°C (n=6)]. The deep summer mean average (21.63°C; n=11) was greater than MassDEP cold water maximum and would place the pond in MassDEP's warm water category for management purposes. The lack of significant temperature differences during given seasons suggest that sediment oxygen demand is significant; sustaining low oxygen concentrations in a well-mixed water column would require strong and sustained sediment oxygen demand. Continuous temperature recordings would help to clarify whether occasional, but regular, temporary temperature layering. No significant temperature trends were noted in the data between 2001 and 2016.

Review of nutrient data showed all of the individual readings were above Cape Cod Ecoregion thresholds. Given the shallowness of the pond and PALS protocols, only one nutrient sample tended to be collected during each sampling run, so distinctions between shallow and deep concentrations are not available. Summer mean average TP concentration (99.7 µg/L; n=20) was higher than spring (66.0 µg/L; n=3), but not significantly higher (although some of the lack of significance may be due to the limited number of spring samples). The overall mean average TP concentration (86.0 µg/L; n=28) was more than 8X higher than Cape Cod Ecoregion threshold (10 µg/L TP). TN concentrations followed a similar pattern with an overall mean average (1.08 mg/L; n=26) more than 3X higher than the respective Cape Cod Ecoregion threshold (0.31 mg/L TN) and all individual readings above the threshold. The summer mean average TN concentration was significantly higher than the spring mean average. Trend analysis indicated no significant trend for TP concentrations between 2001 and 2016, but TN concentrations had a significant decreasing trend (-0.04 mg/L). Further evaluation of watershed changes and the pond sediments would be warranted to help understand the likely causes of this trend.

N:P ratios generally showed water quality in Uncle Israels Pond was controlled by phosphorus, but the ratios were relatively low and reflective of the high concentrations of both nutrients. The overall average mean ratio was 36.1 (n=28), which is approximately 2X the Redfield ratio threshold. As discussed above for most of the other ponds, freshwater ponds typically have N:P ratios of 3X to 6X of the Redfield threshold, although the ratios may be lower in near-sediment waters where extensive TP regeneration is occurring. In Uncle Israels Pond, there was no significant difference between seasonal mean N:P ratio averages (only 3 readings in spring), but there was a significant decreasing trend between 2001 and 2016 (-1.06 per year). The decreasing trend is somewhat consistent with the decreasing trend in TN concentrations. Although phosphorus is the predominant nutrient, the low N:P ratio suggests that water quality management options consider reductions in both phosphorus and nitrogen. Further clarification of these interactions and their implications for management should be developed through spring monitoring, sediment core collection and incubation, and refined continuous measurements at shallow and deep depths.

Chlorophyll and pH readings were only collected during the summer season. All of the individual pH readings were less than the MassDEP minimum of 6.5, which would consistent with the naturally acidic pH of most of Cape Cod ponds and lakes. The mean average pH reading for Uncle Israels Pond was 5.87. Similarly, all of the individual chlorophyll readings were also above the Cape Cod Ecoregion threshold of 1.7 µg/L with a mean average concentration of 17.0 µg/L. The pH readings did not have a significant trend, but chlorophyll readings had a significant decreasing trend (-1.47 µg/L per year) between 2001 and 2016. Since no spring readings were collected, this trend represents only summer conditions, but it would appear to be consistent with the increasing trend in Secchi depth. Clarification of these relationships for development of water quality management strategies would require spring readings and continuous monitoring of DO, pH, and chlorophyll to measure how summer conditions develop and the factors influencing chlorophyll concentration changes. Since pH readings are also influenced by rooted plants, a survey of rooted plants would also be recommended as part of a management plan for Uncle Israels Pond.

Overall Assessment and Identified Data Gaps:

Uncle Israels Pond water quality conditions generally show impaired conditions compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. All nutrient and resulting chlorophyll concentrations were above ecoregion thresholds and overall DO concentrations had a mean average below the MassDEP minimum. Management of the water quality in the pond should focus on both phosphorus and nitrogen management to reduce the large phytoplankton blooms and resultant hypoxia in this shallow pond. Given that Uncle Israels Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context. The primary data gaps appear to be information about the: a) sediment contributions of nutrients and the change in their oxygen demand from April to November, b) spring water quality conditions and how they compare to summer conditions, c) how watershed nitrogen contributions may have changed over time, d) extent of rooted plants and phytoplankton population dynamics from April/May through September, e) presence of freshwater mussels since it appears that sediment management will be considered and f) whether there are any significant stormwater inputs as a potentially significant phosphorus source with clear management options.. All of these can be addressed during the development of a management plan scope/strategy. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of an Uncle Israels Pond Management Plan. It is anticipated that access and the role of legacy land uses will also be significant issues in the Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Uncle Israels Pond because of the increase in impairments measured in the pond during the summer. Sampling in Uncle Israels Pond in April and August/September should continue to follow PALS protocols.

Table III-16. Uncle Israels Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	0.97			1.36		0.87		<	
N	25			5		18			
Max	1.64			1.64		1.44			
Min	0.30			0.92		0.30			
Secchi Depth									
Average (m)	0.58			0.81		0.51			
N	25			5		18			
Max	1.30			1.30		1.01			
Min	0.28			0.50		0.28			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	20.73	21.76	19.94	17.47	15.03	22.79	21.63	>	>
N	49	27	16	6	4	19	11		
Max	26.50	26.50	25.10	21.40	17.20	26.50	25.10		
Min	12.20	15.80	12.20	15.80	12.20	17.80	17.50		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	4.42	4.98	3.25	8.15	6.21	4.12	2.39	<	
N	49	27	16	6	4	19	11		
Max	9.97	9.97	8.70	9.97	8.70	8.10	4.25		
Min	0.08	0.41	0.08	5.31	0.54	0.41	0.08		
N < 5 mg/L DO	33	16	13	0	1	14	11		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	5.87	5.87				5.87			
N	14	14				14			
N < 6.5 pH	14	14				14			
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	17.03	17.03				17.91			
N	17	17				16			
Max	44.50	44.50				44.50			
Min	1.95	1.95				1.95			
N > 1.7 µg/L	17	17				16			
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	86.04	91.95	49.29	65.98	73.84	99.72	-		
N	28	25	2	3	1	20	0		
Max	160.75	160.75	73.84	87.62	-	160.75	-		
Min	11.82	25.93	24.73	25.93	-	43.97	-		
N > 10 µg/L	28	25	2	3	1	20	-		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	1.08	1.12	0.92	0.71	0.73	1.21	-	>	
N	26	23	2	3	1	18	0		
Max	2.37	2.37	1.12	0.85	-	2.37	-		
Min	0.47	0.50	0.73	0.50	-	0.73	-		
N > 0.31 mg/L	26	23	2	3	1	18	-		

III.Q. Uncle Seths Pond

Uncle Seths Pond (PALS# OR-264) is a 5.9 acre pond located just to the west of Route 28, south of Cross Road, and west of Deep Pond (see **Figure I-1**). It is the westernmost pond of an east/west line of shallow, small ponds in South Orleans that includes Sarahs, Twinings, Shoal, and Deep ponds. Review of historic 1943 and the current USGS quad maps do not show any hydroconnections to adjacent ponds or wetlands, but review of historic aerial photographs suggest that there is an outlet stream to Tar Kiln Stream, which flows into Pleasant Bay. It is unclear whether this flows out of the pond continuously or only during periods of high groundwater conditions. The aerial photos also show extensive rooted plants that are submerged during some periods (presumably high groundwater periods) and then emergent and covering more than 50% of the pond area during other periods. Uncle Seths Pond is within Pleasant Bay MEP estuary watershed and the Pleasant Bay Area of Critical Environmental Concern (ACEC). Given that its area is less than 10 acres, it is not considered a Great Pond under Massachusetts law and is not included in the latest MassDEP Integrated List.

Water quality data in the pond has been consistently collected in the PALS Snapshots between 2001 and 2016 with more extensive summer monitoring in 2003-2006 and intermittent spring sampling between 2005 and 2016. Review collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including average deep summer DO concentrations less than the MassDEP regulatory minimum and high surface chlorophyll concentrations. Uncle Seths Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Uncle Seths Pond sampling station was 3.13 m (n=50). Mean average Secchi transparency depth was 1.58 m (n=51) and 52% (n=51) of the total depth (**Table III-17**). Average mean summer total depth was significantly less than mean spring depth, but spring and summer mean average Secchi depth and % Secchi depth were not significantly different. The overall dataset for total depth did not have a significant trend, but both Secchi depth and % Secchi depth had increasing significant trends for all data between 2001 and 2016 (+0.075 m per year and +2% per year, respectively). Increasing Secchi depth is typically related to decreasing chlorophyll concentrations since phytoplankton tends to the primary determinant of clarity in Cape Cod ponds. Given that review of historic aerial photographs show extensive rooted plant growth in Uncle Seths Pond, improving clarity may also be related to increasing rooted plant growth. Further analysis of these relationships should be considered when a water quality management plan is developed for Uncle Seths Pond.

Comparison of data to MassDEP numeric standards show that deep water quality conditions in the pond were often impaired and that the pond was naturally acidic. The majority (61%) of all deep dissolved oxygen concentrations were below the MassDEP warm water minimum of 5 mg/L with a mean summer deep average concentration of 2.18 mg/L (n=24) and 83% of summer deep readings below the MassDEP minimum. Deep mean average DO concentrations were significantly lower than shallow mean averages during both the spring and the summer and summer mean average concentrations at both shallow and deep depths were significantly lower than their spring counterparts. Since significantly lower DO concentrations were generally found deep in the pond between April and November, it suggests that sediment oxygen demand was high during the entire water quality management period. The mean averages showed that conditions become more impaired during the summer, but low oxygen during the spring could create conditions where nutrients are regularly regenerated throughout the key management period. Clarification of these relationships should be resolved during development of a management plan through the use of continuous monitoring and characterization of the sediments (including core collection, and incubation). Most of the pH readings (72%) were less than the MassDEP minimum of 6.5 with the overall mean average of 6.41 (n=26). No significant trends were noted in the overall DO dataset.

Review of temperature readings show that the water column of Uncle Seths Pond generally had significantly colder deep waters, but deep waters were generally warm enough to place the pond in MassDEP's warm water category. Mean average spring shallow temperatures were significantly higher (19.82°C; n=11) than the spring deep mean average (13.33°C; n=11). Summer mean average temperatures at shallow and deep depths were also significantly different and significantly higher than their corresponding spring mean averages (summer shallow = 24.06°C; n=24, summer deep = 20.26°C; n=24). Overall, 54% of deep summer temperature readings were above the MassDEP cold water maximum (20°C). The significant difference between shallow and deep mean averages suggest regular separation of shallow and deep waters, but review of individual temperature profiles also suggest that there are regular thermal mixing events. Installation of continuous temperature recorders would help to clarify how often these circumstances occur, how they develop, and how long they are maintained. No significant temperature trends were noted in the data between 2001 and 2016.

Review of available nutrient data generally showed increases in summer concentrations and most of the individual readings above Cape Cod Ecoregion thresholds. Most of the individual TP and TN concentrations exceeded the respective Cape Cod Ecoregion thresholds: 85% of the TP concentrations exceeded 10 µg/L TP and 84% of the TN concentrations exceeded 0.31 mg/L TN. Neither the TP or TN mean average concentrations showed significant difference between shallow and deep means, although TP summer means were the closest to a significant different (ρ=0.1). Summer shallow and deep mean average TN concentrations were significantly greater than their spring means, but the lack of significant difference between shallow and deep mean averages in either season suggests that this summer increase is likely due to greater watershed inputs or greater transfer to the water column facilitated by the extensive rooted plant community. Additional insights into the cause of these readings should be included in addressing data gaps for an Uncle Seths Pond water quality management plan. No significant trends were noted for shallow or deep TP or deep TN, but shallow TN had a significant decreasing trend (-0.02 mg/L per year) over the whole dataset between 2001 and 2016. This trend reinforces the need to evaluate watershed TN inputs, TN outflows, and TN transfers within the pond by the large rooted plant community.

N:P ratios showed water quality in Uncle Seths Pond was controlled by phosphorus. Average overall ratios were approximately 4X the Redfield ratio threshold at both shallow and deep depths; the shallow mean average N:P ratio was 64.3 (n=40). This ratio is generally consistent with most other Cape Cod ponds. No significant differences were noted in the ratios by depth or by season. This lack of significant differences is consistent with the mean TP and TN concentrations. No significant trends were noted in the overall shallow or deep N:P ratios between 2001 and 2016.

Chlorophyll and pH readings were only collected during the summer season, so seasonal comparisons were not available. Most of the pH readings (72%) were below the MassDEP minimum of 6.5 and the shallow mean average was significantly higher than deep mean average. Photosynthesis tends to raise pH, so shallower areas, where light is more readily available, generally tend to have higher pH. Refined pH readings in Uncle Seths Pond may be complicated by accounting for the impacts of the large rooted plant community, their impact on light penetration, and seasonal changes. The deep chlorophyll mean average concentration (31.15 µg/L; n=20) was greater than the shallow mean average (13.07 µg/L; n=23), but the difference was not statistically significant largely due to the high variability of the concentrations. Overall, 87% of all shallow chlorophyll concentrations were above the Cape Cod Ecoregion threshold (1.7 µg/L). Typically higher deep chlorophyll concentrations, especially in shallow ponds, are due to an active phytoplankton population with regular and extensive settling of decaying phytoplankton. This situation seems to exist in this pond, but there are likely large amounts of nutrients contained in the extensive rooted plant community and nutrient availability may vary depending on the growth status of this community and the nutrient utilization preferences of the individual species. Collection of spring chlorophyll samples could provide comparison with summer readings and clarify whether these conditions also exist during the spring, but these should also be paired with an assessment of the rooted plants. No significant chlorophyll or pH trends were noted.

Overall Assessment and Identified Data Gaps:

Uncle Seths Pond water quality conditions generally show impaired conditions compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. Nutrient and resulting chlorophyll concentrations were very high with bottom hypoxia. Management of the water quality in the pond should focus on phosphorus management. Given that Uncle Seths Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context. The primary data gaps appear to be information about the: a) extent of rooted plants and their impact on nutrient cycling in the pond, b) characterization of phytoplankton population dynamics throughout an extended summer (April to October) with accompanying continuous monitoring to assess DO, temperature, pH, and chlorophyll, c) characterization of the potential hydroconnection to Tar Kiln Creek, d) characterization of available sediment nutrients, including core collection and incubation and separate characterization of open water and rooted plant areas, and e) assessment of the presence of freshwater mussels if sediment management is considered. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of a Uncle Seths Pond Management Plan. It is anticipated that access and the role of legacy land uses will also be significant issues in the Management Plan.

Prior to the development of a Management Plan, it is recommended that low-level maintenance monitoring continue with sampling in the spring and late summer. This information will provide a contemporary baseline for evaluating the efficacy of any management activities that are pursued and help to fill in data gaps in the available record. On this later issue, it is recommended that the Town consider addition of pH and chlorophyll, at a minimum, to the usual parameters included in the spring sampling that the Town regularly conducts and ensure that this sampling occurs prior to the end of April. Having spring readings of these parameters will establish baseline readings for each year for comparison to results from the PALS Snapshot and over the long run, quantify average baseline conditions. These considerations are especially important in Uncle Seths Pond because of the increase in impairments measured in the pond during the summer. Sampling in Uncle Seths Pond in April and August/September should continue to follow PALS protocols.

Table III-17. Uncle Seths Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.

	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	3.13			3.23		3.06		<	
N	50			11		23			
Max	3.70			3.50		3.60			
Min	2.45			3.00		2.45			
Secchi Depth									
Average (m)	1.58			1.89		1.54			
N	51			11		24			
Max	2.93			2.93		2.72			
Min	0.67			0.97		0.75			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	20.14	22.92	17.34	19.82	13.33	24.06	20.26	>	>
N	198	51	51	11	11	24	24		
Max	29.00	29.00	26.80	24.40	20.10	29.00	26.80		
Min	8.80	10.90	8.80	15.10	8.80	19.00	13.50		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	5.47	7.46	3.55	8.98	6.16	6.46	2.18	<	<
N	196	51	51	11	11	24	24		
Max	13.45	11.61	12.76	10.52	12.76	10.38	7.45		
Min	0.07	3.31	0.08	7.23	0.34	3.31	0.08		
N < 5 mg/L DO	73	4	31	0	3	4	20		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	6.41	6.54	6.28	-	-	6.54	6.28		
N	36	18	18	0	0	18	18		
N < 6.5 pH	26	11	15	-	-	11	15		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	21.48	13.07	31.15	-	-	13.66	32.61		
N	43	23	20	0	0	21	19		
Max	183.29	60.50	183.29	-	-	60.50	183.29		
Min	0.01	0.01	0.01	-	-	0.01	0.01		
N > 1.7 µg/L	38	20	18	-	-	19	17		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	30.81	25.15	35.20	23.17	27.79	29.88	45.90		
N	81	40	39	6	6	24	23		
Max	144.34	73.54	144.34	67.40	54.80	73.54	144.34		
Min	4.33	4.33	5.80	4.33	6.10	6.00	7.00		
N > 10 µg/L	69	33	39	4	5	22	21		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.54	0.54	0.53	0.38	0.42	0.60	0.57	>	>
N	79	40	37	6	6	24	22		
Max	1.31	1.31	0.97	0.58	0.55	1.31	0.97		
Min	0.23	0.24	0.23	0.24	0.23	0.31	0.28		
N > 0.31 mg/L	66	34	30	3	4	23	19		

III.R. Wash Pond

Wash Pond (PALS# OR-203) is a 1.4 acre pond located near the town border with the Town of Brewster and within the Town of Orleans public water supply watershed (see **Figure I-1**). Review of historic 1943 and the current USGS quad maps do not show any hydroconnections to adjacent ponds or wetlands. Review of available historic aerial photos show extensive rooted plants around most of the margin of the pond. These rooted plants are submerged during some periods (presumably high groundwater periods) and emergent and covering approximately half of the pond area during other periods (presumably low groundwater periods). Wash Pond is within Pleasant Bay MEP estuary watershed, a designated Massachusetts Natural Heritage Priority Habitat, and the Town of Orleans Water Department Zone II (*e.g.*, wellhead protection area). Given that its area is less than 10 acres, it is not considered a Great Pond under Massachusetts law and is not included in the latest MassDEP Integrated List.

Water quality data in the pond was collected almost exclusively during PALS Snapshots (August/September) and only between 2001 and 2009; there is one May sampling that was conducted in 2007. This restricted dataset prevented seasonal comparisons and limited the power of the trend analysis since the number of readings was small. Review of collected data in the 2007 Orleans Ponds Report showed that the pond had impaired conditions, including average DO concentrations less than the MassDEP regulatory minimum at all depths except the surface and high surface chlorophyll concentrations. Wash Pond was not selected by the town for refined assessment during the 2007 project.

Data in the current Orleans Pond and Lake unified database found that the mean average depth at the Wash Pond sampling station was 2.96 m (n=9). Mean average Secchi transparency depth was 1.66 m (n=10) and 59% (n=10) of the total depth (**Table III-18**). As noted, only one spring sampling run was completed, so seasonal comparisons were not available. Among the available August/September data, there were no significant trends for total depth, Secchi depth, or % Secchi depth.

Comparison of available data to MassDEP numeric standards show that most of the summer water column had impaired dissolved oxygen conditions and that the pond was naturally acidic. The majority (75%) of all available dissolved oxygen concentrations were below the MassDEP warm water minimum of 5 mg/L with an overall mean average concentration of 3.63 mg/L (n=36). Shallow and deep mean average summer DO concentrations were both below the MassDEP minimum and the deep average (1.74 mg/L; n=12) was significantly less than the shallow average (4.96 mg/L; n=9). Since spring data was not available, it is unclear whether these conditions generally persist throughout the summer or only develop in August/September. Resolving this question for the development of management strategies could be addressed by installing continuous recording devices between April and October. All of the available pH readings were less than the MassDEP minimum of 6.5 with the overall mean average of 5.47 (n=17). No significant trends were noted in the overall DO datasets.

Review of temperature readings show that the water column of Wash Pond generally was well-mixed in August/September with slightly cooler deep waters, but no significant difference between shallow and deep mean average temperatures. Deep waters had an average summer temperature of 19.95°C (n=12), which is generally warm enough to place the pond in

MassDEP's warm water category. Average mean shallow temperature was 21.52°C (n=9). Installation of continuous temperature recorders would help to clarify how these temperature profiles develop. Trend analysis found that shallow and deep temperatures had significant decreasing trends (-0.7°C) in August/September readings between 2001 and 2009. Further comparison to other PALS-only data for other ponds would clarify whether this trend is anomalous; changes in local groundwater flow paths or changes in volume might help to explain this trend. Collection of continuous temperature readings would address this data gap if the Town develops a Wash Pond management plan.

Review of available nutrient data generally showed most of the individual readings in Wash Pond were above Cape Cod Ecoregion thresholds and noted a significant increase in summer deep TP concentrations. Most (25 of 26 readings) of the individual TP concentrations exceeded the 10 µg/L TP ecoregion threshold. Similarly, 24 of 26 individual TN concentrations exceeded the 0.31 mg/L TN ecoregion threshold. Neither the TP nor TN mean average concentrations showed significant difference between shallow and deep means, which would be consistent with a well-mixed water column and relatively consistent internal and/or external inputs. Without spring water quality data, it is impossible to determine whether the average summer conditions are present throughout the April to October management period or only develop during the late summer. Additional clarifications regarding the roles of the plant community (both rooted and phytoplankton) in determining water column nutrient concentrations is also warranted if the Town decides to develop a Wash Pond management plan. No significant summer trends were noted for shallow or deep concentrations of TN. Shallow TP also had no significant trend, but August/September deep TP had a significant increasing trend (+3.0 µg/L TP per year). This increasing trend should be accompanied by a decreasing DO trend, but none was noted and this suggests that the increasing TP trend may be due to facilitated transfer by the rooted plant community. Further evaluation of the sediments, their interaction with the plants, and the seasonal increases in TP would be a data gaps that should be addressed if the Town decides to pursue a pond management plan.

N:P ratios showed water quality in Wash Pond was generally controlled by phosphorus. Average mean summer shallow ratios were approximately 4X the Redfield ratio threshold, while the deep average mean was approximately 3X the ratio threshold. These mean average ratios were not significantly different when only the summer data was evaluated, but when the two May and June datapoints were include the overall ratios were significantly different. This finding generally reinforces the importance of collecting data outside of the PALS Snapshot period in order to provide better context for how individual pond ecosystems function and specifically, the importance of having this data for Wash Pond if the Town is going to pursue a management plan. The only significant trend in the N:P ratio data was a decreasing trend in the shallow N:P ratio (-1.4 per year). Decreases in N:P ratios generally are found in deeper waters where phosphorus regenerated from the sediments causes the ratio to decline. In Wash Pond, the shallow ratio decrease was not matched by shallow nutrient trends; collection of additional data discussed above should help to clarify these nutrient relationships. Overall, management of phosphorus is the key for water quality management in Wash Pond, but additional data is necessary to clarify if this occurs throughout the summer and which sources are the keys to manage phosphorus.

Chlorophyll and pH readings were only collected during the summer season (*i.e.,* PALS Snapshots), so seasonal comparisons were not available. All of the pH readings (n=17) were below the MassDEP minimum of 6.5 with no significant difference between shallow and deep mean average readings (5.52 and 5.43, respectively). The consistency of the pH readings throughout the water column was consistent with the pattern seen in the nutrient data. Photosynthesis tends to raise pH from the naturally acid conditions seen in most Cape Cod ponds, so shallower areas, where light is most readily available, generally tend to have higher pH. Refined pH readings in Wash Pond would likely be complicated by accounting for the large rooted plant community, their role in light penetration, and seasonal impacts. Chlorophyll concentrations were also similar for shallow and deep mean averages and all the individual readings were above the Cape Cod Ecoregion threshold (1.7 µg/L). Shallow and deep chlorophyll mean average concentrations were 23.78 µg/L (n=11) and 20.19 (n=6), respectively. Both of these concentrations were greater than 10X the chlorophyll ecoregion threshold. Definitive conclusions about these concentrations would need the support of spring readings and a better understanding of the rooted plant community. Chlorophyll readings did not have significant trends in the overall dataset between 2001 and 2009, but shallow and deep pH readings had significant increasing trends (+0.06 per year) in the August/September data (only PALS data available). The rise in pH without an accompanying rise in chlorophyll concentrations suggests that rooted plants have a more significant role in the pond ecosystem than phytoplankton. Additional data would be necessary to put this data into a more refined context necessary for development of reliable management strategies.

Overall Assessment and Identified Data Gaps:

Wash Pond water quality conditions generally show impaired conditions compared to both MassDEP regulatory limits and Cape Cod Ecoregion thresholds. Nutrient and resulting chlorophyll concentrations were very high with resultant bottom water hypoxia. Management of the water quality in the pond should focus on phosphorus management to reduce high phytoplankton levels and low oxygen conditions. Given that Wash Pond is not a Great Pond, overall management largely depends on the Town's specific uses and resource quality objectives.

As mentioned above, data gaps would need to be addressed in order to put available water quality data into proper context. The primary data gaps appear to be information about the: a) extent of rooted plants and their impact on nutrient cycling in the pond, b) characterization of phytoplankton population dynamics throughout an extended summer (April to October) with accompanying continuous monitoring to assess DO, temperature, pH, and chlorophyll, c) characterization of available sediment nutrients and relationship of summer regeneration to high summer phytoplankton levels, including core collection and incubation and separate characterization of open water and rooted plant areas, and d) assessment of the presence of freshwater mussels if sediment management is considered. Stormwater runoff does not initially appear to be an issue based on the review of aerial photographs. Other data gaps may arise if other significant management objectives are identified through discussions with the Town or other users of the pond. Once data gaps are adequately addressed, the Town should consider development of a Wash Pond Management Plan. It is anticipated that access and the role of legacy land uses will also be significant issues in the Management Plan.

Since volunteer monitoring was discontinued in 2009, it appears that Wash Pond is not a priority pond for continued monitoring or development of a management plan. It is recommended that the Town proactively decide whether management of water quality in Wash Pond is desired or not. If management is established as a goal, a longer term plan of monitoring, including regular spring and summer monitoring prior to more intensive data gap surveys would provide a benefit for development of future management strategies. If longer term, twice annual monitoring is pursued, it should include all PALS parameters, at a minimum.

Table III-18. Wash Pond Water Quality Summary. Statistically significant differences in shallow and deep means/averages are shaded blue. Significant differences between seasonal means (Apr/May vs. Aug/Sept) are indicated in the last two columns. Statistics are based on database with outliers removed.									
	All data	All data		Apr/May		Aug/Sept		Seasonal difference	
		shallow	deep	shallow	deep	shallow	deep	shallow	deep
Total Depth									
Average (m)	2.96					2.90			
N	9			0		8			
Max	3.45					3.29			
Min	2.48					2.48			
Secchi Depth									
Average (m)	1.66					1.50			
N	10			0		9			
Max	3.09					2.57			
Min	0.53					0.53			
Temperature: MassDEP Warm Water Maximum = 28.3°C; Cold Water Maximum = 20°C									
Average (°C)	20.11	21.01	19.95			21.52	19.95		
N	36	10	12	0	0	9	12		
Max	24.60	24.60	23.60			24.60	23.60		
Min	14.50	16.40	16.30			17.30	16.30		
Dissolved Oxygen: MassDEP Regulatory Warm Water Minimum = 5 mg/L									
Average (mg/L)	3.63	5.44	1.74			4.96	1.74		
N	36	10	12	0	0	9	12		
Max	9.72	9.72	6.10			8.65	6.10		
Min	0.03	2.81	0.03			2.81	0.03		
N < 5 mg/L DO	27	4	11			4	11		
pH: MassDEP Regulatory Minimum = 6.5									
Average (stnd)	5.47	5.52	5.43			5.52	5.43		
N	17	9	8	0	0	9	8		
N < 6.5 pH	17	9	8			9	8		
Chlorophyll: Cape Cod Ecoregion Threshold = 1.7 µg/L									
Average (µg/L)	22.51	23.78	20.19			23.78	20.19		
N	17	11	6	0	0	11	6		
Max	100.18	100.18	68.09			100.18	68.09		
Min	2.39	2.50	2.39			2.50	2.39		
N > 1.7 µg/L	17	11	6			11	6		
Total Phosphorus: Cape Cod Ecoregion Threshold = 10 µg/L									
Average (µg/L)	22.49	22.10	23.03			23.49	24.05		
N	26	15	11	0	0	13	9		
Max	54.96	54.96	41.41			54.96	41.41		
Min	6.50	10.27	6.50			12.39	6.50		
N > 10 µg/L	25	15	10			13	8		
Total Nitrogen: Cape Cod Ecoregion Threshold = 0.31 mg/L									
Average (mg/L)	0.57	0.56	0.57			0.60	0.60		
N	26	14	12	0	0	12	10		
Max	0.79	0.79	0.70			0.79	0.70		
Min	0.30	0.30	0.31			0.35	0.43		
N > 0.31 mg/L	24	13	11			12	10		

IV. Conclusions

Organization of available pond water quality data for the Town of Orleans revealed some findings that should be incorporated into current and future monitoring and data review:

a. **All of the monitored ponds are impaired**
   Review of water quality data for the 18 freshwater ponds that have been regularly monitored within the Town of Orleans showed that each of ponds had water quality impairments from nutrient enrichment, frequently with associated high phytoplankton levels, low water clarity and bottom water hypoxia. Impairment was defined by comparing the results to MassDEP regulatory standards and Cape Cod Ecoregion thresholds.

b. **Each pond is unique**
   The intensive review of the available water quality data showed that even though all of the ponds are impaired, the level of impairment and the likely sources of impairment differ in substantial ways in each pond. This finding was reinforced by the differing mean average values for the reviewed parameters, varying number of readings over regulatory or ecoregion thresholds, and the variety of results from the trend analyses. When limited review of supplementary information (*e.g.*, watershed delineations, bathymetry, surface water hydroconnections, proximity to roads, past and present land uses, and extent of rooted emergent plants), were also considered the unique characteristics of each pond was clearly illustrated. All of these factors should be considered as the Town works to develop water quality management strategies for its ponds and lakes.

c. **Each pond has similar data gaps**
   The available monitoring data provides various measurements of what water column conditions were on the day the measurements were collected. Data was collected frequently at the same time of the year, which provided more insights into the variability in these conditions and, given what is known of general pond ecology, some ideas about what was causing these conditions. The next steps to move from monitoring to management are to measure the likely sources of the contaminants measured in the water column that are causing impairment. The list of these sources will tend to be similar for each pond (*e.g.*, sediments, stormwater runoff), but because each pond is unique how these source measurement are completed will be different for each pond. Addressing these data gaps is the key of developing reliable management strategies that will succeed in restoring acceptable water quality.

d. **Pond water quality management will require a pond-by-pond approach**
   Management of pond water quality will have to involve community discussions about goals, including use of the pond (*e.g.*, boating, swimming, fishing), natural resource concerns (e.g., herring runs, plant coverage), and land uses around the pond (e.g., natural buffers, stormwater runoff). Since these issues will also differ slightly from pond to pond, this reinforces the unique nature of each pond and the need to address management for each pond in a focused way.

V. Recommendations

Based on the preparation of the pond water quality database and review of the water quality data, project staff has a number of recommendations:

a. Prioritization of pond management plans should be revisited annually

The Pond Working Group has reviewed available information about all the monitored ponds and selected Uncle Harveys Pond for development of the first pond management plan in Orleans, including targeted surveys to address identified data gaps during the next 10 months. This group has also selected Pilgrim Lake for targeted surveys within this same period with anticipation of a pond management plan the next year. As these tasks proceed, town managers and committees will gather insights about pond assessment and management techniques and additional data will be gathered on the other ponds in town. It is recommended that the town consider an annual revisiting of pond management priorities, hopefully in mid-winter to allow preparations to be made for the upcoming water quality sampling season.

b. Data should be reviewed more frequently

The majority of the Orleans ponds water quality dataset is composed of data collected through the PALS snapshots. PALS snapshots have been completed for the last 16 years through the efforts of trained volunteers following the same protocols and analytical services provided by CSP/SMAST without any cost to the towns of Cape Cod. Since this effort did not have any funding attached to it for data review, water quality was delivered to the towns each year, but generally warehoused until some data analysis funding was developed. This lag in review often meant that data issues, including differing formatting of reporting and data outliers, were not addressed for a period of years. It is recommended that the town consider a regular review schedule to allow more frequent feedback to volunteers and to the town for management purposes. It is further recommended that this review schedule be tiered to provide annual limited feedback and more extensive review and feedback every 3 years.

c. Prior to the completion of pond management plans, data collection should be aligned with assessment goals

The 2007 Ponds Report recommended that the town implement an April monitoring and that this monitoring should include the same parameters as included in PALS. This recommendation was made to create a portion of the dataset that would allow some context for whether water quality conditions in the PALS Snapshot window (August 15 to September 30) were present at the beginning of the primary water quality management period or whether they developed during the course of the summer. Review of the data during the current project showed that the April sampling was often delayed until May (when initial warming had often already occurred) and that pH and chlorophyll were not included in the lab assays of the spring samplings. These changes from the recommended approach created limits in understanding of the other parameters and how the ponds were functioning that will generally need to be addressed in the data gap analysis. The town should consider options to ensure that water quality monitoring matches assessment goals and, after management plans are completed, management goals.

d. Changes in laboratories or data equipment should be carefully considered

Review of the ponds water quality database showed a variety of laboratory detection limits and methods. Generally these were not substantial obstacles to considering all assay results from different labs, but there were some circumstances where samples were collected and results were not reliable. It is recommended that the Town assess any potential data usage limitations when water quality samples are assayed by different laboratories.

e. Sampling locations should be standardized

The PALS approach has relied on volunteers identifying the deepest location from either local knowledge or review of available bathymetric maps. It was anticipated that this approach would have some variability, including variability associated with groundwater level fluctuations. Review of the database shows some of this variability. In order to remove some uncertainties about this variability, it is recommended that GPS coordinates be established for sampling points and tools be provided to volunteers to ensure that this site is located during each future sampling event.

f. An Orleans Pond Water Quality Sampling QAPP should be prepared

Recommendations b. through e. are sampling procedure and data reporting activities that could all be addressed through preparation of the Orleans Ponds Water Quality Sampling Quality Assurance Project Plan (QAPP). QAPPs are generally required for all monitoring associated with federal or state-funded projects and any regulatory projects. These documents, which are approved by involved regulatory agencies, describes all sampling and lab procedures, frequency and procedures for data review, responsible parties, etc. and ensures that everyone using the collected data understands how it was collected and developed. Sampling to date in Orleans has generally followed the PALS Snapshot procedures that were developed by scientists that are still associated with the PALS program and were used to train volunteers. Development of an Orleans Ponds QAPP would ensure that all procedures are documented and also ensure that all data will be accepted by state and county regulators.

g. Try to integrate/coordinate management objectives across all resources

Much of the current Cape Cod 208 implementation is focused on estuary nitrogen TMDLs. At this point, it appears the compliance with these TMDLs will take continued water quality monitoring each summer with periodic (3-5 yr) assessment of eelgrass and bottom animal communities. It is less clear how freshwater ponds and their potential TMDLs and compliance will be conducted, but it is highly likely that water quality monitoring will also be a fundamental component of compliance. Since both estuaries and ponds will require monitoring for TMDL compliance and natural nitrogen removal in fresh water ponds was an integral part of the watershed analyses completed by the Massachusetts Estuaries Project (MEP), addressing both surface waters within an overarching water quality management structure presents an opportunity for towns to coordinate water quality feedback on both types of systems and create integrated and adaptive management options. Better quantification of the natural nitrogen removals in freshwater ponds based on addressing the identified lake and pond data gaps may additionally allow updating of MEP-era results and support better integration and refinement of water quality management of both estuaries and ponds.

VII. References

CSP/SMAST Technical Memorandum: Lake Wequaquet Dissolved Oxygen Monitoring Program, August – October 2014.). February 3, 2015. From: Eichner, E., B. Howes, and D. Schlezinger. To: Rob Gatewood, Conservation Administrator, Town of Barnstable. 24 p.

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Eichner, E.M. 1993. Watershed protection: A Cape Cod perspective on national efforts. *Environmental Science and Technology.* 27(9): 1736—1740.

Eichner, E.M., J. Scanlon, G. Heufelder, and J. Wood. 2001. Baker Pond Water Quality Assessment. Prepared for Town of Orleans and Massachusetts Department of Environmental Protection. Cape Cod Commission. Barnstable, MA.

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.

GHD, Inc. 2013. Stormwater Sampling Plan, Town of Orleans, MA. Hyannis, MA. 120 pp.

Massachusetts Department of Environmental Protection. December, 2015. Massachusetts Year 2014 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.

Mello, M.J. 1982. Investigation of Bloom Conditions of Aphanizomenon flos-aquae in Crystal Lake with Recommendations for its Prevention. Provincetown Center for Coastal Studies.

Scanlon, J. and G. Meservey. 2001. 3 Ponds Study, Orleans, MA. Crystal Lake, Pilgrim Lake, Baker's Pond.

School of Marine Science and Technology, University of Massachusetts Dartmouth. 2003. Coastal Systems Program, Analytical Facility, Laboratory Quality Assurance Plan. New Bedford, MA.

Wilson, H.J. 1984. The Public Trust Doctrine in Massachusetts Land Law. 11 *B.C. Envtl. Aff. L. Rev.* 839. http://lawdigitalcommons.bc.edu/ealr/vol11/iss4/6 (accessed 8/22/16).

APPENDIX A

Water Quality Laboratory Information
Town of Orleans Pond Water Quality Database

CSP/SMAST Analyte Details for Cape Cod PALS Ponds Monitoring Program					
Analyte	**units**	**Reporting Limit**	**Accuracy/Precision**	**Analysis Method/Type**	**Max Holding Time**
Alkalinity	mg/l as CaCO3	0.5	80-120% Std. Value	Acid Titration [1]	6 hrs
Chlorophyll *a*/ Phaeophytin *a*	μg/l	0.1	80-120% Std. Value	Acetone extraction [2]	24 hrs
Nitrogen, Total	μM	0.1	80-120% Std. Value	Persulfate digestion [3]	Frozen 60 days[6]
pH	stnd units	NA	±0.2 of QC standard	Electrode [4]	6 hrs
Phosphorus, Total	μM	0.1	80-120% Std. Value	Persulfate digestion [5]	Preserved 28 days

Notes:

a) Accuracy is determined by the analysis of spiked samples and comparison to known standards, except as noted in the table. QC sample recoveries may also be used to assess accuracy when spiked sample analysis is not possible. The general data quality observation for all analyte blanks are no exceedances of the MDL. All procedures, methods, and lab SOPs are documented in the SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (2003)
b) For accuracy determination, comparison of spike samples and known standards is preferred.
c) Overall precision is measured using the Relative Percent Difference, RPD (or std. deviation for n > 2) of field duplicate samples. Lab precision is based on an estimate of the RPD between duplicate aliquots of the same lab sample.

Methods details:

1) Standard Methods 19th Edition, Method 2320-B
2) Parsons, T.R., Y. Maita and C. Lalli. 1989. Manual of Chemical and Biological Methods for seawater analysis. Pergamon Press, 173 pp. Analysis using Turner Designs - AU-10.
3) Standard Methods 19th Edition, Method 4500-Norg-D D'Elia, C.F., P.A. Steudler and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22:760-764.
4) Standard Methods 19th Edition, Method 4500-H+B
5) Standard Methods 19th Edition, Method 4500-P-B.5, persulfate digestion and assay as orthophosphate (molybdate/ascorbic acid method).
6) Avanzino, R. J., and V. C. Kennedy (1993), Long-term frozen storage of stream water samples for dissolved orthophosphate, nitrate plus nitrite, and ammonia analysis, Water Resour. Res., 29(10), 3357–3362, doi:10.1029/93WR01684

CCNS/NPS LAB INFO							
		Analyte	units	mdl	Method Reference	Instrument	Additional References
2001	NPS	SO_4^{2-}	mg/L	0.01	Standard Methods 4500-SO_4^{2-} E (Turbidimetric Method-buffer B)	Milton Roy Spec 21	
2001	NPS	Cl^-	mg/L	0.01	Standard Methods 4500-Cl^- C (Mercuric Nitrate Method)	Hach Kit Model 16900	
2001	NPS	Mg	mg/L	0.01	Standard Methods 3111 B (Direct Air-Acetylene Flame Method)	Perkin Elmer AAnalyst 300	Analytical Methods for Atomic Absorption Spectrometry, pg. 87 (Perkin Elmer, 1994)
2001	NPS	Ca	mg/L	0.02	Standard Methods 3111 B (Direct Air-Acetylene Flame Method)	Perkin Elmer AAnalyst 300	Analytical Methods for Atomic Absorption Spectrometry, pg. 62 (Perkin Elmer, 1994)
2001	NPS	Na	mg/L	0.20	Standard Methods 3500-Na B (*Flame Emission Photometric Method)	Perkin Elmer AAnalyst 300	Analytical Methods for Atomic Absorption Spectrometry, pg. 90 (Perkin Elmer, 1994)
2001	NPS	K	mg/L	0.02	Standard Methods 3500-K B (*Flame Emission Photometric Method)	Perkin Elmer AAnalyst 300	Analytical Methods for Atomic Absorption Spectrometry, pg. 83 (Perkin Elmer, 1994)
2001	NPS	TP	ug/L	1 ug/L (0.03 uM)	Lachat QC Method 10-115-01-1-F	Lachat FIA+ 8000 Series	
2001	NPS	PO_4	ug/L	0.62 ug/L (0.02 uM)	Lachat QC Method 31-115-01-1-G	Lachat FIA+ 8000 Series	
2001	NPS	NO_3/NO_2	ug/L	1.68 ug/L (0.12 uM)	Lachat QC Method 31-107-04-1-A	Lachat FIA+ 8000 Series	
2001	NPS	NH4	ug/L	4 ug/L (0.29 uM)	Lachat QC Method 10-107-06-1-C	Lachat FIA+ 8000 Series	
2001	NPS	Chlorophyll a	ug/L	0.01	Standard Methods 10200H	Milton Roy Spec 21	
2001	NPS	Alkalinity	mg/L	0.1	Standard Methods 2320	Dosimat Autotitrator/Denver Sci. pH meter	
2001	NPS	*Na and K analysis by emission starting 7/10/01, all other AA work by absorption					
2009	NPS	2009 file:	Minimum detection level for Ammonium = 8 µg/L for Nitrite/Nitrate = 7 µg/L				

BARNSTABLE COUNTY DEPARTMENT OF HEALTH AND THE ENVIRONMENT
(laboratory info from 2000-2001)

MDL Conc	mg/l	ug/l

	pH	Cl	NO3-N	O-P	TP	SO4	NH3-N	TKN	Ca	Mg	K	Na	TOC	ALK	SAL	CHLA	Phaeo
BCDHE MDL	0.1	1.0	0.01	0.005	0.005	1.0	0.1	0.5	0.1	0.1	0.1	1.0	1.0				
BCDHE METHOD	EPA 150.1	EPA 300.0	EPA 300.0	EPA 365.2	EPA 365.4	EPA 300.0	EPA 350.1	EPA 351.2	SM 3111B	SM 3111B	SM 3111B	SM 3111B	EPA 415.1				
CCNSS MDL		0.01	1.68	0.62	1	0.01	4		0.02	0.01	0.02	0.2		0.1		0.01	
CCNSS Method		SM 4500	Lachat QC Method 31-107-04-1-A	Lachat QC Method 31-115-01-1-G	Lachat QC Method 10-115-01-1-F	SM 4500	Lachat QC Method 10-107-06-1-C		SM 3111B	SM 3111B	SM 3500B	SM 3500B		SM 2320		SM 10200H	

CCS Laboratory info (2013-2016)

	Parameter	Field Precision	Lab Precision	Accuracy	Blank Cleanliness	MDL[1]
2013	Nitrate+Nitrite	<30% RPD[2] for field duplicates	<10% RPD for instrument duplicates	± 15% PD[3] based on recovery of standards	Method procedural blank ≤5 x MDL	0.05 uM
2013					Field Blank ≤5 x MDL	
2013	Ammonia	<30% RPD for field duplicates	<10% RPD for instrument duplicates	± 15% PD[3] based on recovery of standards	Method procedural blank ≤5 x MDL	0.05 uM
2013					Field Blank ≤5 x MDL	
2013	Ortho-phosphate	<30% RPD for field duplicates	<10% RPD for instrument duplicates	± 15% PD[3] based on recovery of standards	Method procedural blank ≤5 x MDL	0.02 uM
2013					Field Blank ≤5 x MDL	
2013	Silicate	<30% RPD for field duplicates	<10% RPD for instrument duplicates	± 15% PD[3] based on recovery of standards	Method procedural blank ≤5 x MDL	0.05 uM
2013					Field Blank ≤5 x MDL	
2013	Total nitrogen	<30% RPD for field duplicates	<10% RPD for laboratory duplicates	± 15% PD[3] based on recovery of standards	Field Blank ≤5 x MDL	1.07 uM
2013						
2013	Total phosphorus	<30% RPD for field duplicates	<10% RPD for laboratory duplicates	± 15% PD[3] based on recovery of standards	Field Blank ≤5 x MDL	0.23 uM
2013						
2013	Chlorophyll *a* and Phaeophytin	<50% RPD for field duplicates	<15% RPD for laboratory (instrument) duplicates	± 15% PD[3] based on recovery of standards	Filter Blank ≤5 x MDL	0.02 ug/L
2013						
2013						

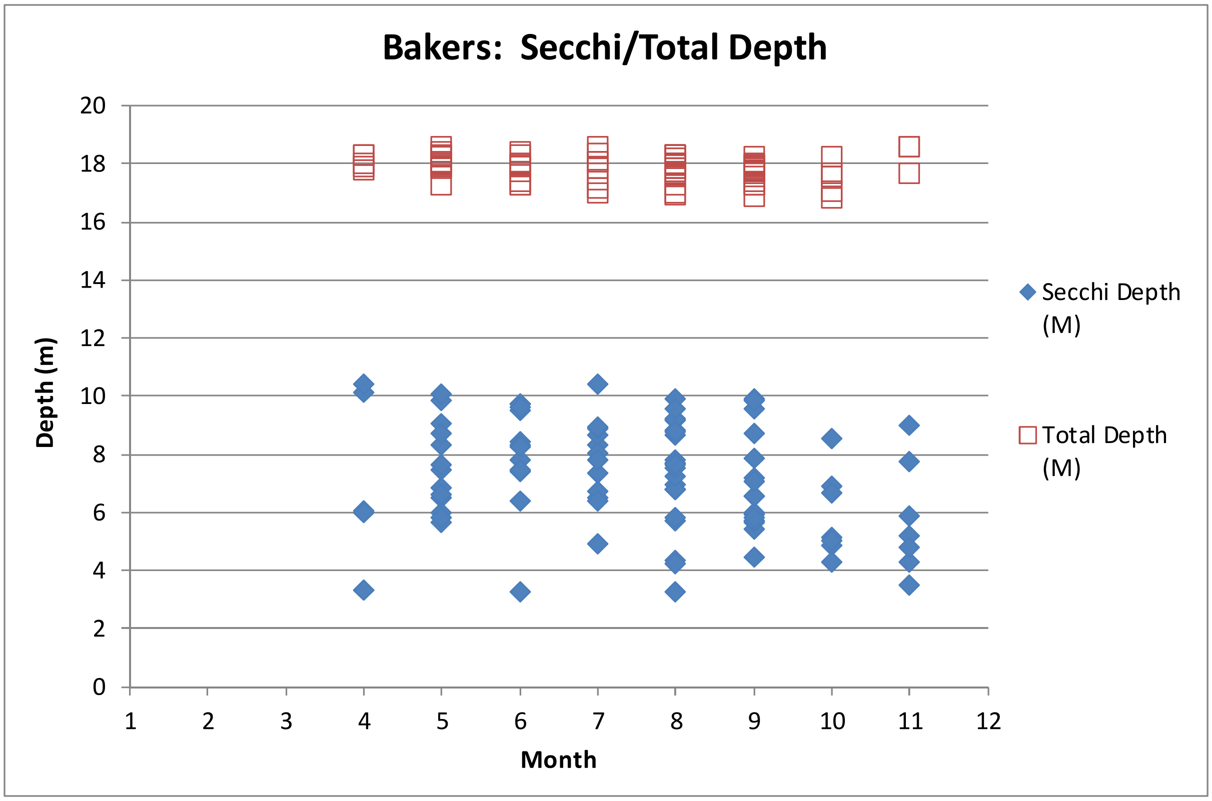
APPENDIX B

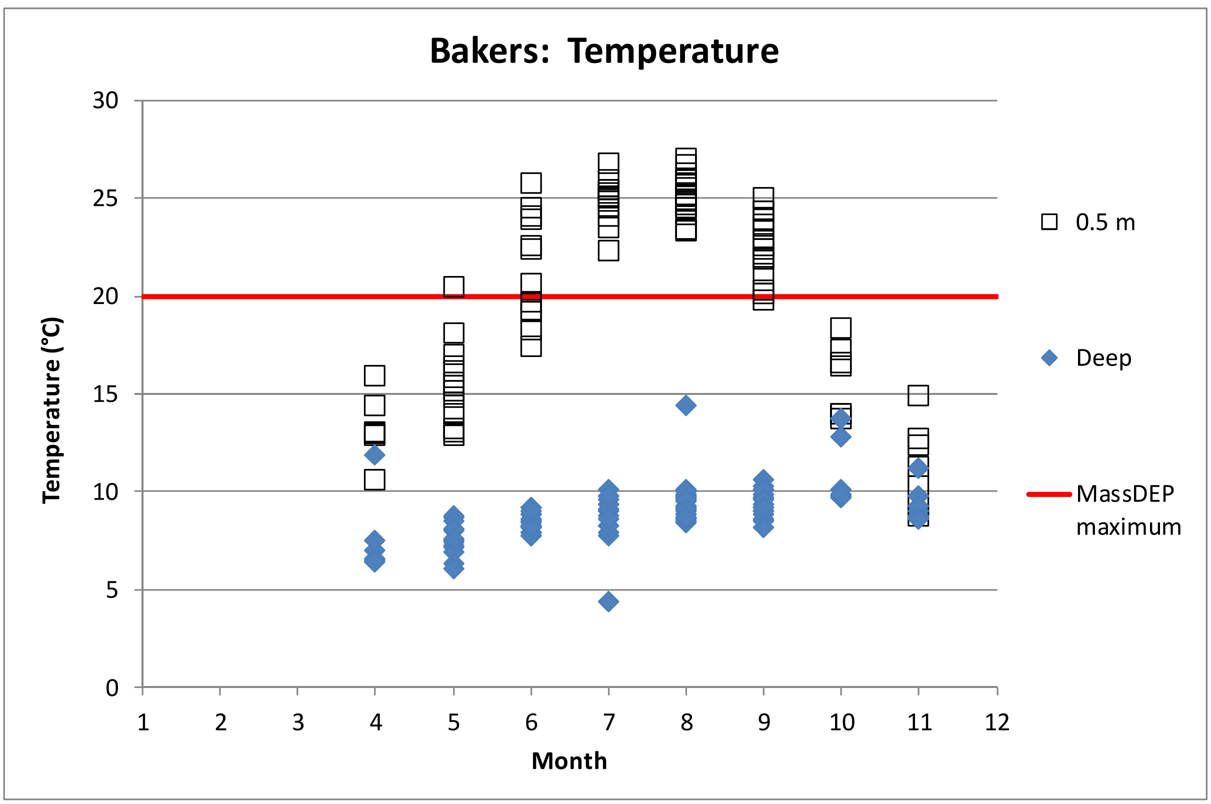
Pond Water Quality Graphs
Town of Orleans Pond Water Quality Database

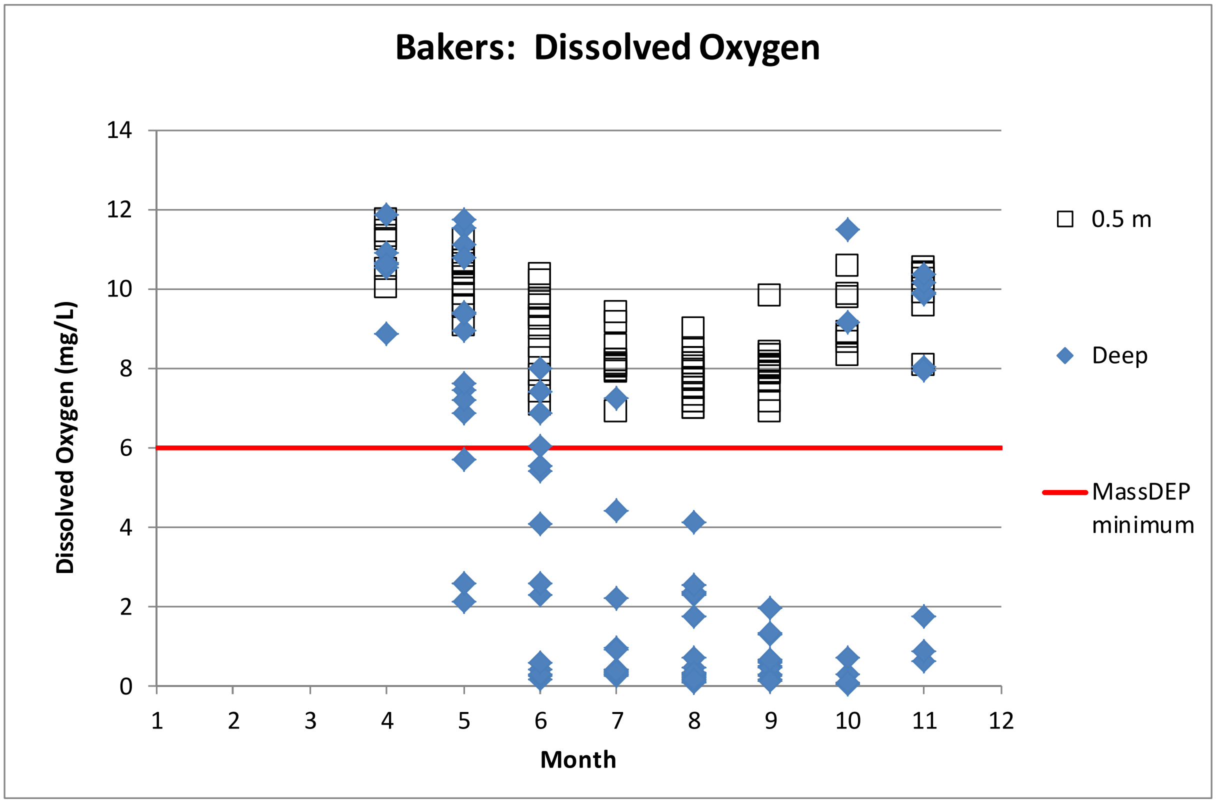
Data presented are from 2000 through 2016, including all PALS Snapshot data (save 2016 lab data). Graphs show individual readings by month. Graphs are presented in the following order: Secchi transparency and station depth, temperature, dissolved oxygen, % saturation of dissolved oxygen, total nitrogen, total phosphorus, N:P ratio, chlorophyll, and pH. Graphs also include available MassDEP surface water regulatory limits (314 CMR 4) or Cape Cod-specific Ecoregion threshold concentrations developed using the 2001 PALS Snapshot results and an EPA guidance concentration calculation method (Eichner, *et al.*, 2003). Presented data have outliers removed. These graphs can be used to evaluate the range of conditions measured during each month throughout the available years and the comparison of these conditions to the regulatory limits and ecoregion thresholds. More refined analyses of the data can be completed during the development of pond management plans.

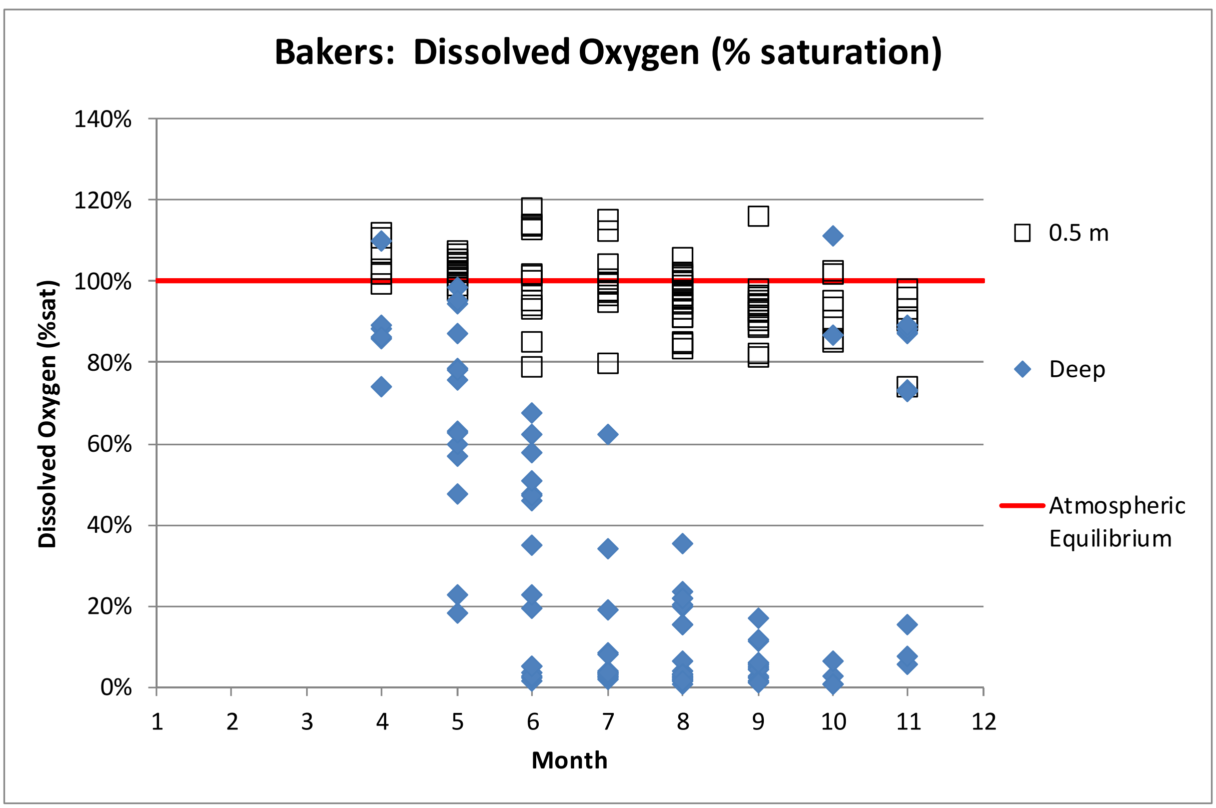
Ponds	
Bakers	Pilgrim
Boland	Reubens
Critchetts	Sarahs
Crystal	Shoal
Deep	Twinings
Gould	Uncle Harveys
Icehouse	Uncle Israels
Kettle	Uncle Seths
Meadow Bog	Wash

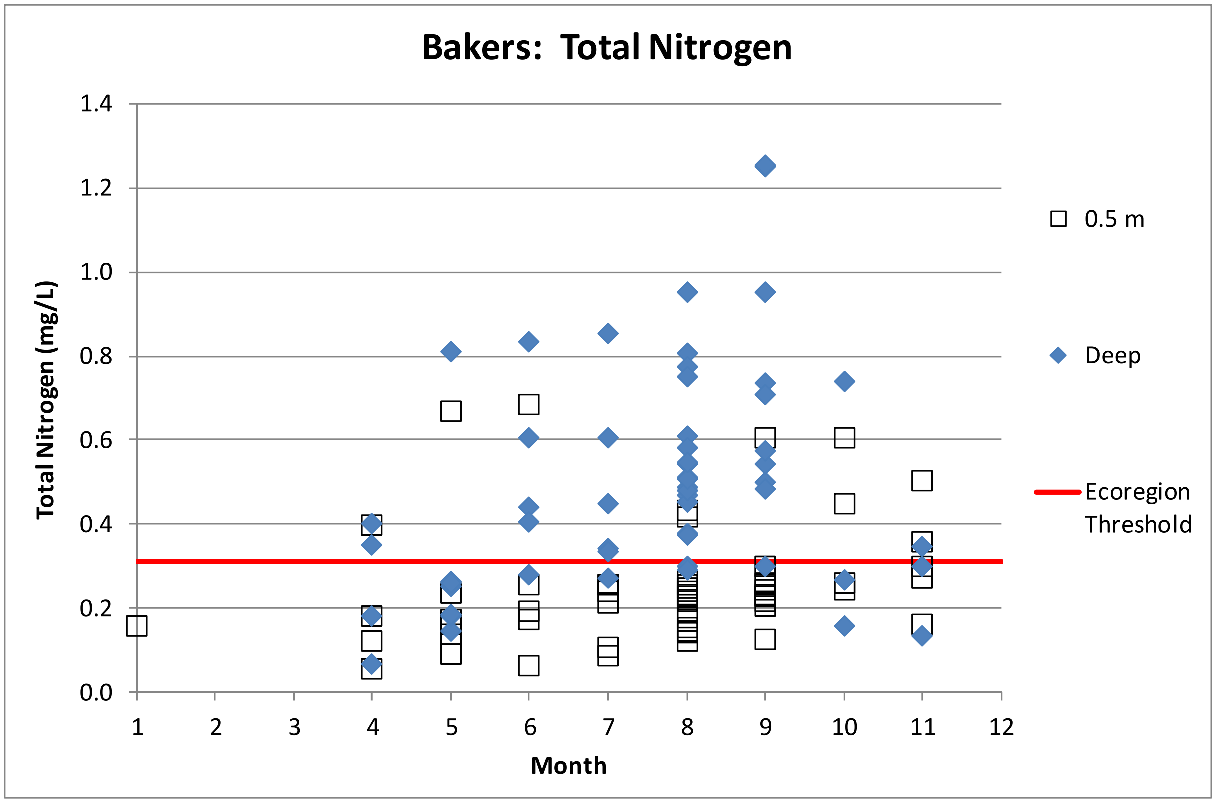
Bakers Pond


Bakers: Secchi/Total Depth
Depth (m)
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)

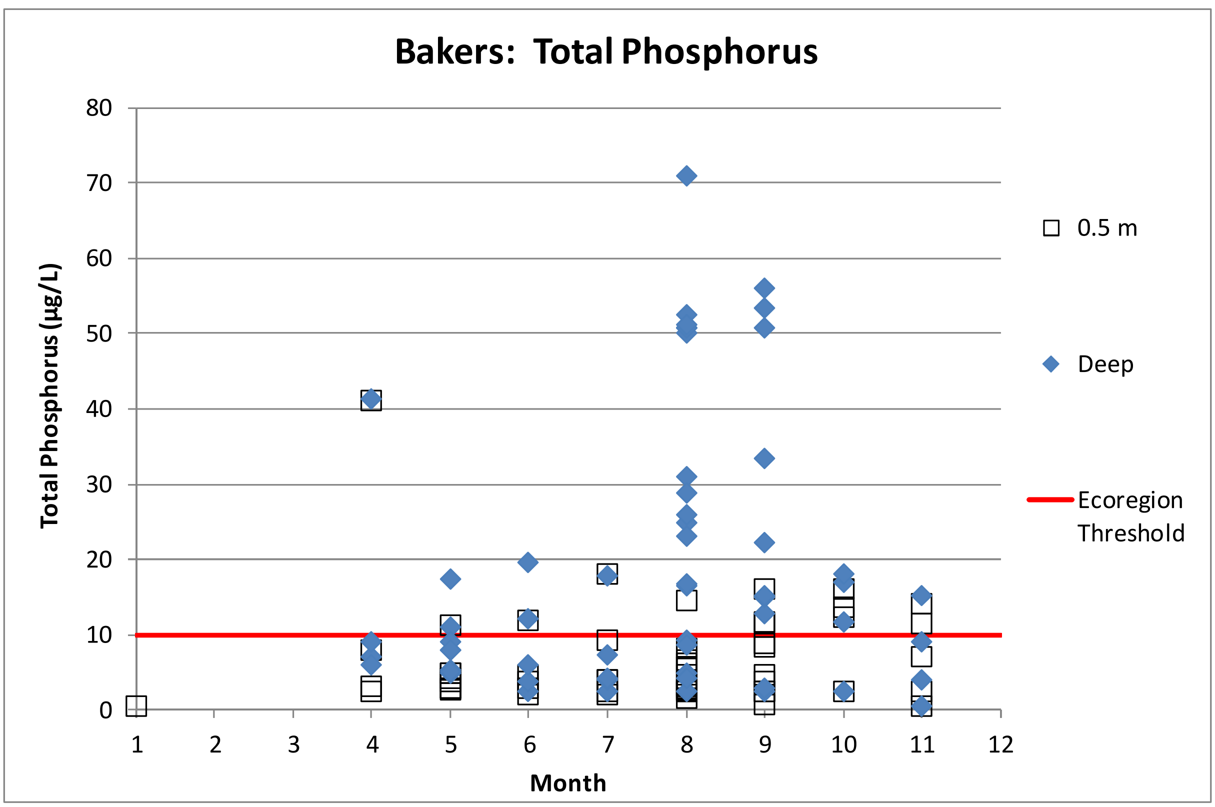

Bakers: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP maximum


Bakers: Dissolved Oxygen
Dissolved Oxygen (mg/L)
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

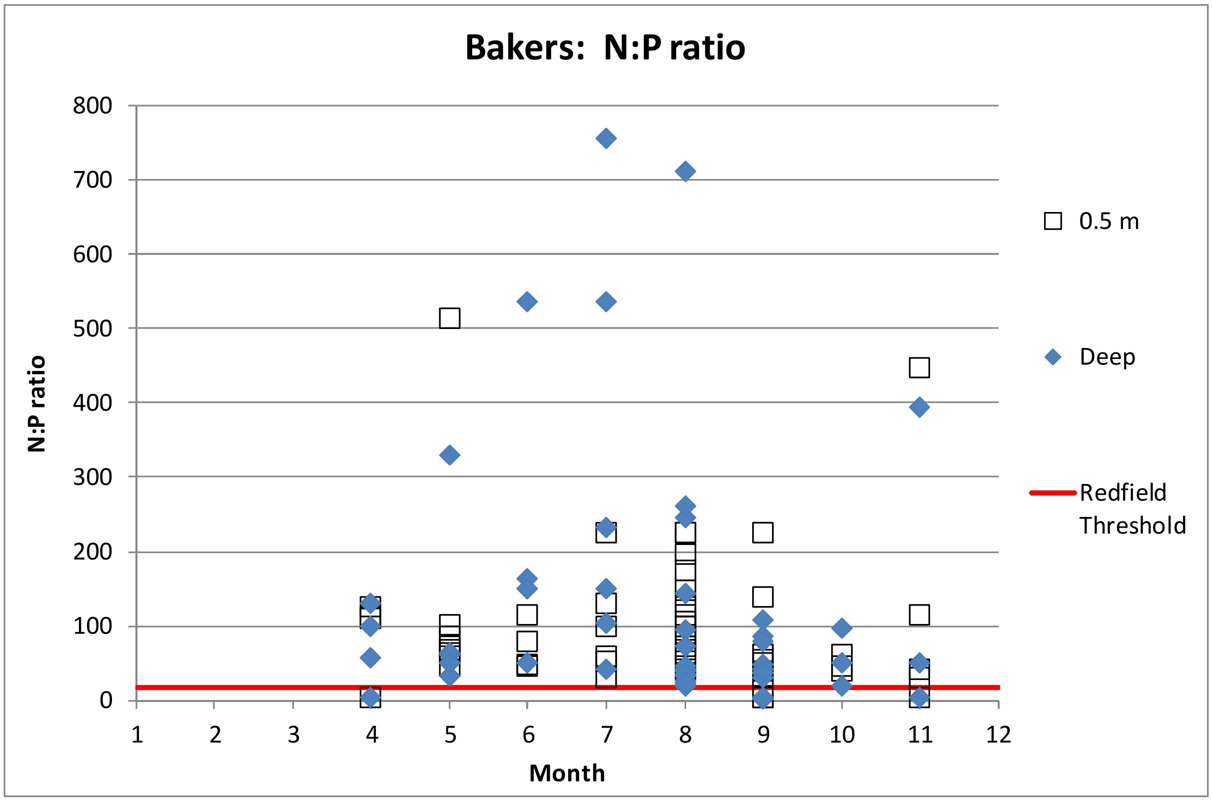

Bakers: Dissolved Oxygen (% saturation)
Dissolved Oxygen (%sat)
0%
20%
40%
60%
80%
100%
120%
140%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium



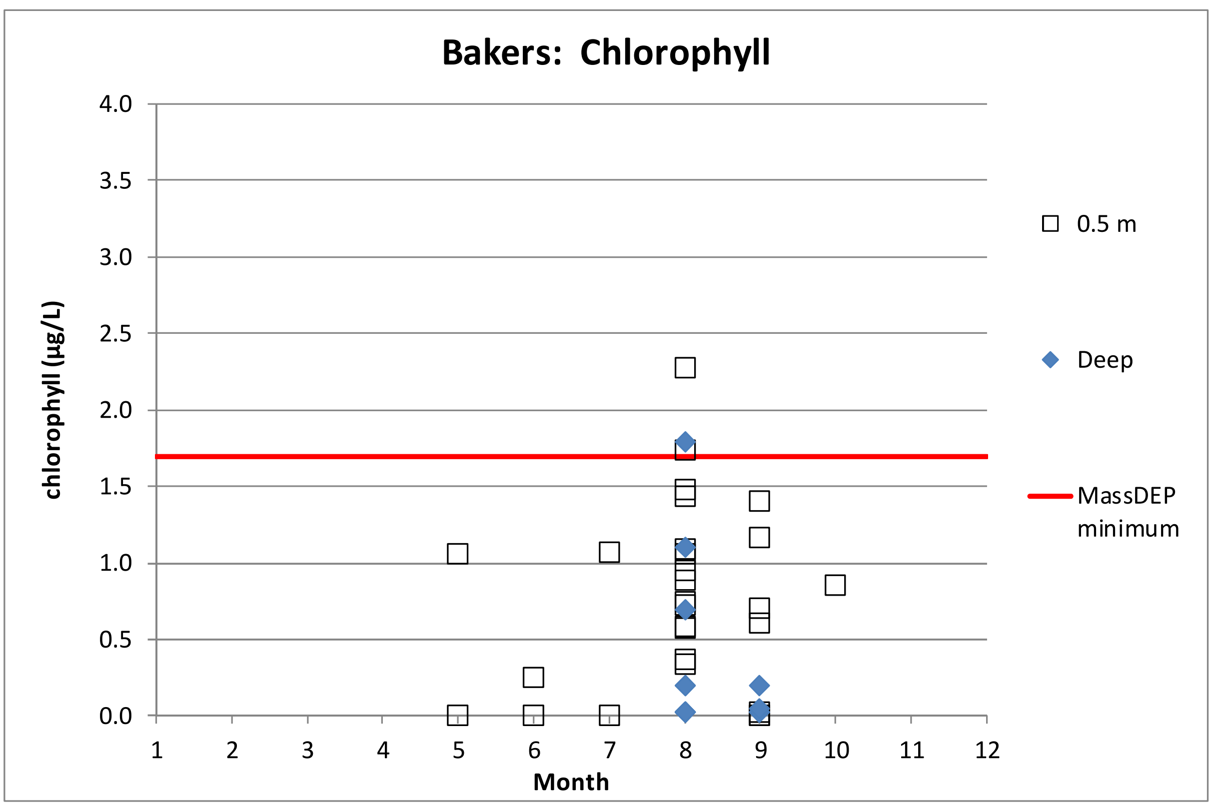
Bakers: Total Nitrogen
Total Nitrogen (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold



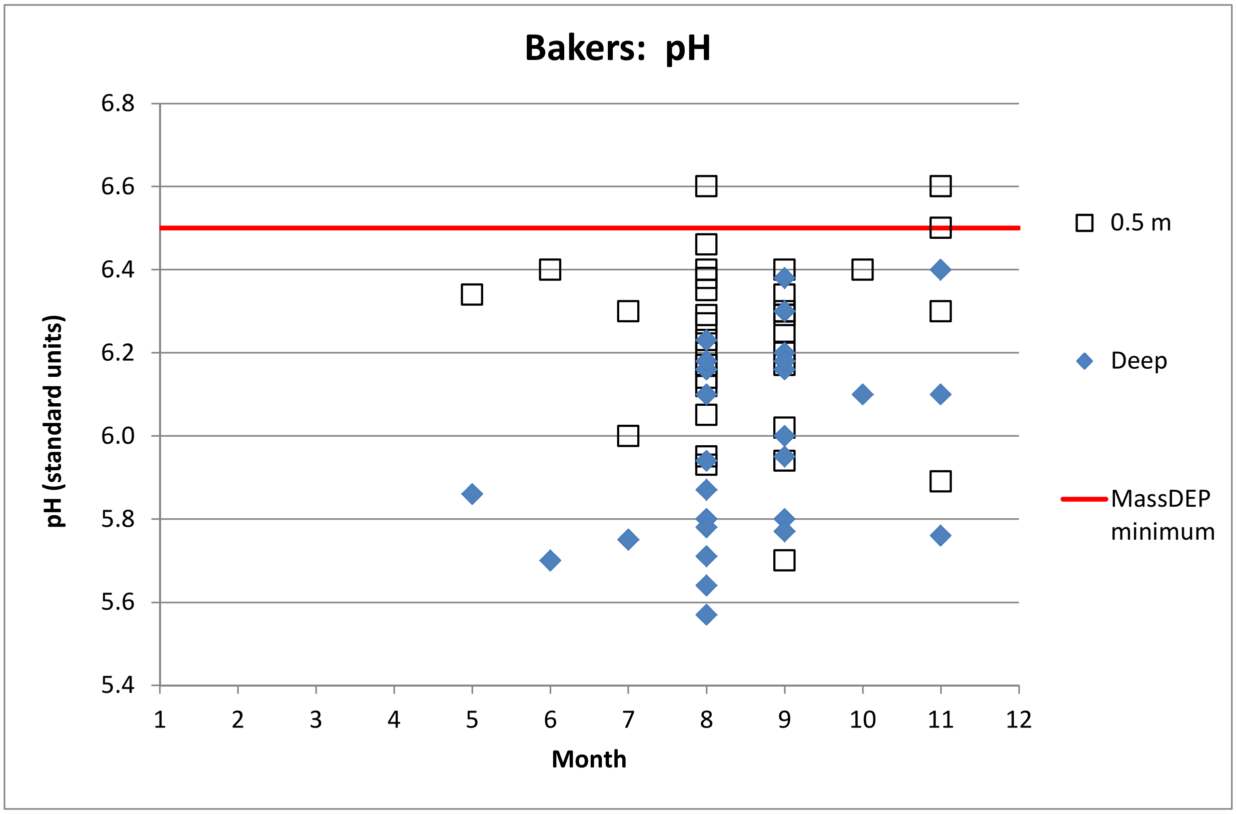
Bakers: Total Phosphorus
Total Phosphorus (µg/L)
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold



Bakers: N:P ratio
N:P ratio
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield Threshold

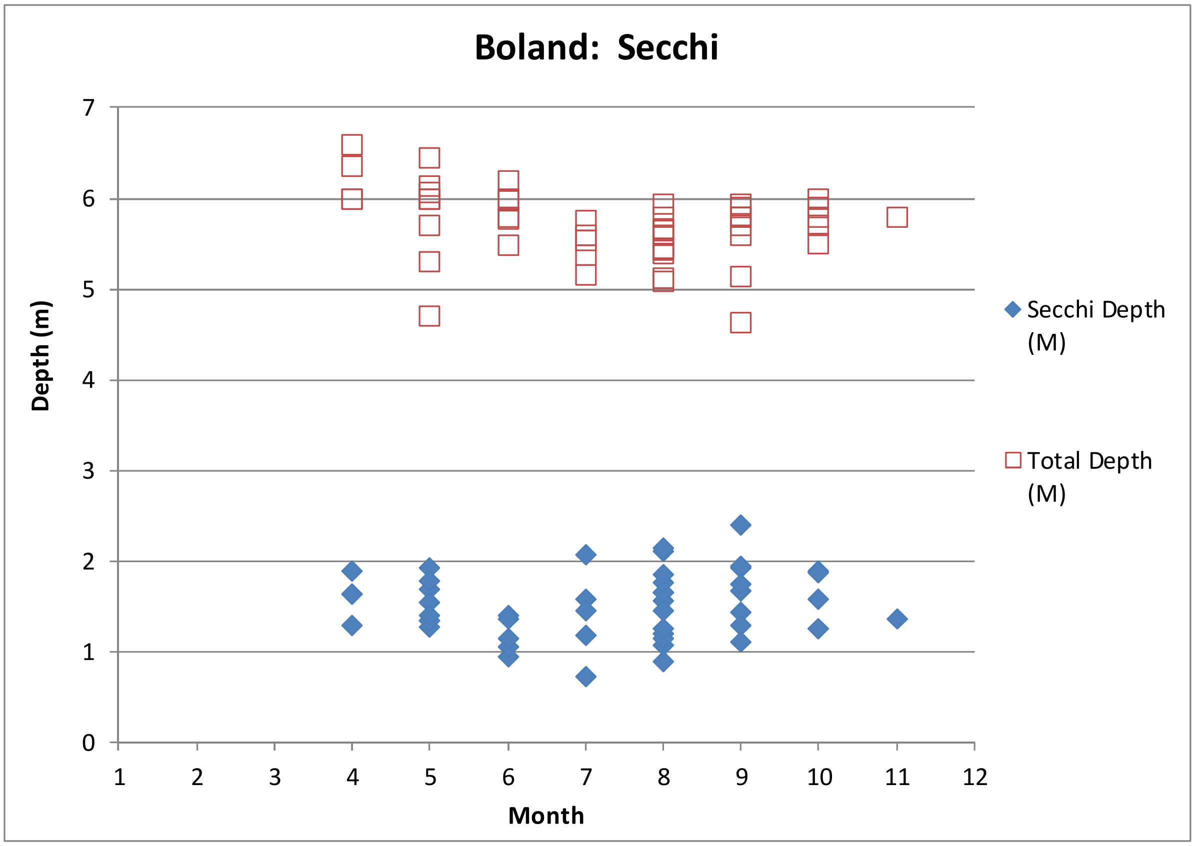


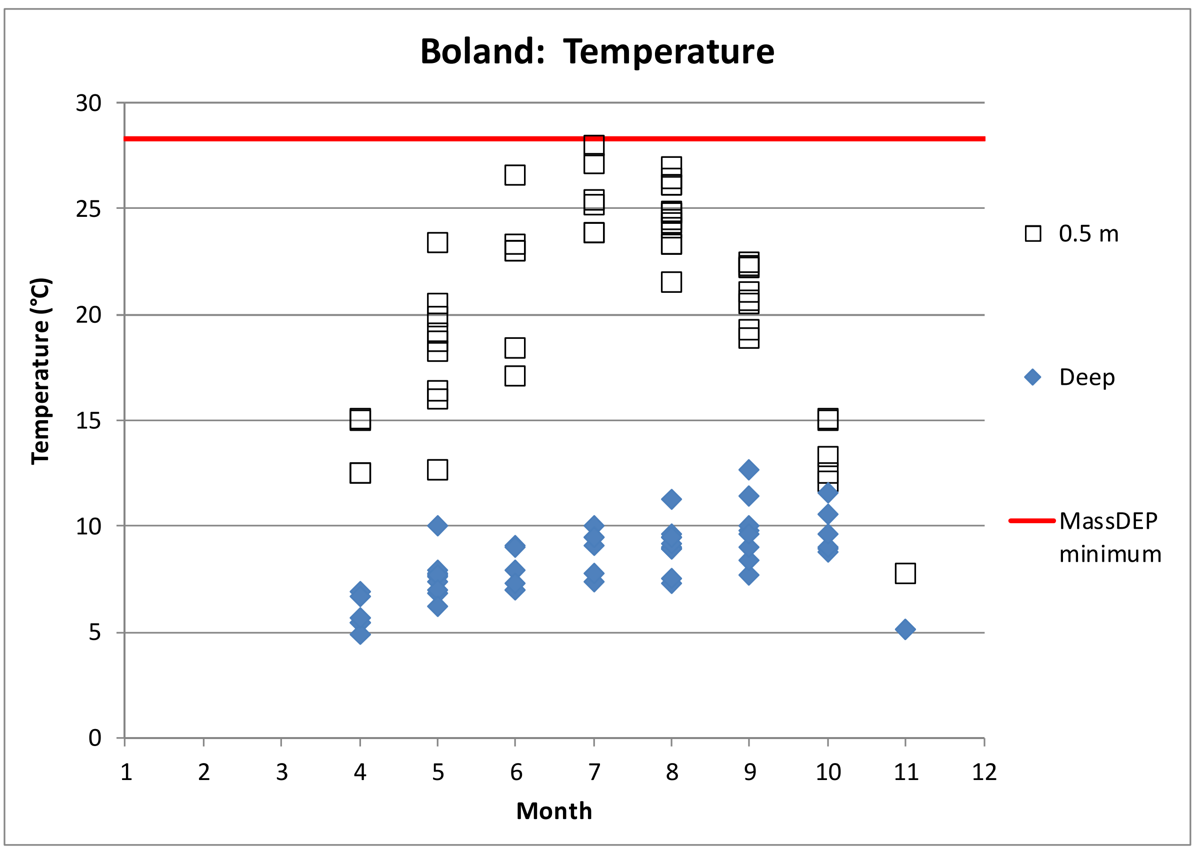
Bakers: Chlorophyll
chlorophyll (µg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

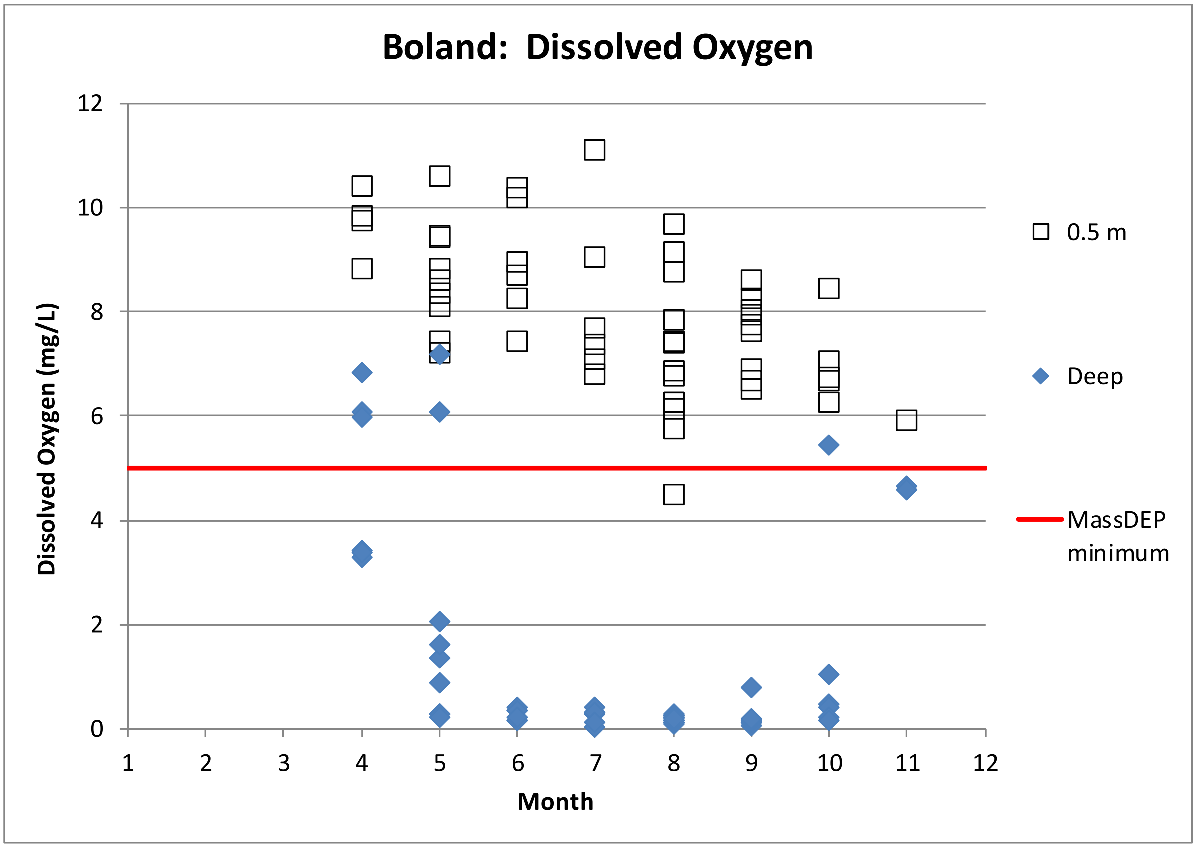


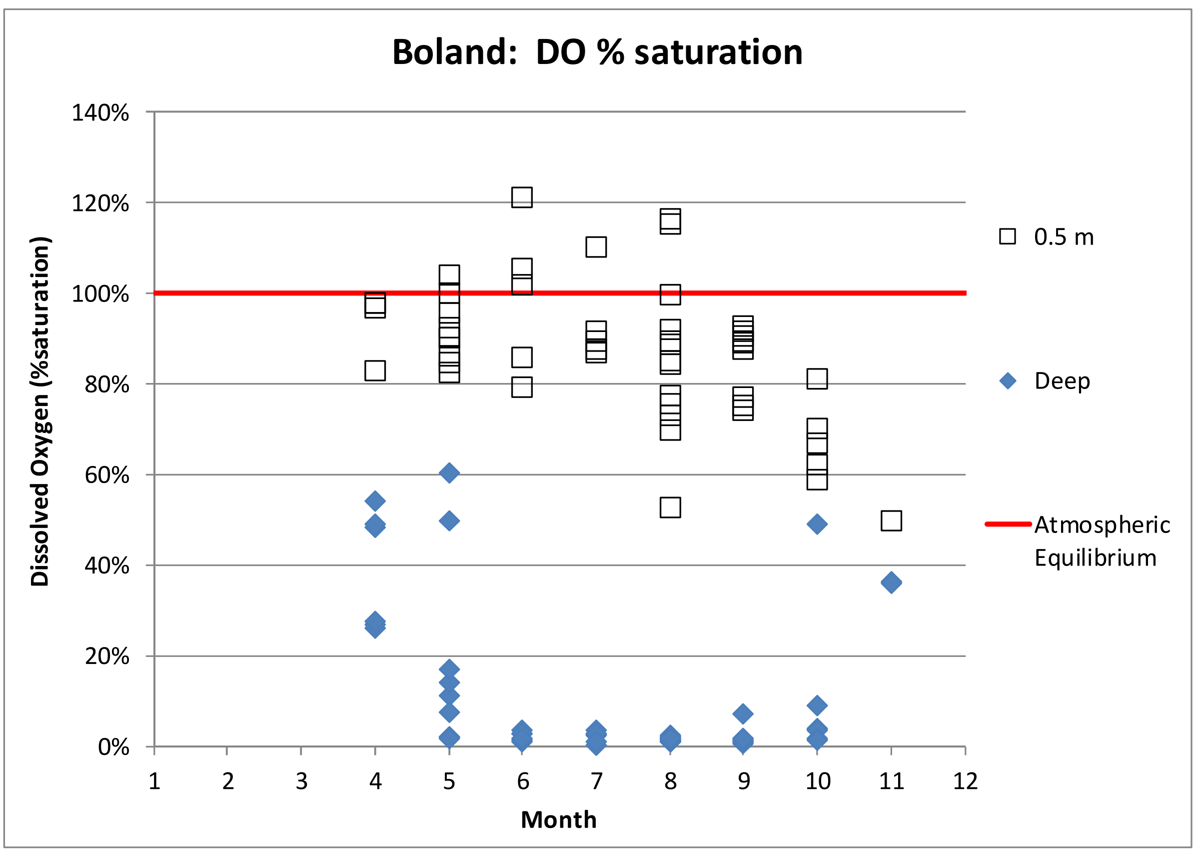
Bakers: pH
pH (standard units)
6.8
6.6
6.4
6.2
6.0
5.8
5.6
5.4
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

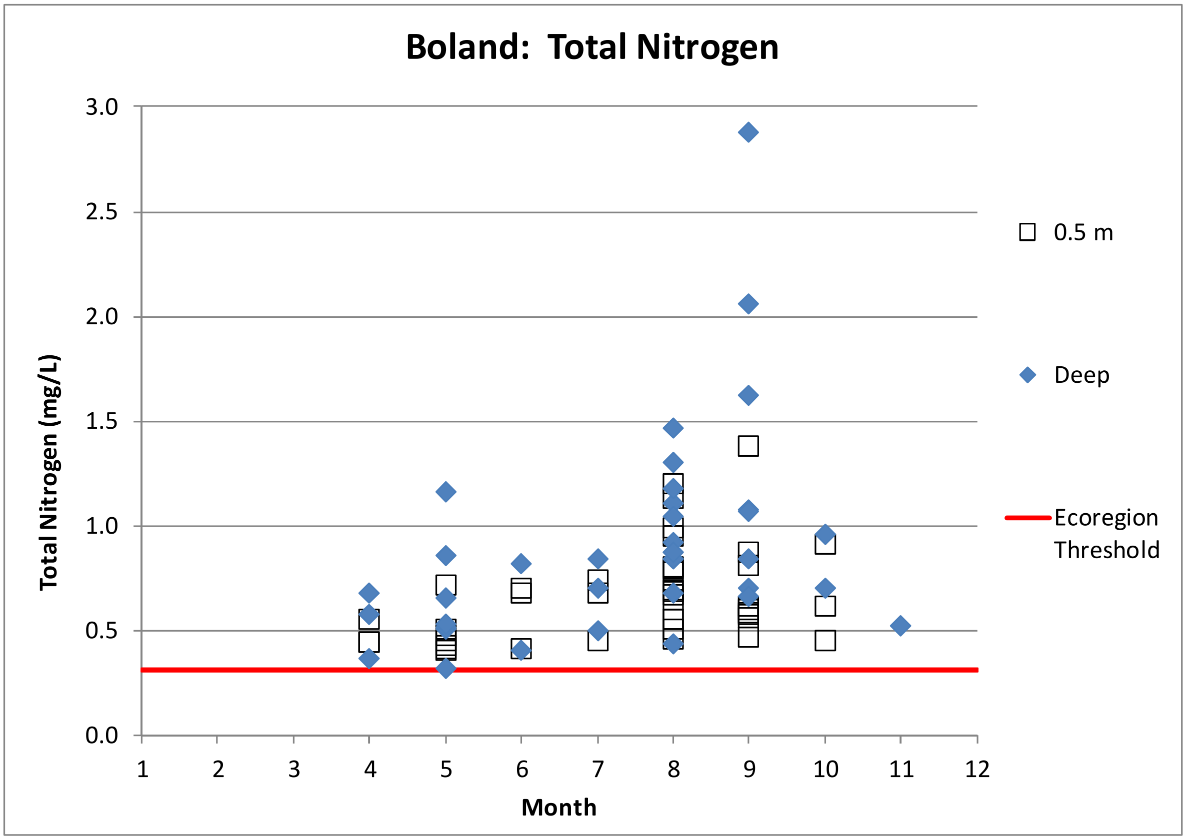
Boland Pond

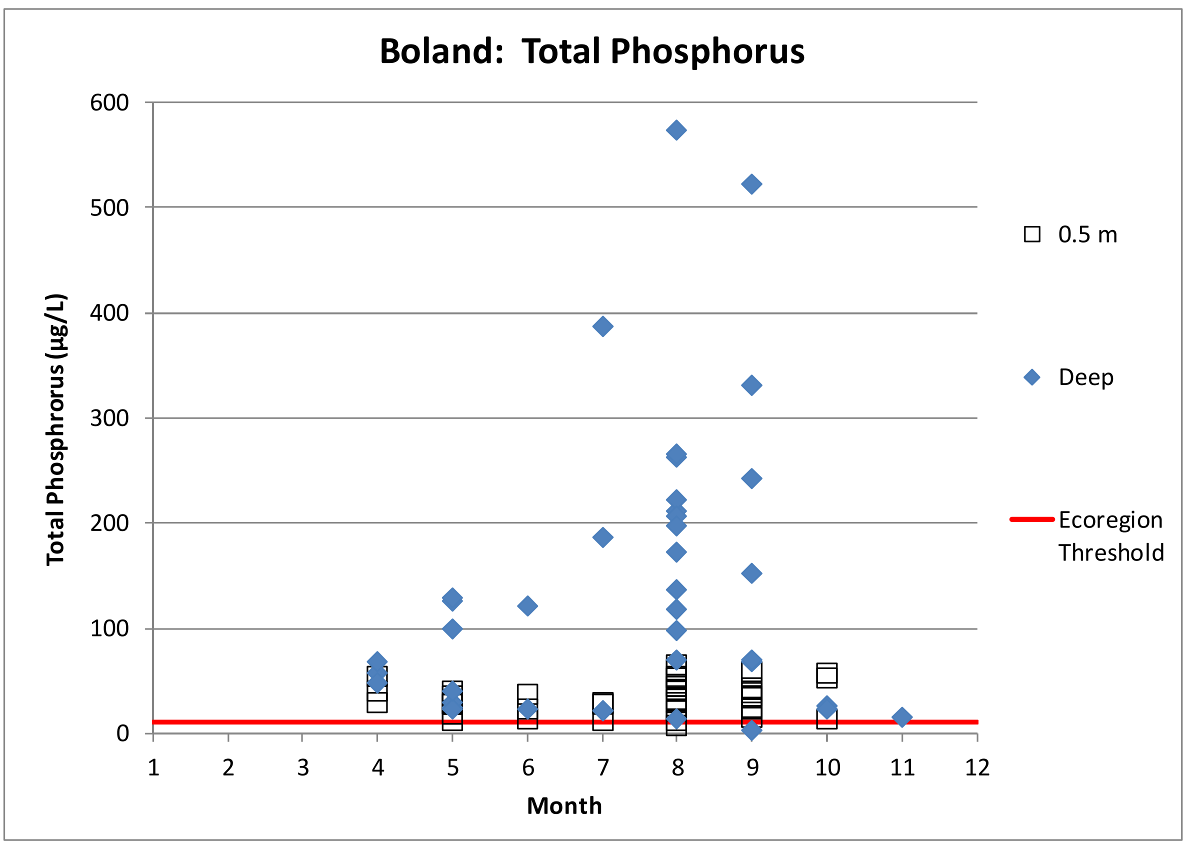

Boland: Secchi
Depth (m)
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)

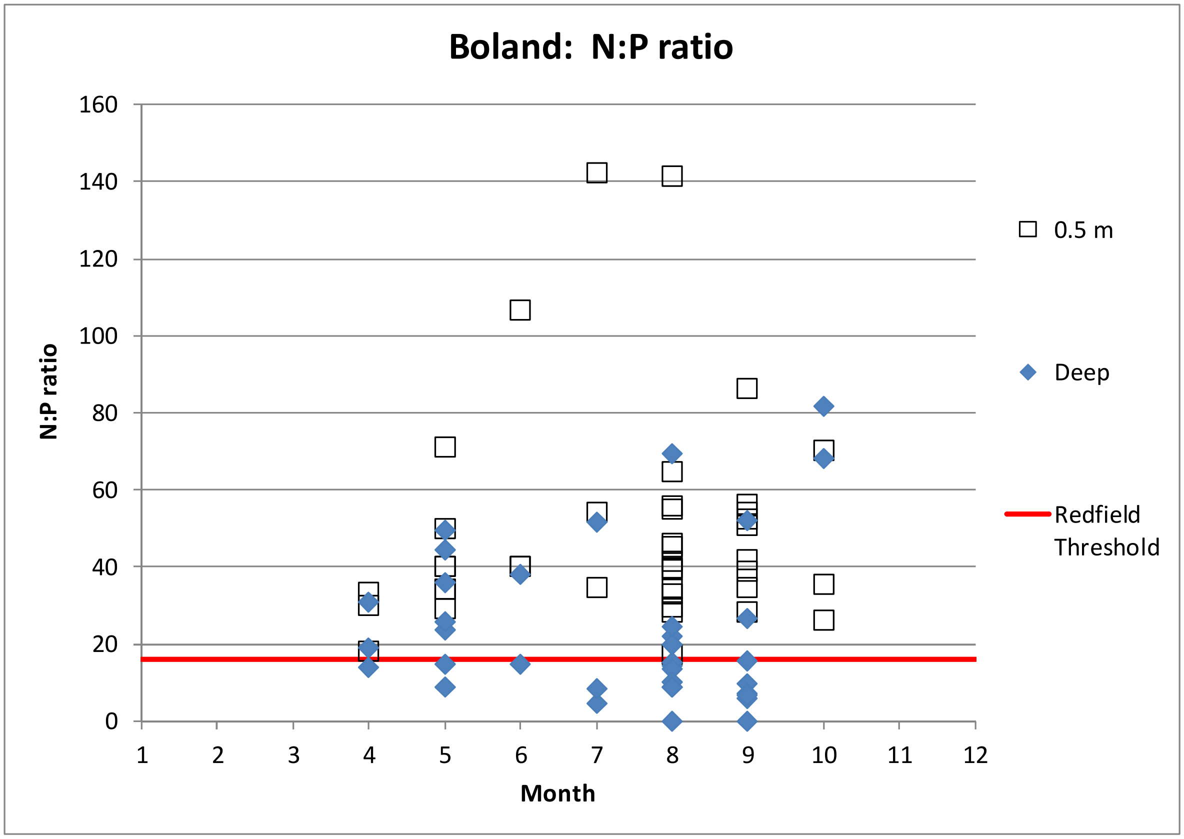

Boland: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

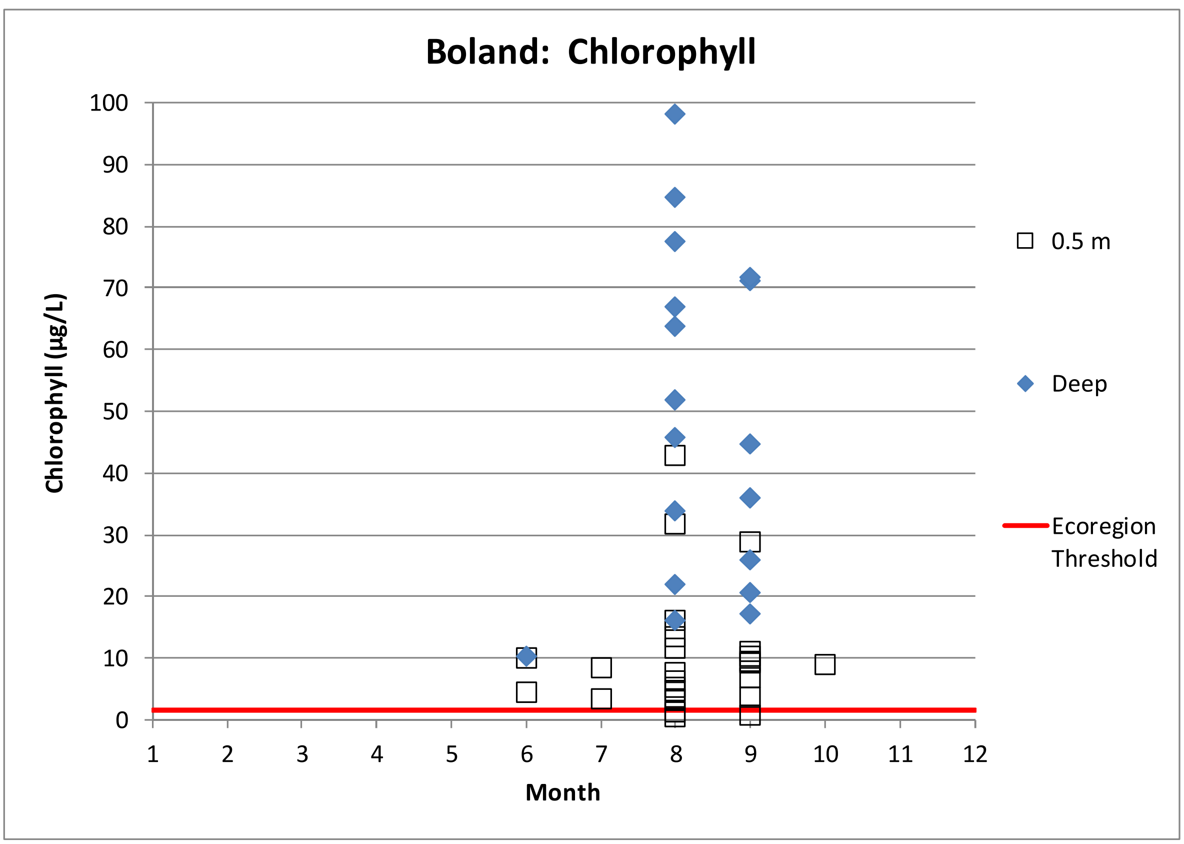

Boland: Dissolved Oxygen
Dissolved Oxygen (mg/L)
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

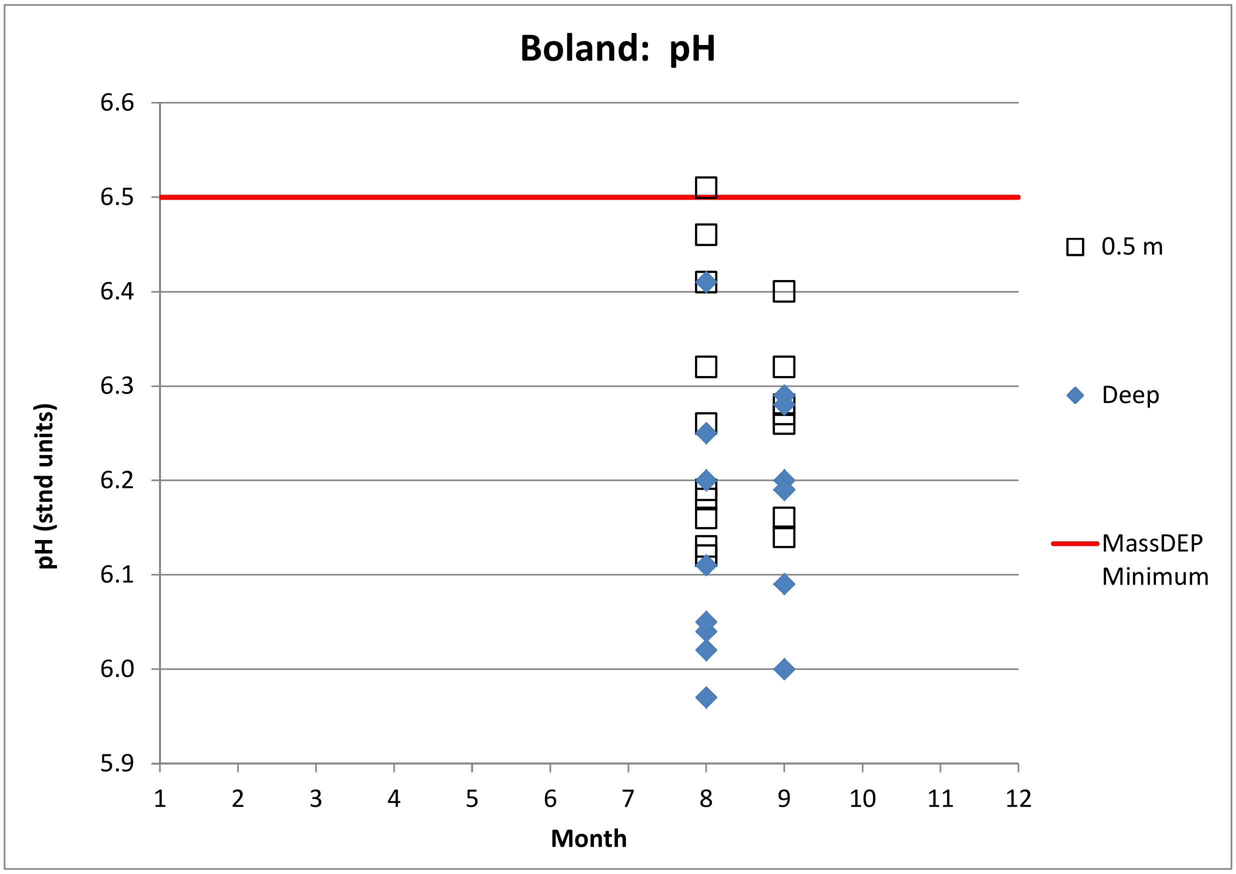

Boland: DO % saturation
Dissolved Oxygen (%saturation)
140%
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium


Boland: Total Nitrogen
Total Nitrogen (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

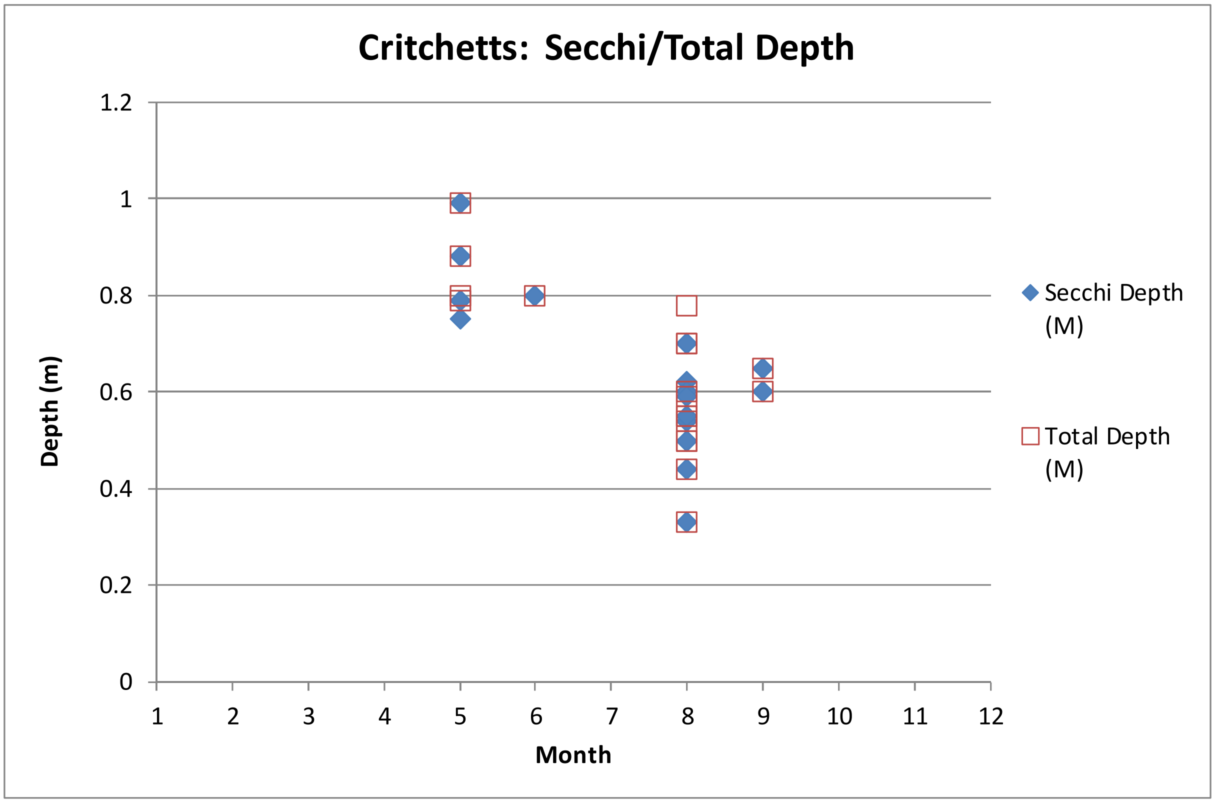

Boland: Total Phosphorus
Total Phosphrorus (µg/L)
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

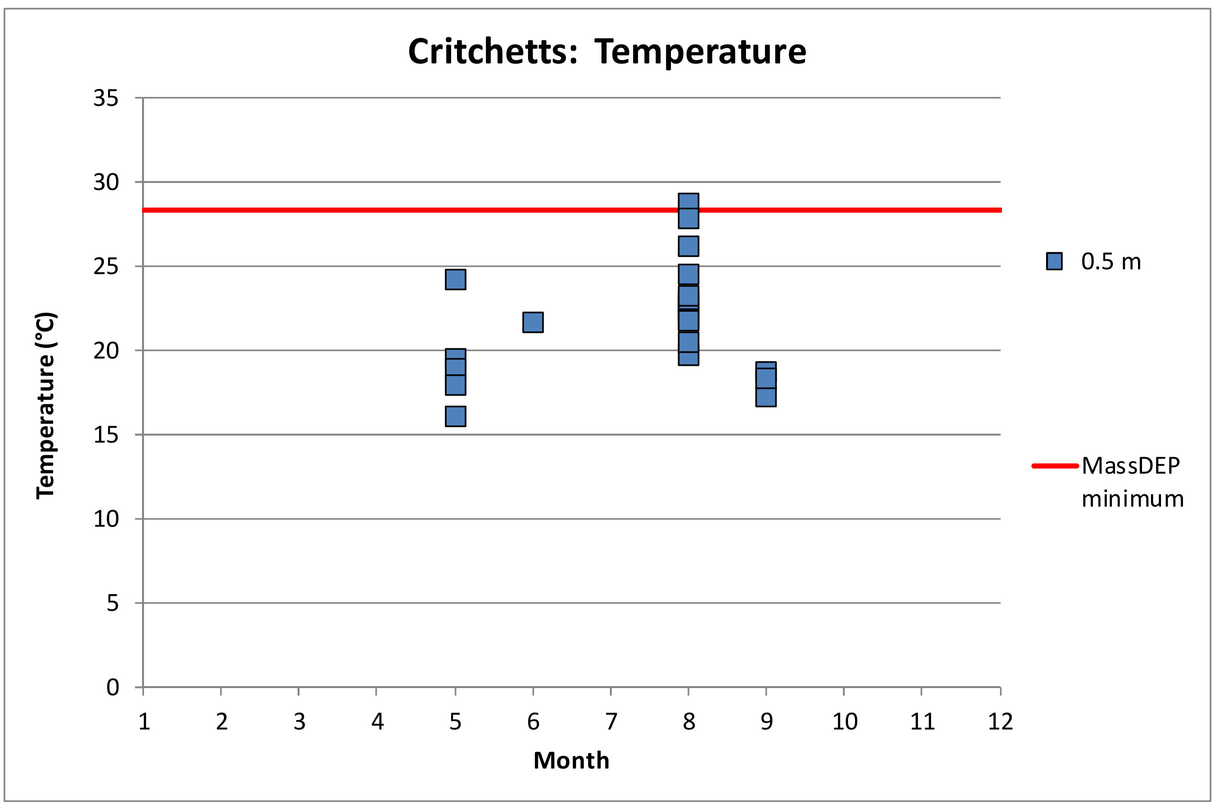

Boland: N:P ratio
160
140
120
100
80
60
40
20
0
N:P ratio
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield Threshold

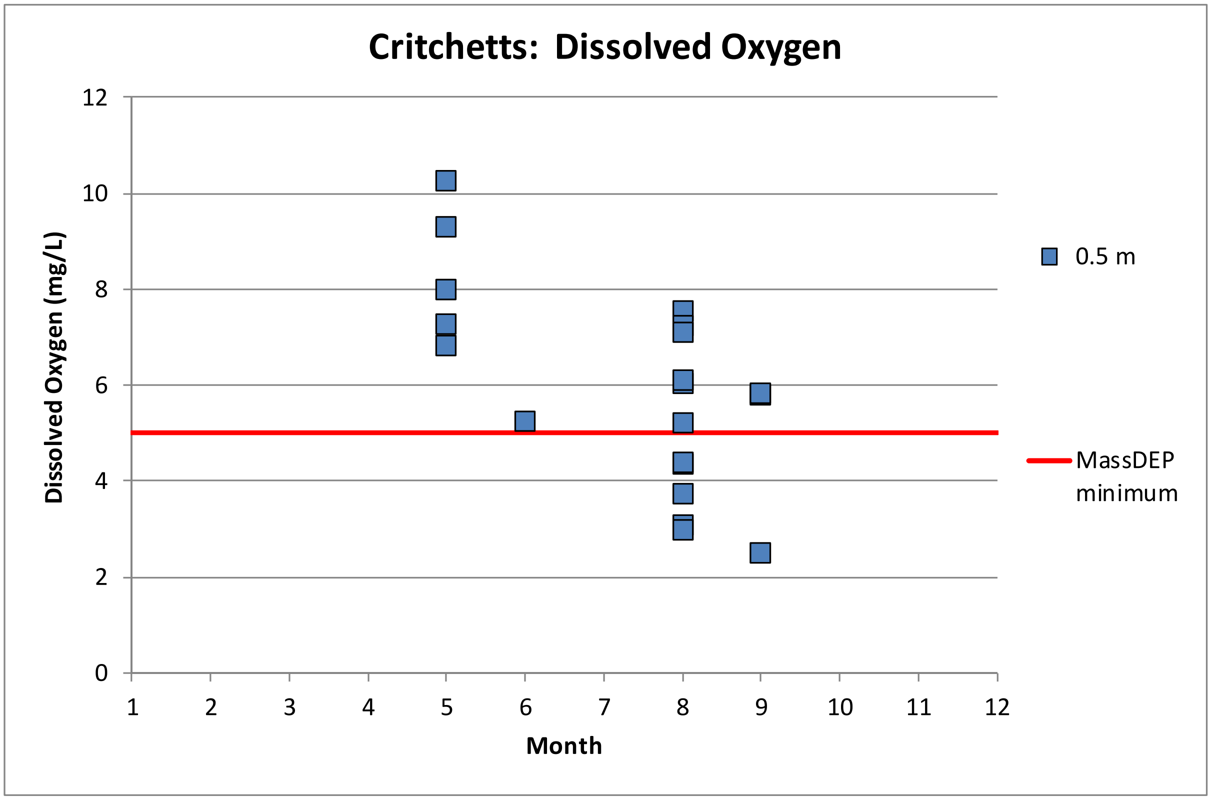

Boland: Chlorophyll
100
90
80
70
60
50
40
30
20
10
0
Chlorophyll (µg/L)
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

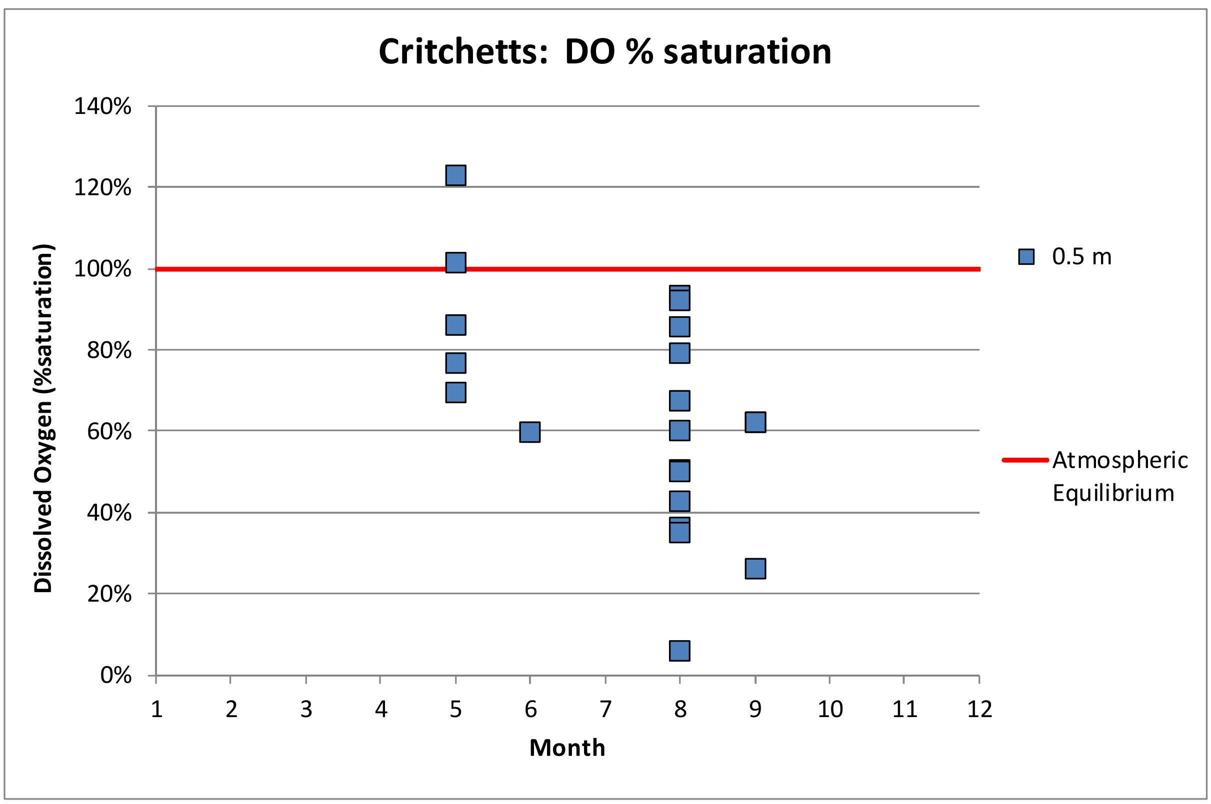

Boland: pH
6.6
6.5
6.4
6.3
6.2
6.1
6.0
5.9
pH (stnd units)
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP Minimum

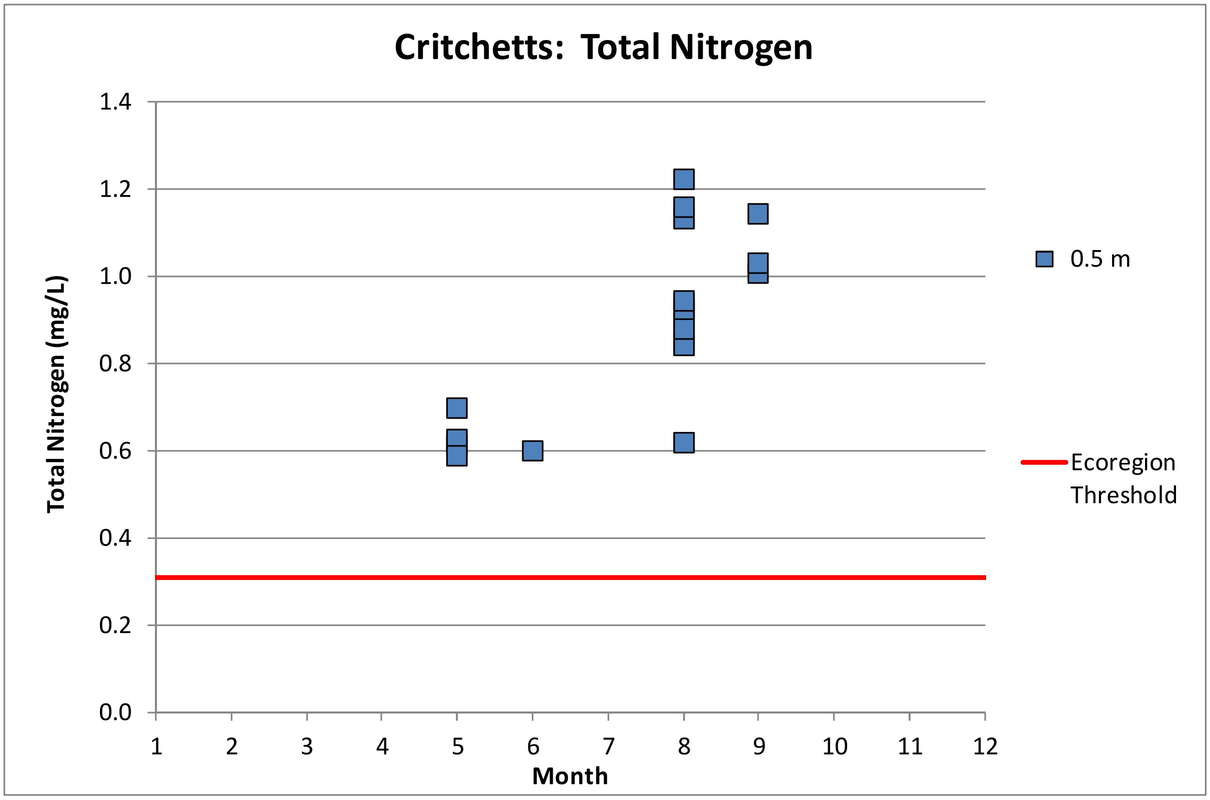
Critchetts Pond

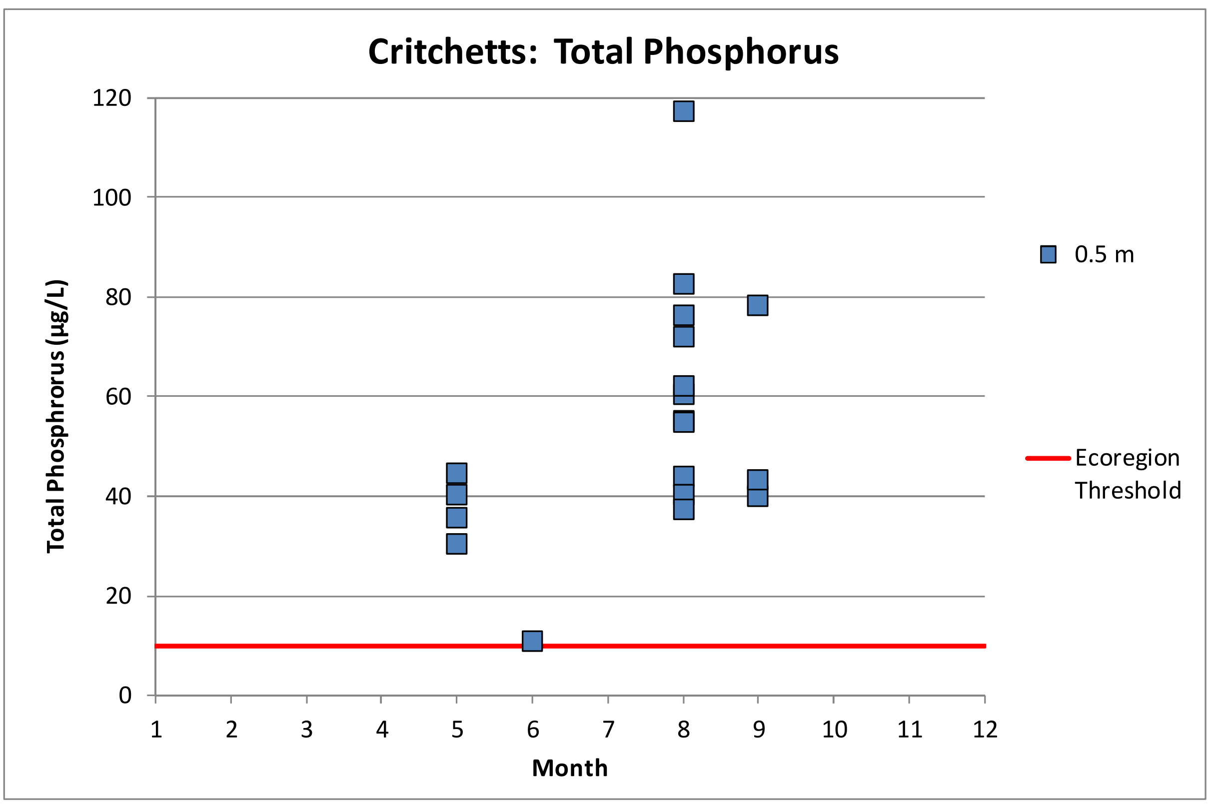

Critchetts: Secchi/Total Depth
Depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)

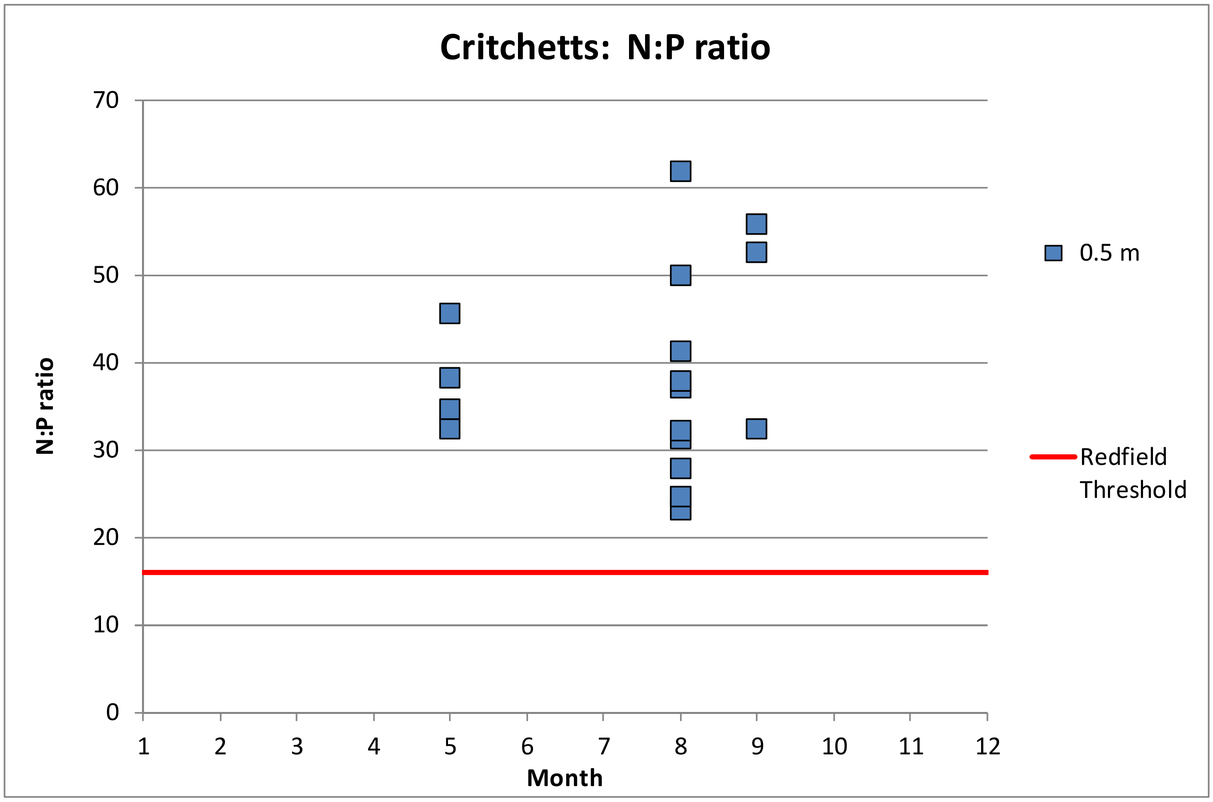

Critchetts: Temperature
Temperature (°C)
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
MassDEP minimum


Critchetts: Dissolved Oxygen
Dissolved Oxygen (mg/L)
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
MassDEP minimum

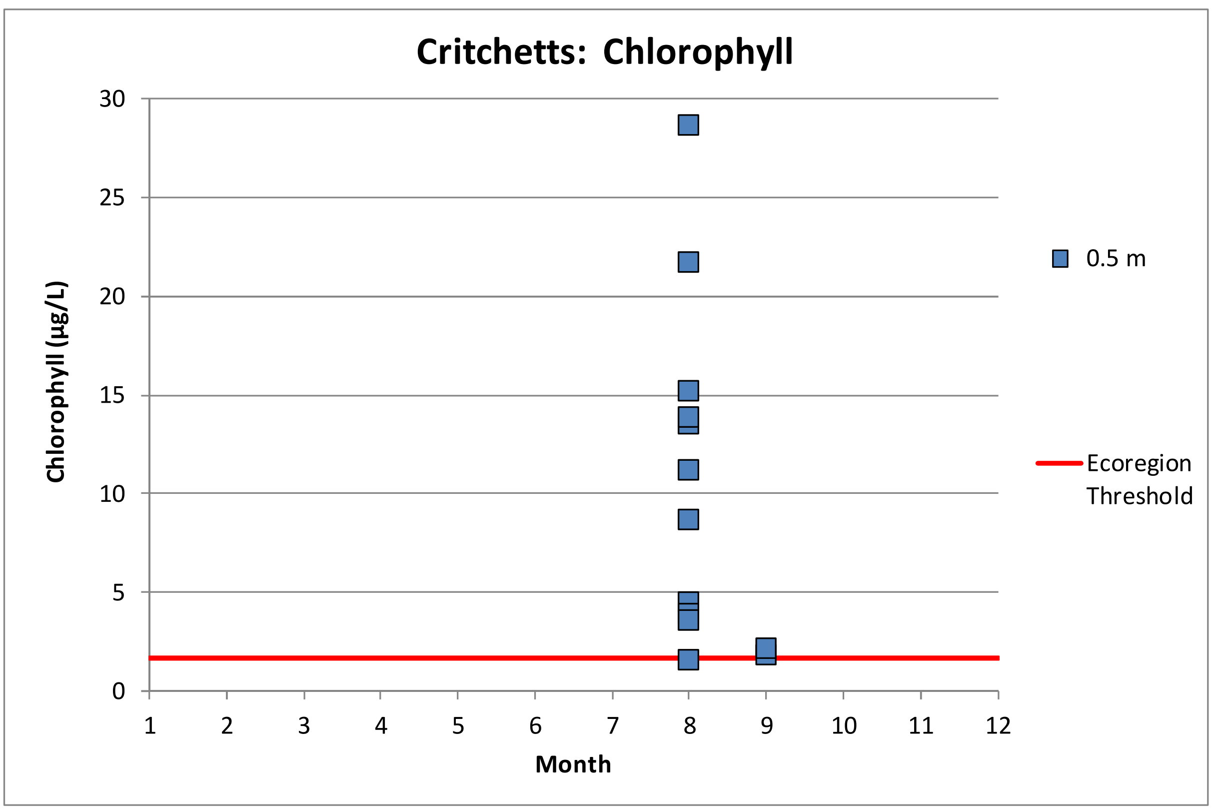

Critchetts: DO % saturation
Dissolved Oxygen (%saturation)
140%
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Atmospheric Equilibrium


Critchetts: Total Nitrogen
Total Nitrogen (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Ecoregion Threshold

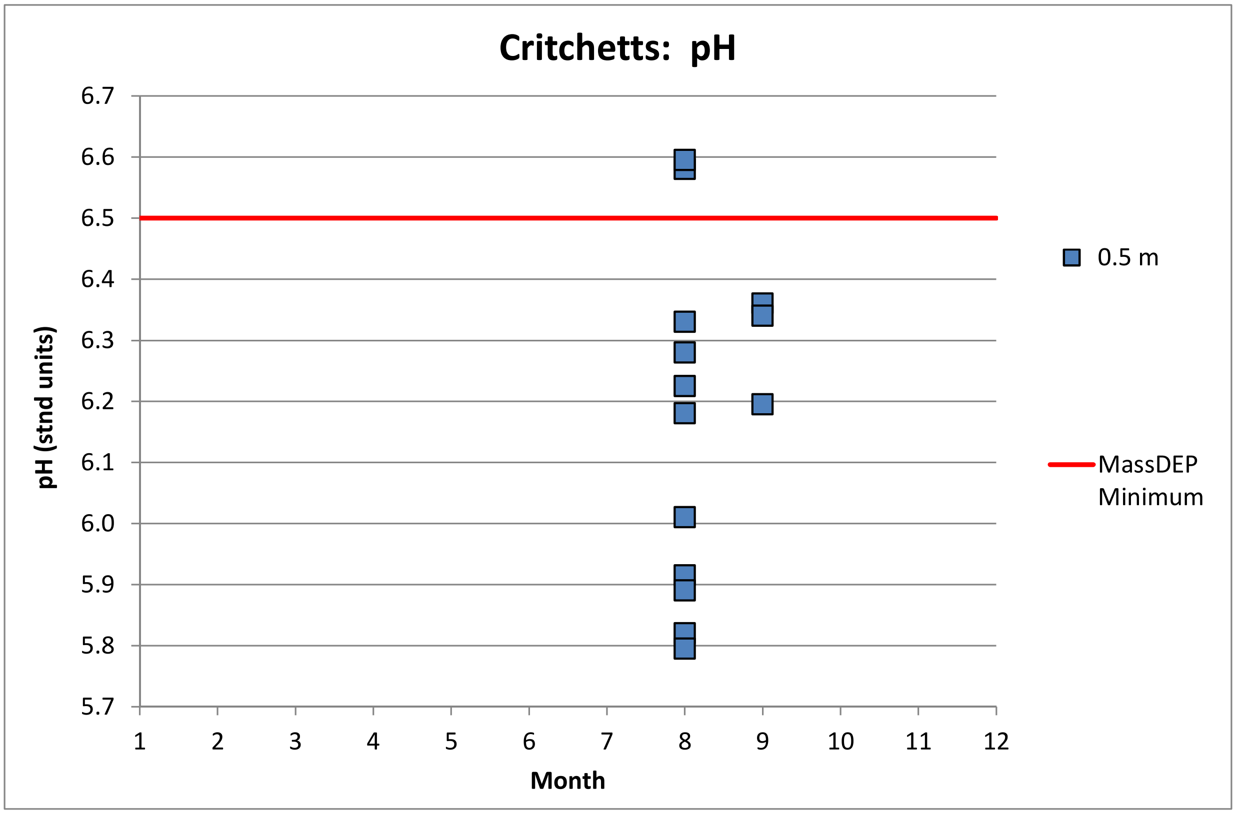

Critchetts: Total Phosphorus
Total Phosphrorus (µg/L)
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Ecoregion Threshold



Critchetts: N:P ratio
70
60
50
40
30
20
10
0
N:P ratio
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Redfield Threshold

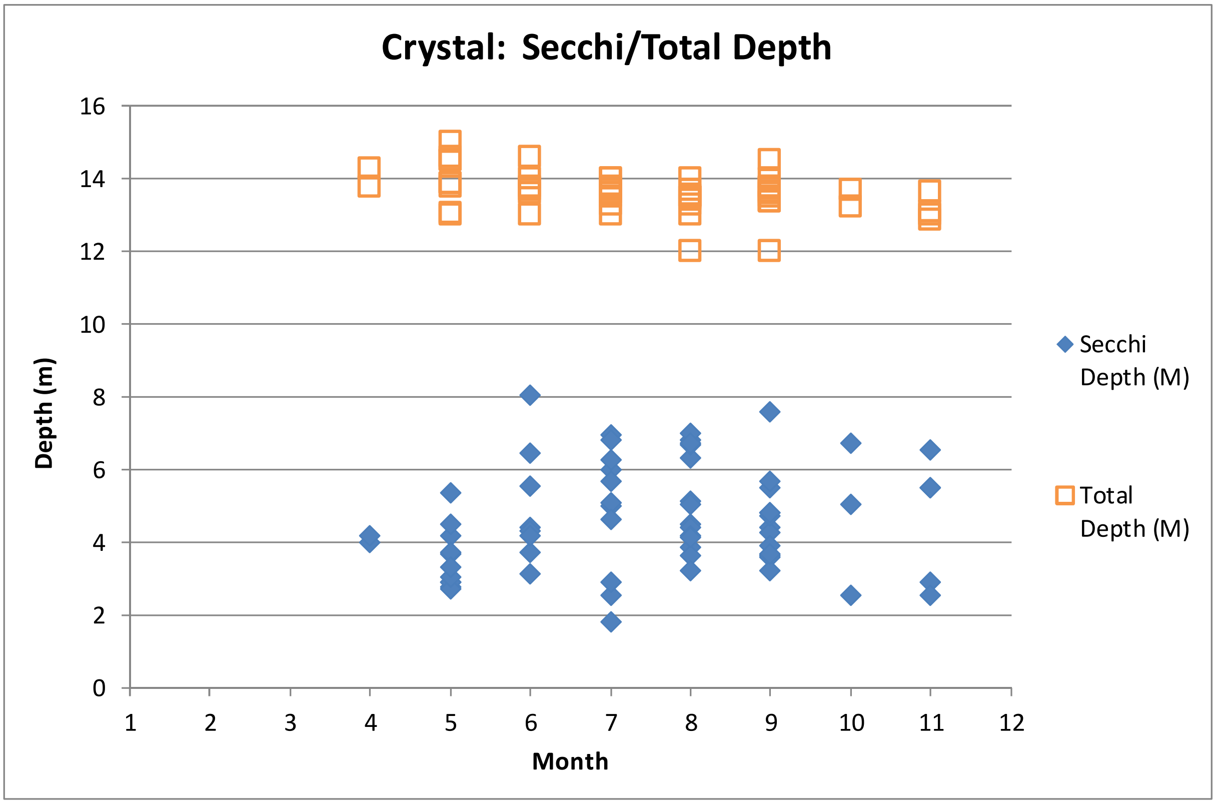


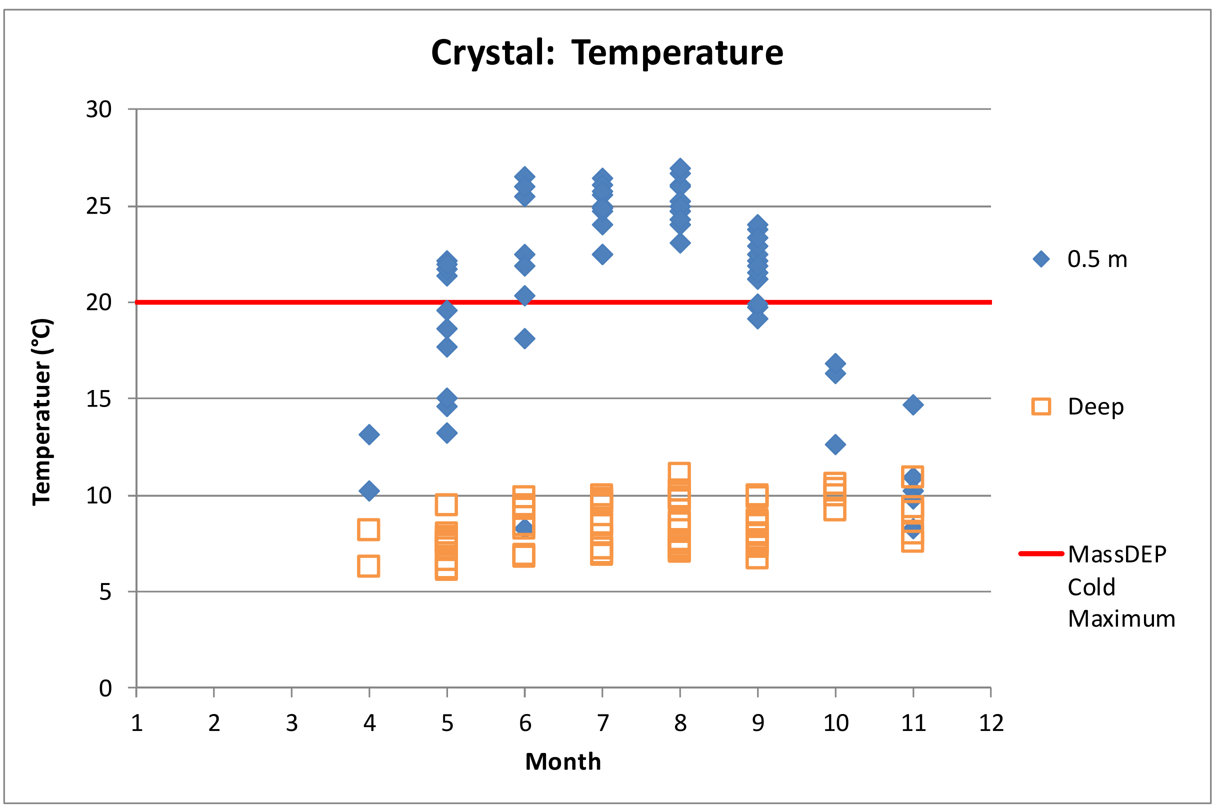
Critchetts: Chlorophyll
30
25
20
15
10
5
0
Chlorophyll (µg/L)
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Ecoregion Threshold

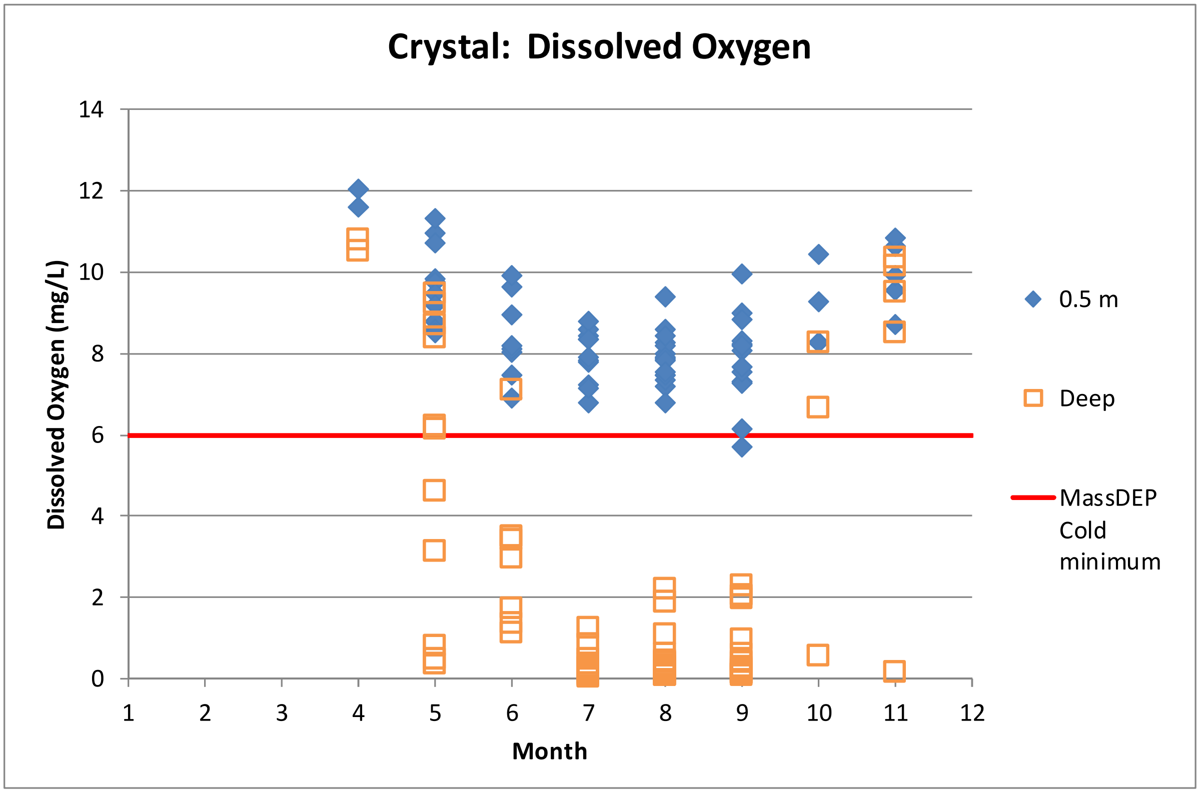


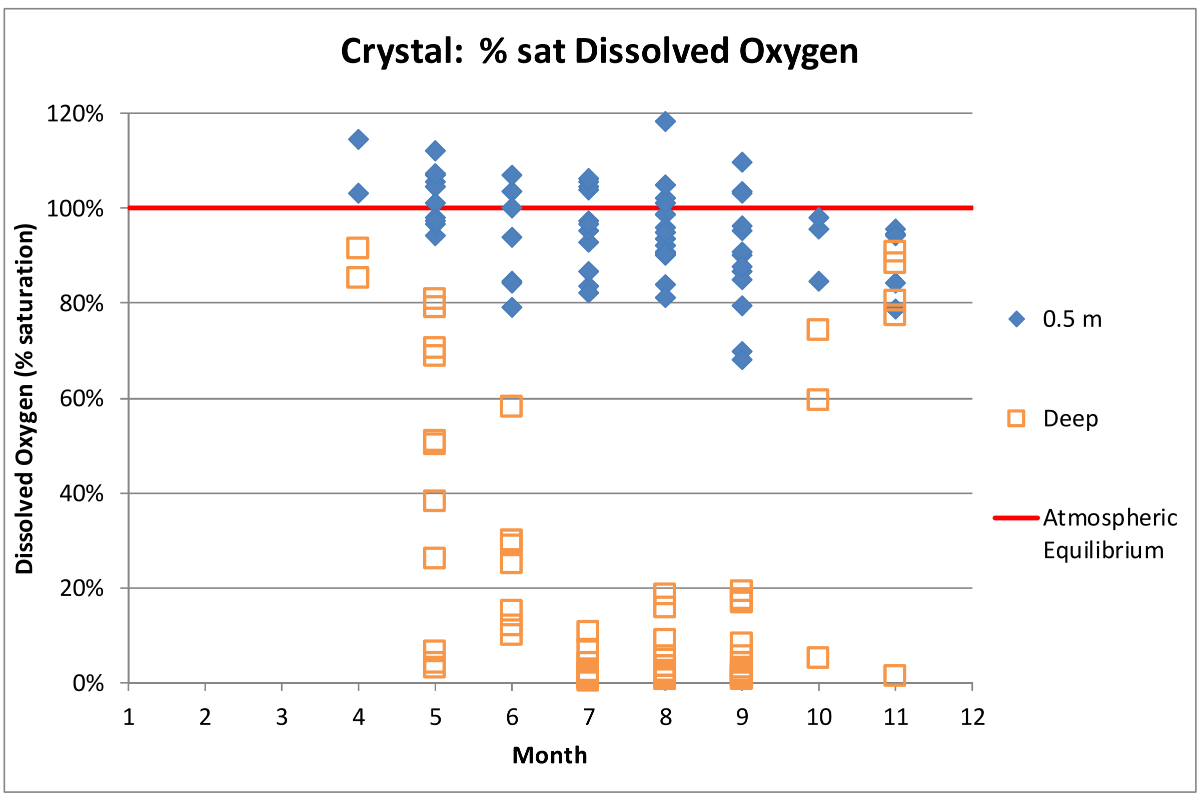
Critchetts: pH
pH (stnd units)
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6.0
5.9
5.8
5.7
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
MassDEP Minimum

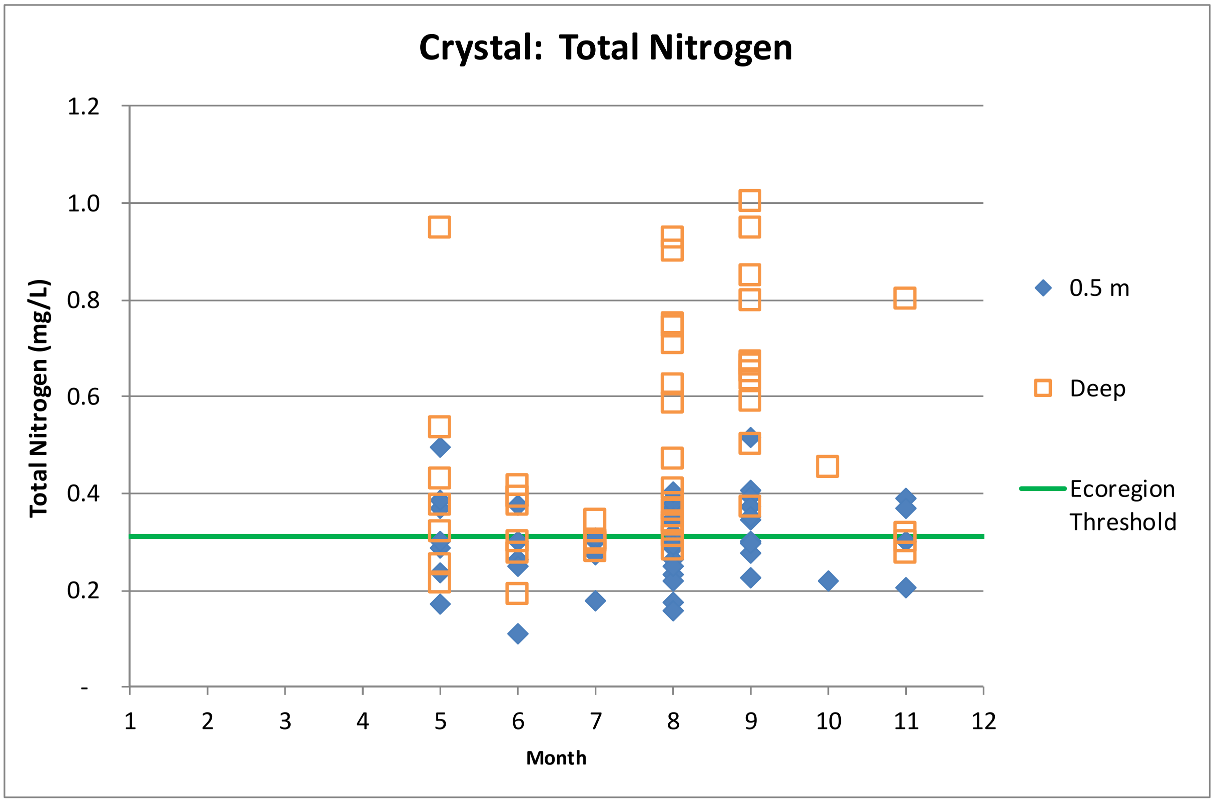
Crystal Lake

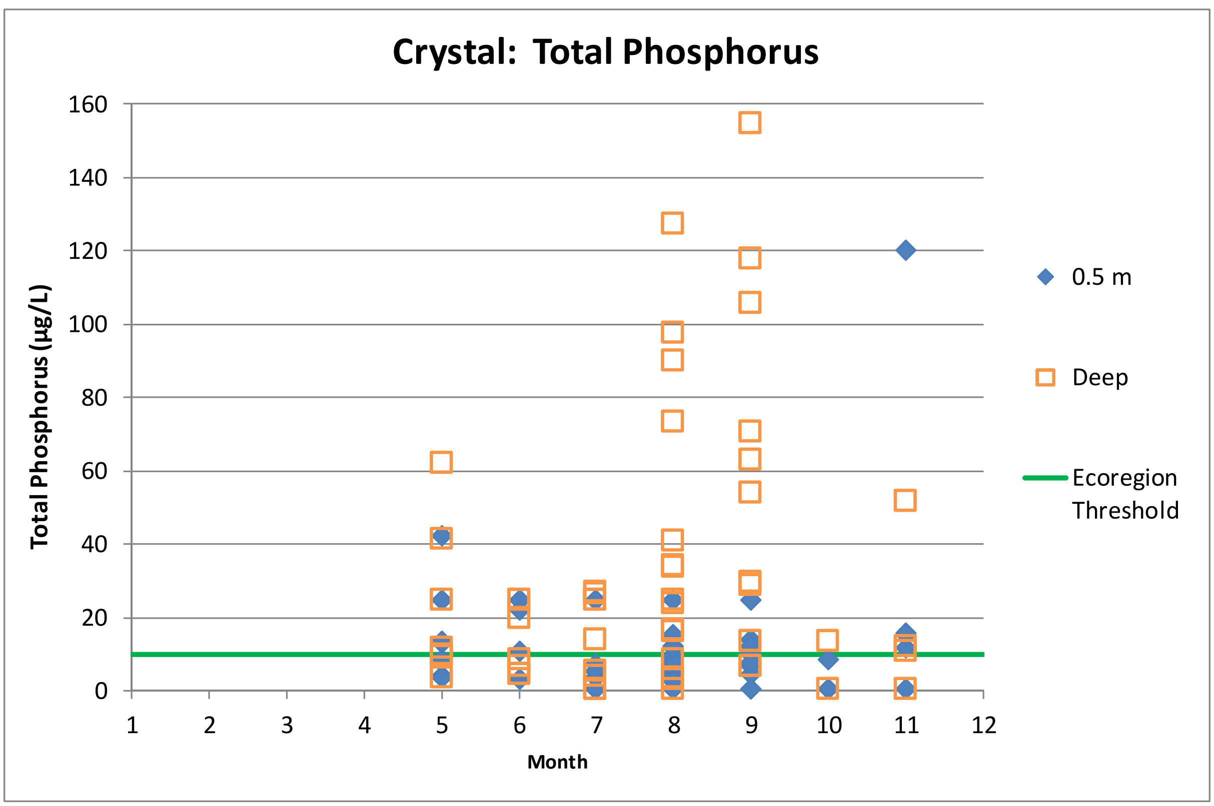

Crystal: Secchi/Total Depth
Depth (m)
Month
Secchi Depth (M)
Total Depth (M)
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12

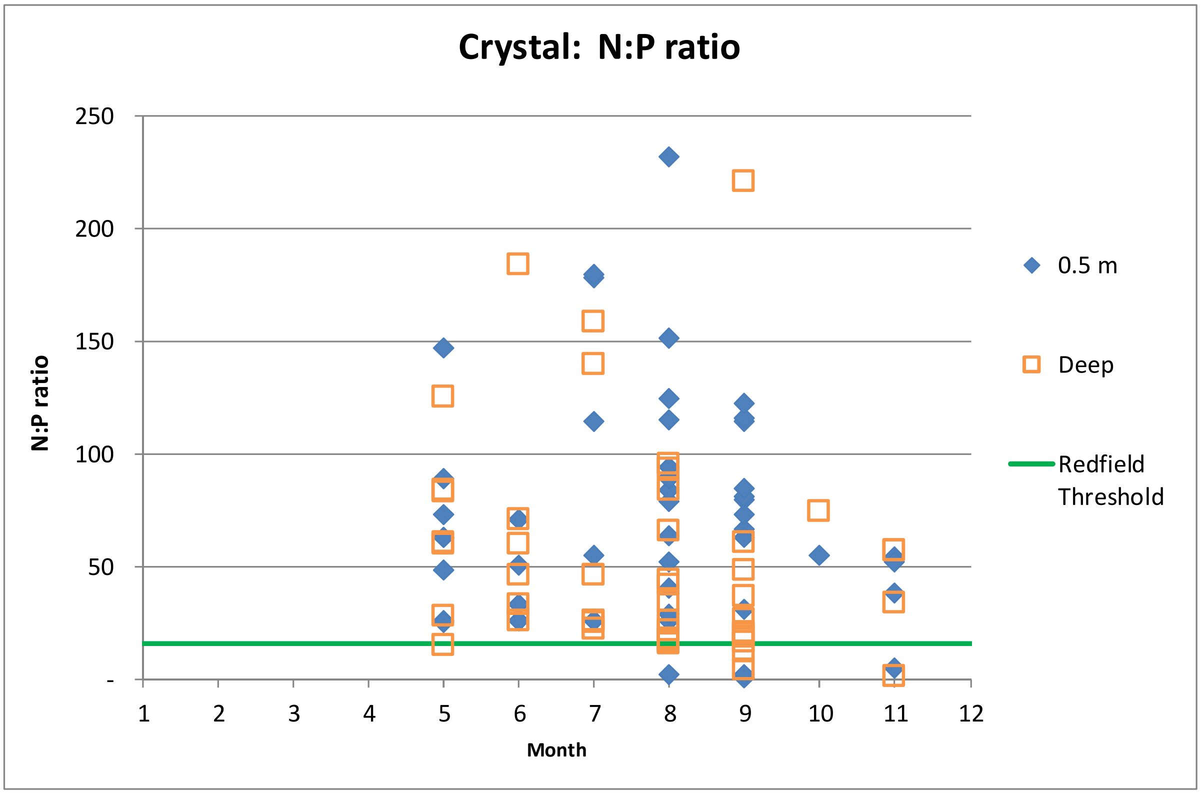

Crystal: Temperature
Temperatuer (°C)
Month
0.5 m
Deep
MassDEP Cold Maximum
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12

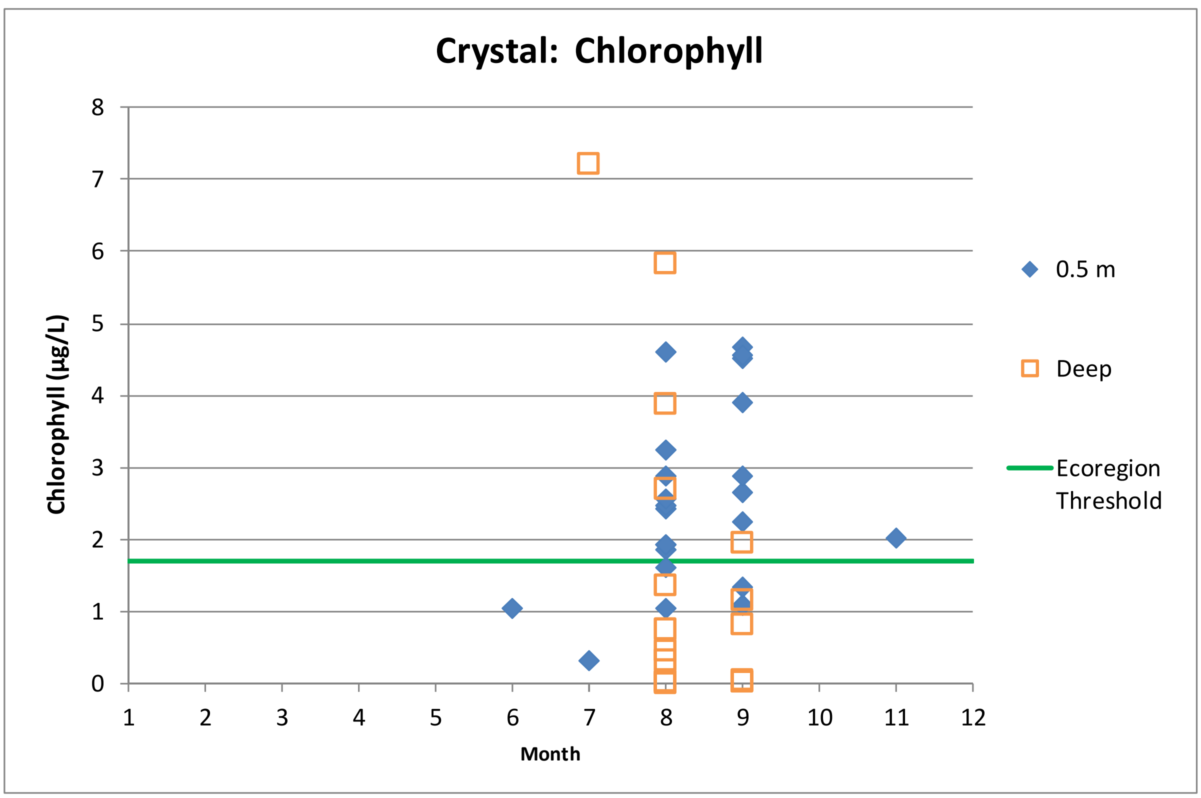

Crystal: Dissolved Oxygen
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP Cold minimum

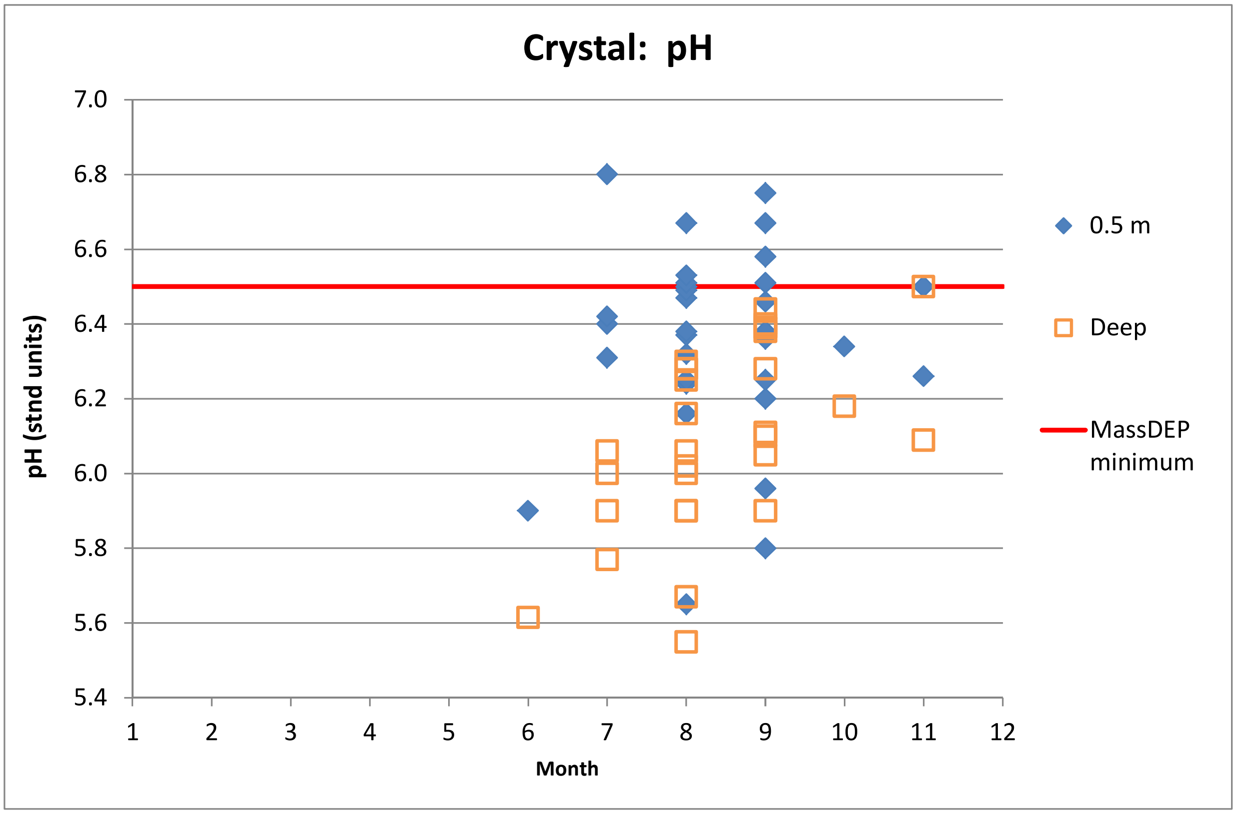

Crystal: % sat Dissolved Oxygen
Dissolved Oxygen (% saturation)
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium


Crystal: Total Nitrogen
Total Nitrogen (mg/L)
1.2
1.0
0.8
0.6
0.4
0.2
-
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold


Crystal: Total Phosphorus
Total Phosphorus (µg/L)
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

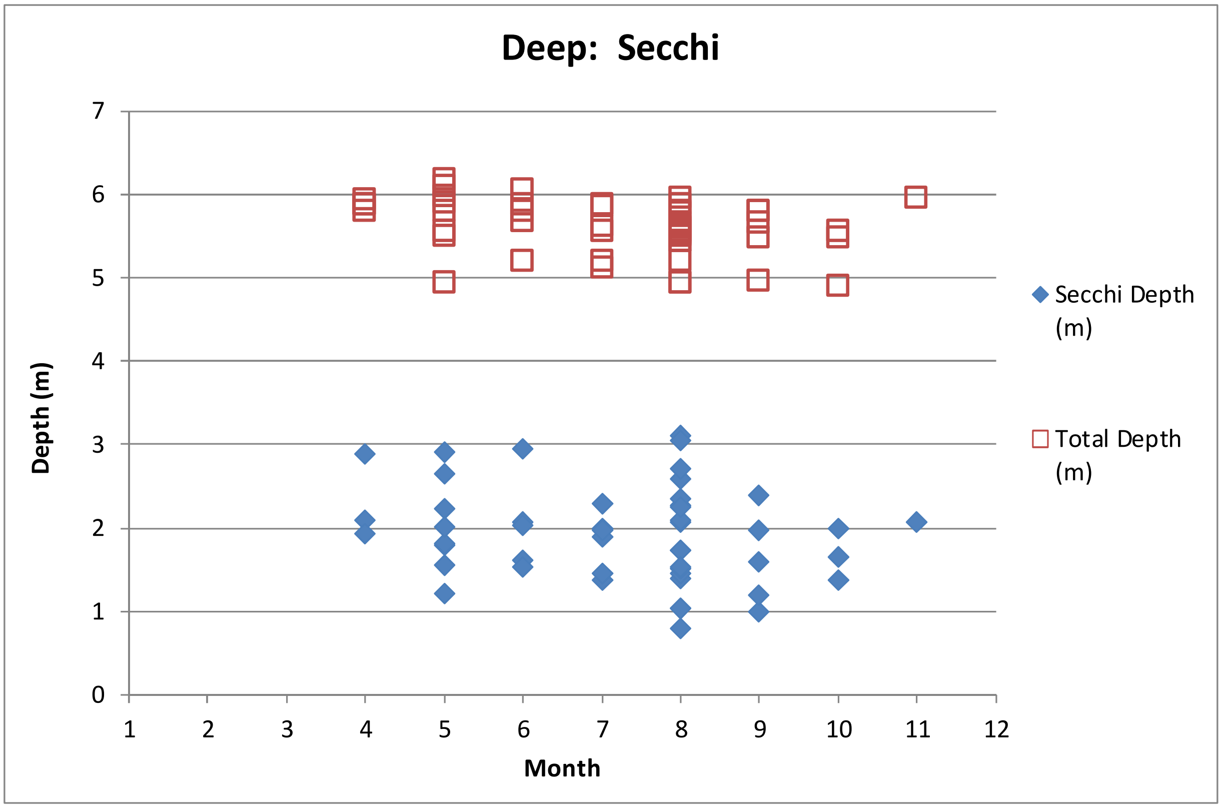

Crystal: N:P ratio
250
200
150
100
50
-
N:P ratio
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Redfield Threshold

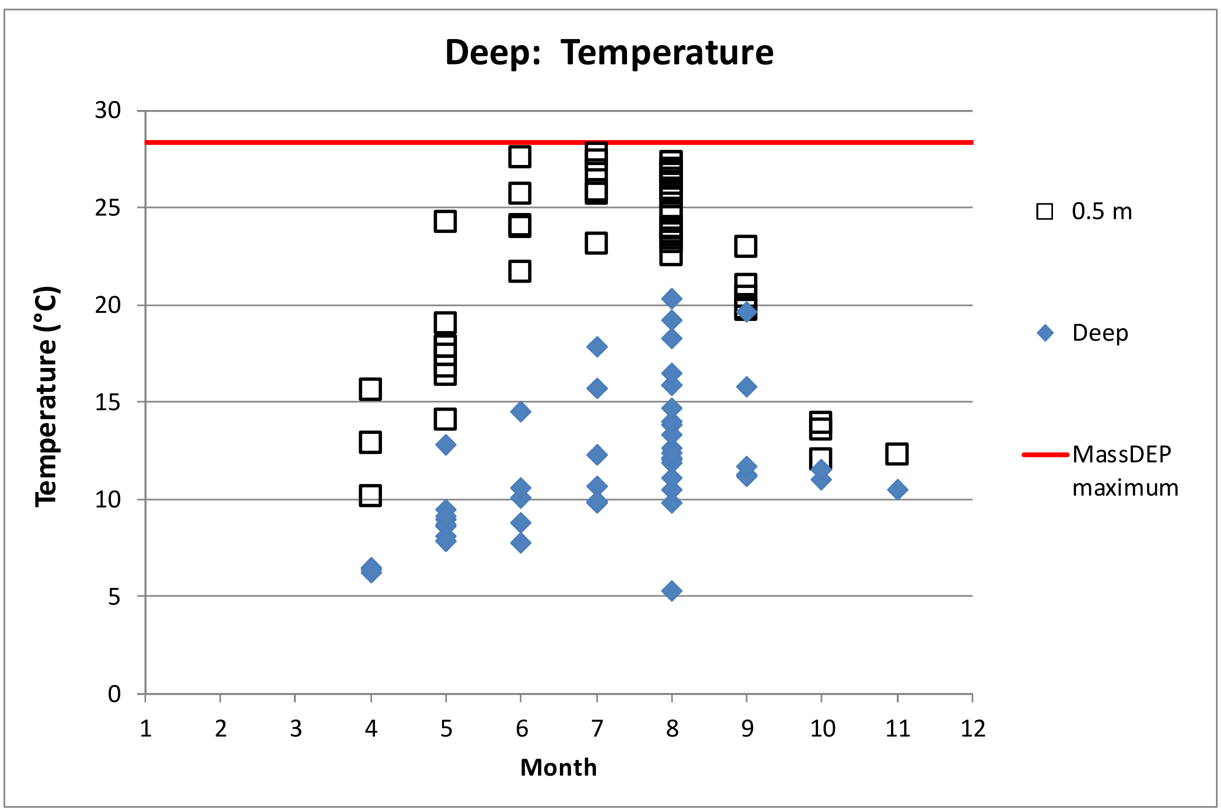

Crystal: Chlorophyll
8
7
6
5
4
3
2
1
0
Chlorophyll (µg/L)
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Ecoregion Threshold

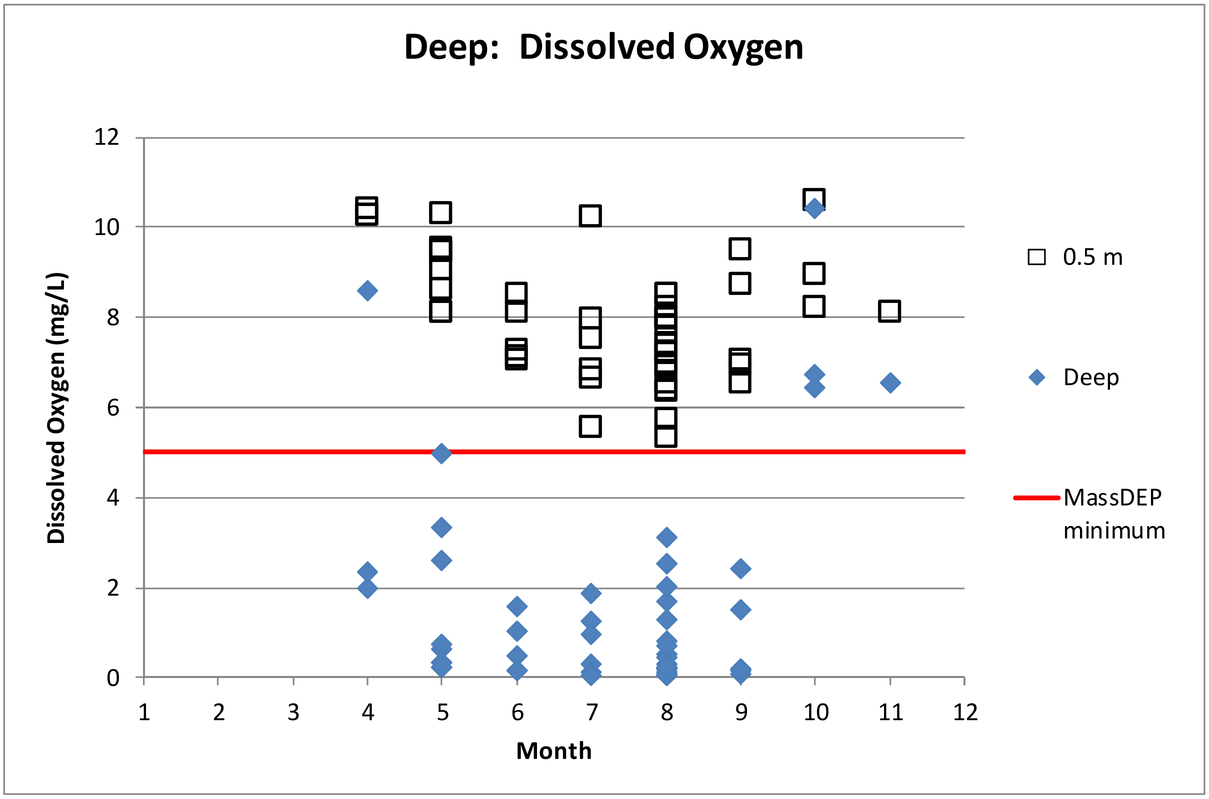


Crystal: pH
pH (stnd units)
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
5.4
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

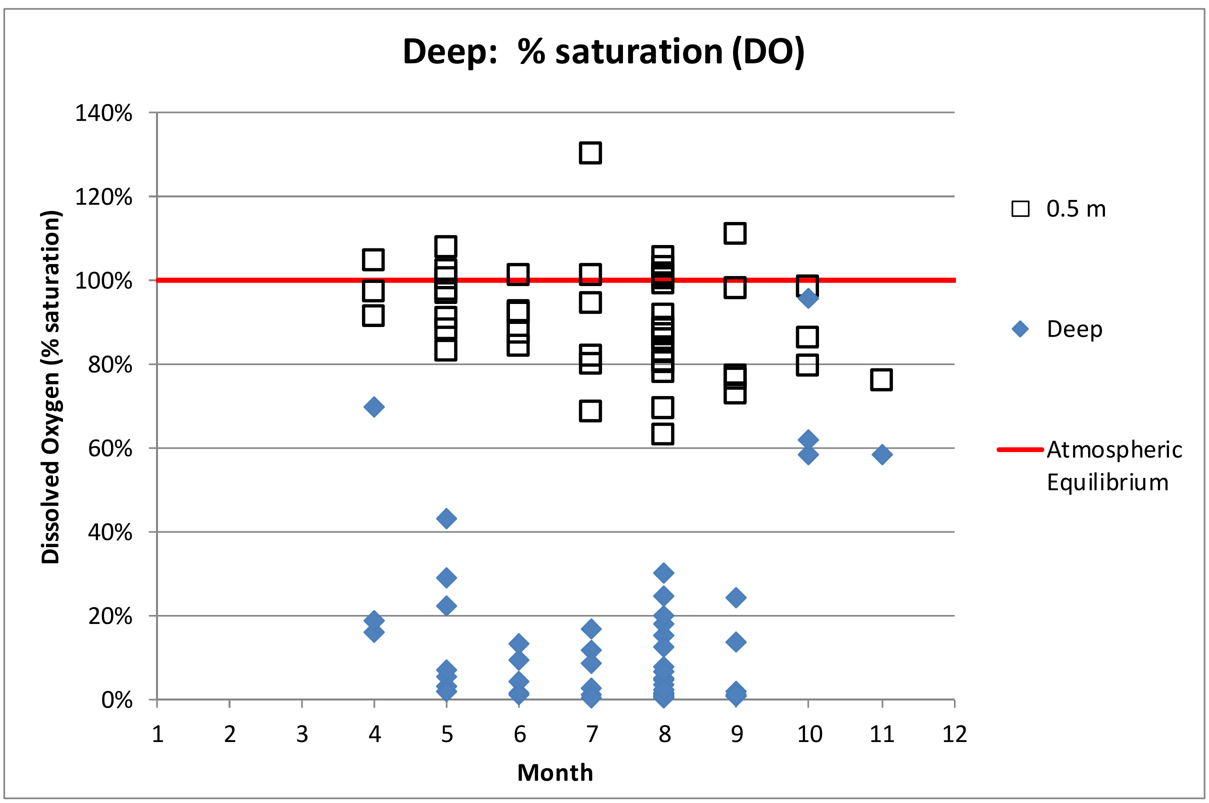
Deep Pond


Deep: Secchi
Depth (m)
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (m)
Total Depth (m)

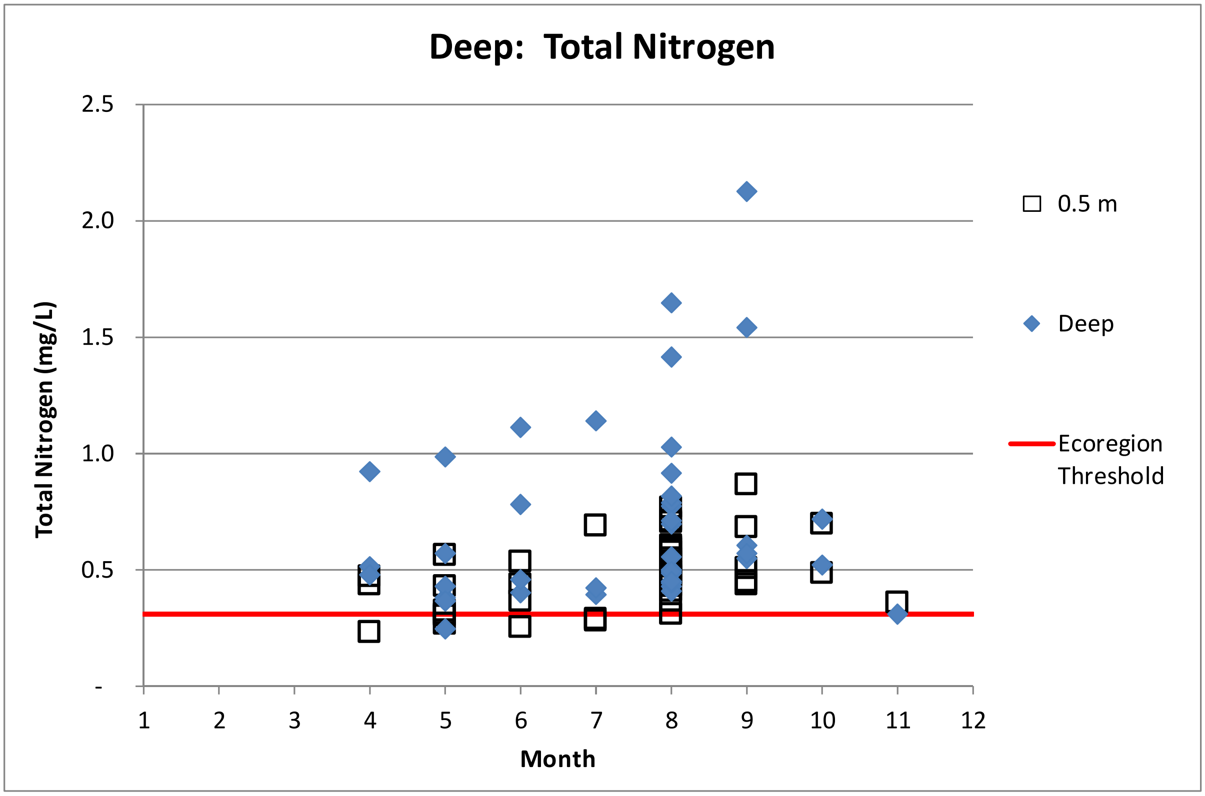

Deep: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP maximum

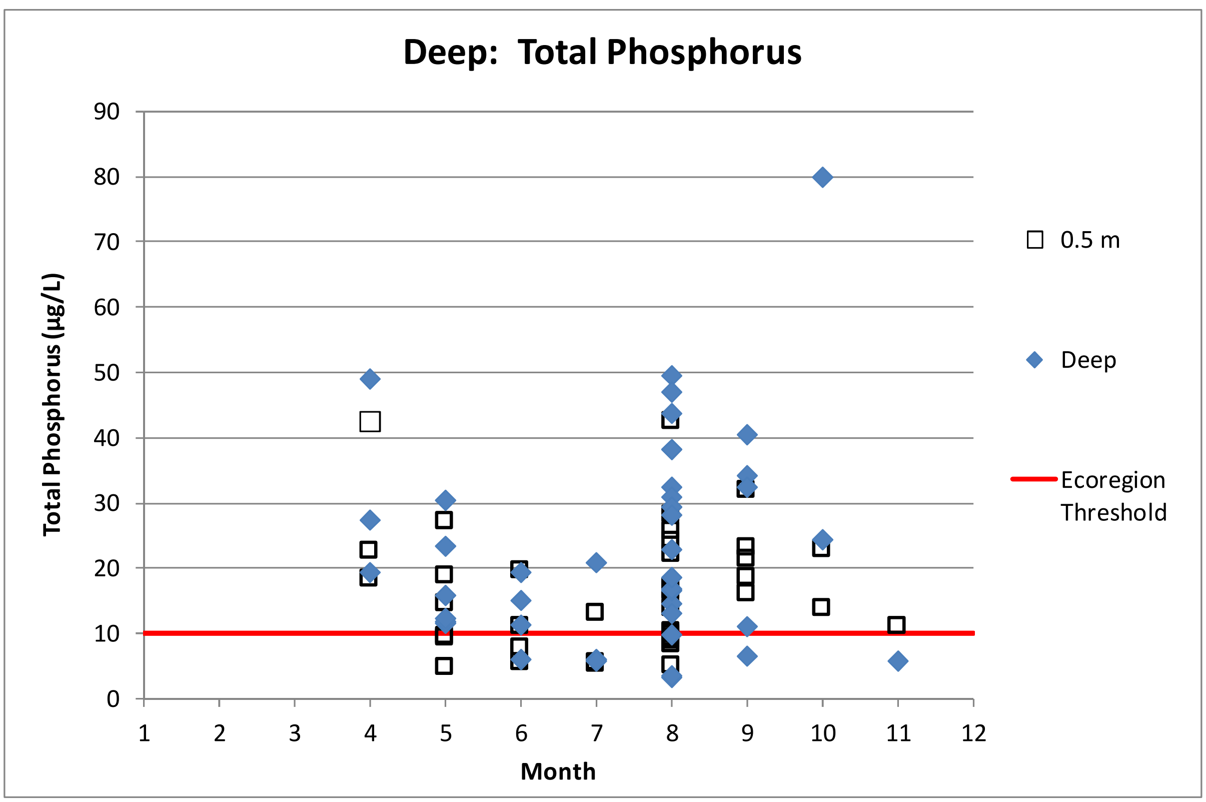


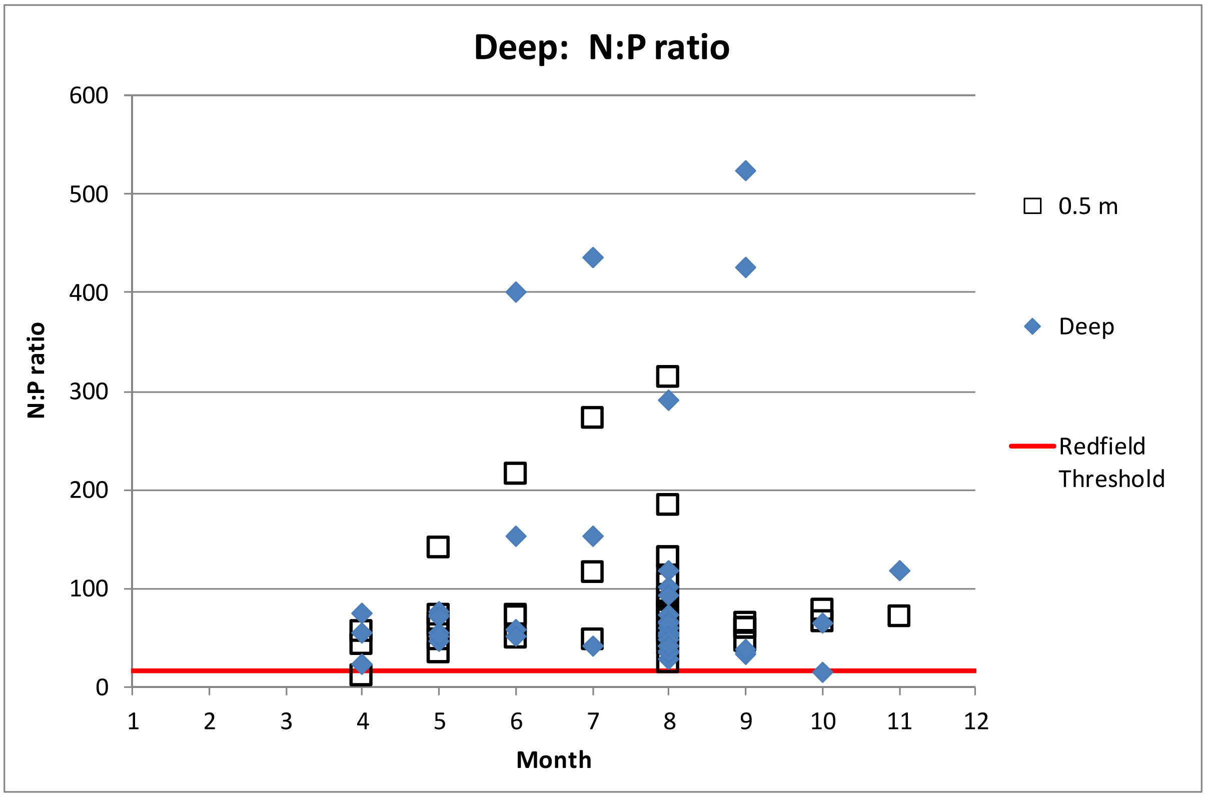
Deep: Dissolved Oxygen
Dissolved Oxygen (mg/L)
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

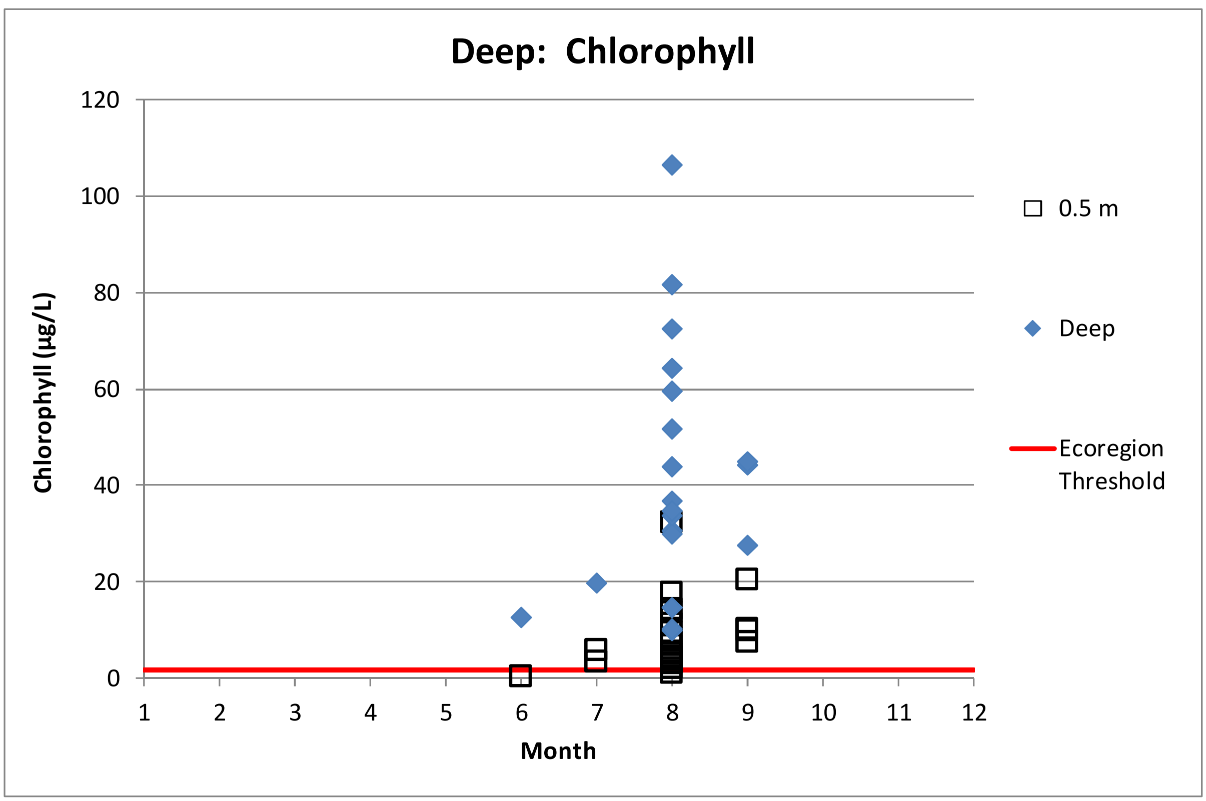


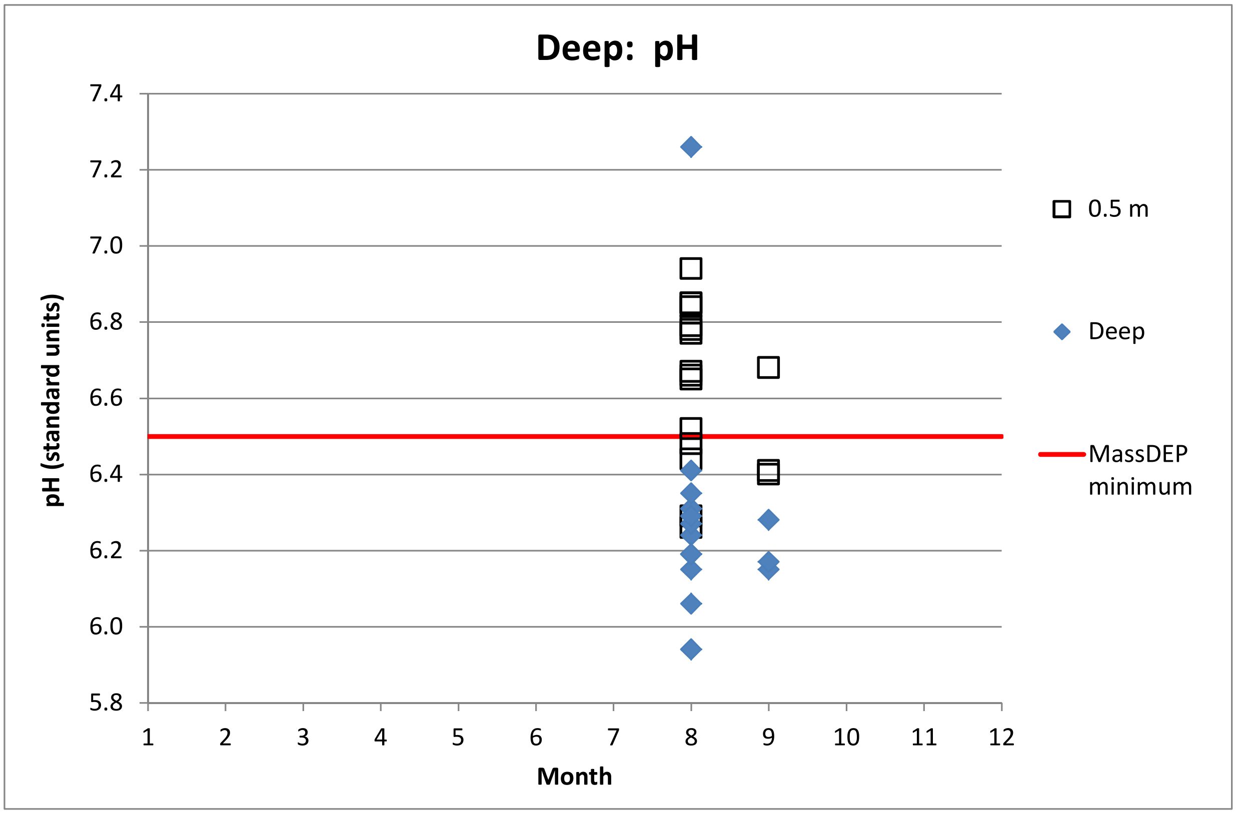
Deep: % saturation (DO)
Dissolved Oxygen (% saturation)
140%
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium


Deep: Total Nitrogen
2.5
2.0
1.5
1.0
0.5
-
1 2 3 4 5 6 7 8 9 10 11 12
Month
Total Nitrogen (mg/L)
0.5 m
Deep
Ecoregion Threshold

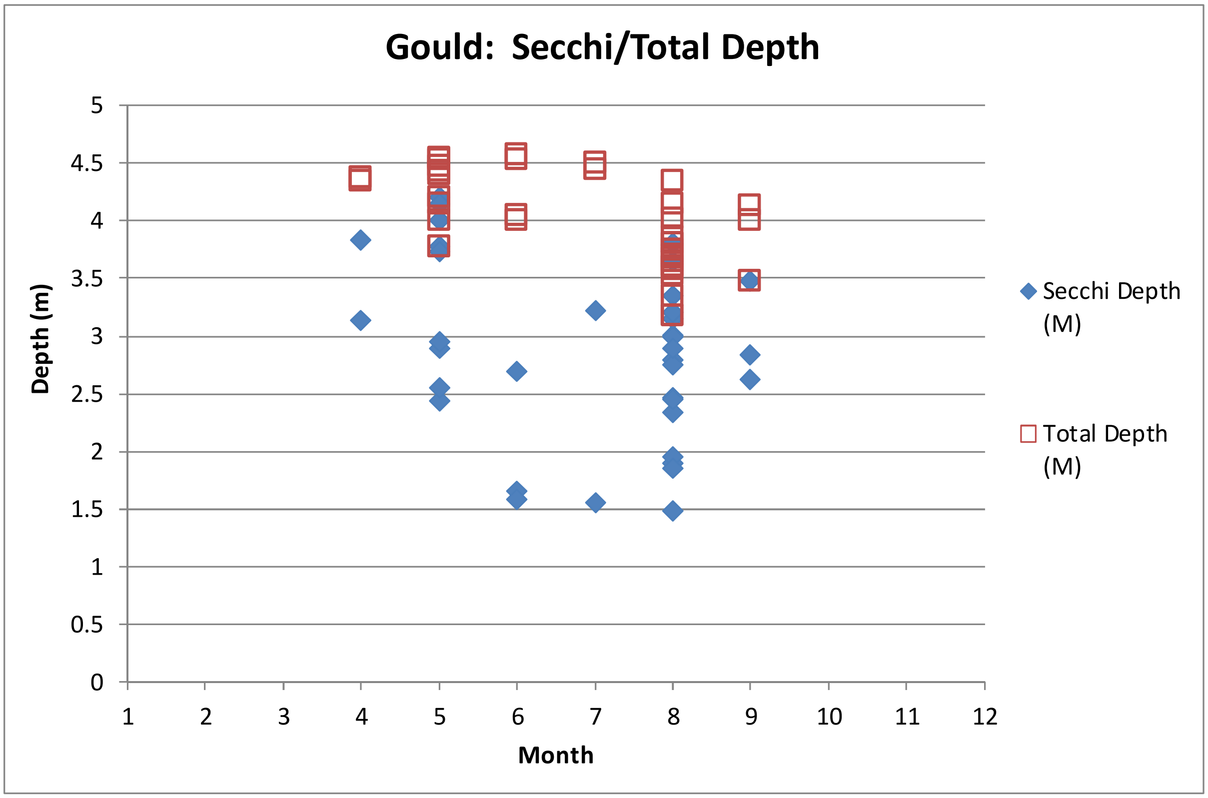

Deep: Total Phosphorus
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Total Phosphorus (µg/L)
0.5 m
Deep
Ecoregion Threshold

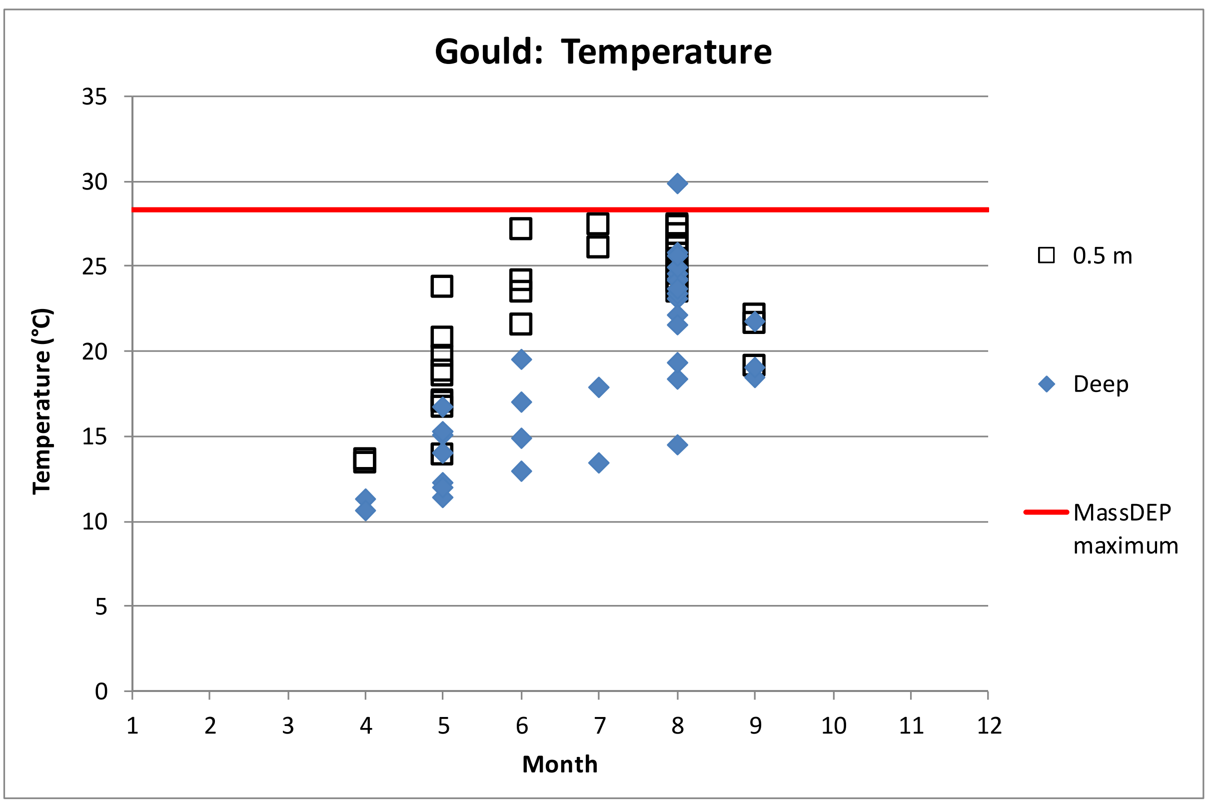

Deep: N:P ratio
600
500
400
300
200
100
0
N:P ratio
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield Threshold

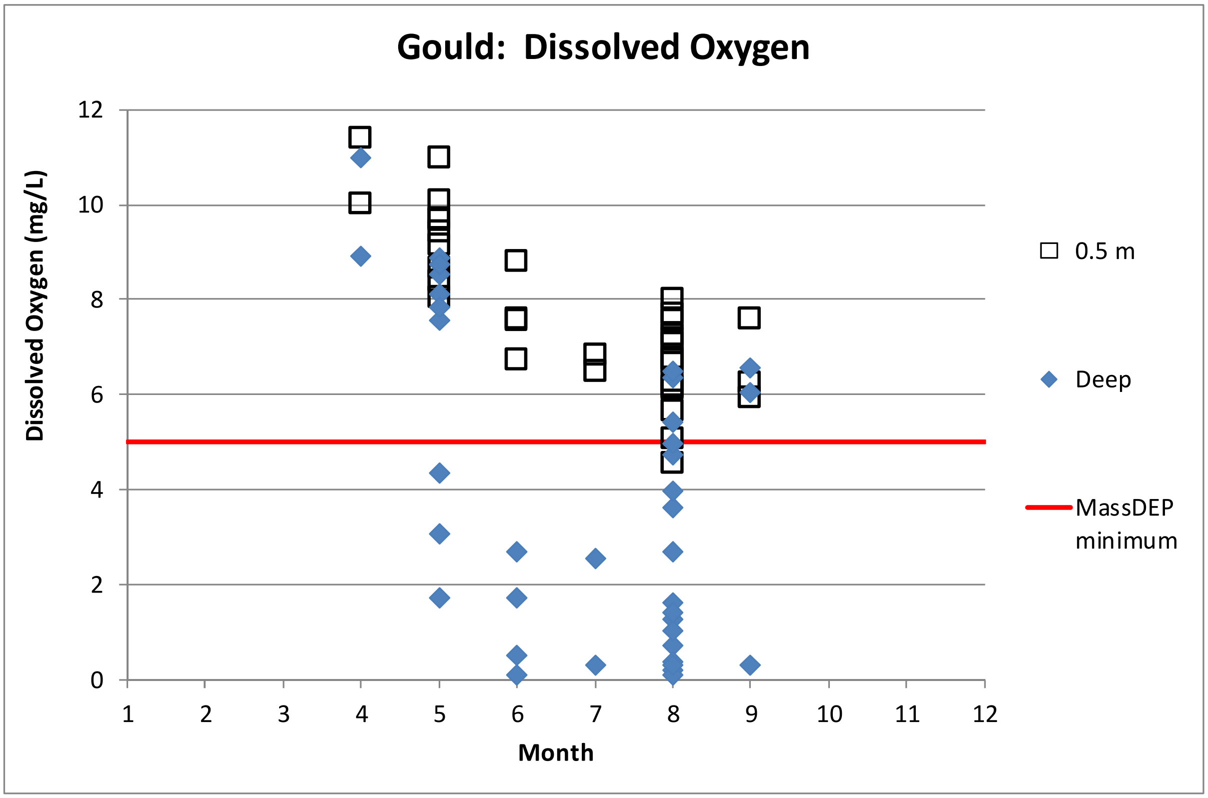

Deep: Chlorophyll
120
100
80
60
40
20
0
Chlorophyll (µg/L)
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold


Deep: pH
pH (standard units)
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

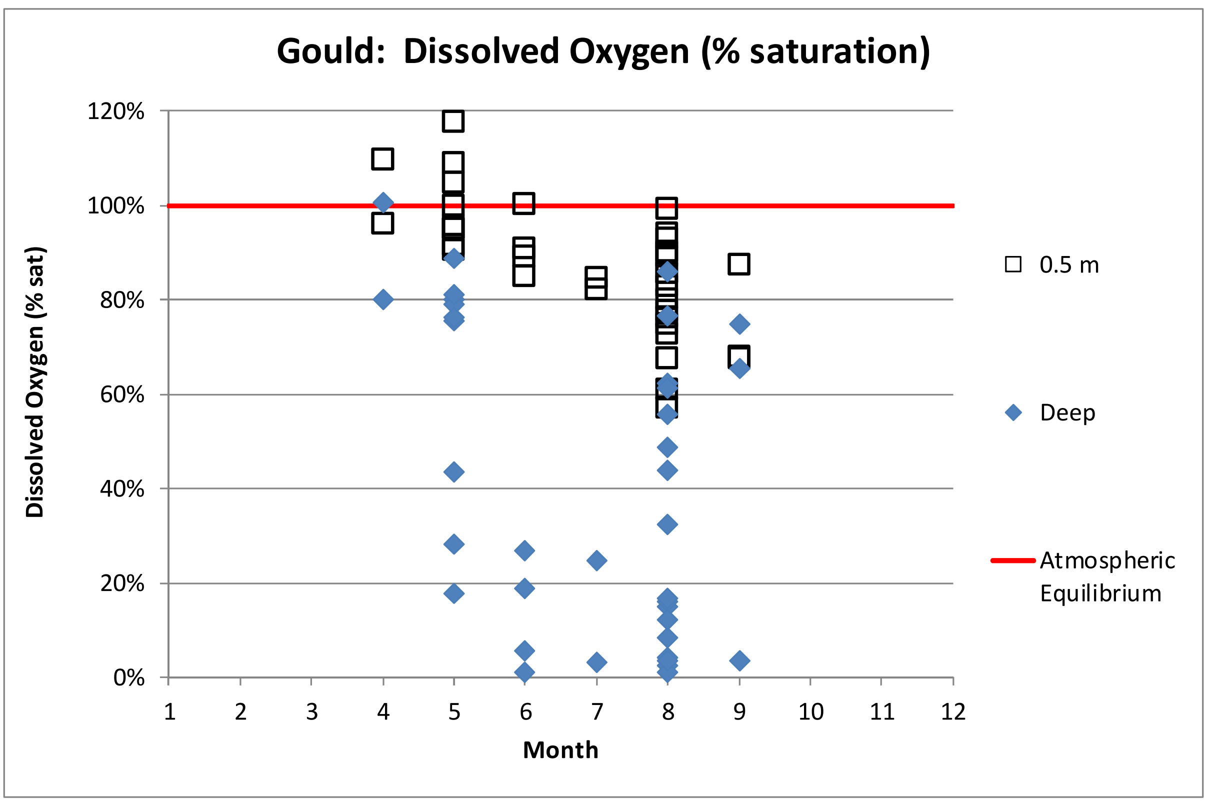
Gould Pond


Gould: Secchi/Total Depth
Depth (m)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Secchi Depth (M)
Total Depth (M)

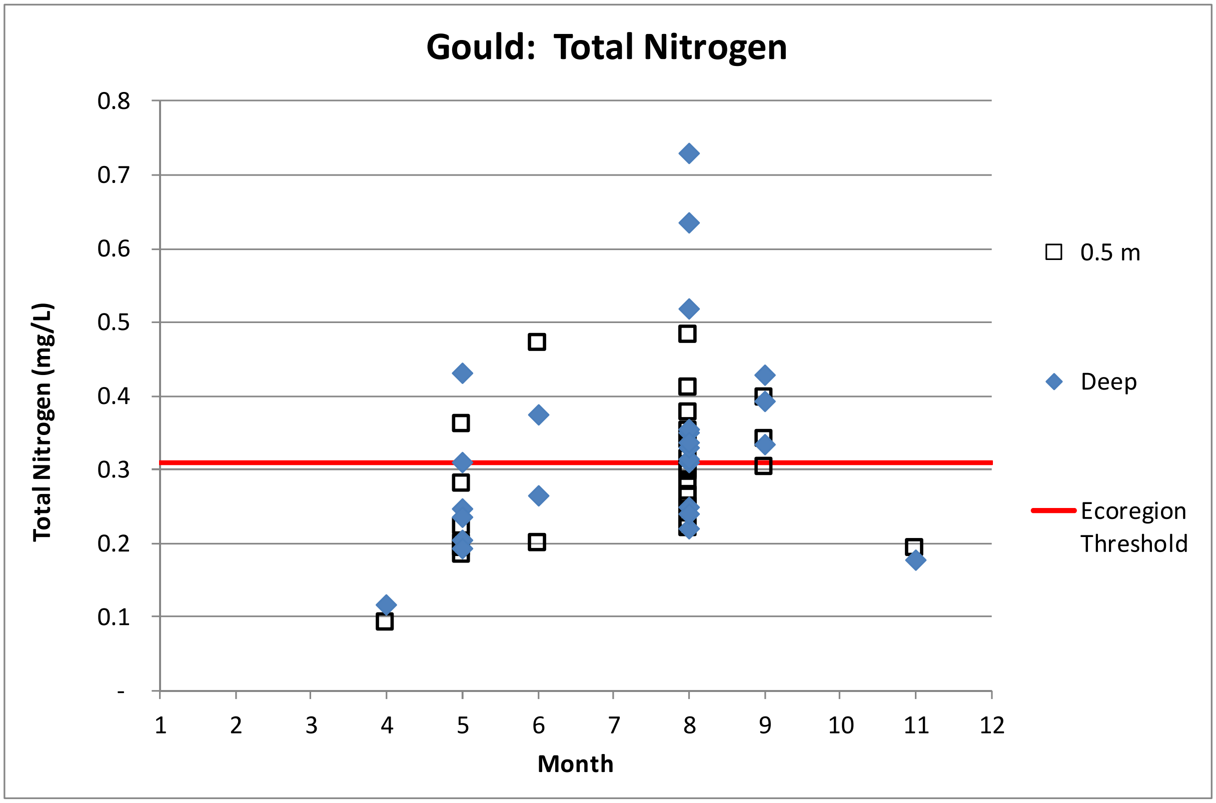

Gould: Temperature
Temperature (°C)
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
MassDEP maximum

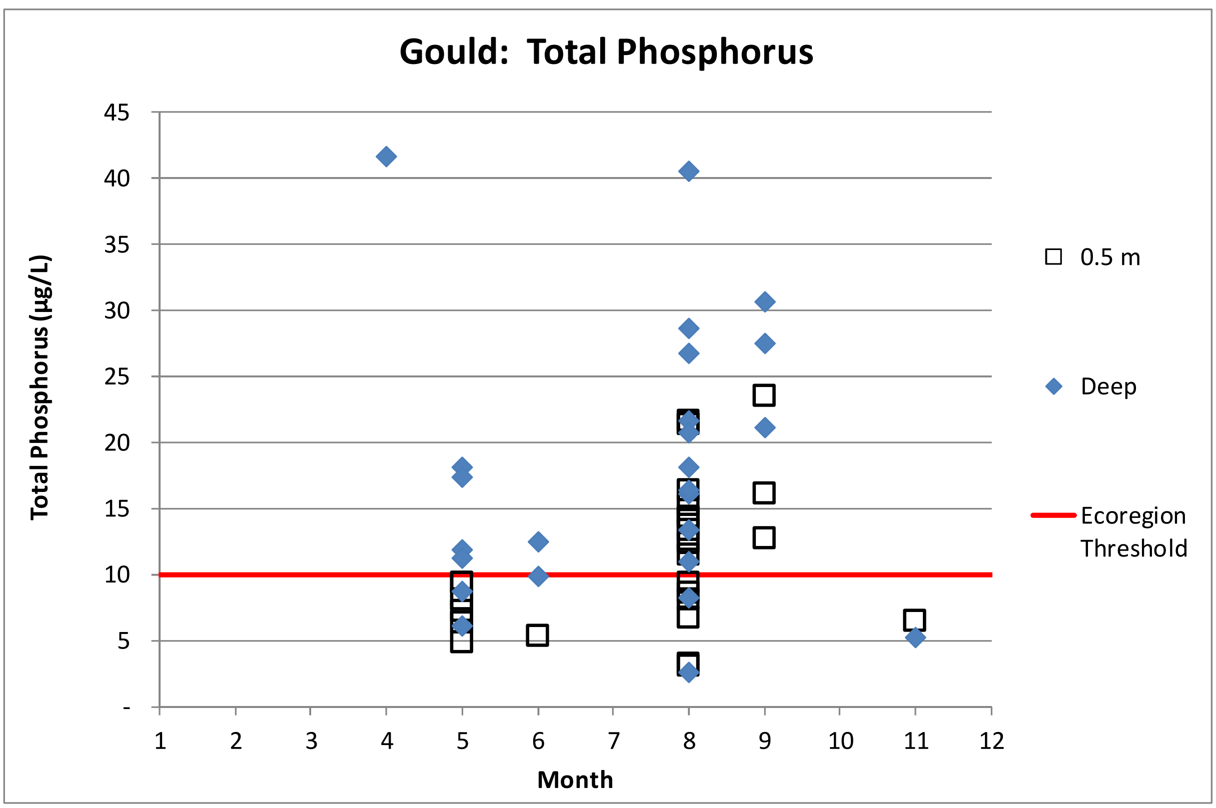


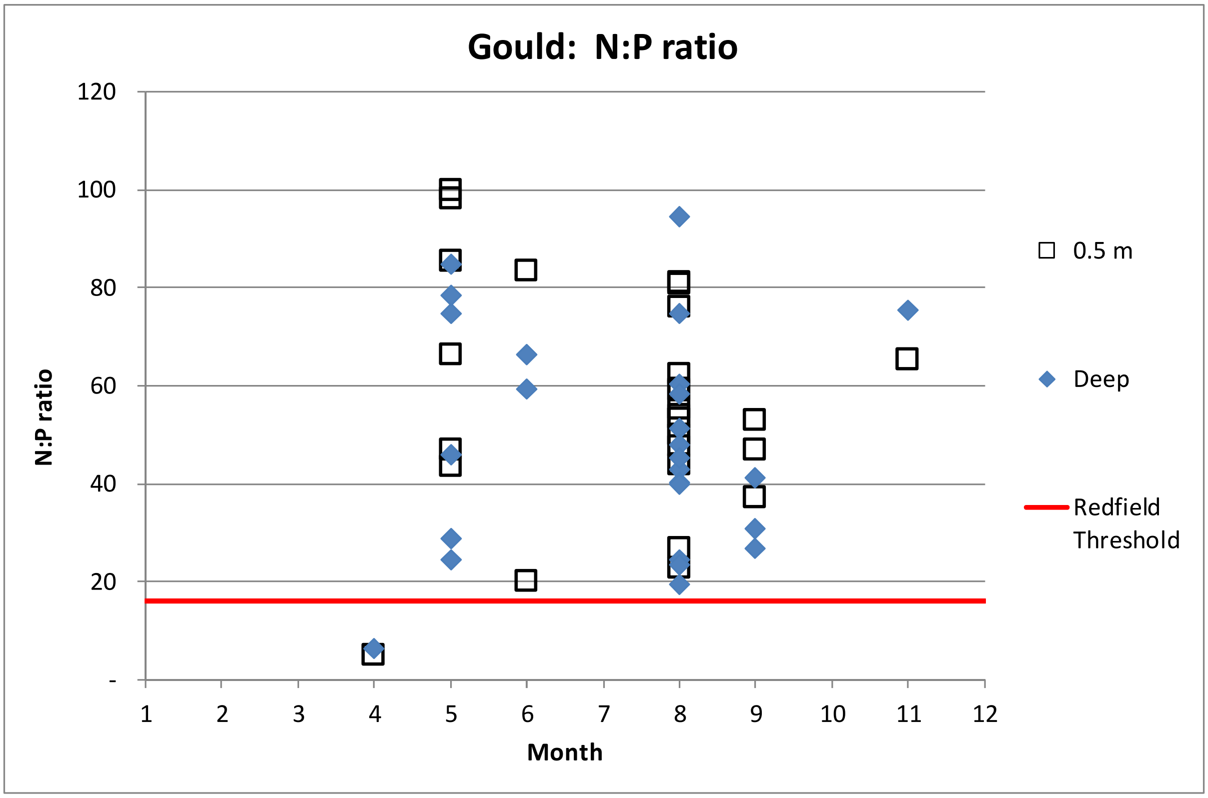
Gould: Dissolved Oxygen
Dissolved Oxygen (mg/L)
0
2
4
6
8
10
12
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

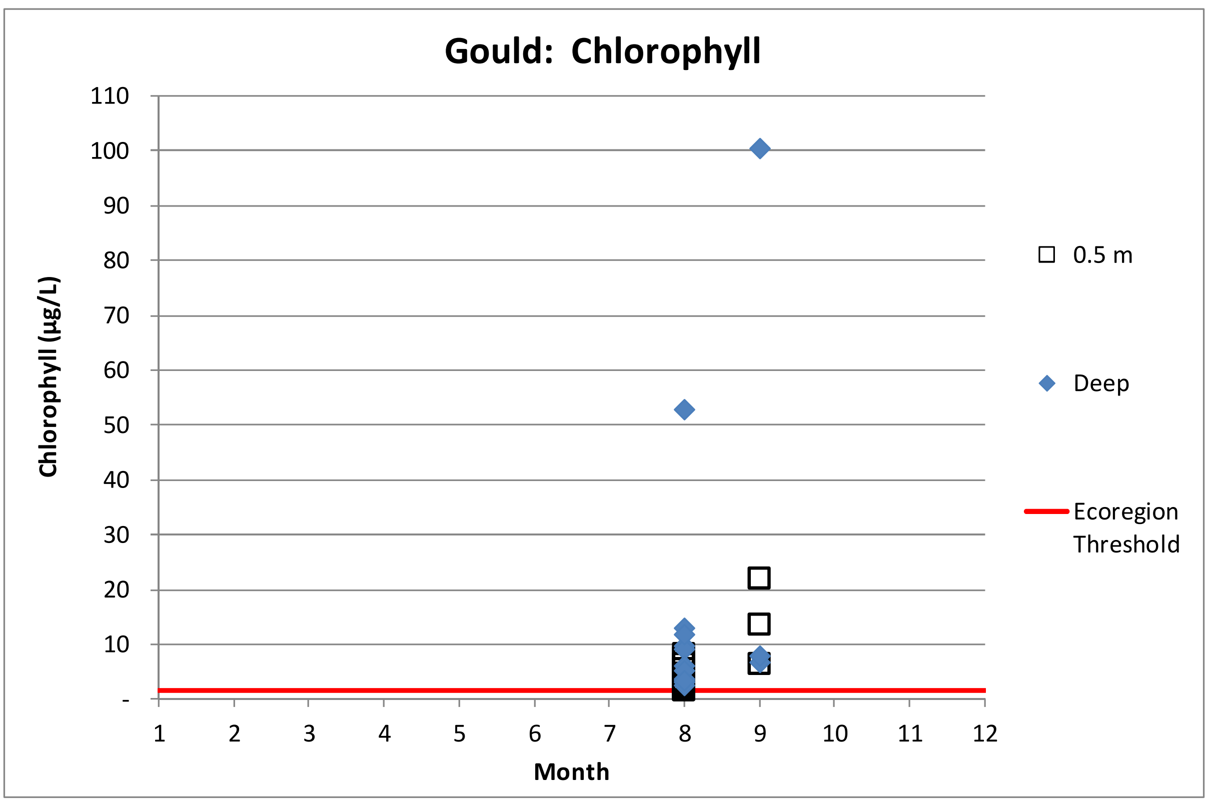


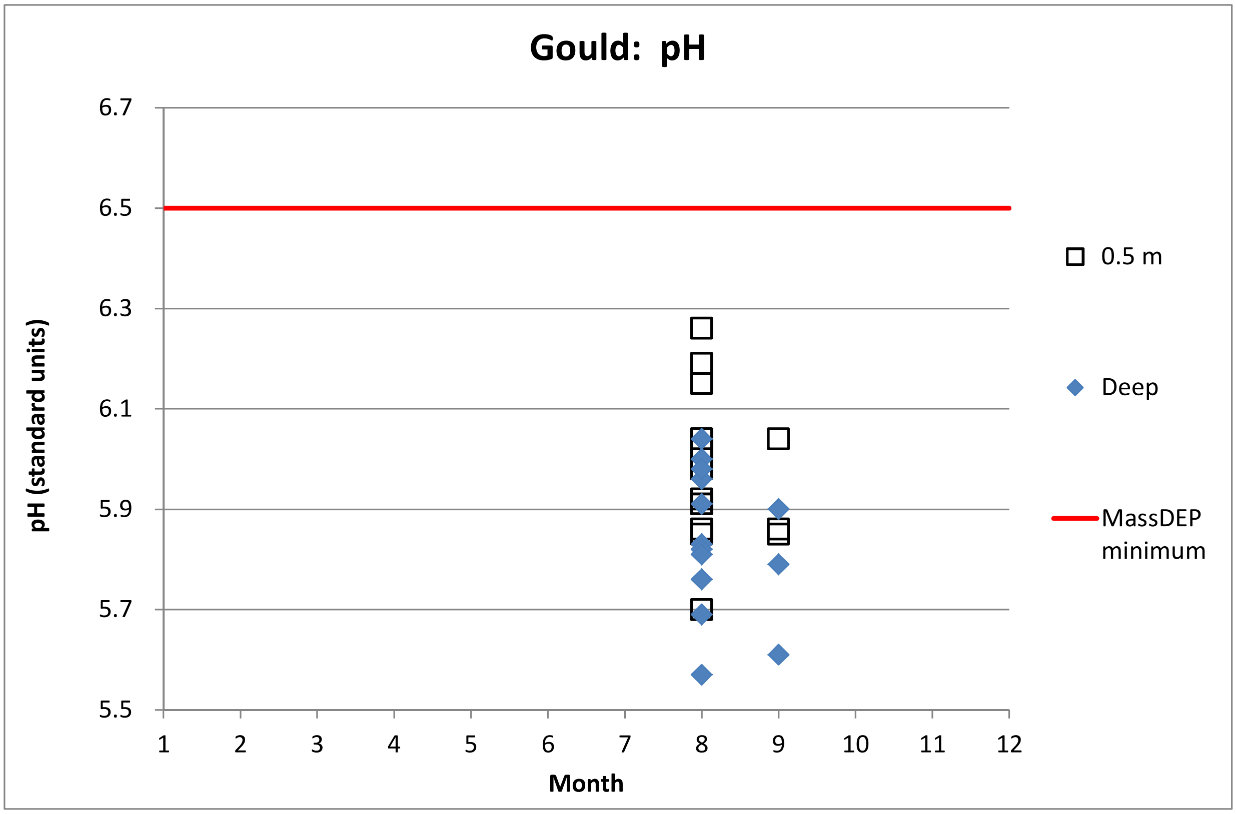
Gould: Dissolved Oxygen (% saturation)
Dissolved Oxygen (% sat)
0%
20%
40%
60%
80%
100%
120%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium


Gould: Total Nitrogen
Total Nitrogen (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Ecoregion Threshold


Gould: Total Phosphorus
Total Phosphorus (µg/L)
45
40
35
30
25
20
15
10
5
-
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Ecoregion Threshold

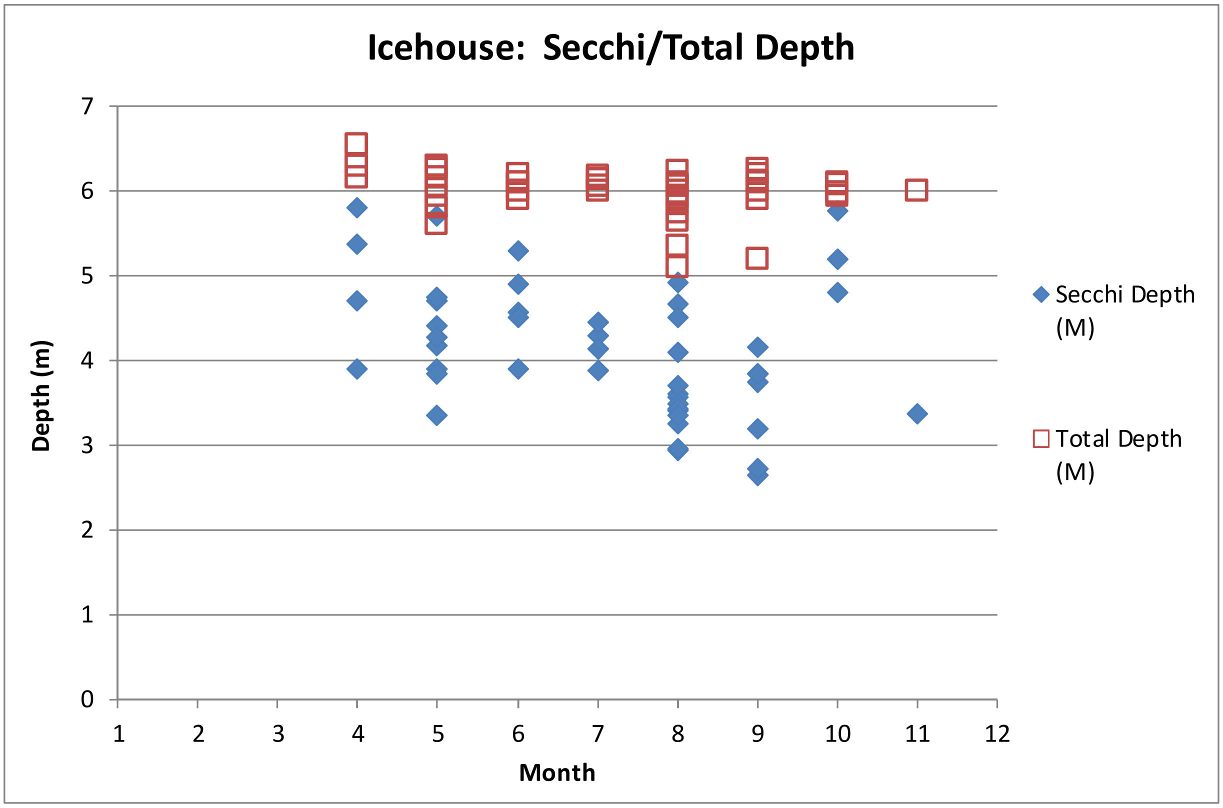

Gould: N:P ratio
N:P ratio
Month
0.5 m
Deep
Redfield Threshold
120
100
80
60
40
20
-
1 2 3 4 5 6 7 8 9 10 11 12

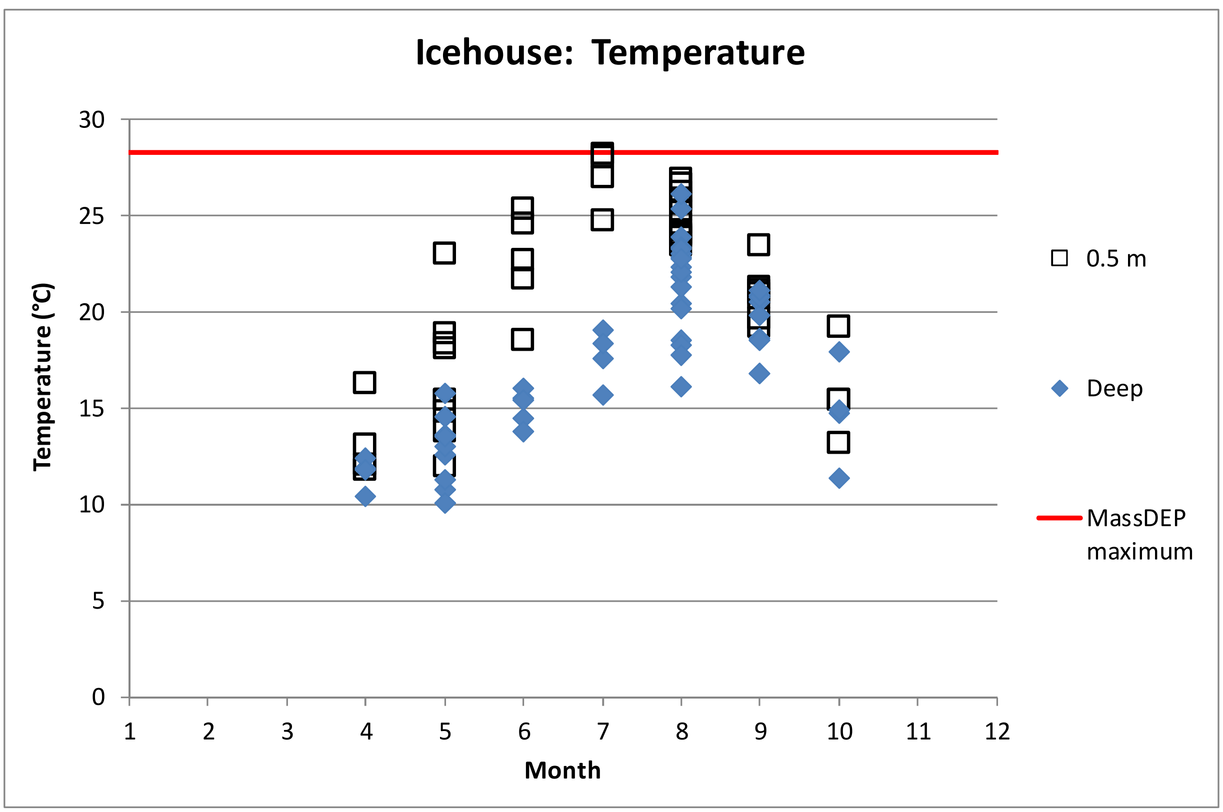

Gould: Chlorophyll
Chlorophyll (µg/L)
Month
0.5 m
Deep
Ecoregion Threshold
110
100
90
80
70
60
50
40
30
20
10
-
1 2 3 4 5 6 7 8 9 10 11 12

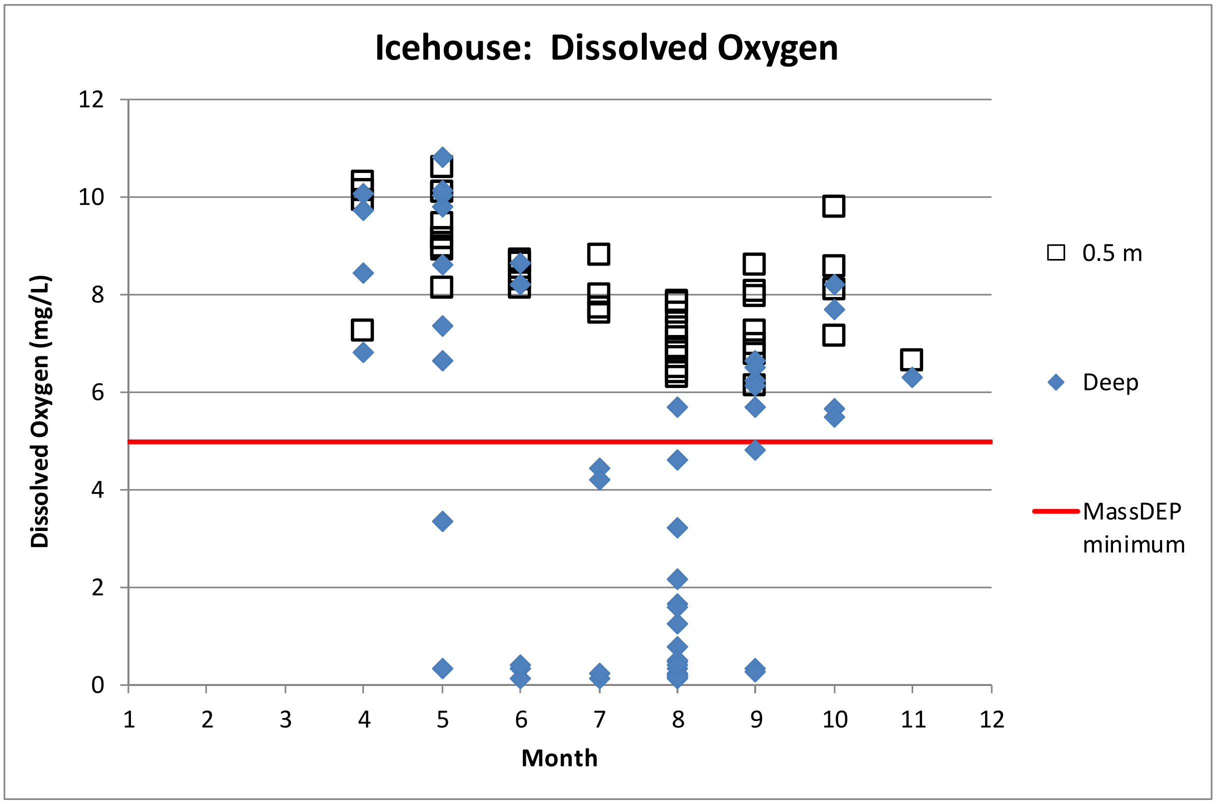


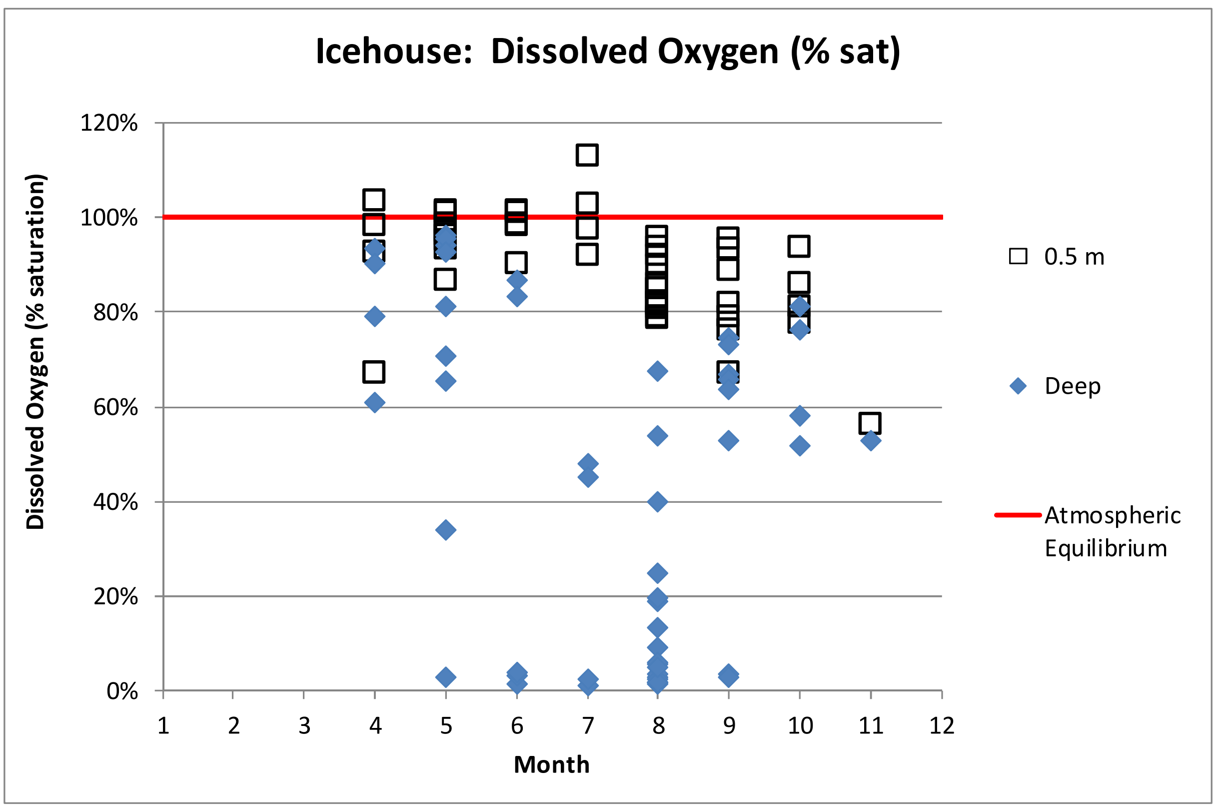
Gould: pH
6.7
6.5
6.3
6.1
5.9
5.7
5.5
pH (standard units)
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

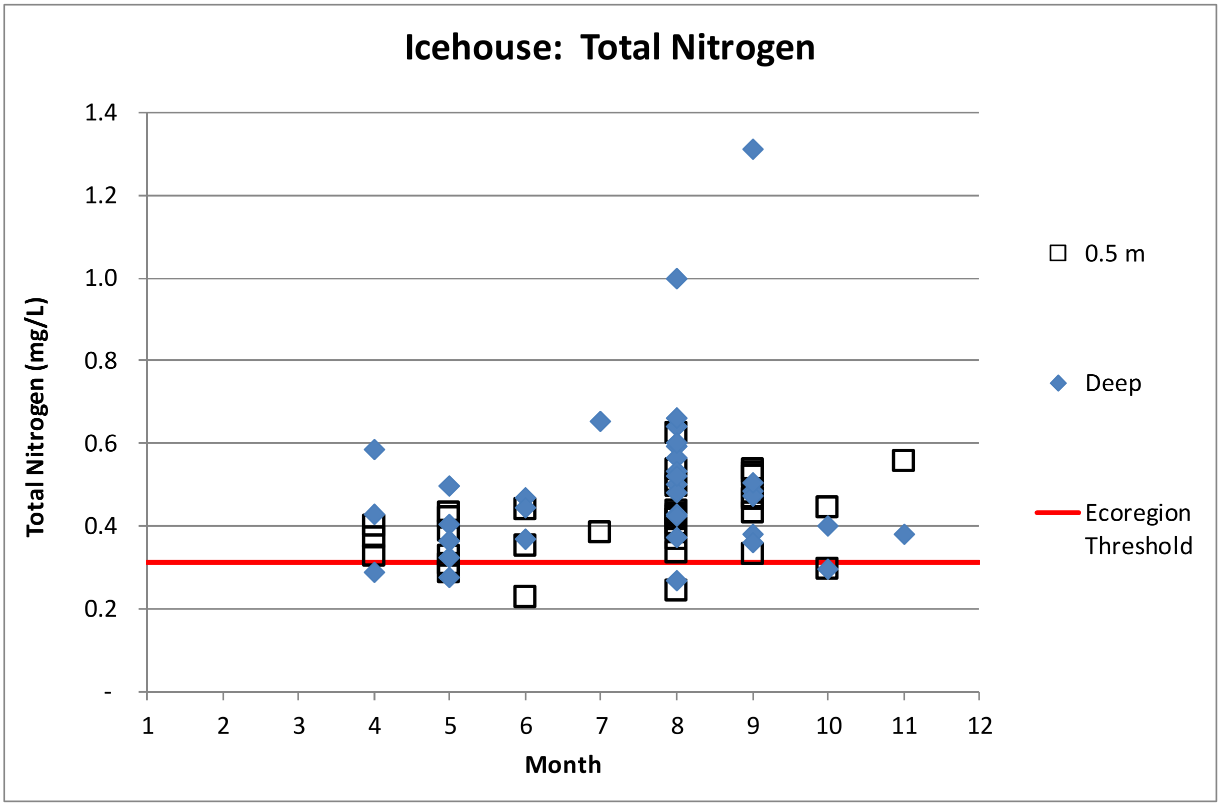
Icehouse Pond

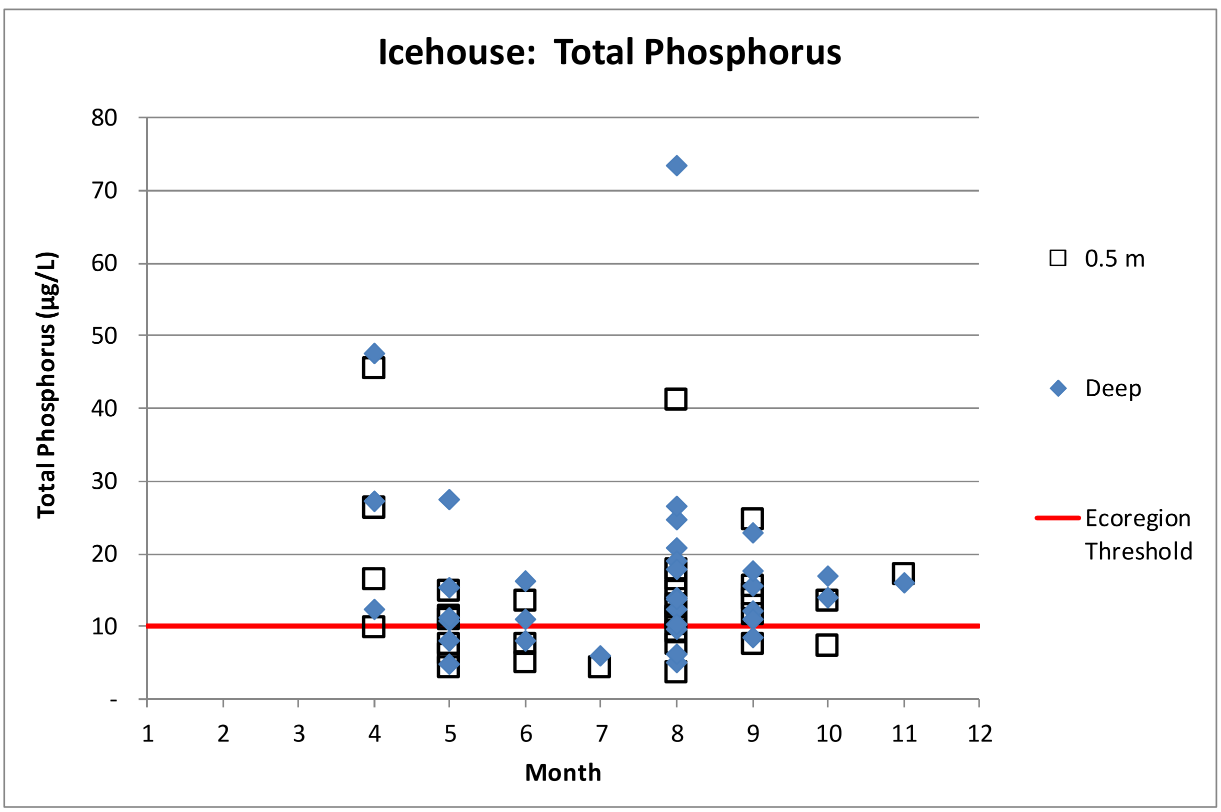

Icehouse: Secchi/Total Depth
Depth (m)
0
1
2
3
4
5
6
7
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)

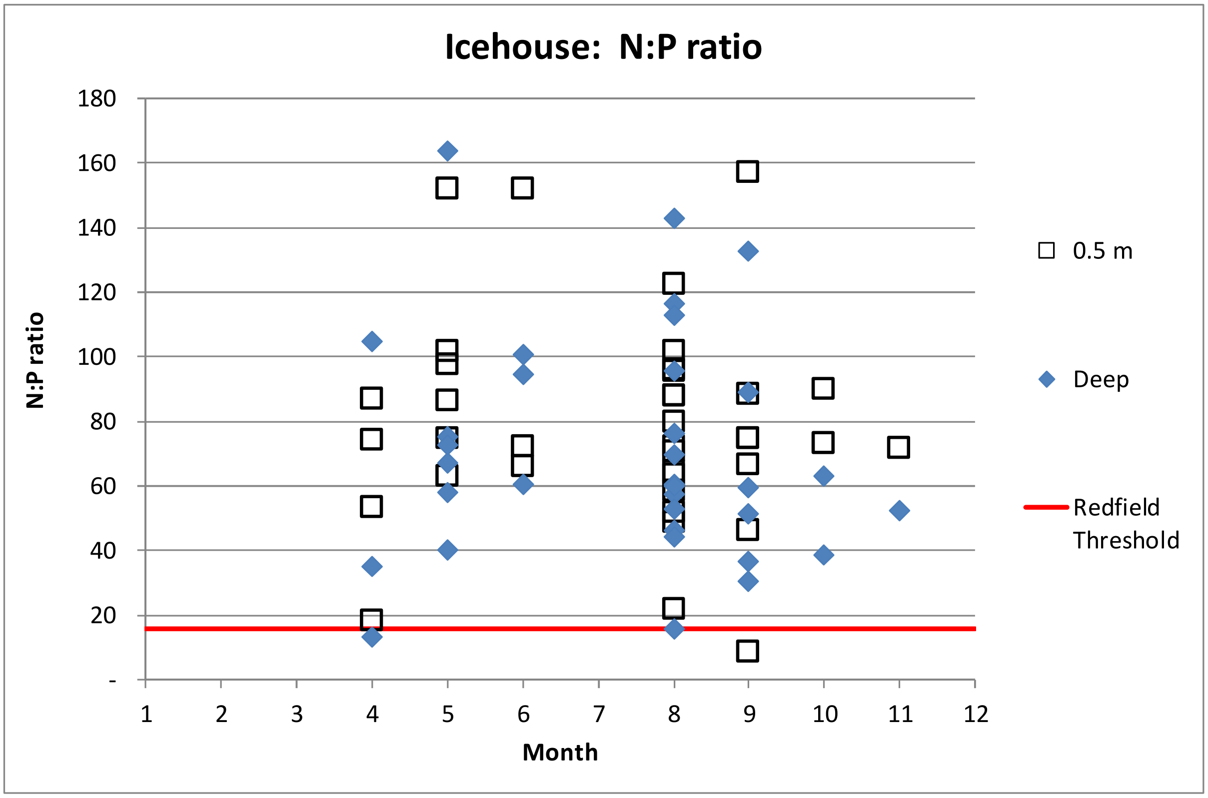

Icehouse: Temperature
Temperature (°C)
0
5
10
15
20
25
30
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP maximum


Icehouse: Dissolved Oxygen
Dissolved Oxygen (mg/L)
Month
0.5 m
Deep
MassDEP minimum

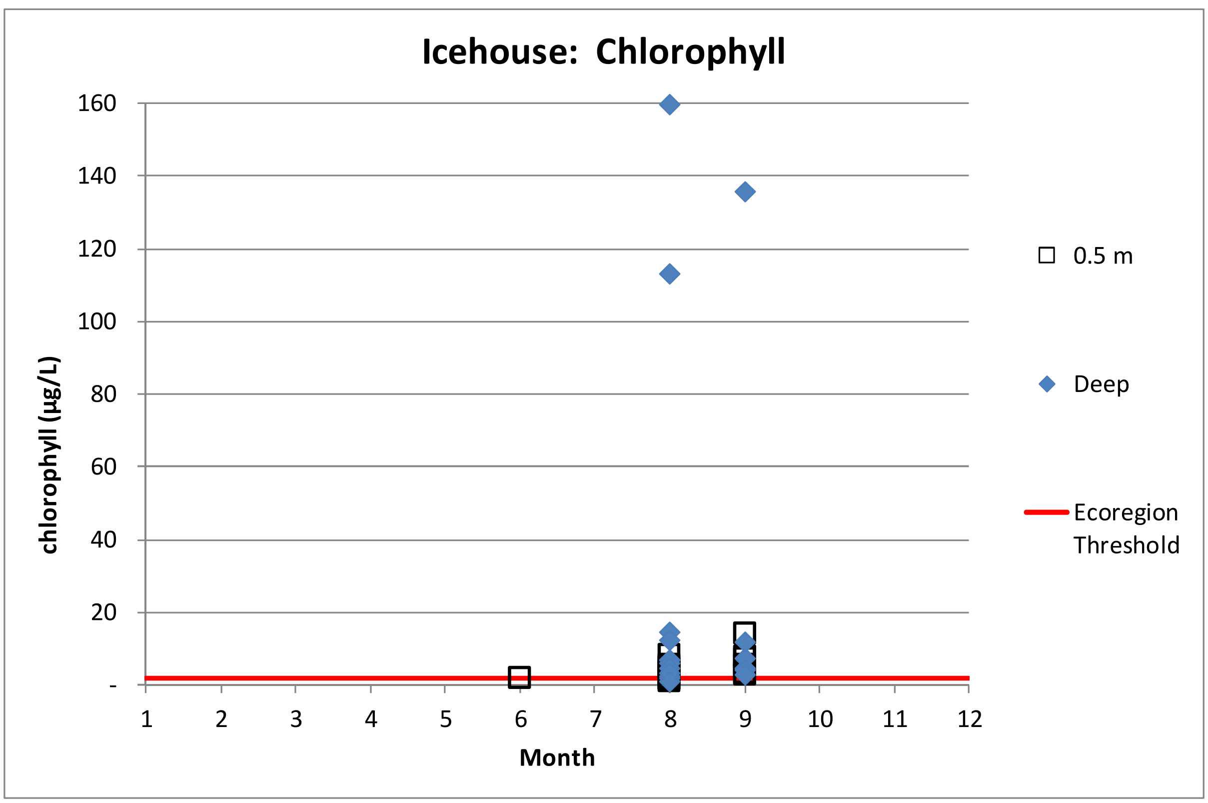

Icehouse: Dissolved Oxygen (% sat)
Dissolved Oxygen (% saturation)
Month
0.5 m
Deep
Atmospheric Equilibrium


Icehouse: Total Nitrogen
Total Nitrogen (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

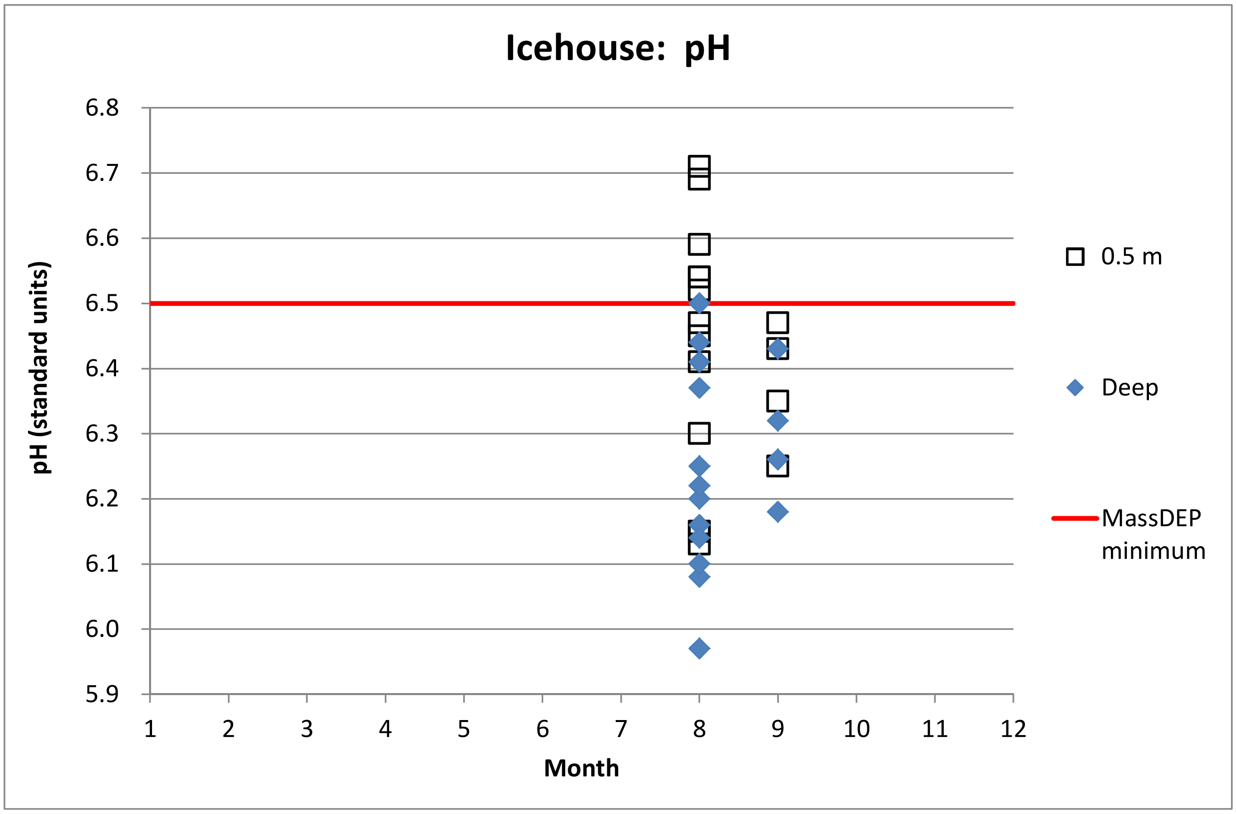

Icehouse: Total Phosphorus
Total Phosphorus (µg/L)
80
70
60
50
40
30
20
10
-
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold



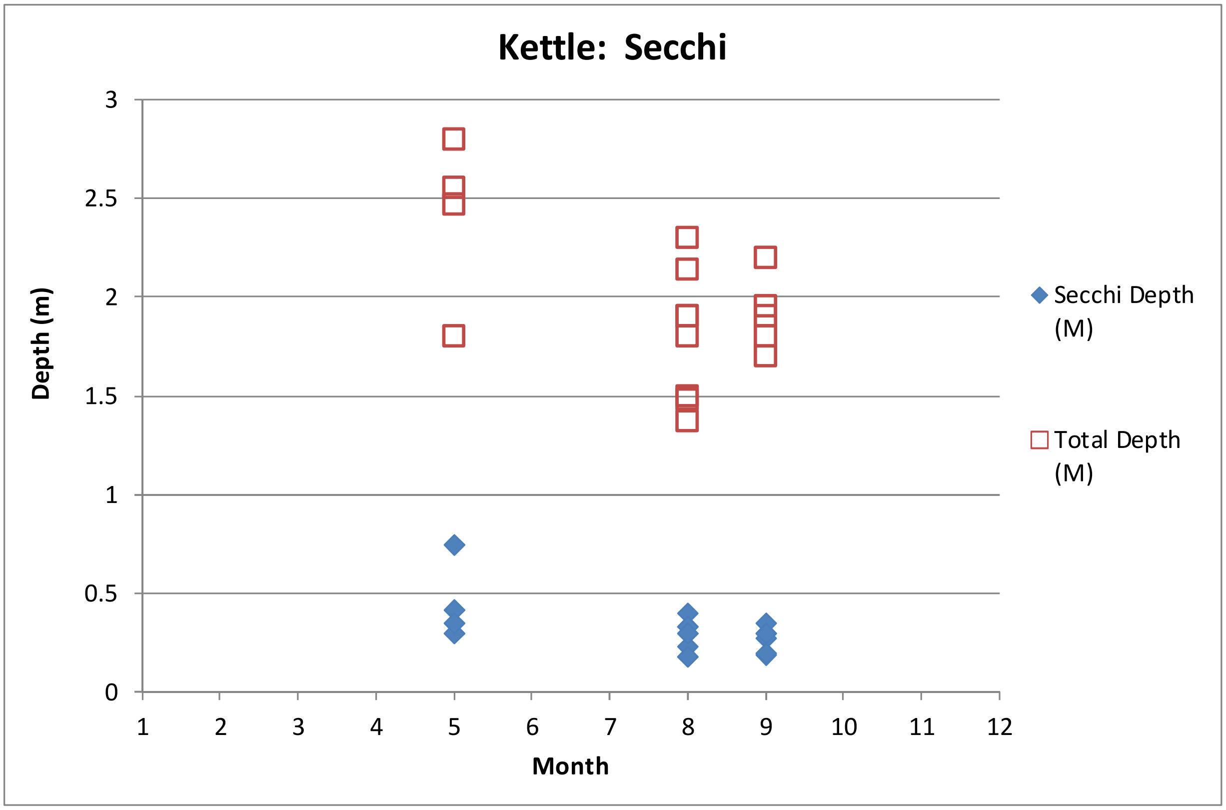
Icehouse: N:P ratio
N:P ratio
180
160
140
120
100
80
60
40
20
-
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield Threshold

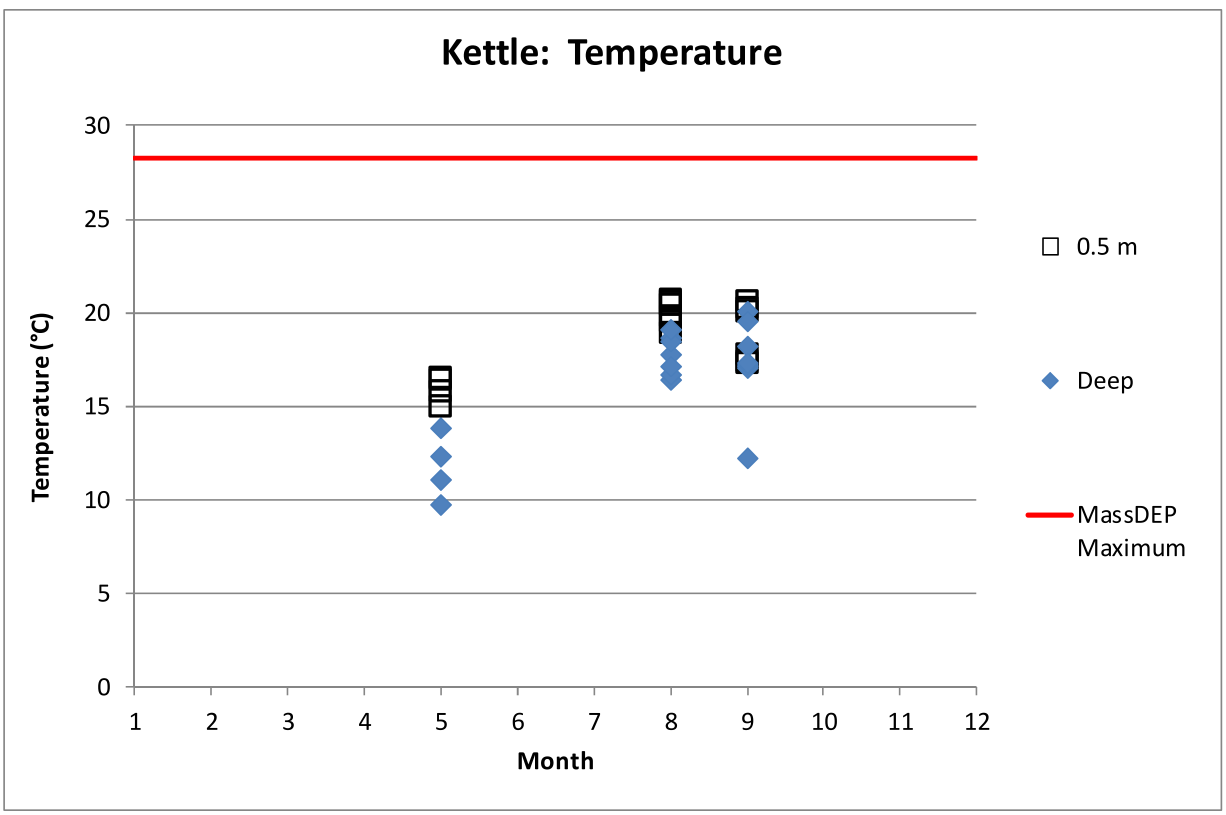


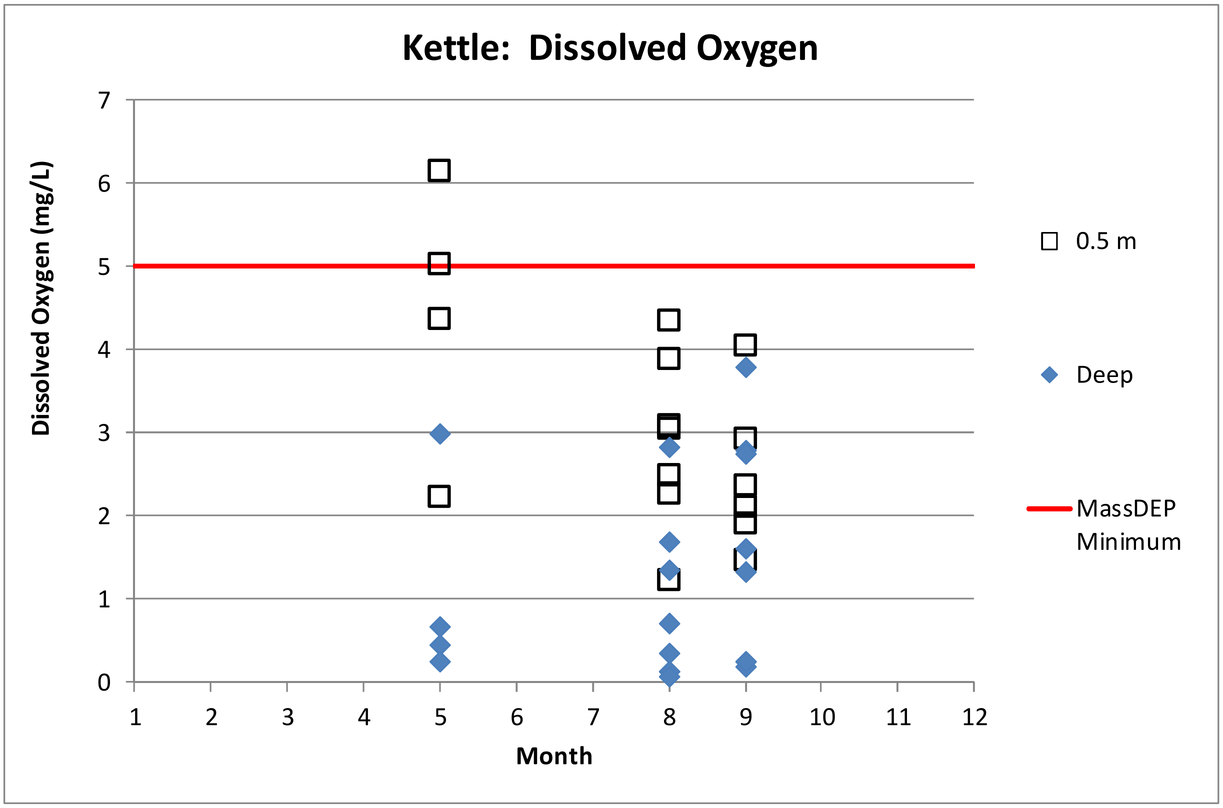
Icehouse: Chlorophyll
chlorophyll (µg/L)
160
140
120
100
80
60
40
20
-
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold


Icehouse: pH
pH (standard units)
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6.0
5.9
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

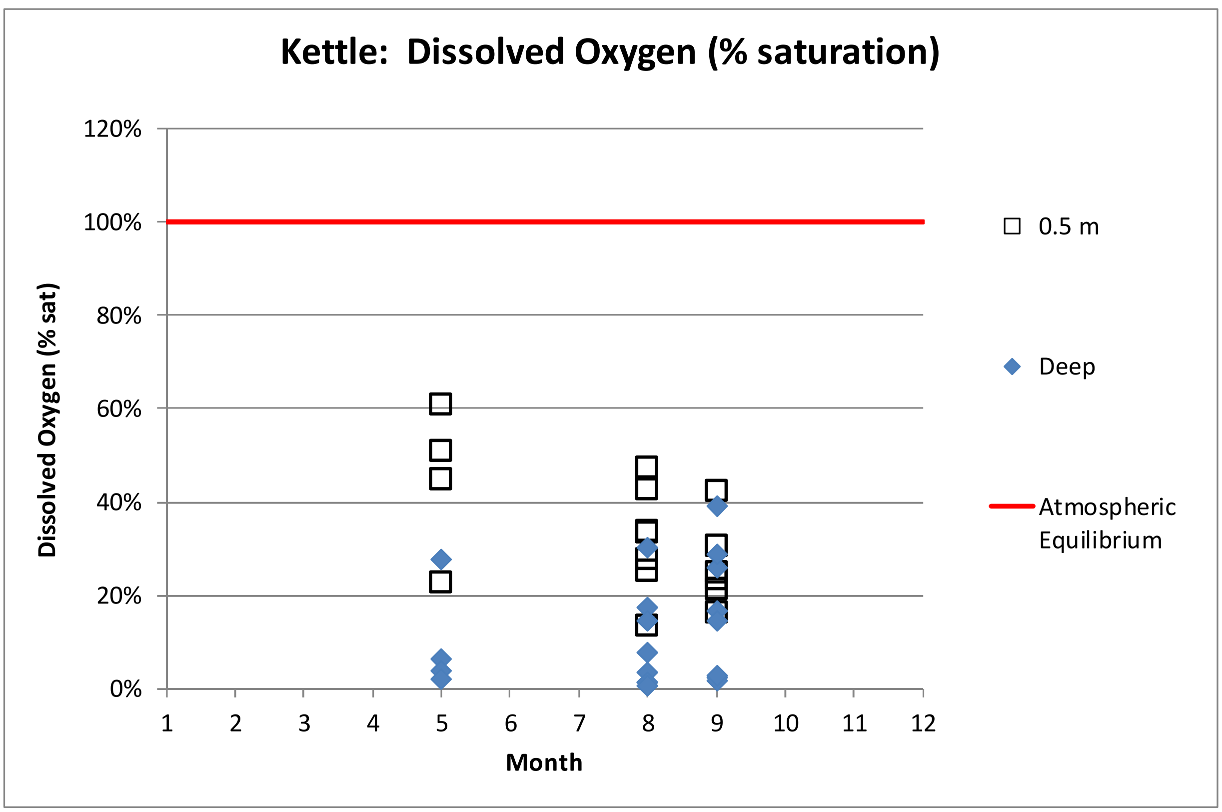
Kettle Pond


Kettle: Secchi
Depth (m)
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)

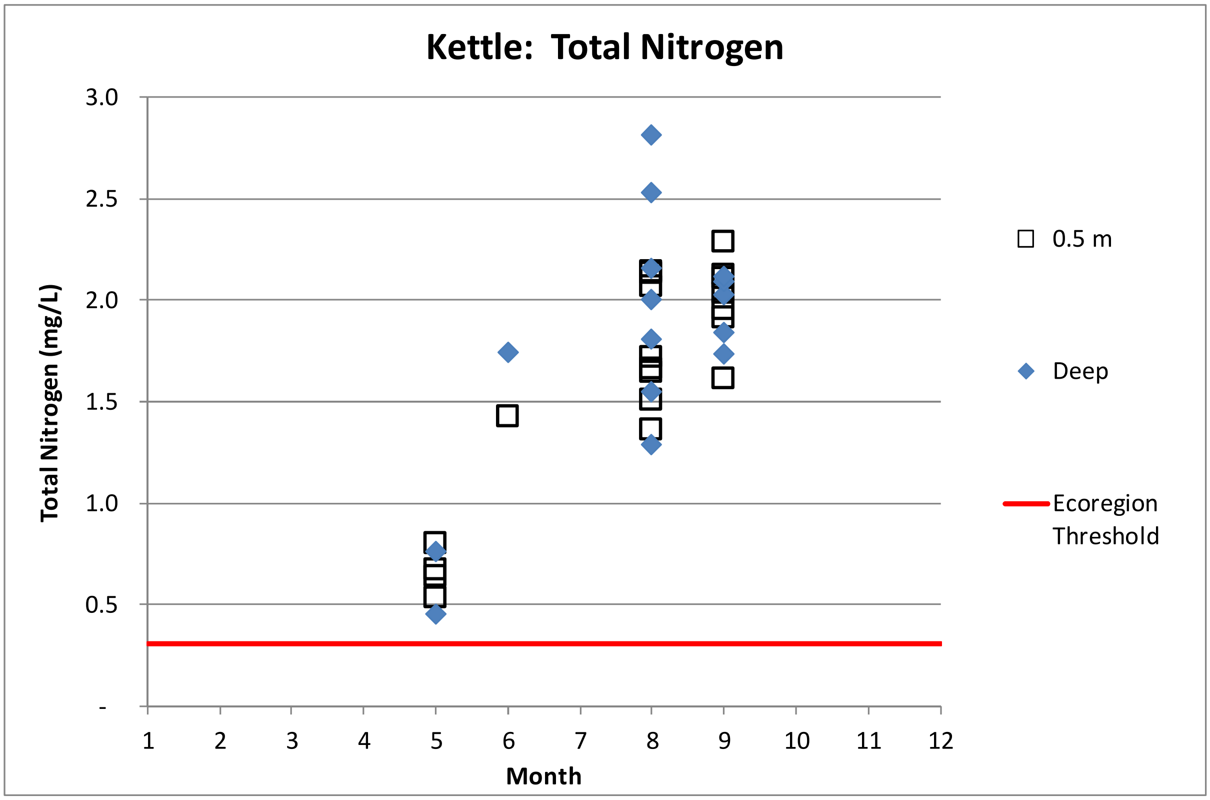

Kettle: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP Maximum

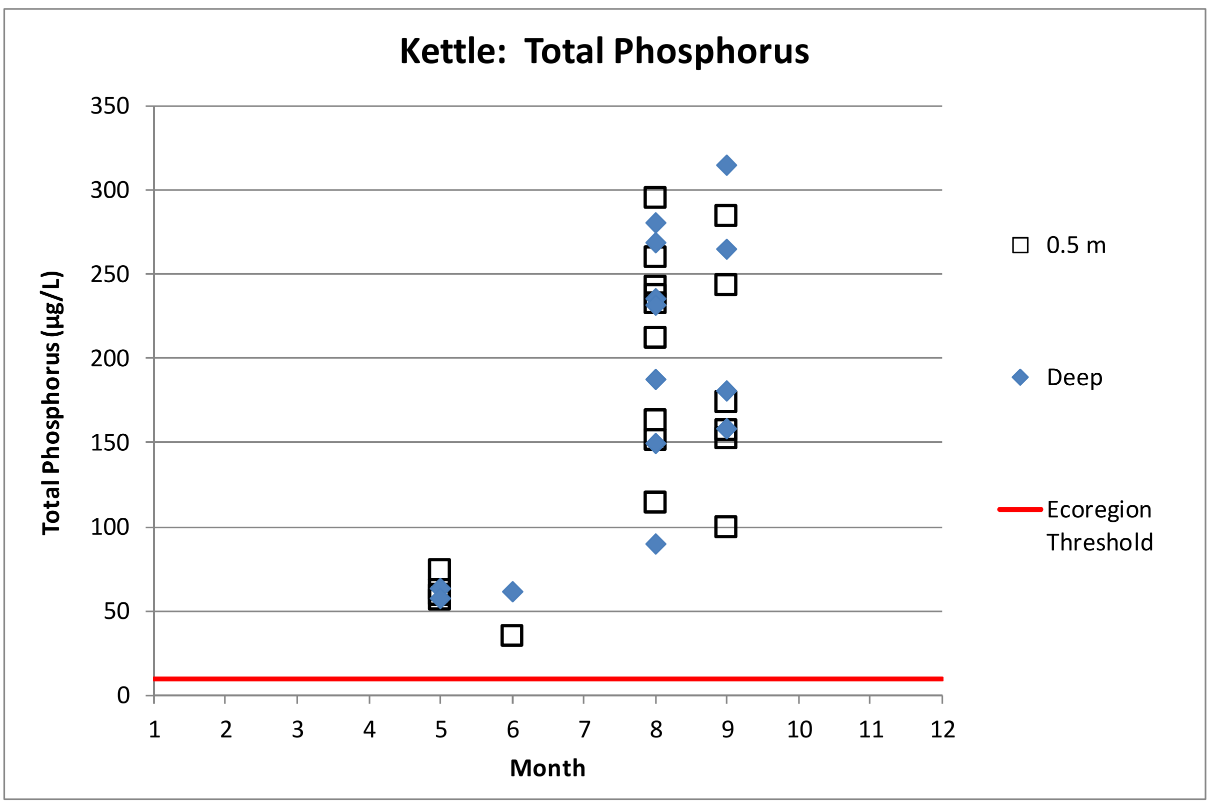


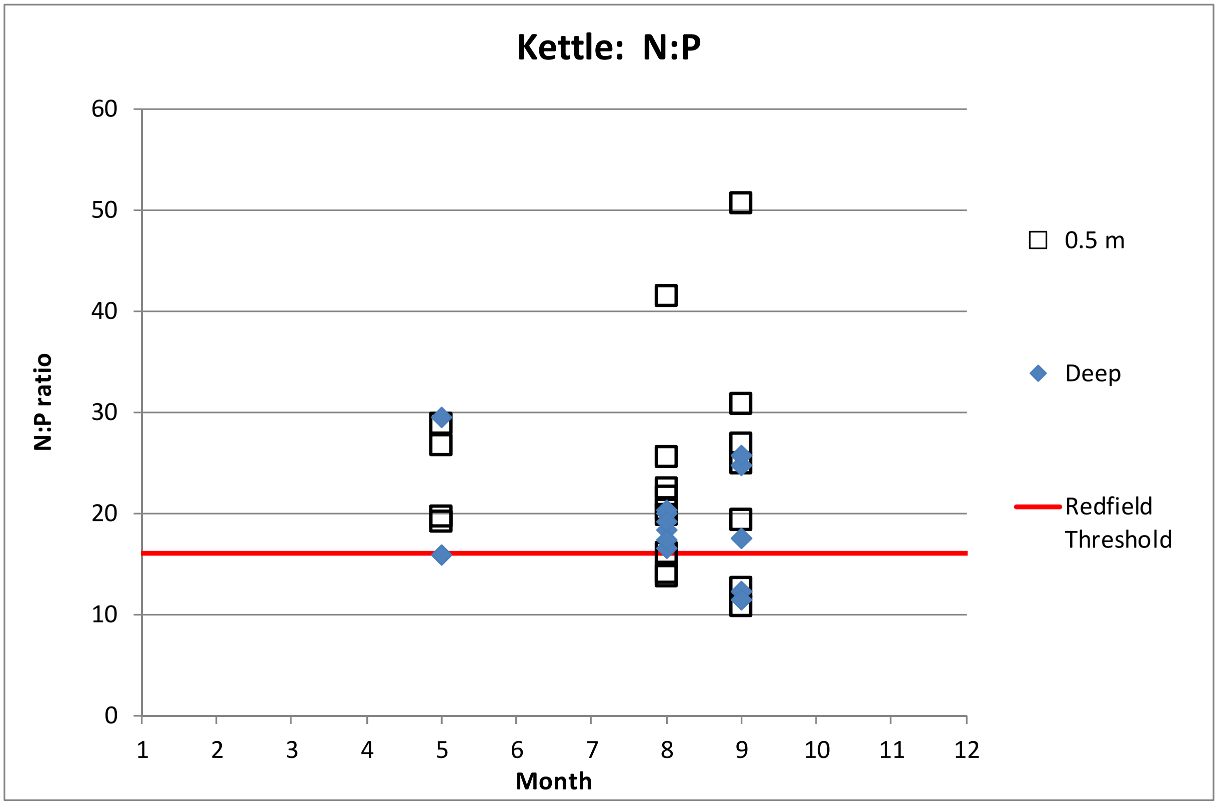
Kettle: Dissolved Oxygen
Dissolved Oxygen (mg/L)
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP Minimum

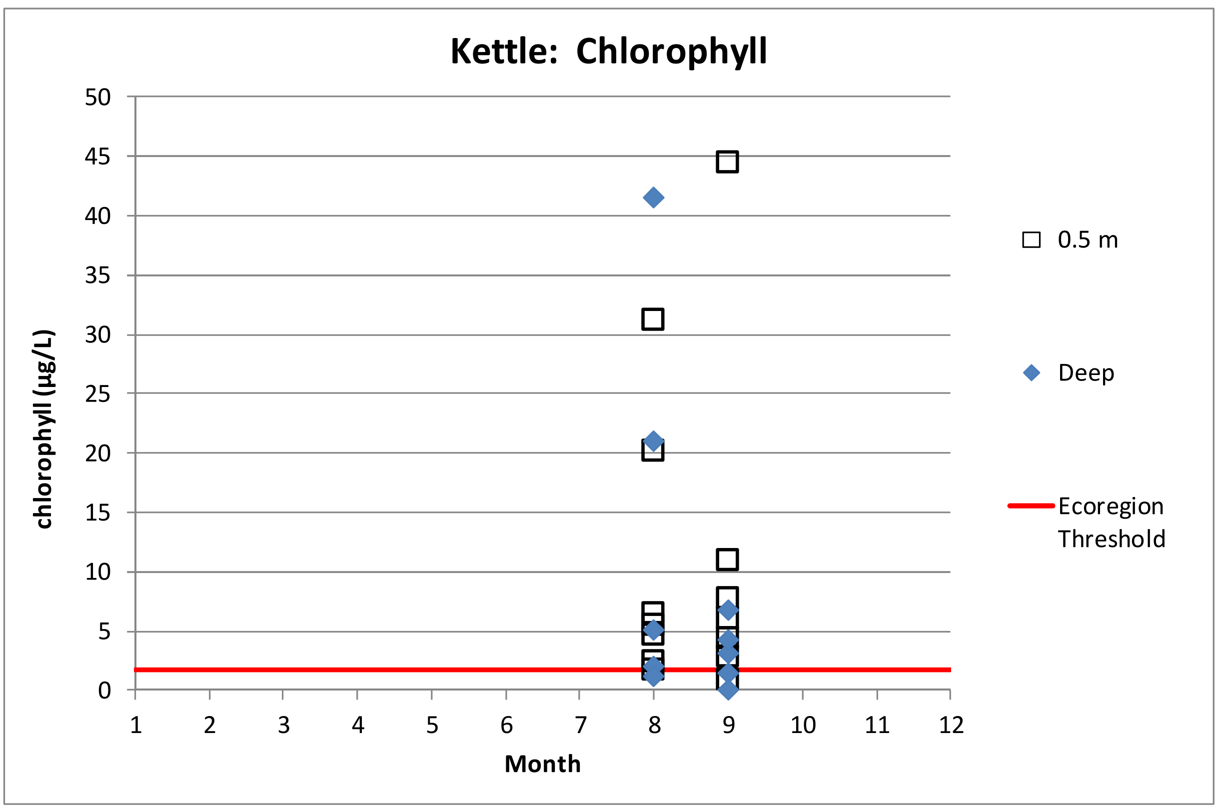


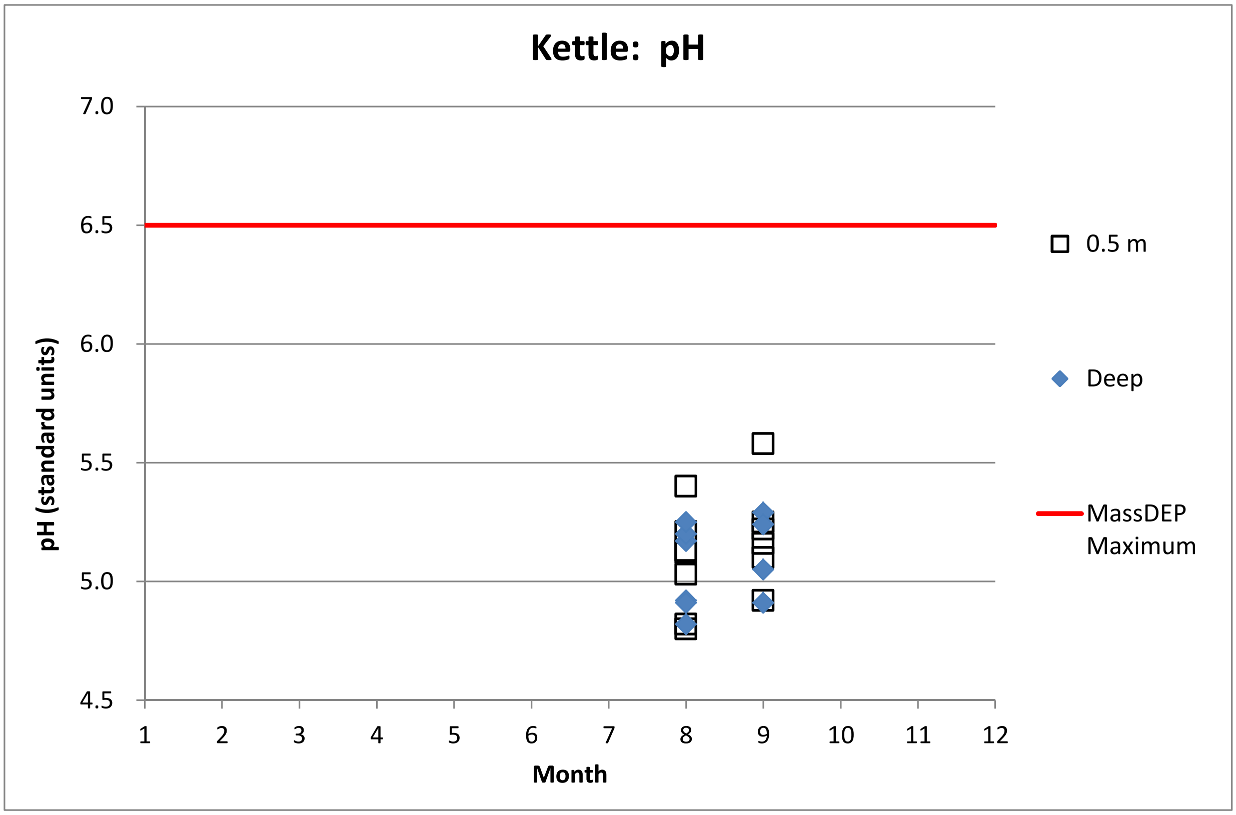
Kettle: Dissolved Oxygen (% saturation)
Dissolved Oxygen (% sat)
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium


Kettle: Total Nitrogen
3.0
2.5
2.0
1.5
1.0
0.5
-
Total Nitrogen (mg/L)
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold


Kettle: Total Phosphorus
350
300
250
200
150
100
50
0
Total Phosphorus (µg/L)
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

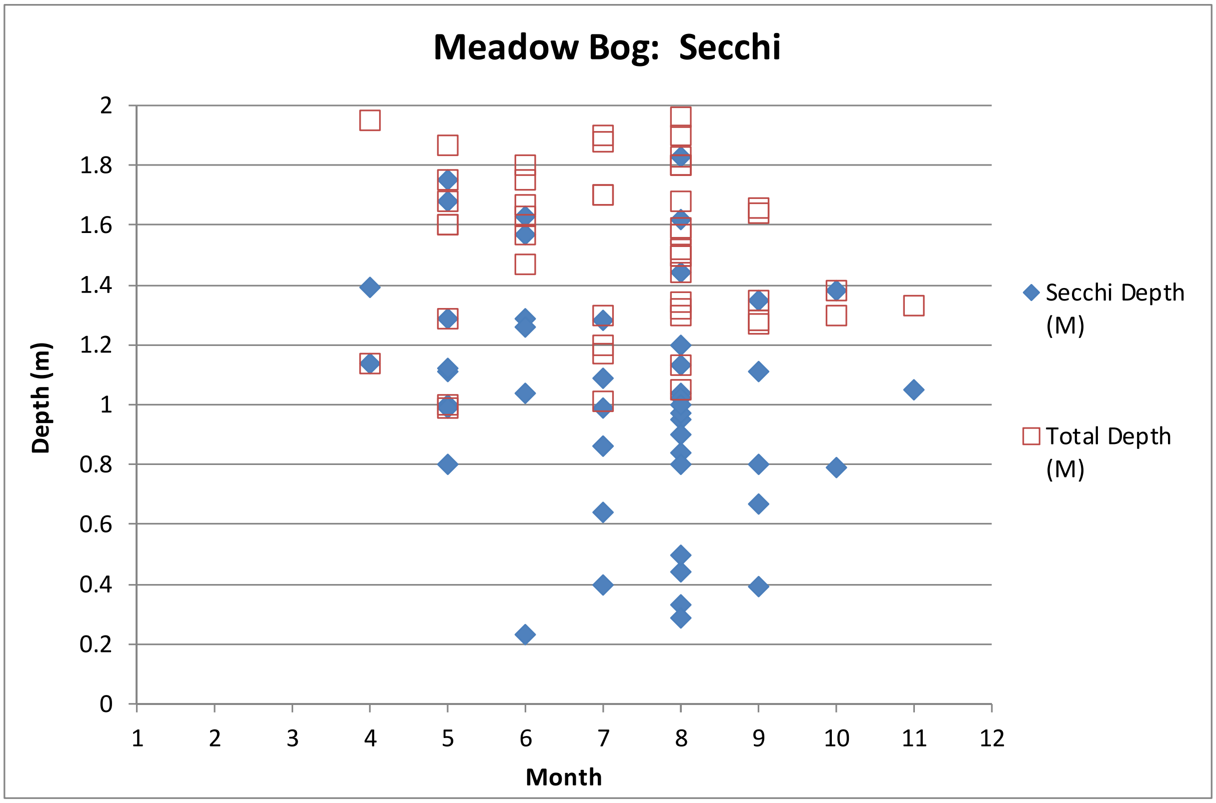

Kettle: N:P
N:P ratio
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield Threshold


Kettle: Chlorophyll
chlorophyll (µg/L)
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

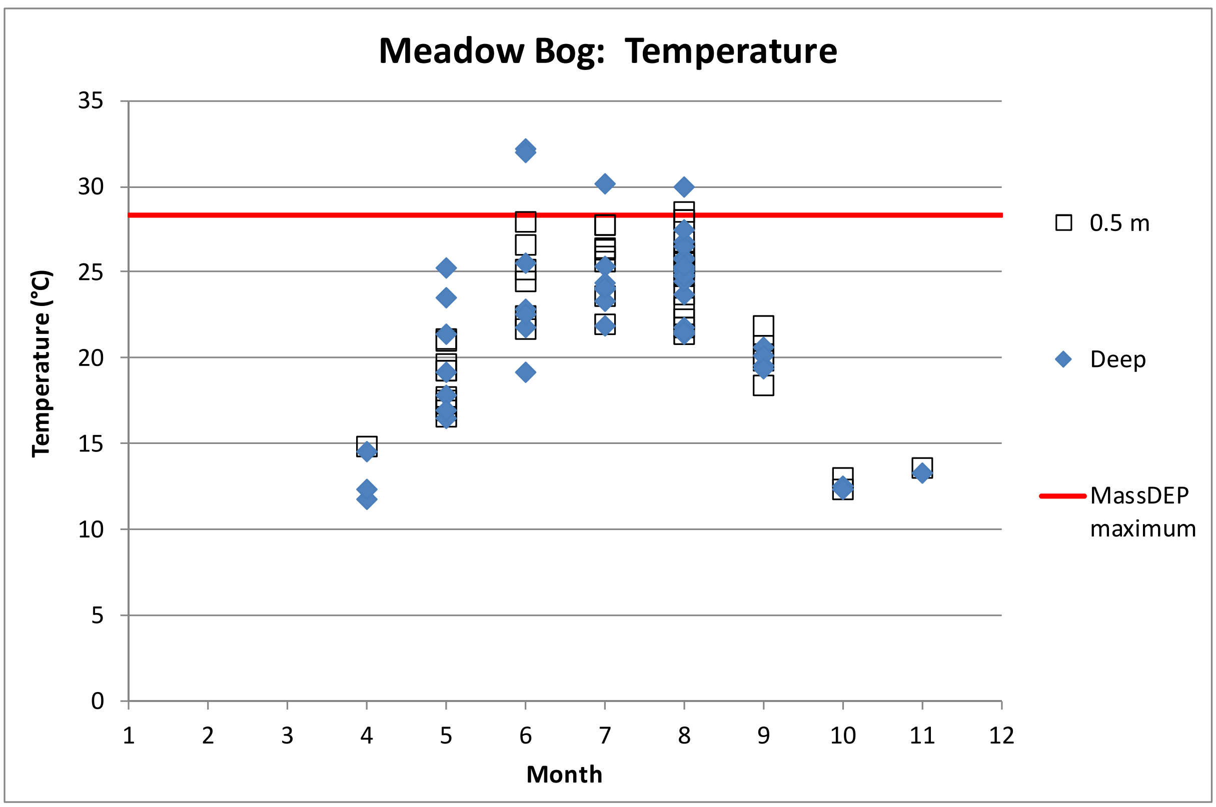


Kettle: pH
7.0
6.5
6.0
5.5
5.0
4.5
pH (standard units)
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP Maximum

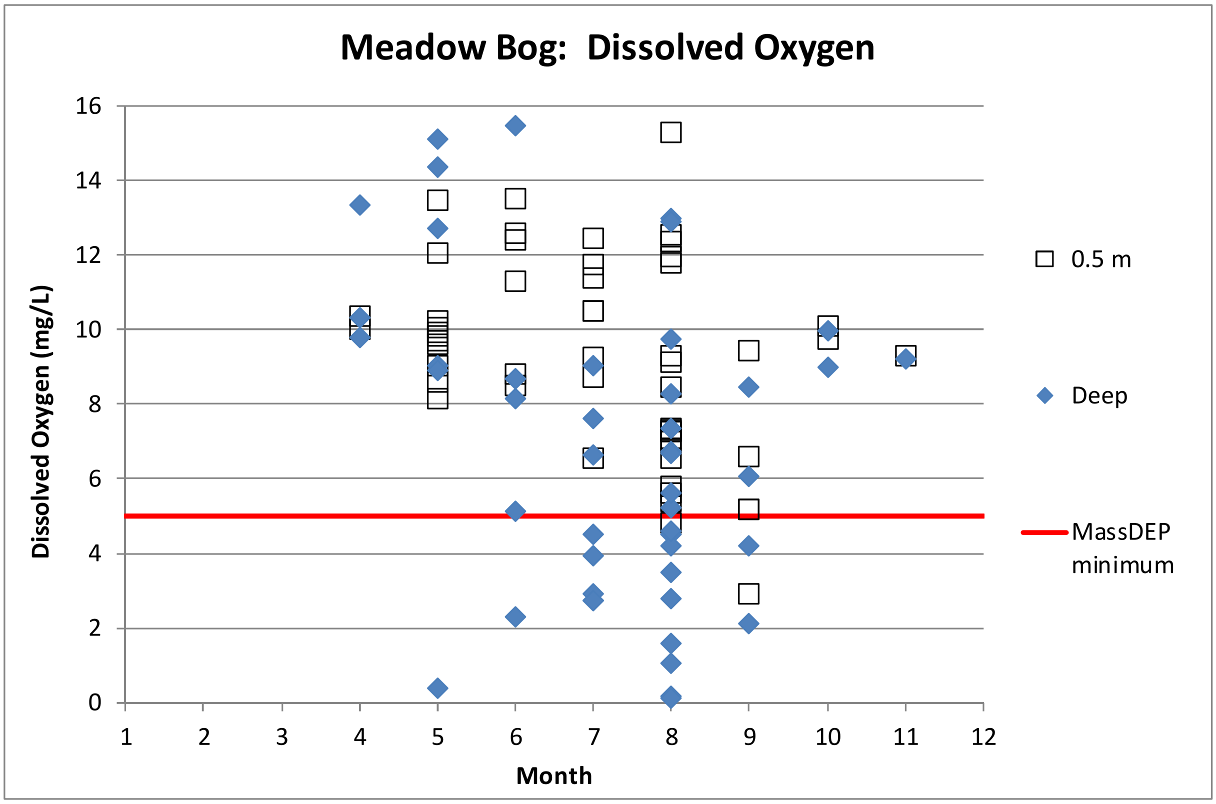
Meadow Bog Pond



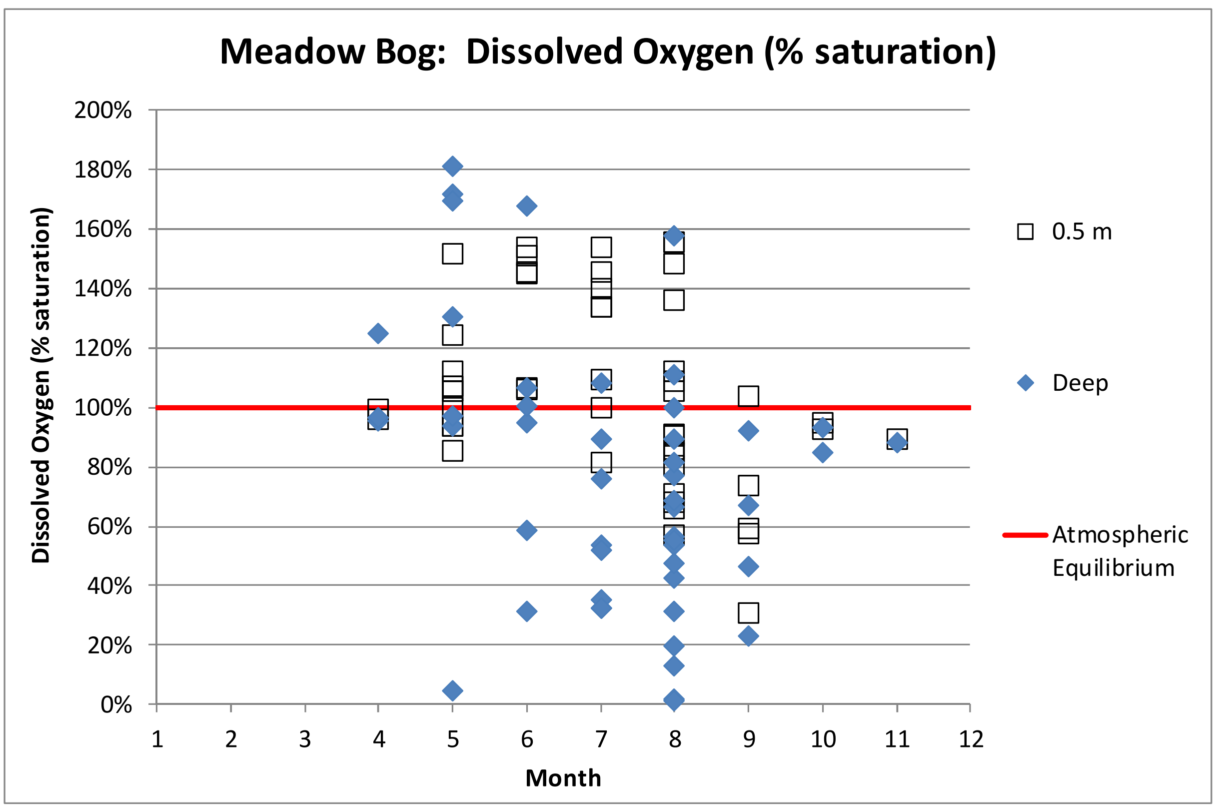
Meadow Bog: Secchi
Depth (m)
Month
Secchi Depth (M)
Total Depth (M)



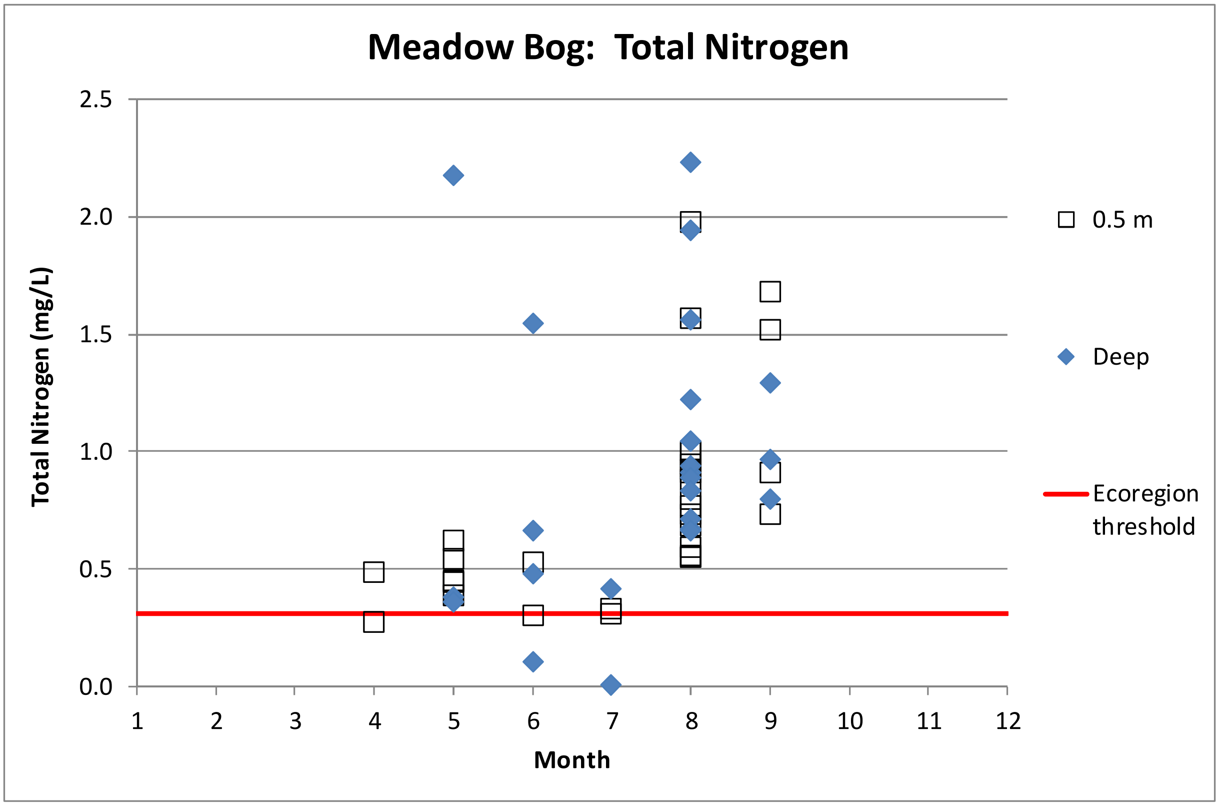
Meadow Bog: Temperature
Temperature (°C)
Month
0.5 m
Deep
MassDEP maximum



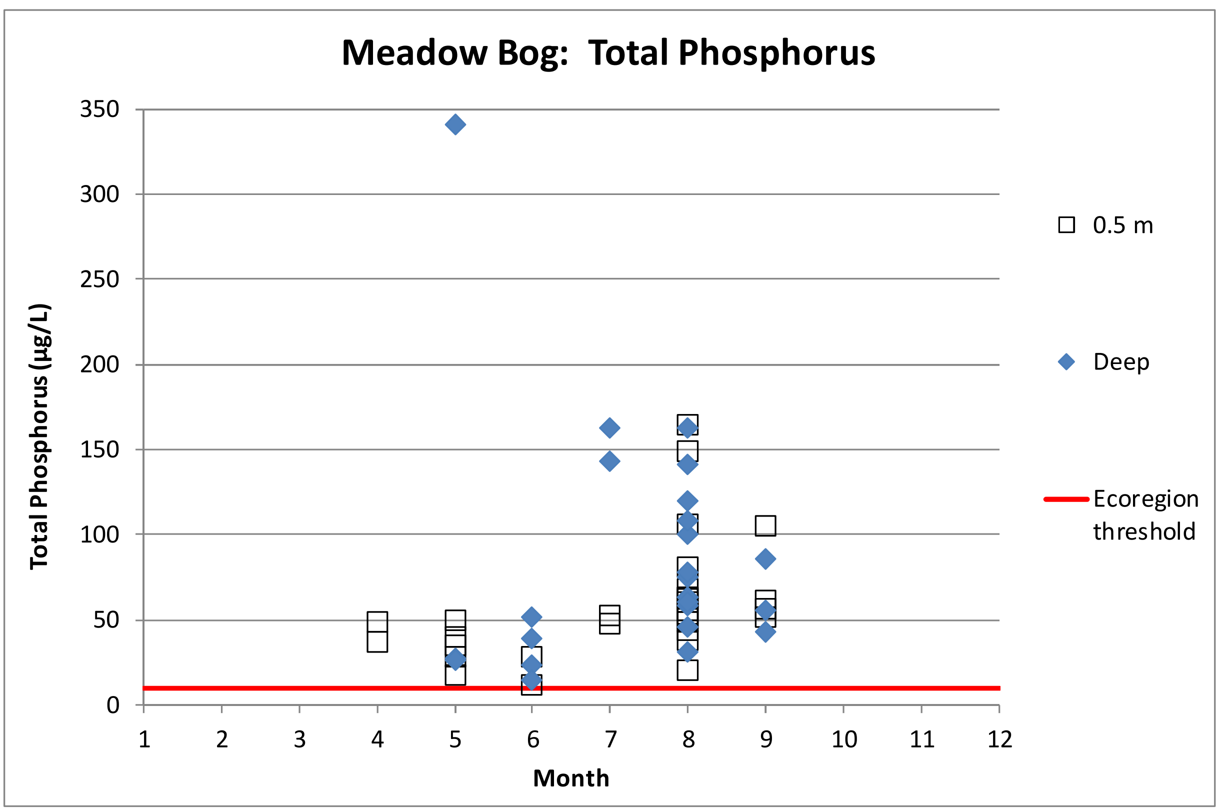
Meadow Bog: Dissolved Oxygen
Dissolved Oxygen (mg/L)
0
2
4
6
8
10
12
14
16
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum



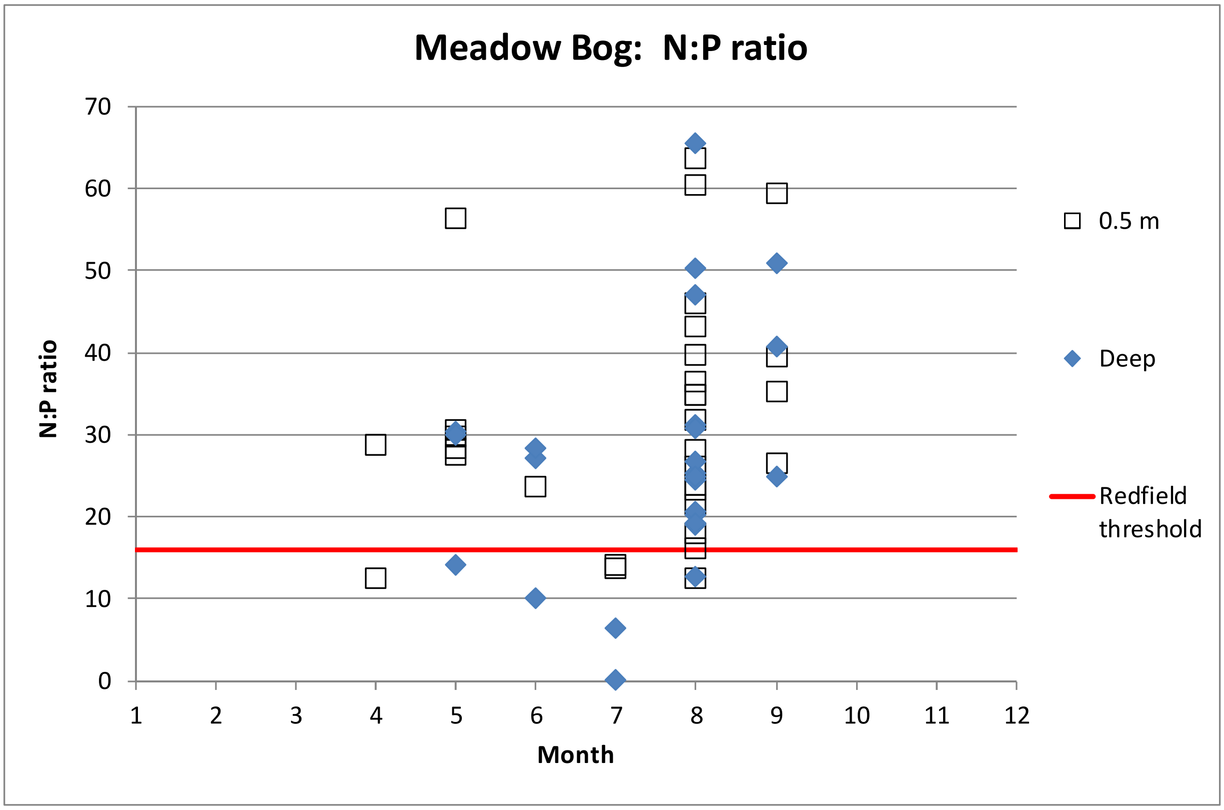
Meadow Bog: Dissolved Oxygen (% saturation)
Dissolved Oxygen (% saturation)
0%
20%
40%
60%
80%
100%
120%
140%
160%
180%
200%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium



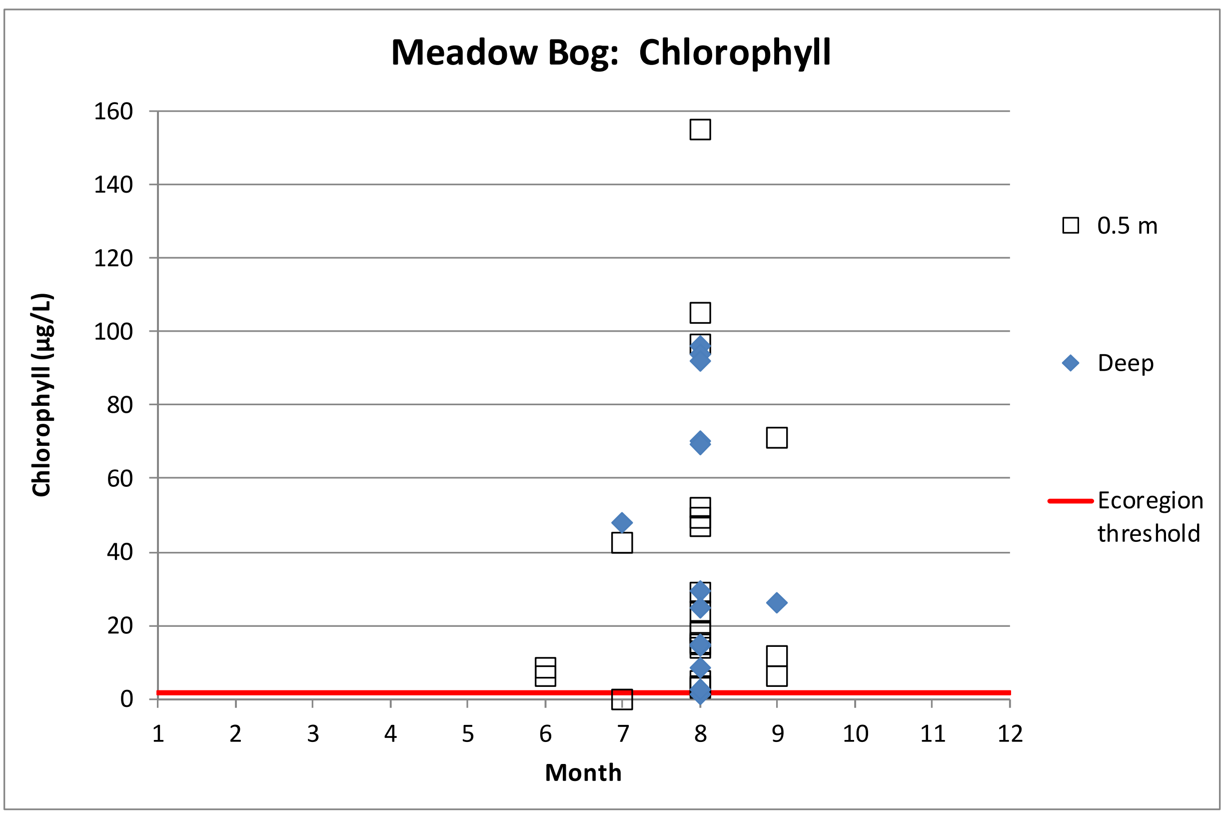
Meadow Bog: Total Nitrogen
Total Nitrogen (mg/L)
2.5
2.0
1.5
1.0
0.5
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion threshold



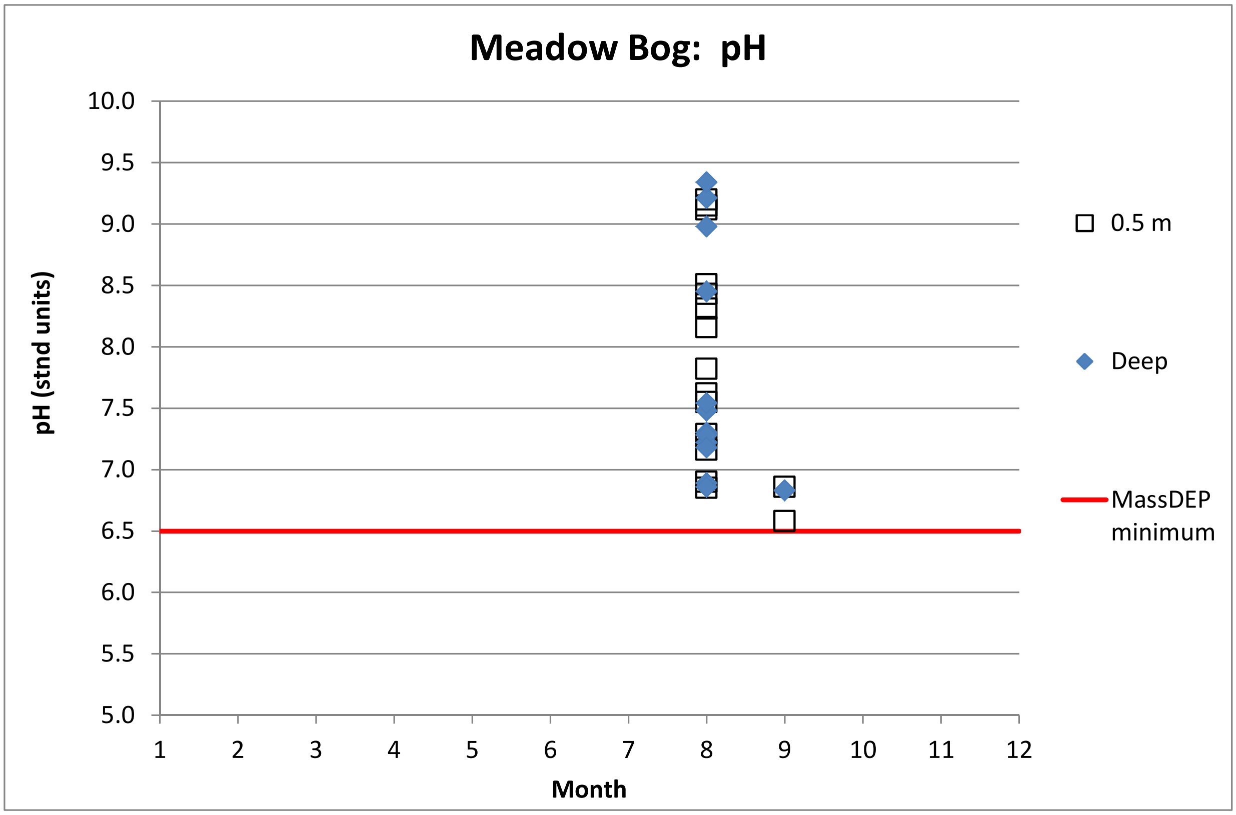
Meadow Bog: Total Phosphorus
Total Phosphorus (µg/L)
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion threshold



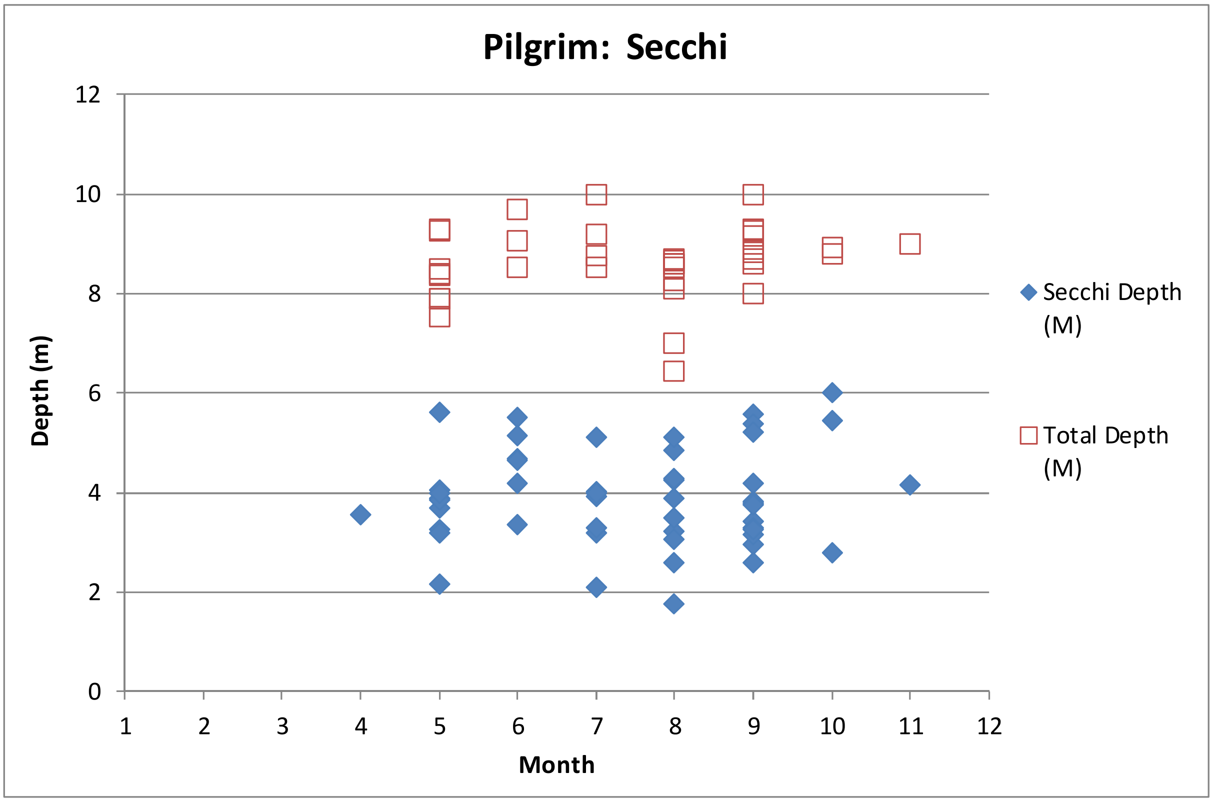
Meadow Bog: N:P ratio
N:P ratio
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield threshold



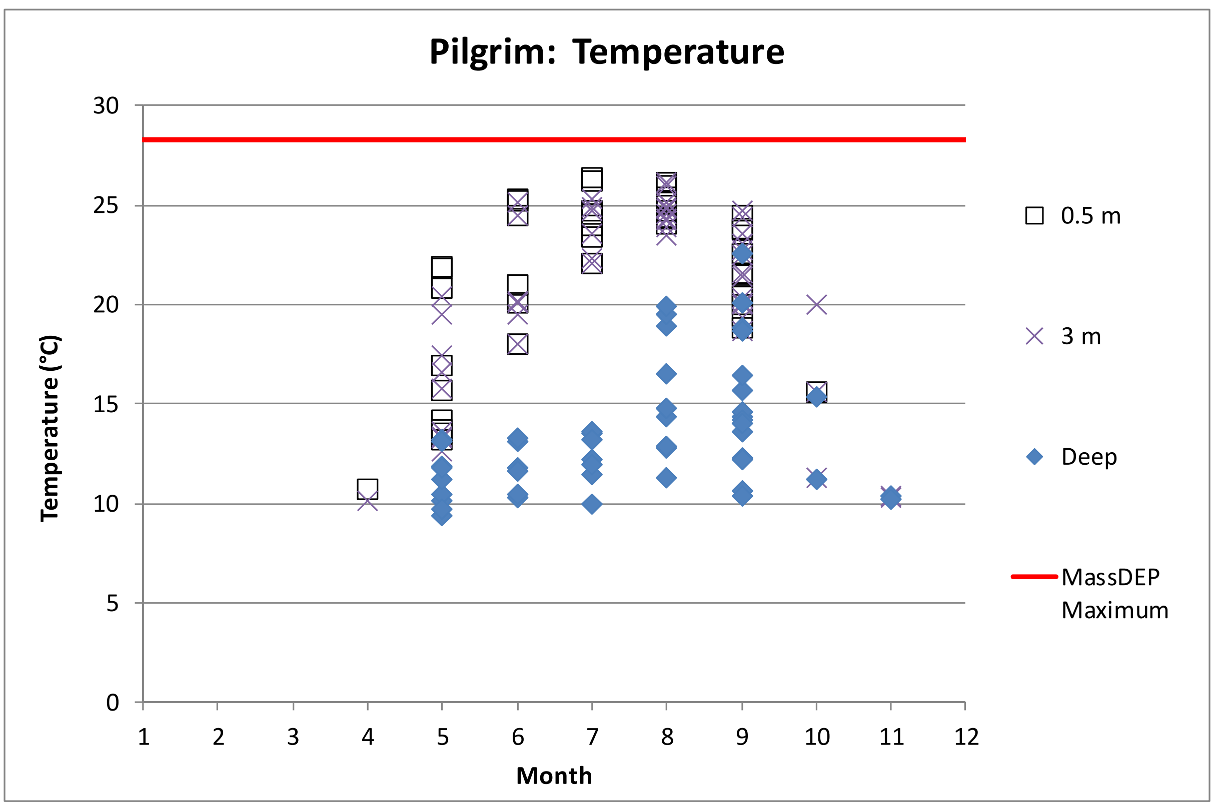
Meadow Bog: Chlorophyll
Chlorophyll (µg/L)
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion threshold


Meadow Bog: pH
pH (stnd units)
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

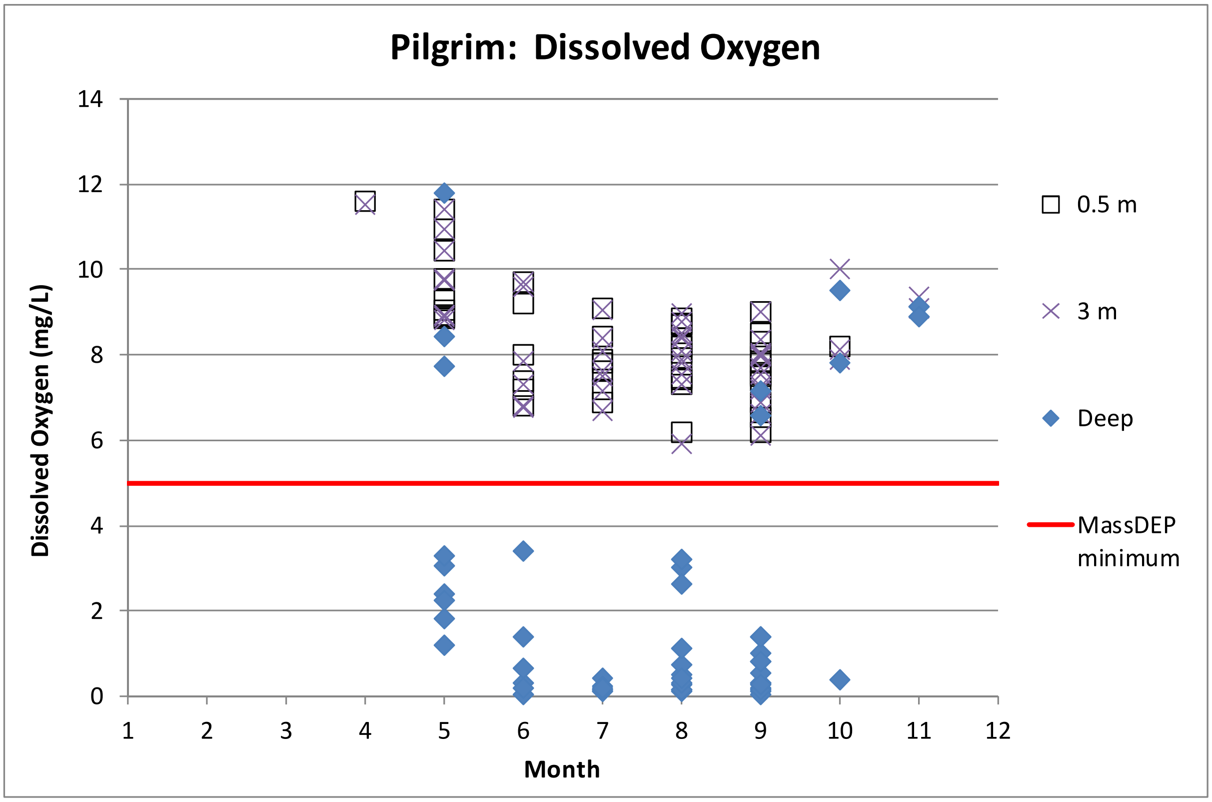
Pilgrim Lake

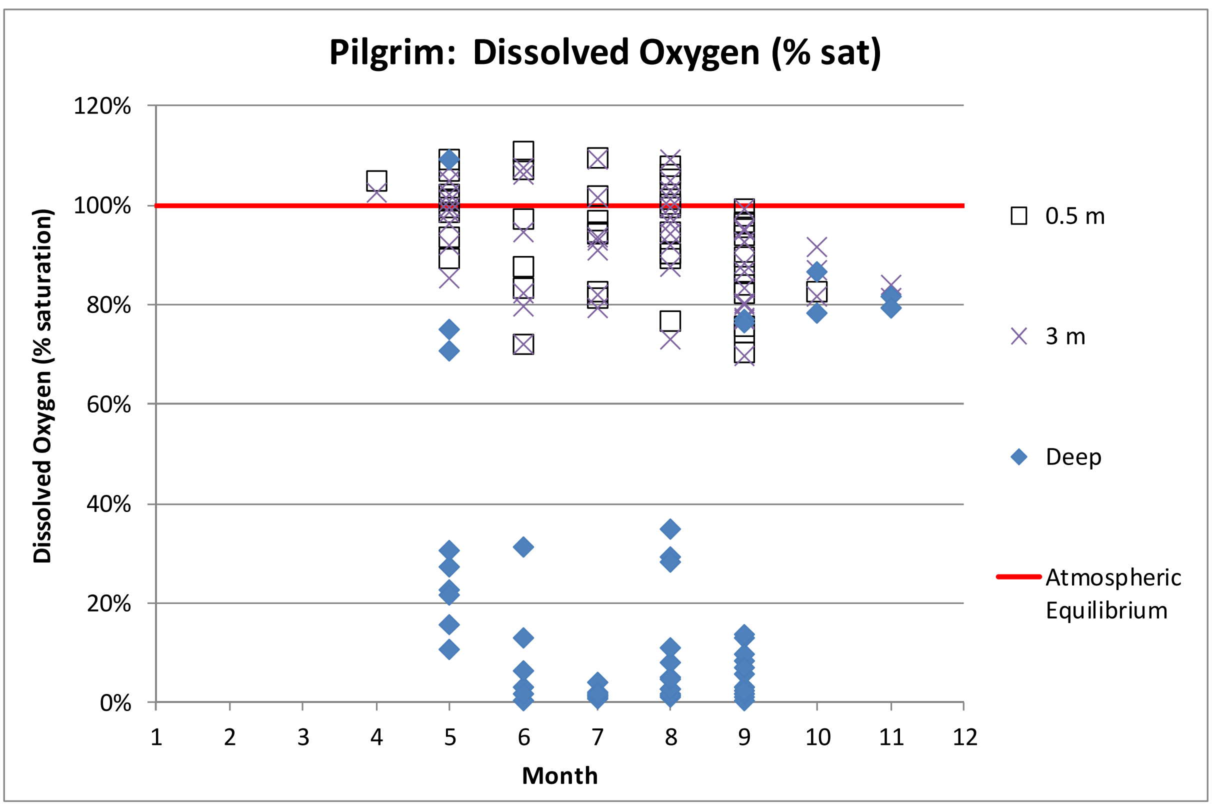


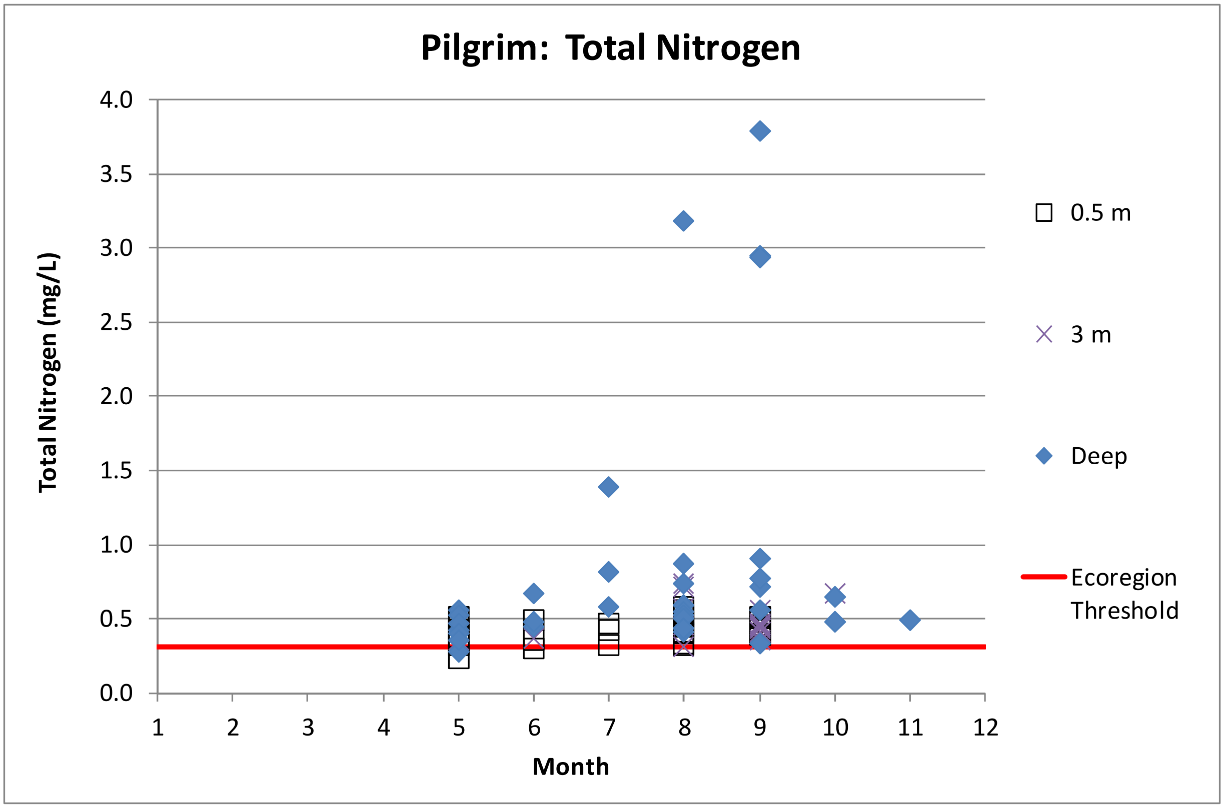
Pilgrim: Secchi
Depth (m)
Month
Secchi Depth (M)
Total Depth (M)

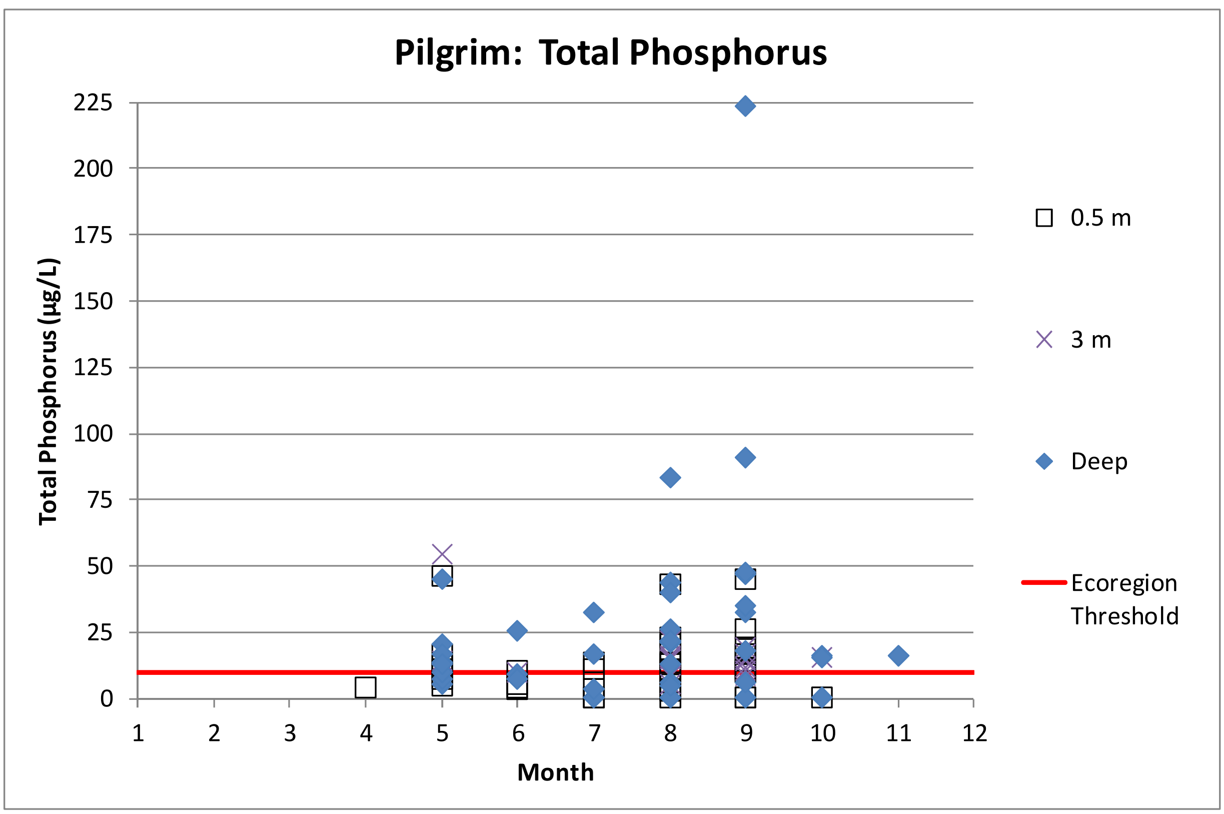


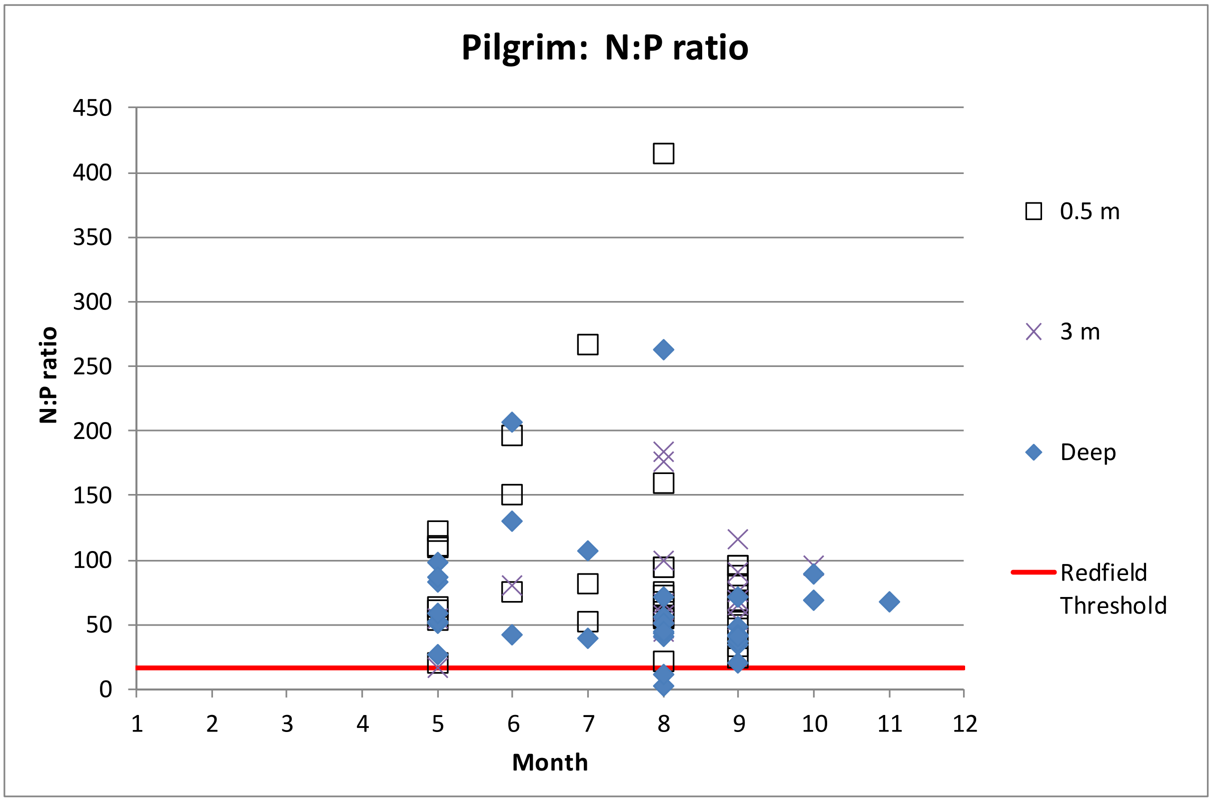
Pilgrim: Temperature
Temperature (°C)
Month
0.5 m
3 m
Deep
MassDEP Maximum


Pilgrim: Dissolved Oxygen
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
3 m
Deep
MassDEP minimum

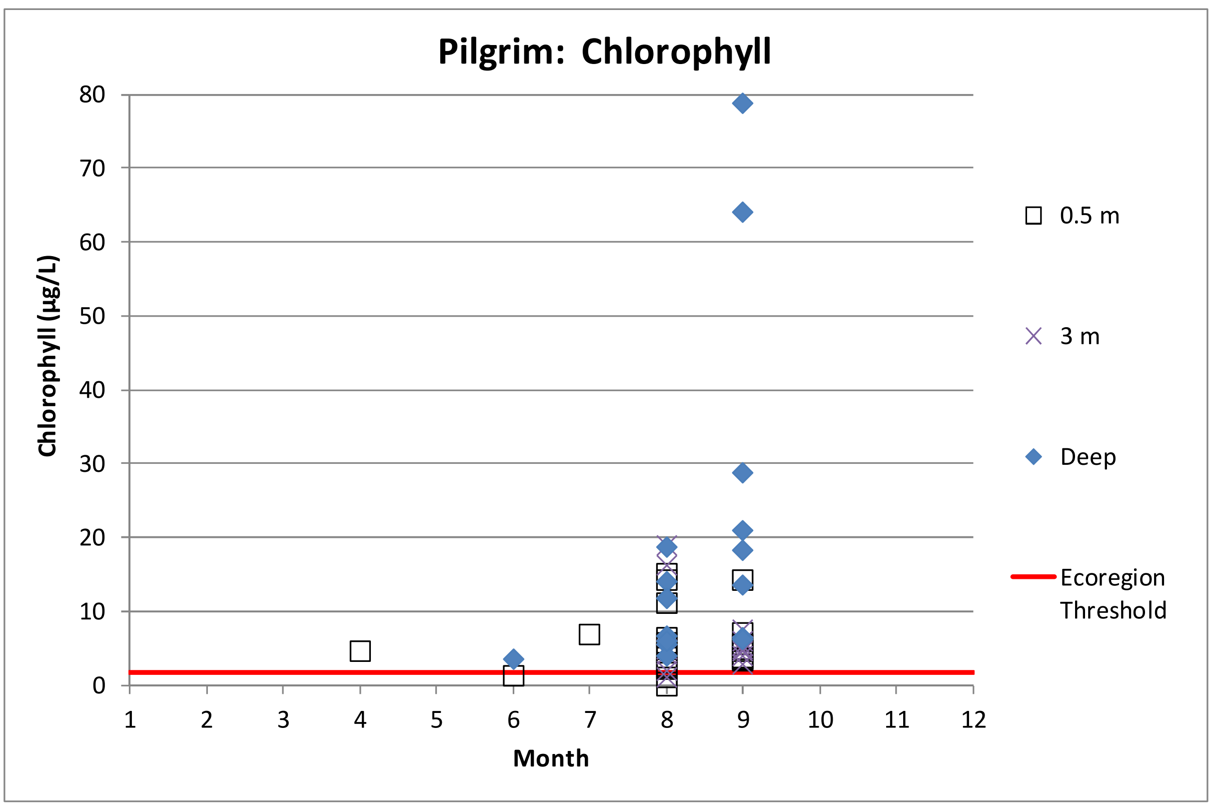

Pilgrim: Dissolved Oxygen (% sat)
Dissolved Oxygen (% saturation)
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
3 m
Deep
Atmospheric Equilibrium


Pilgrim: Total Nitrogen
Total Nitrogen (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
3 m
Deep
Ecoregion Threshold

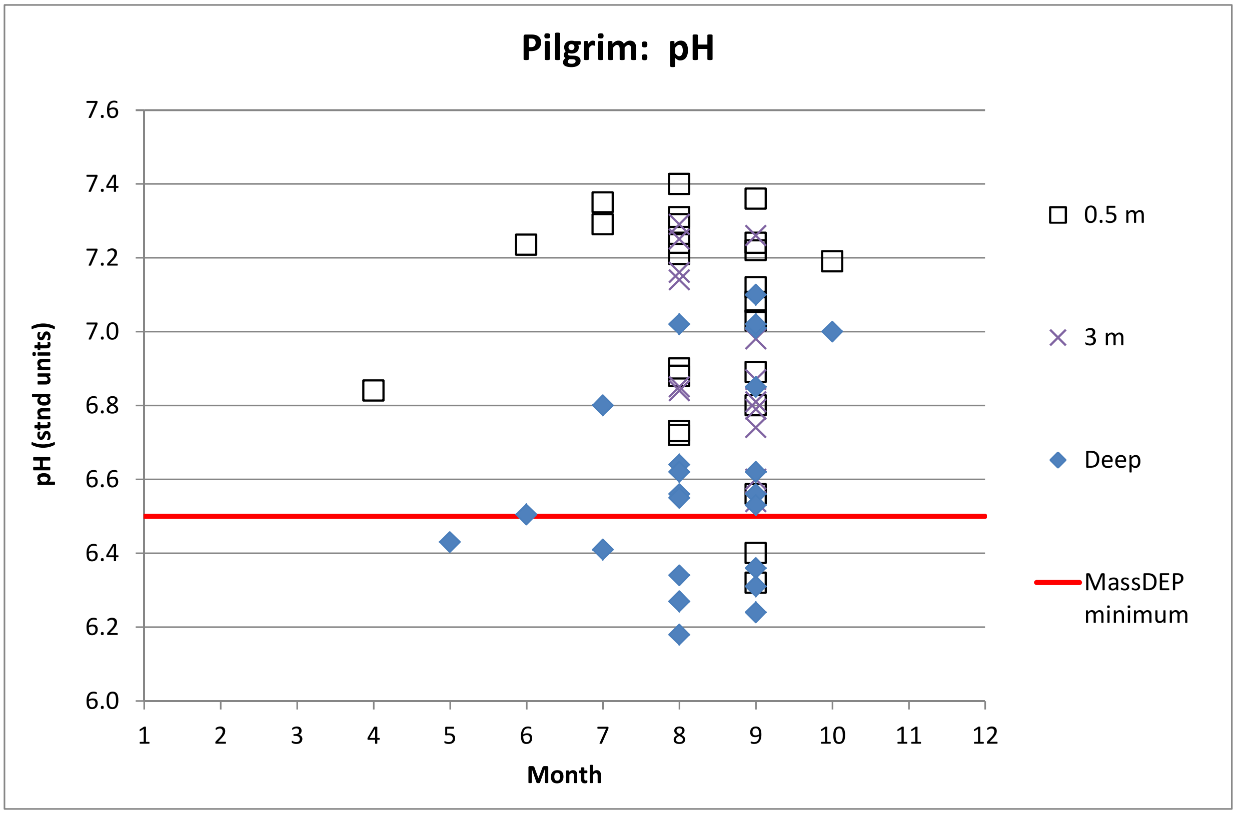

Pilgrim: Total Phosphorus
Total Phosphorus (µg/L)
225
200
175
150
125
100
75
50
25
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
3 m
Deep
Ecoregion Threshold



Pilgrim: N:P ratio
N:P ratio
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
3 m
Deep
Redfield Threshold

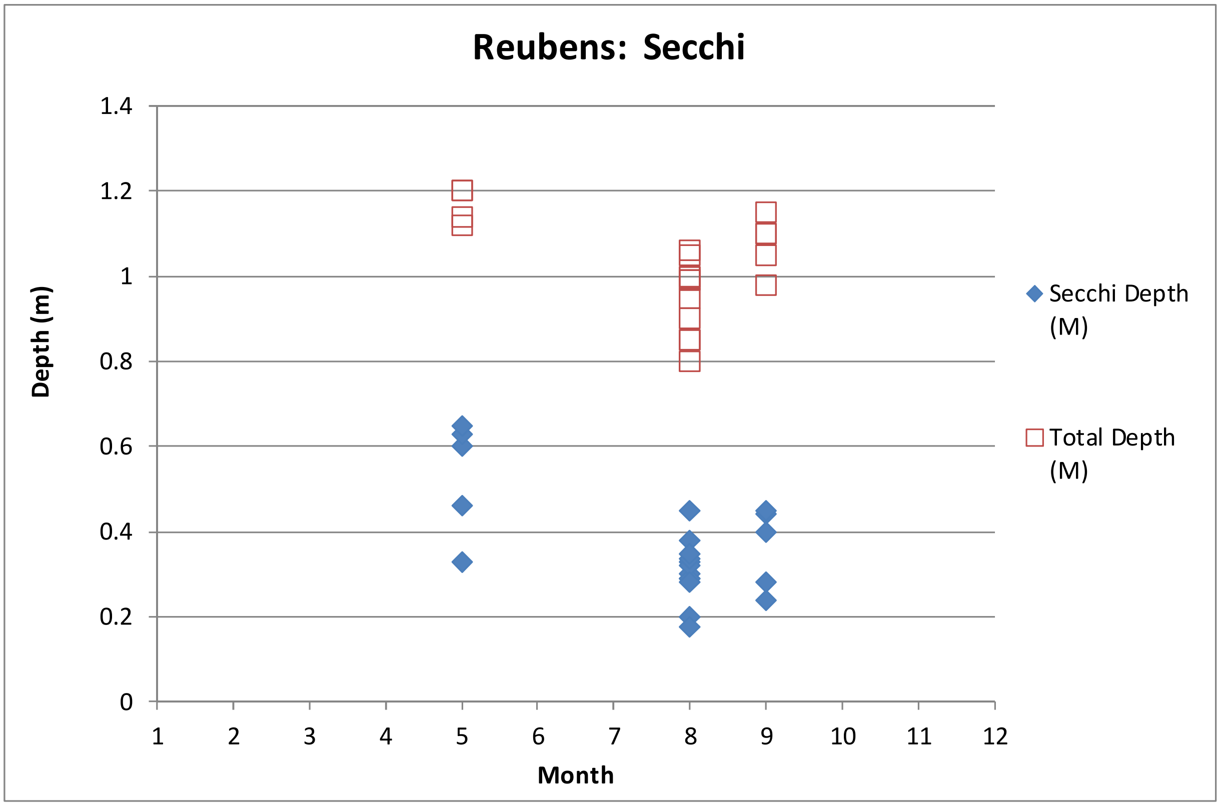


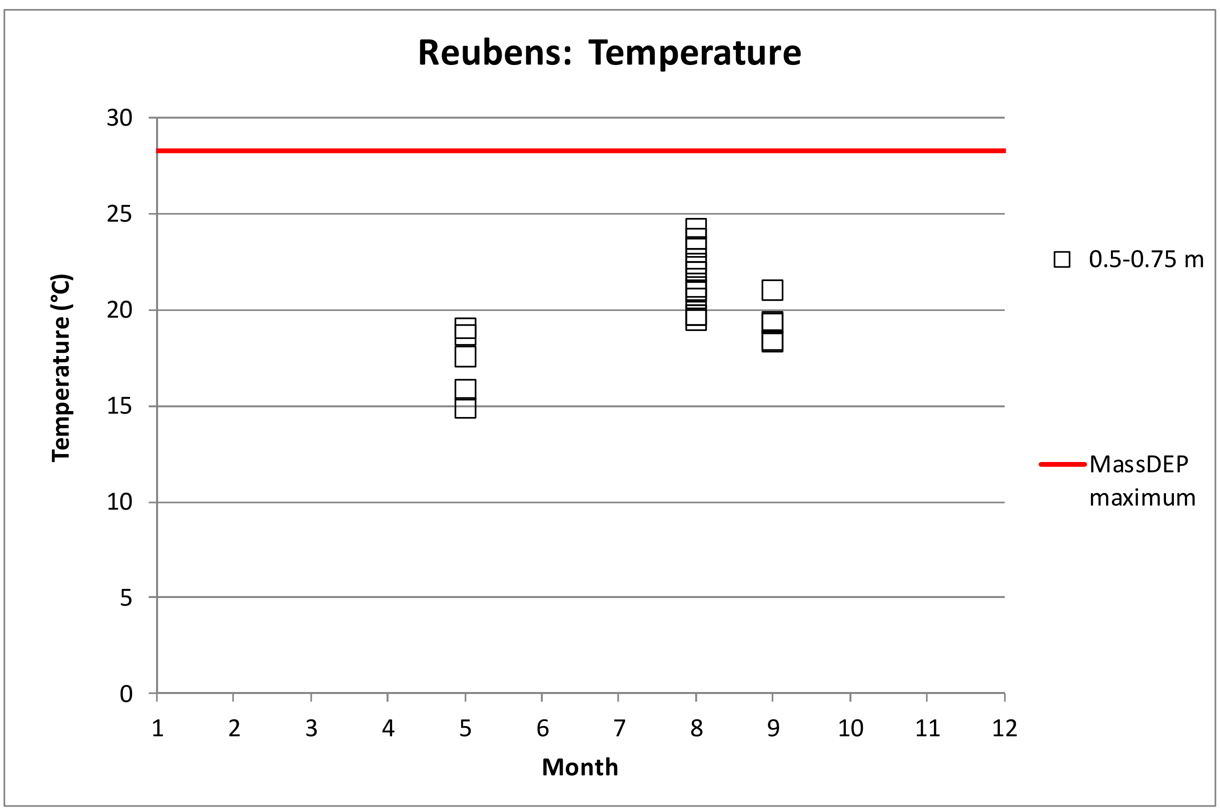
Pilgrim: Chlorophyll
Chlorophyll (µg/L)
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
3 m
Deep
Ecoregion Threshold

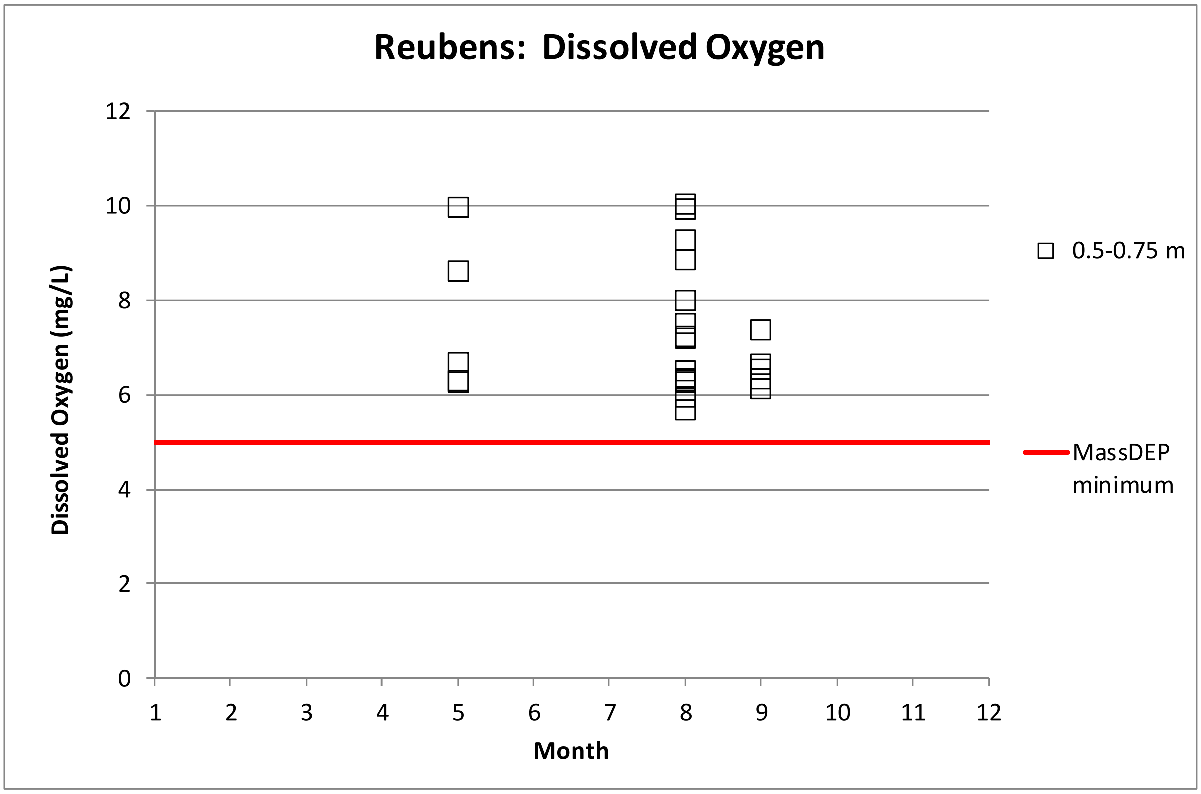


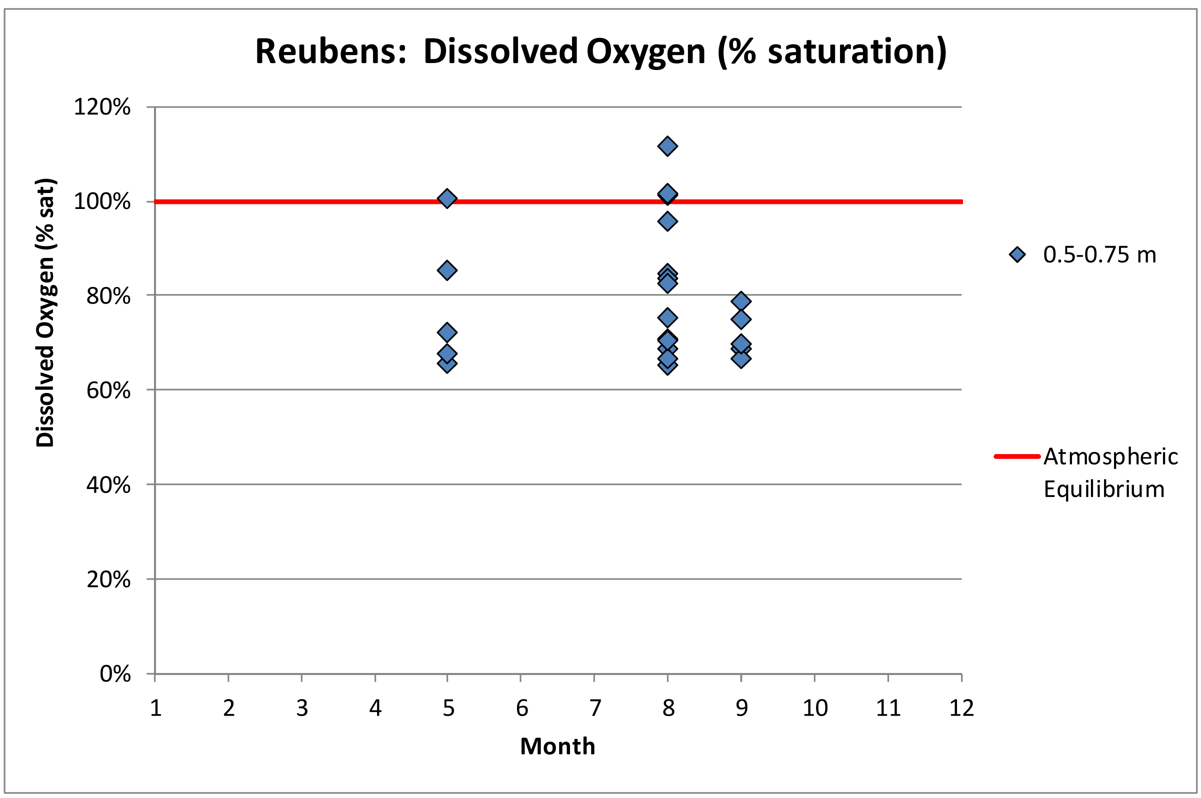
Pilgrim: pH
pH (stnd units)
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
3 m
Deep
MassDEP minimum

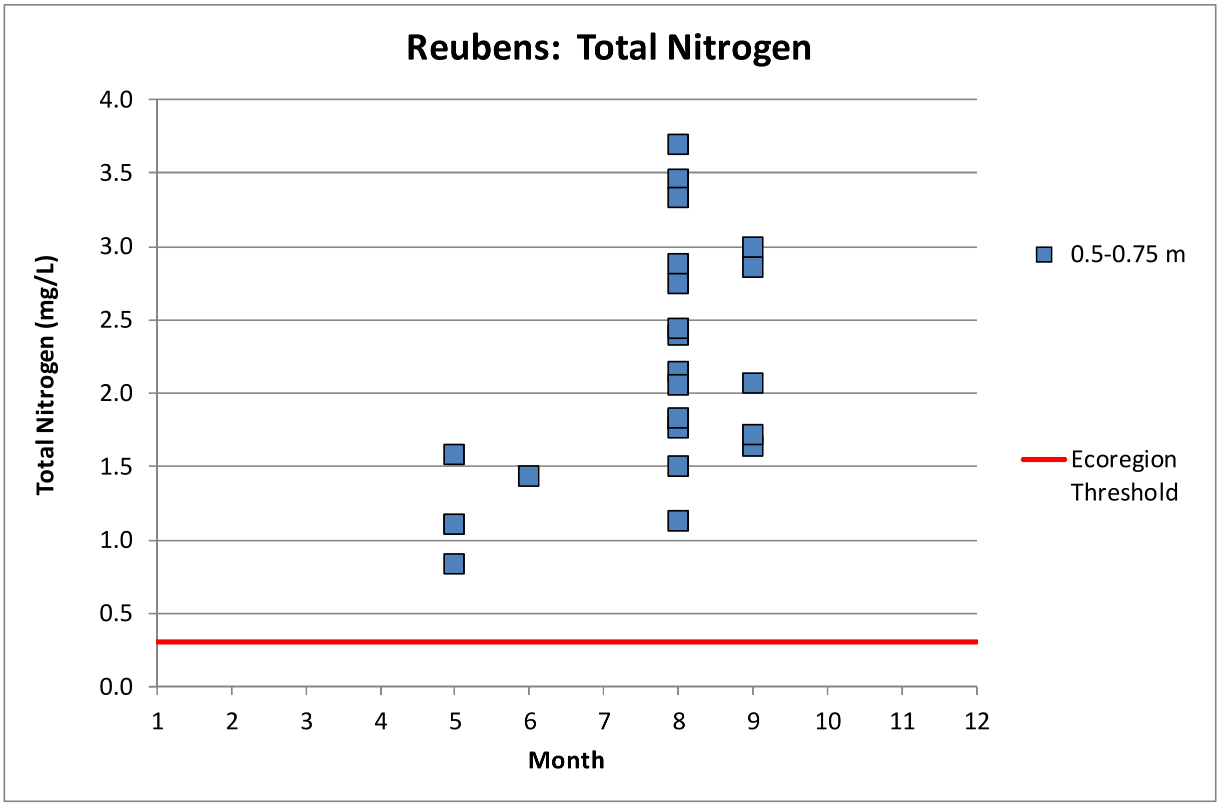
Reubens Pond

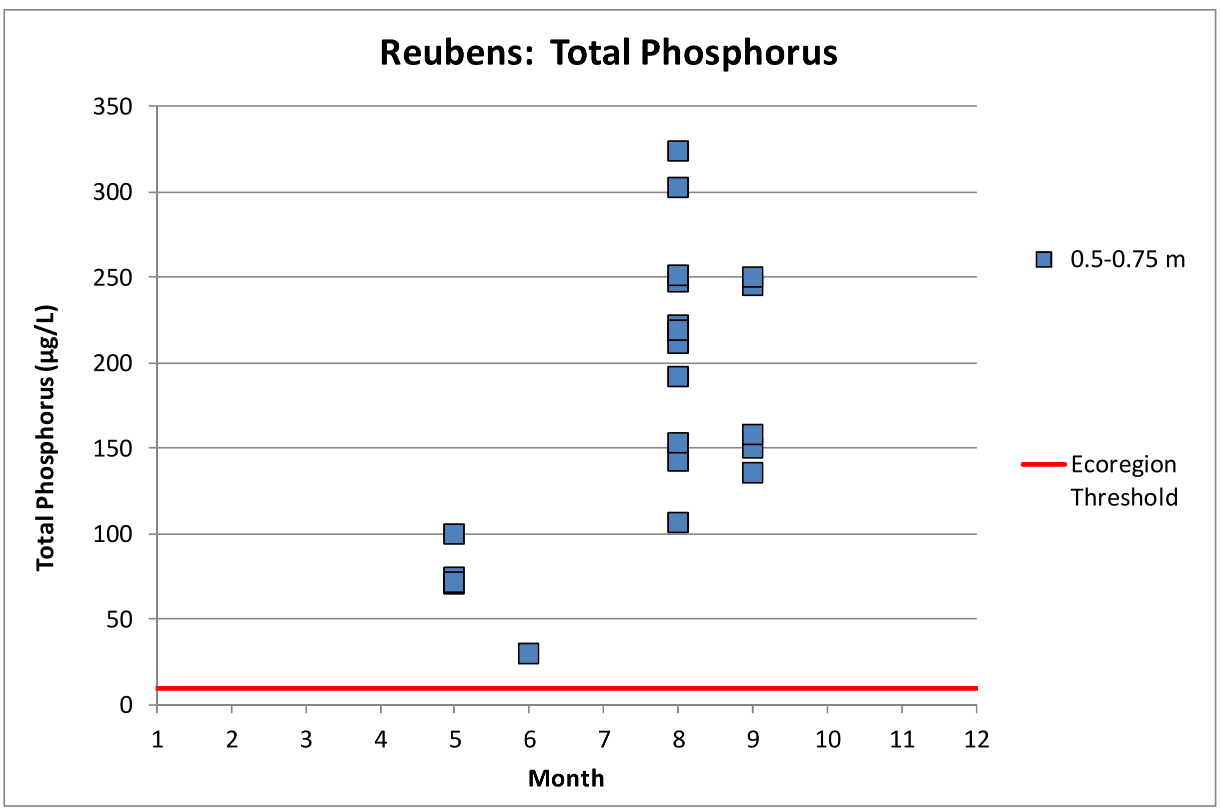

Reubens: Secchi
Depth (m)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Secchi Depth (M)
Total Depth (M)

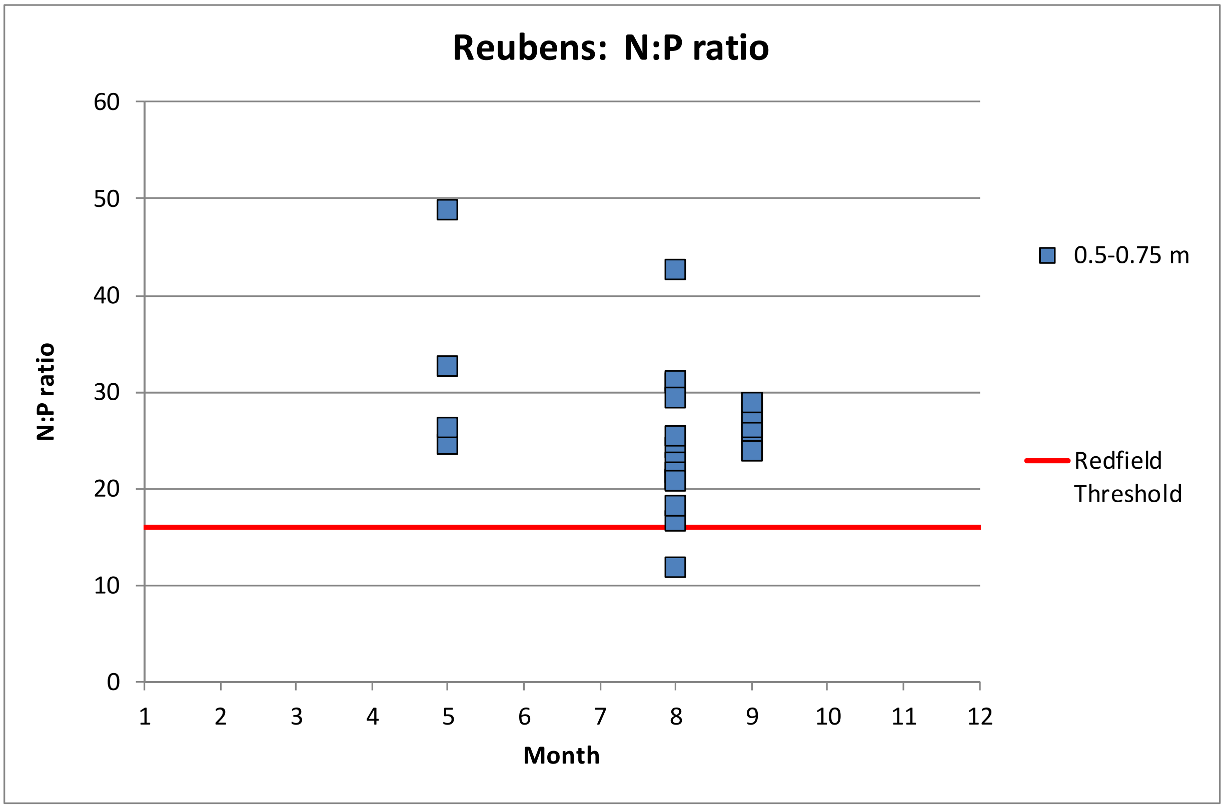

Reubens: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5-0.75 m
MassDEP maximum

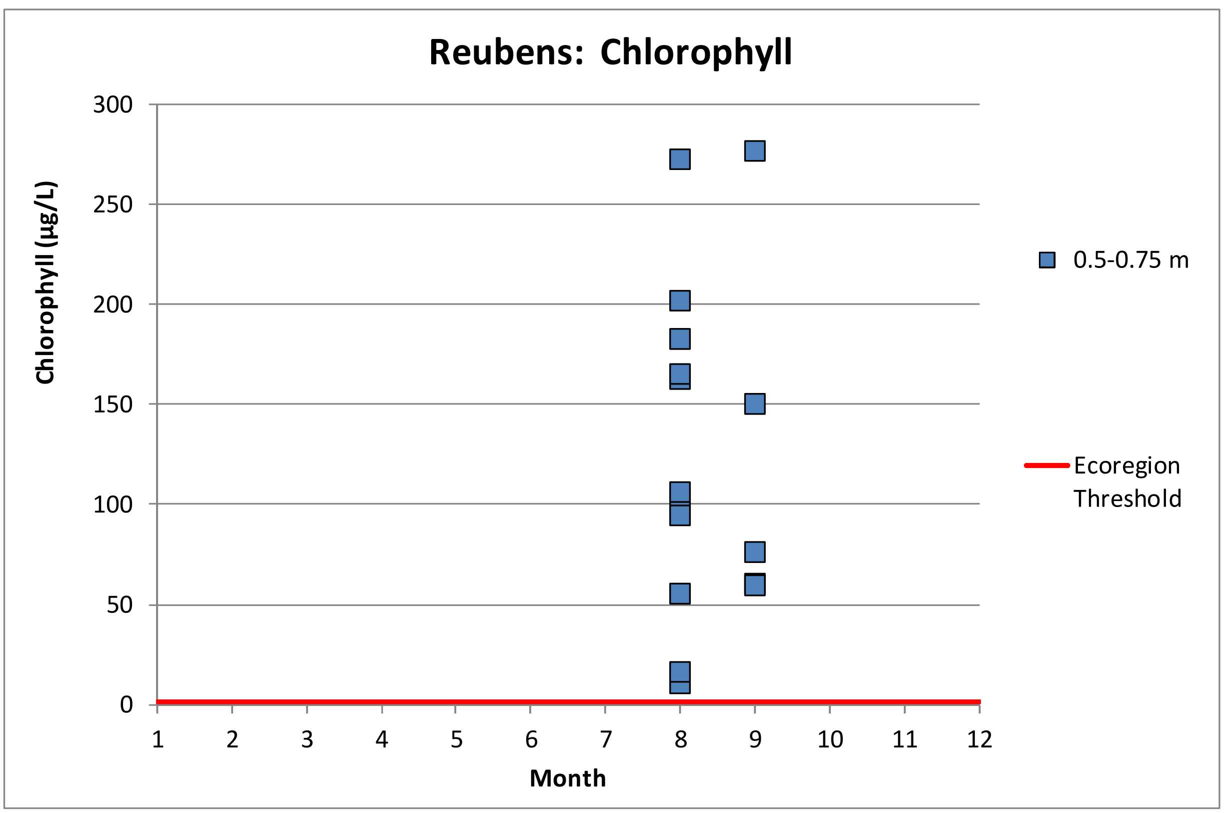

Reubens: Dissolved Oxygen
Dissolved Oxygen (mg/L)
0
2
4
6
8
10
12
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5-0.75 m
MassDEP minimum

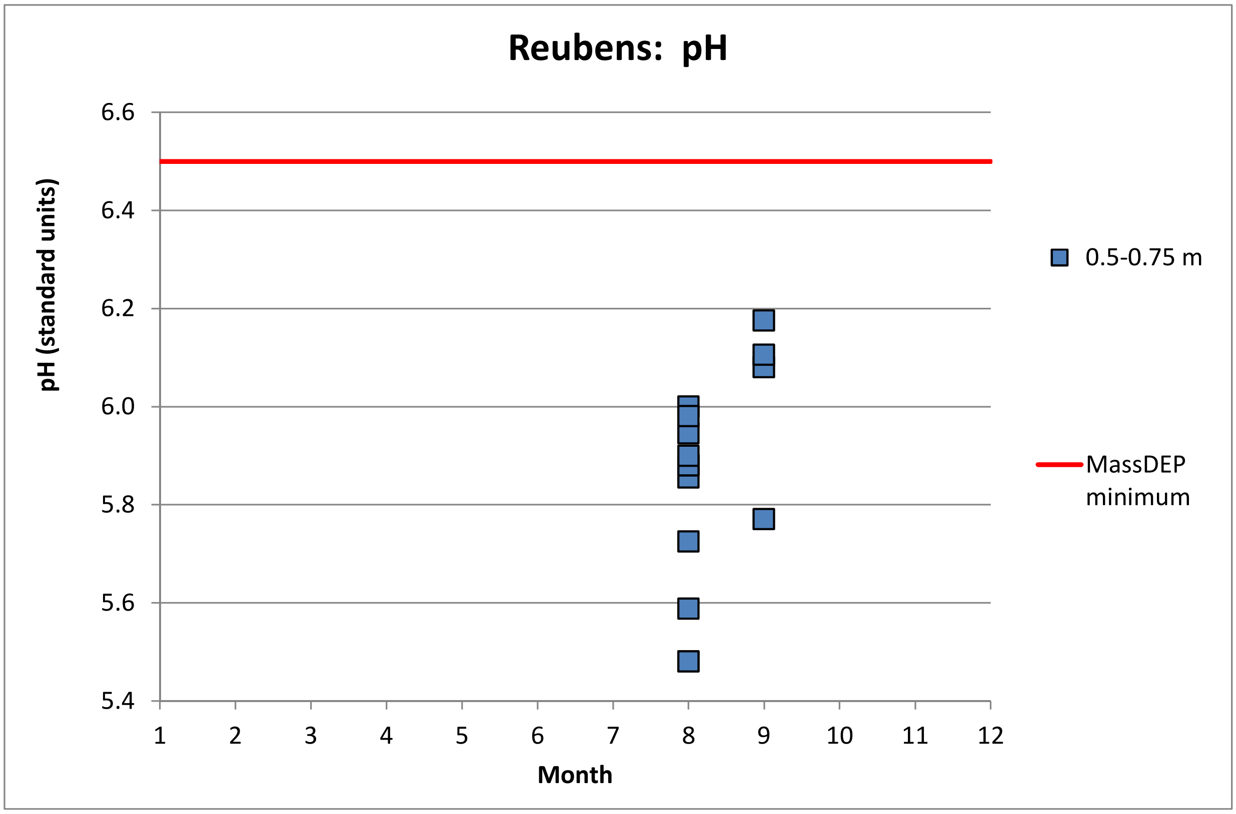

Reubens: Dissolved Oxygen (% saturation)
Dissolved Oxygen (% sat)
0%
20%
40%
60%
80%
100%
120%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5-0.75 m
Atmospheric Equilibrium


Reubens: Total Nitrogen
Total Nitrogen (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5-0.75 m
Ecoregion Threshold

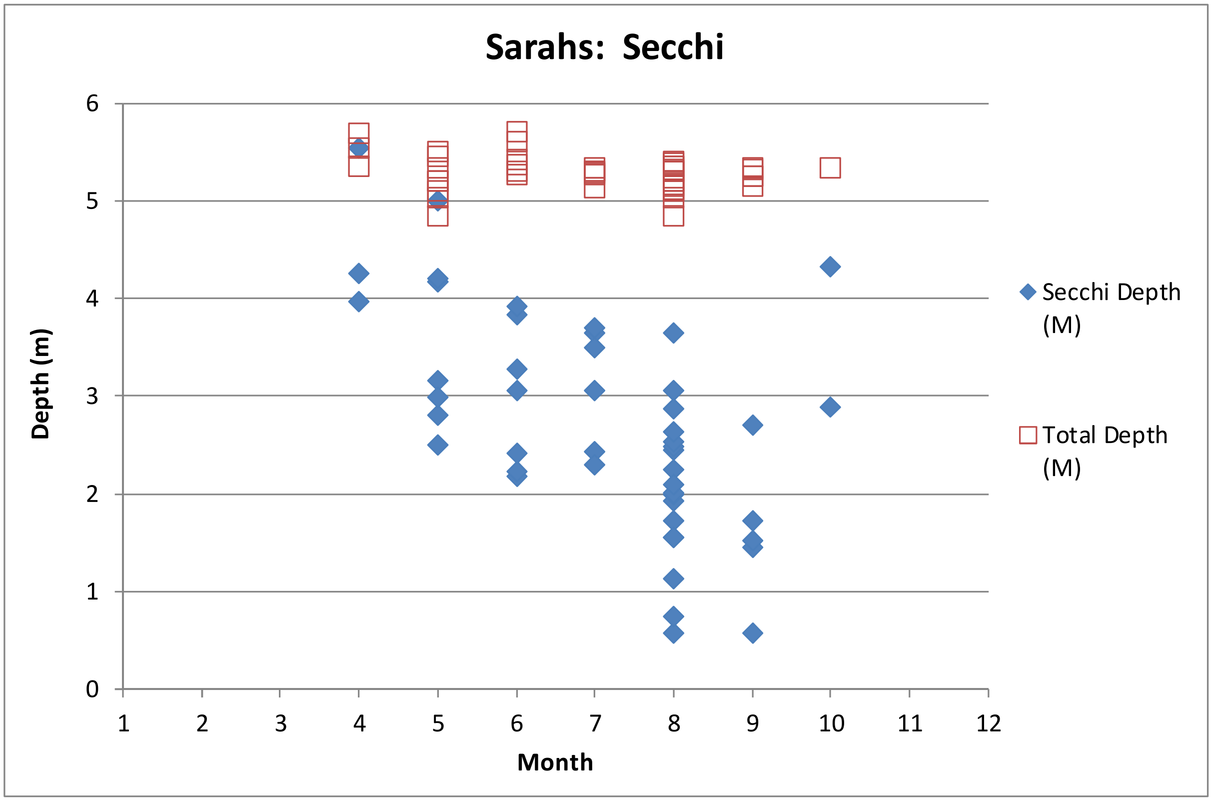

Reubens: Total Phosphorus
Total Phosphorus (µg/L)
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5-0.75 m
Ecoregion Threshold

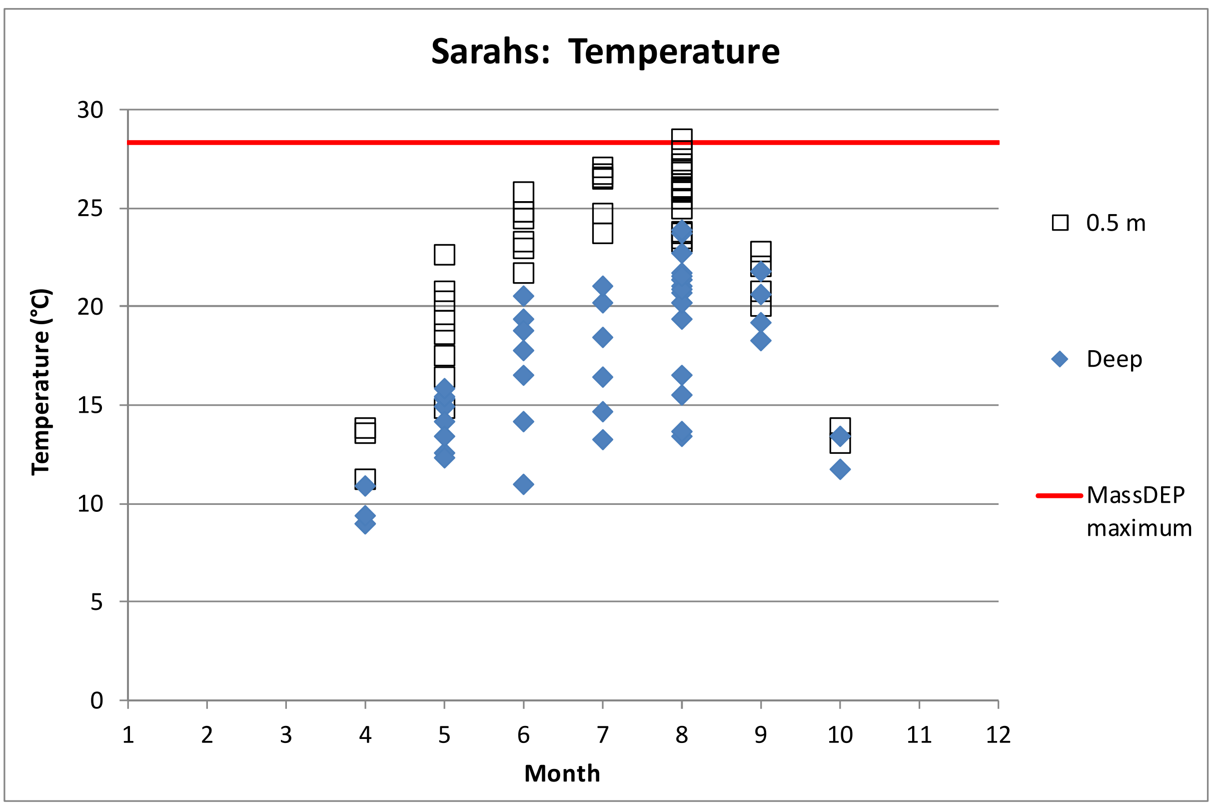

Reubens: N:P ratio
N:P ratio
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5-0.75 m
Redfield Threshold

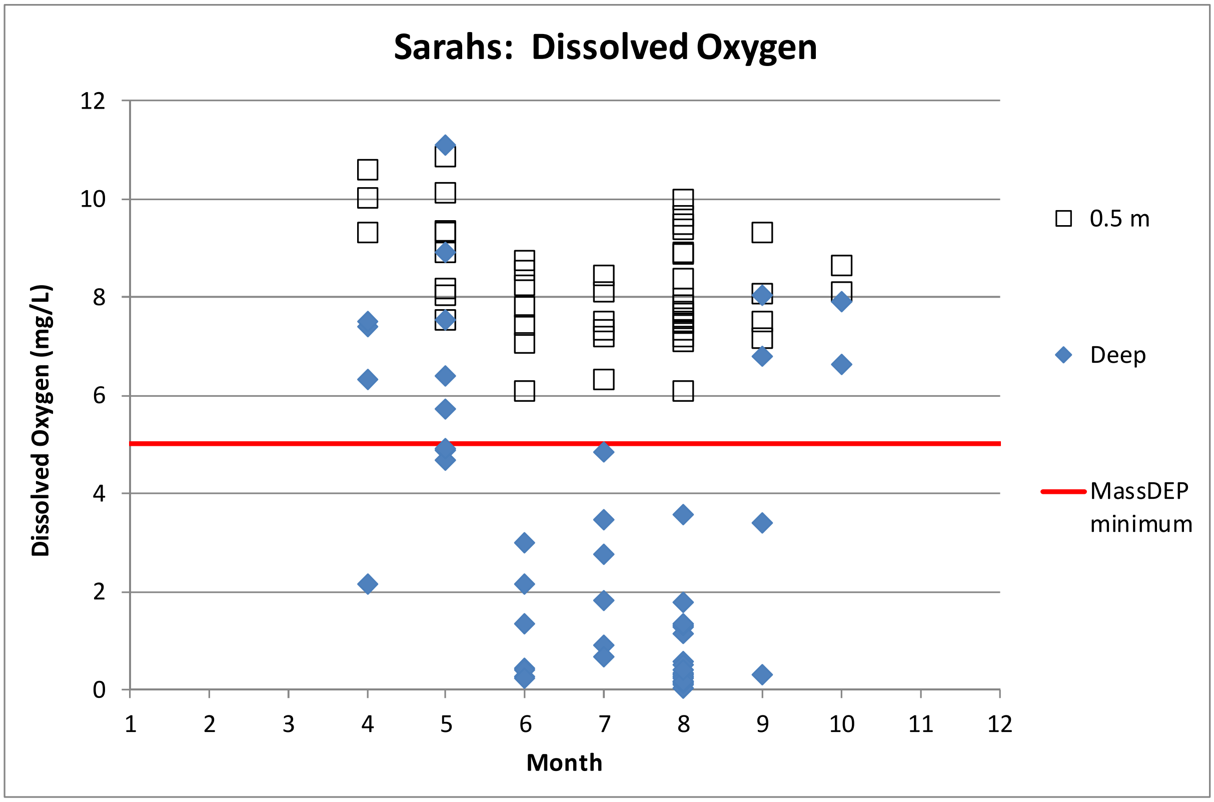

Reubens: Chlorophyll
Chlorophyll (µg/L)
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5-0.75 m
Ecoregion Threshold

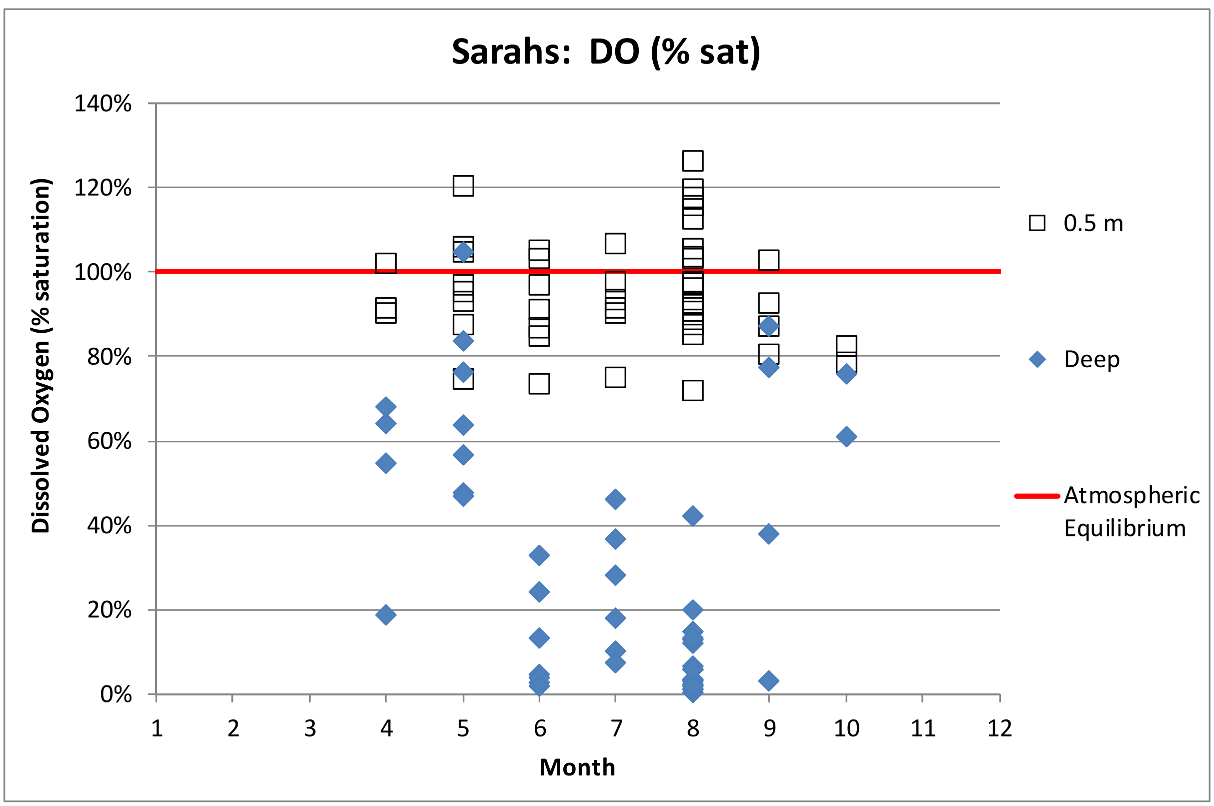

Reubens: pH
pH (standard units)
6.6
6.4
6.2
6.0
5.8
5.6
5.4
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5-0.75 m
MassDEP minimum

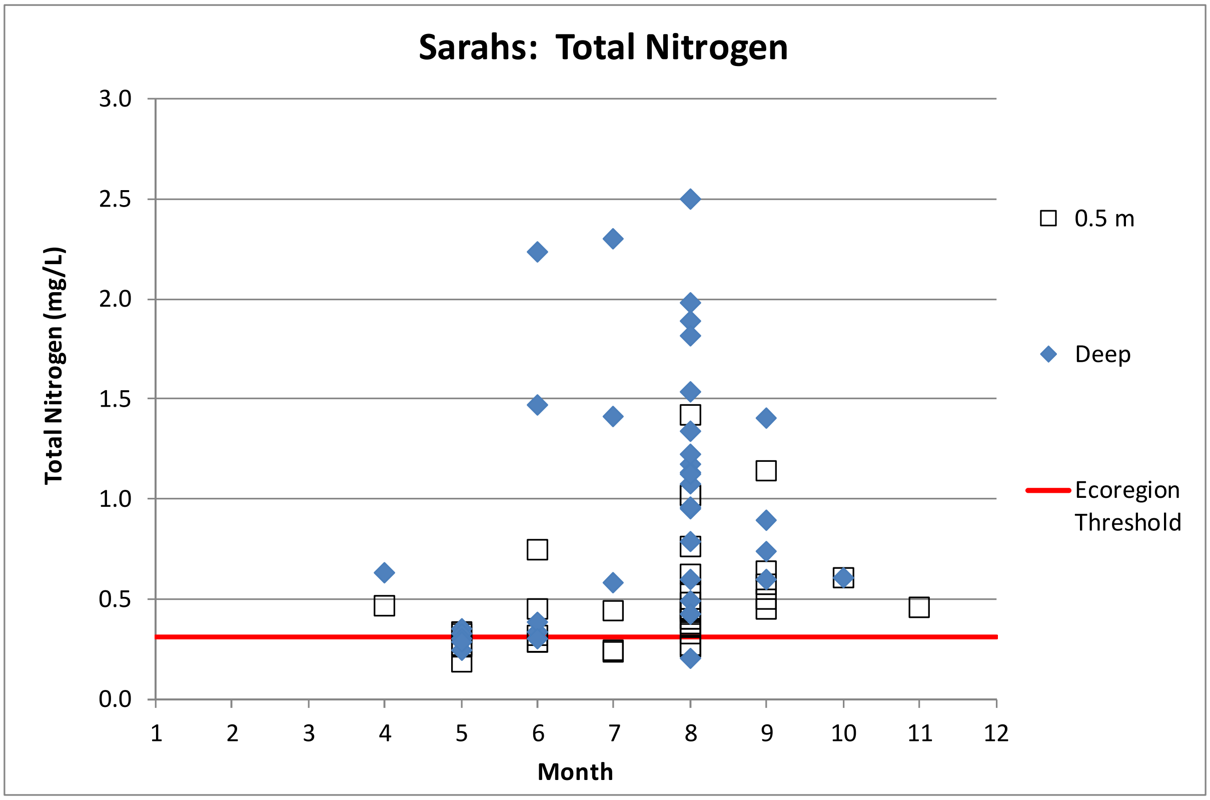
Sarahs Pond


Sarahs: Secchi
Depth (m)
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)

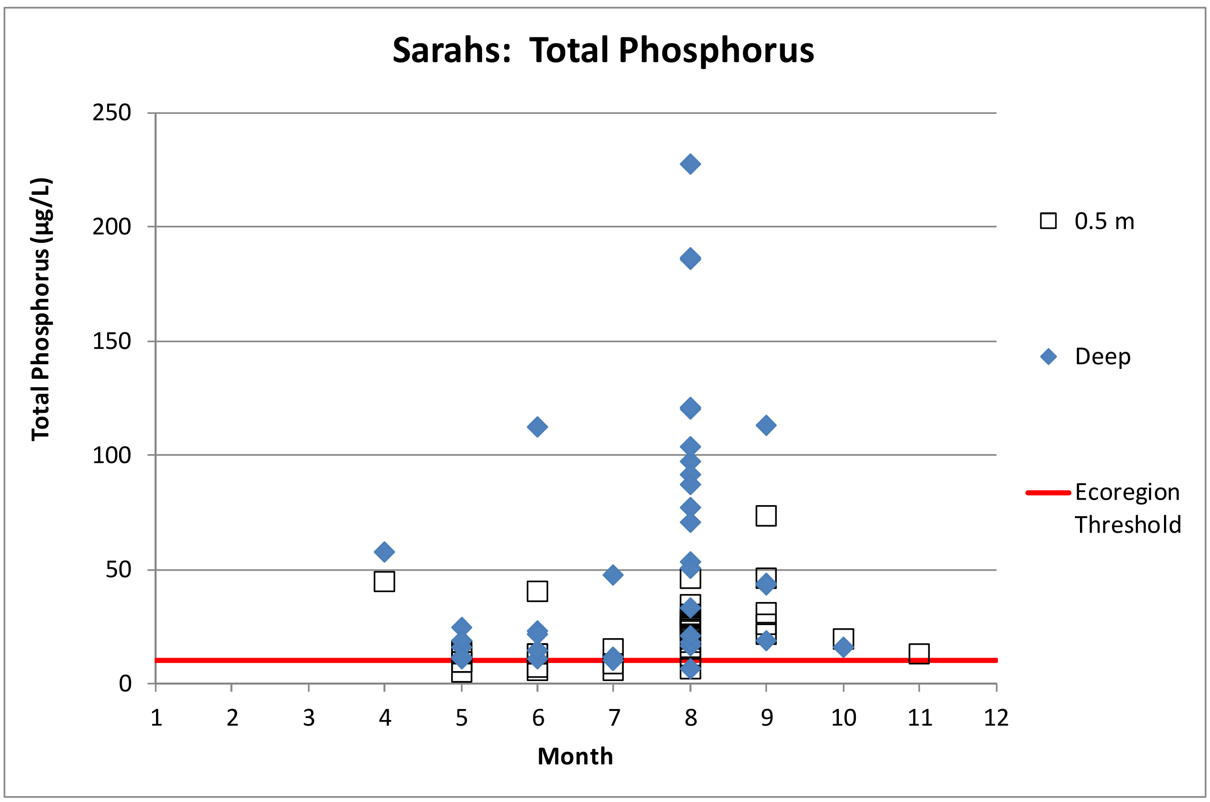

Sarahs: Temperature
Temperature (°C)
0
5
10
15
20
25
30
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP maximum


Sarahs: Dissolved Oxygen
Dissolved Oxygen (mg/L)
Month
0.5 m
Deep
MassDEP minimum
0
2
4
6
8
10
12
1
2
3
4
5
6
7
8
9
10
11
12

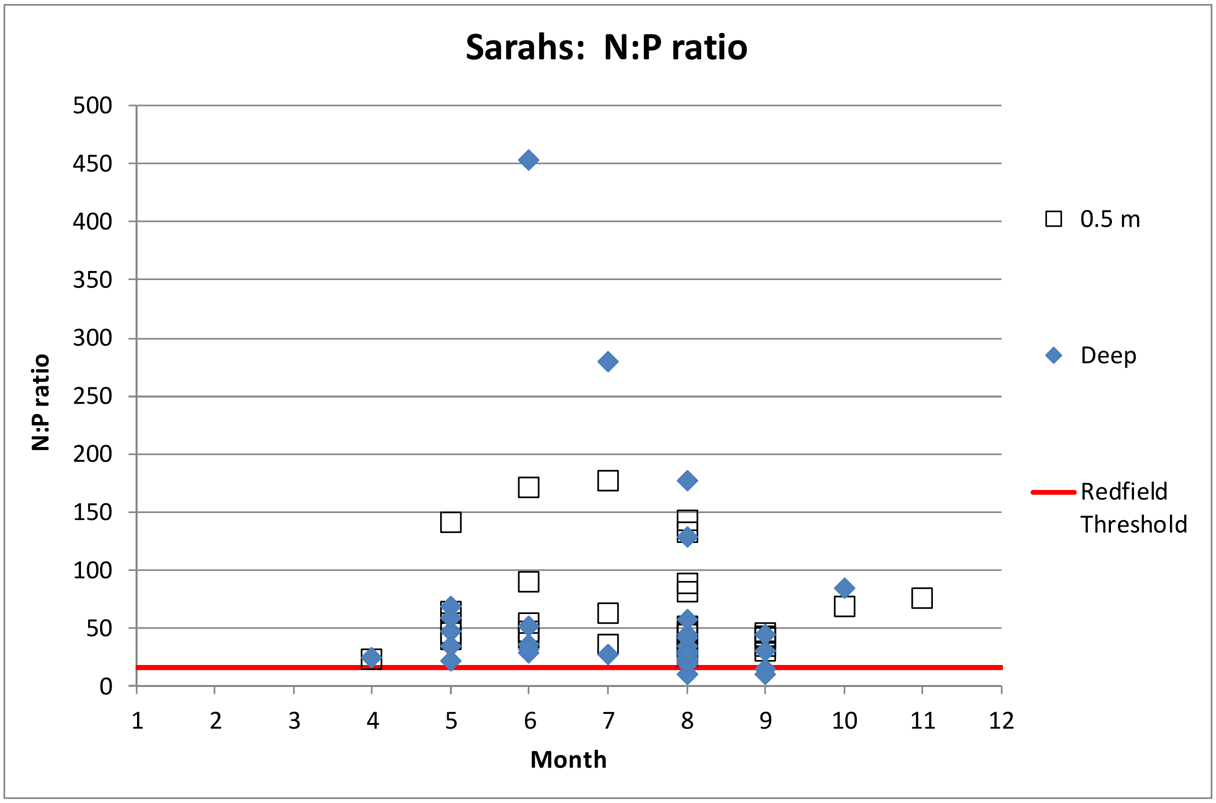

Sarahs: DO (% sat)
Dissolved Oxygen (% saturation)
Month
0.5 m
Deep
Atmospheric Equilibrium
0%
20%
40%
60%
80%
100%
120%
140%
1
2
3
4
5
6
7
8
9
10
11
12

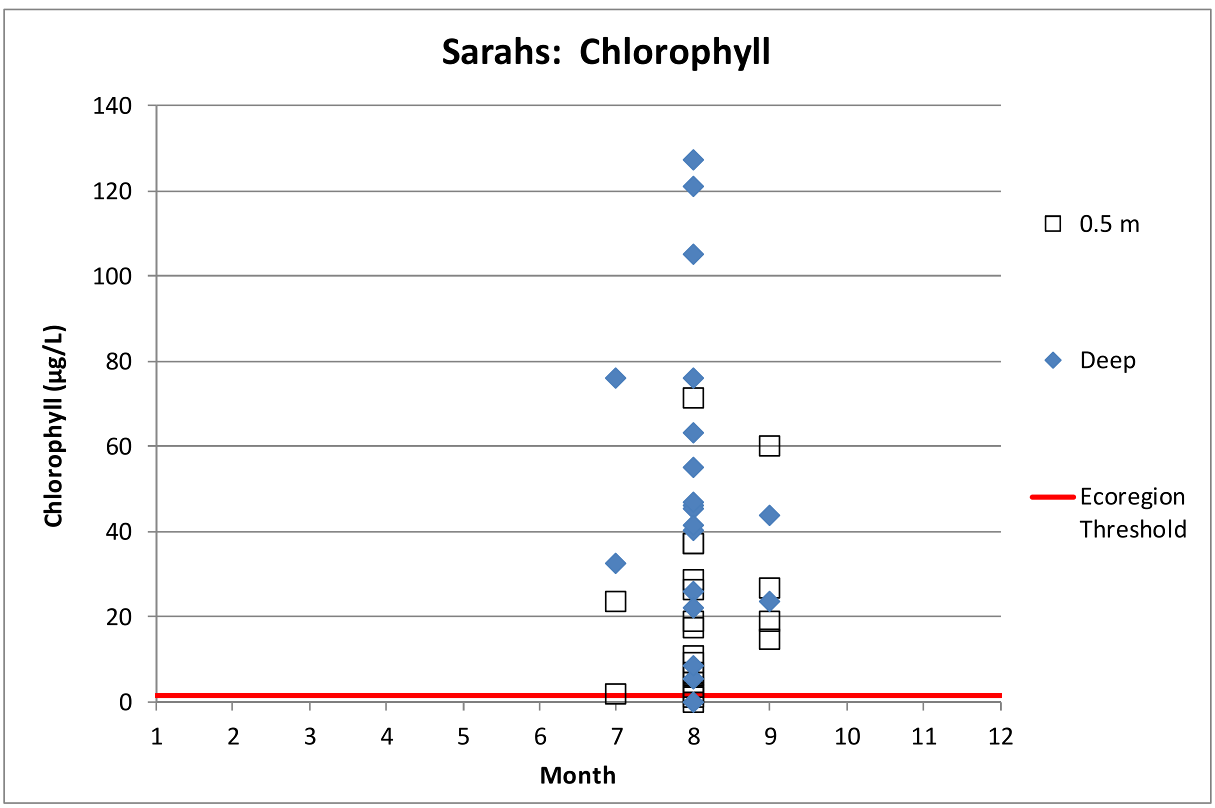


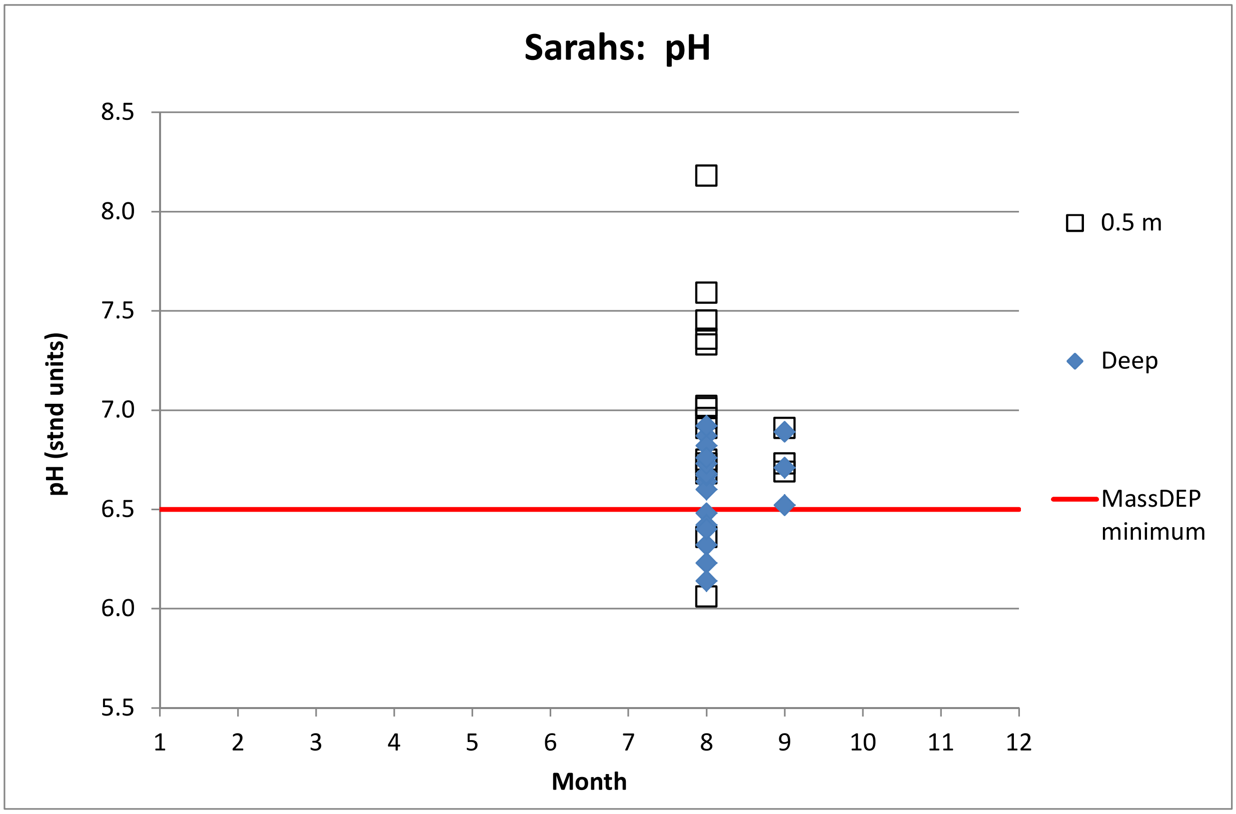
Sarahs: Total Nitrogen
Total Nitrogen (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold



Sarahs: Total Phosphorus
Total Phosphorus (µg/L)
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

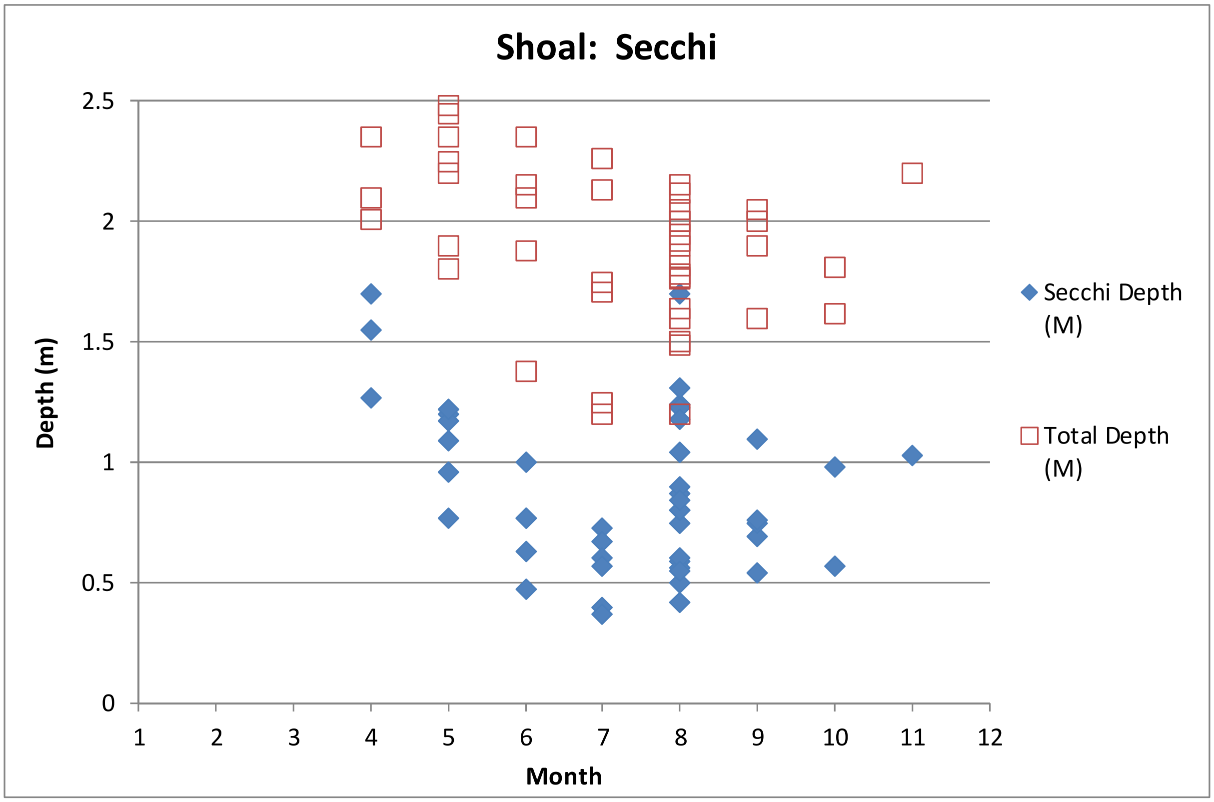

Sarahs: N:P ratio
N:P ratio
500
450
400
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Redfield Threshold

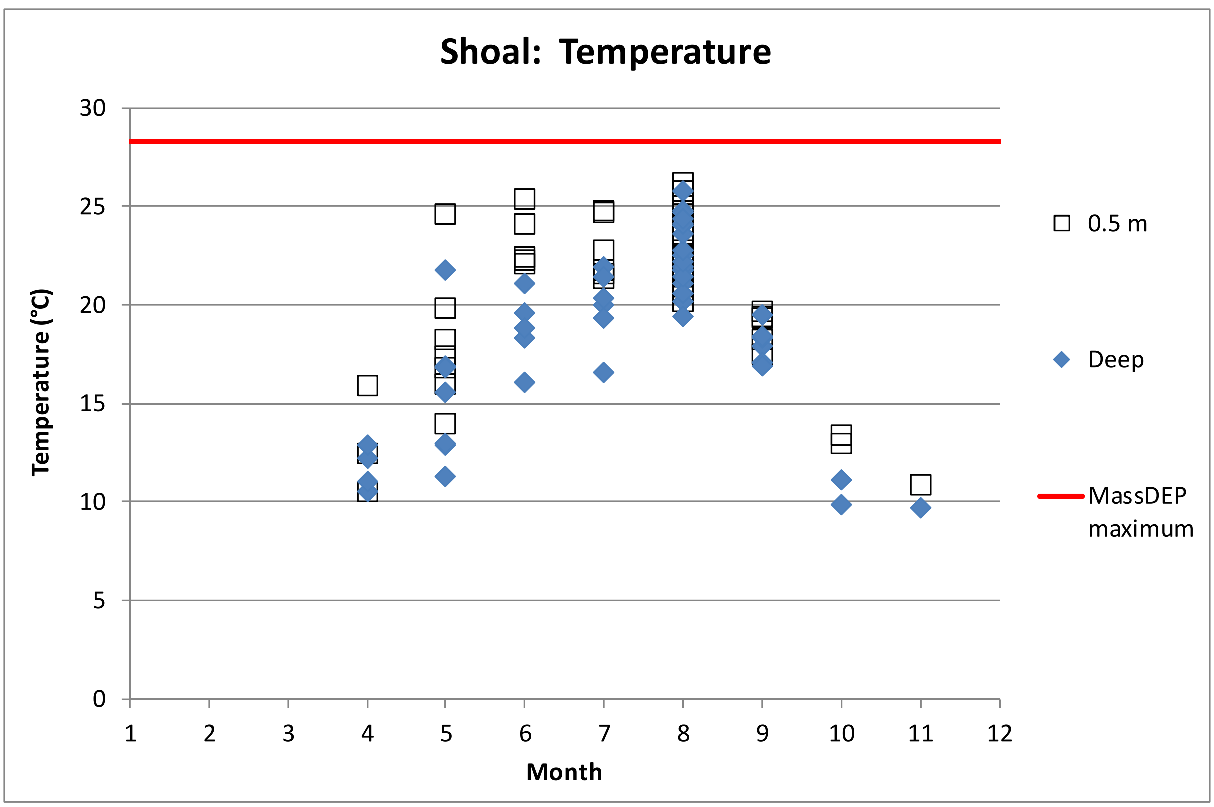

Sarahs: Chlorophyll
Chlorophyll (µg/L)
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Ecoregion Threshold

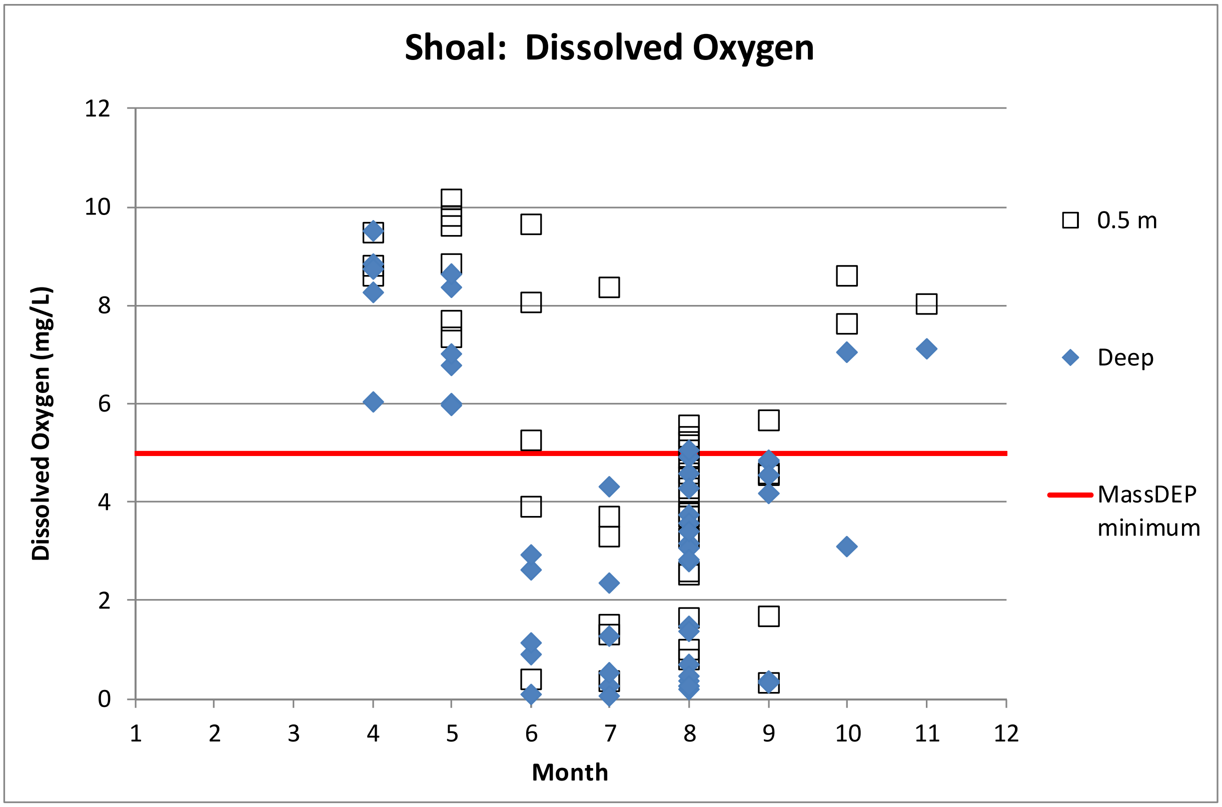


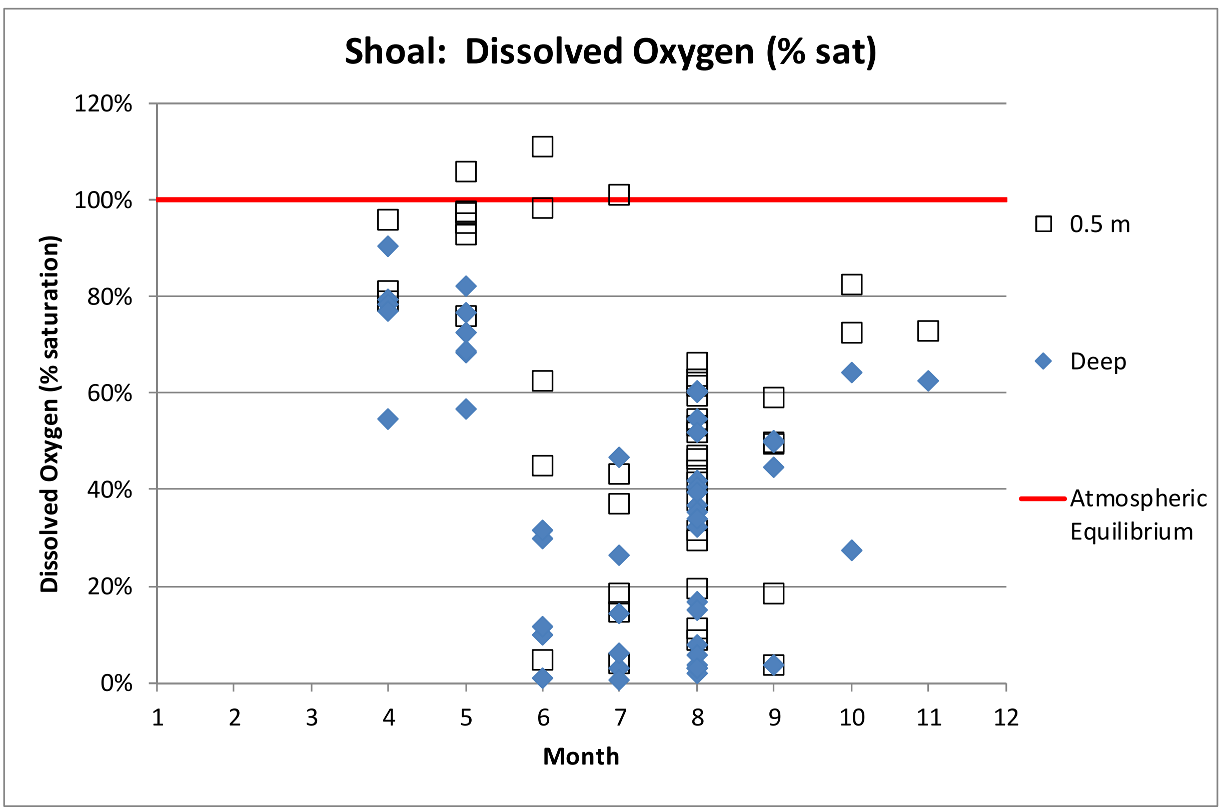
Sarahs: pH
8.5
8.0
7.5
7.0
6.5
6.0
5.5
pH (stnd units)
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

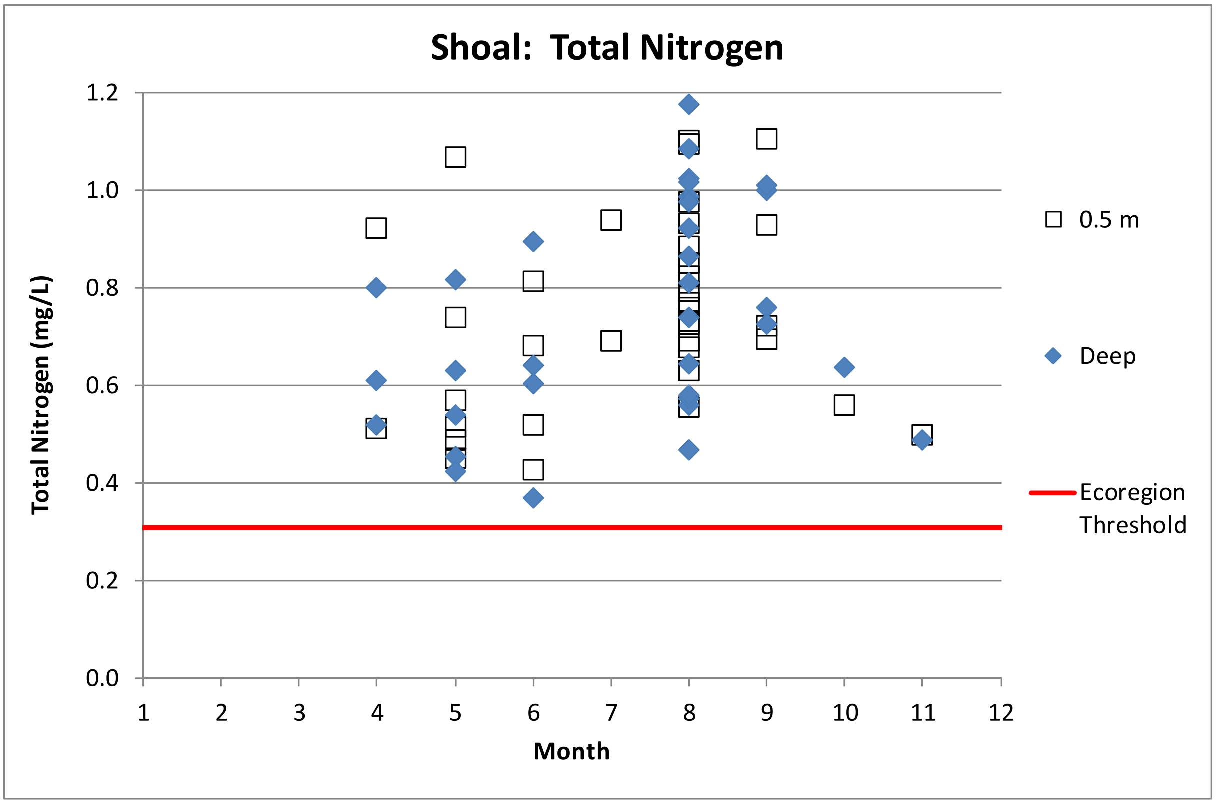
Shoal Pond

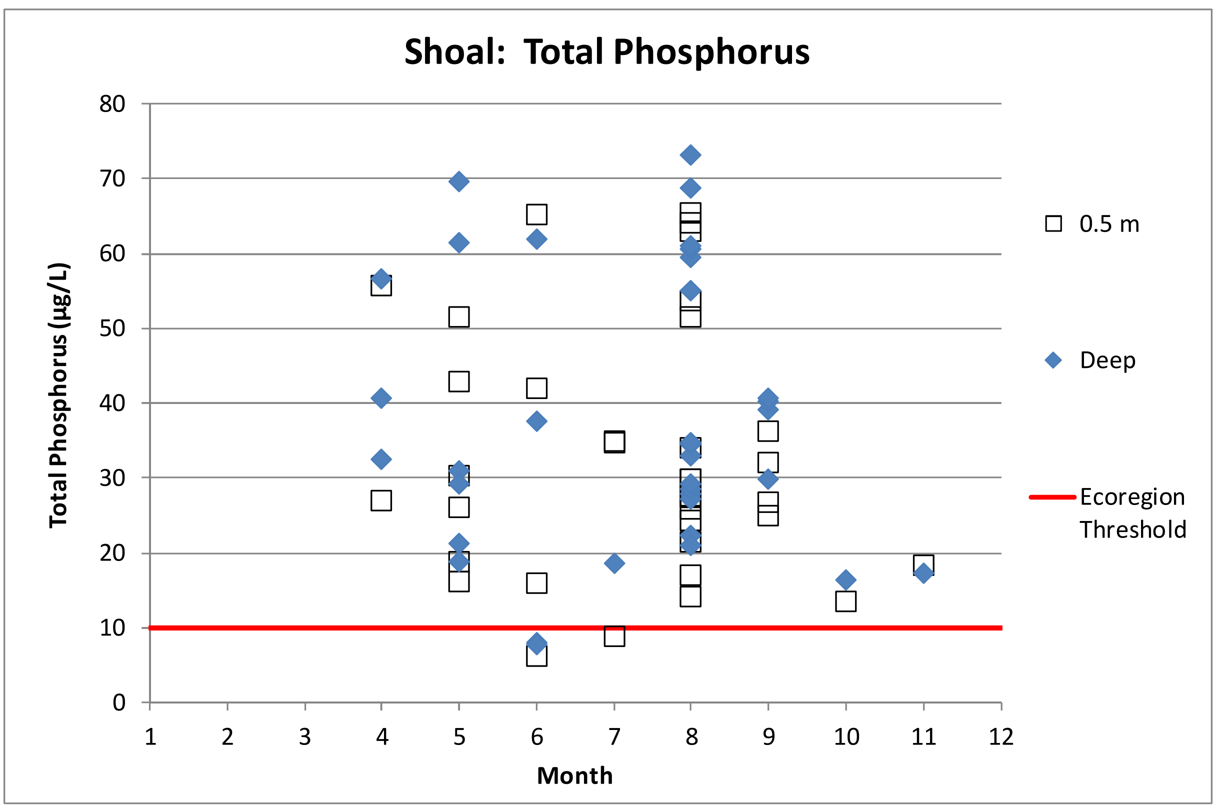

Shoal: Secchi
Depth (m)
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)

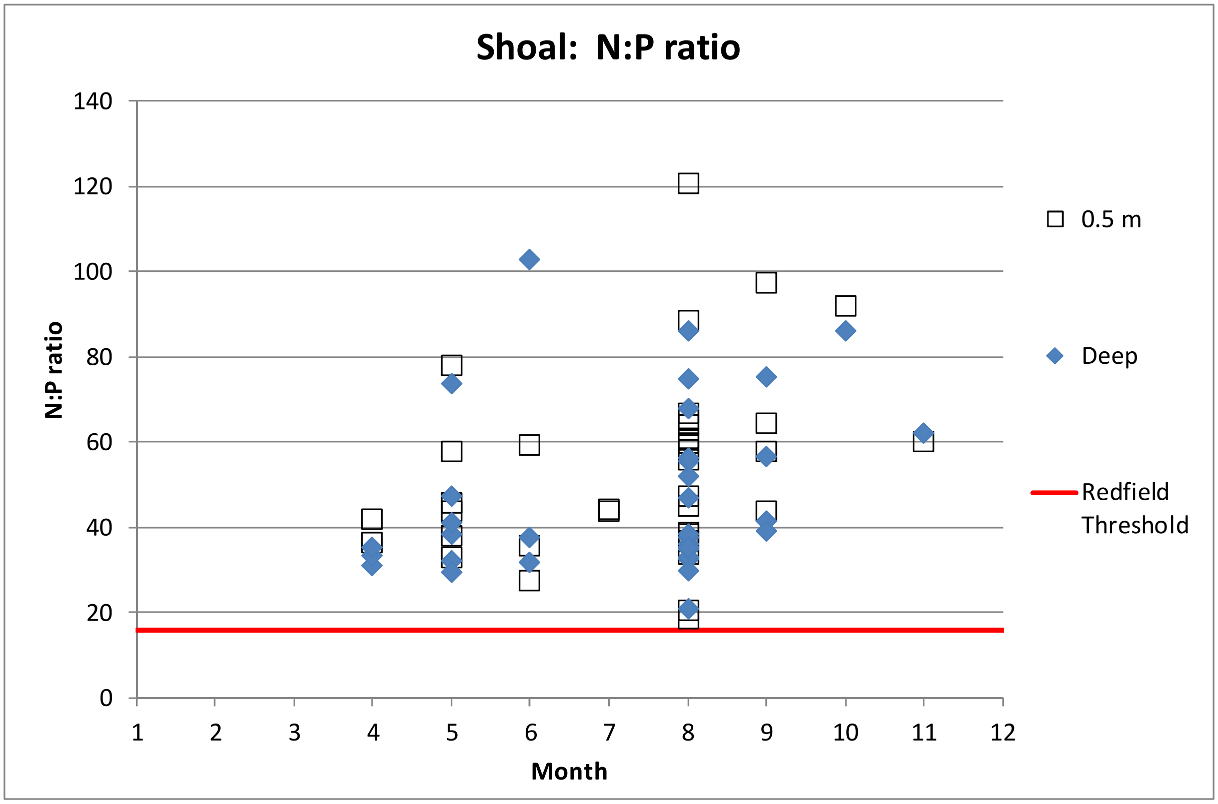

Shoal: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP maximum

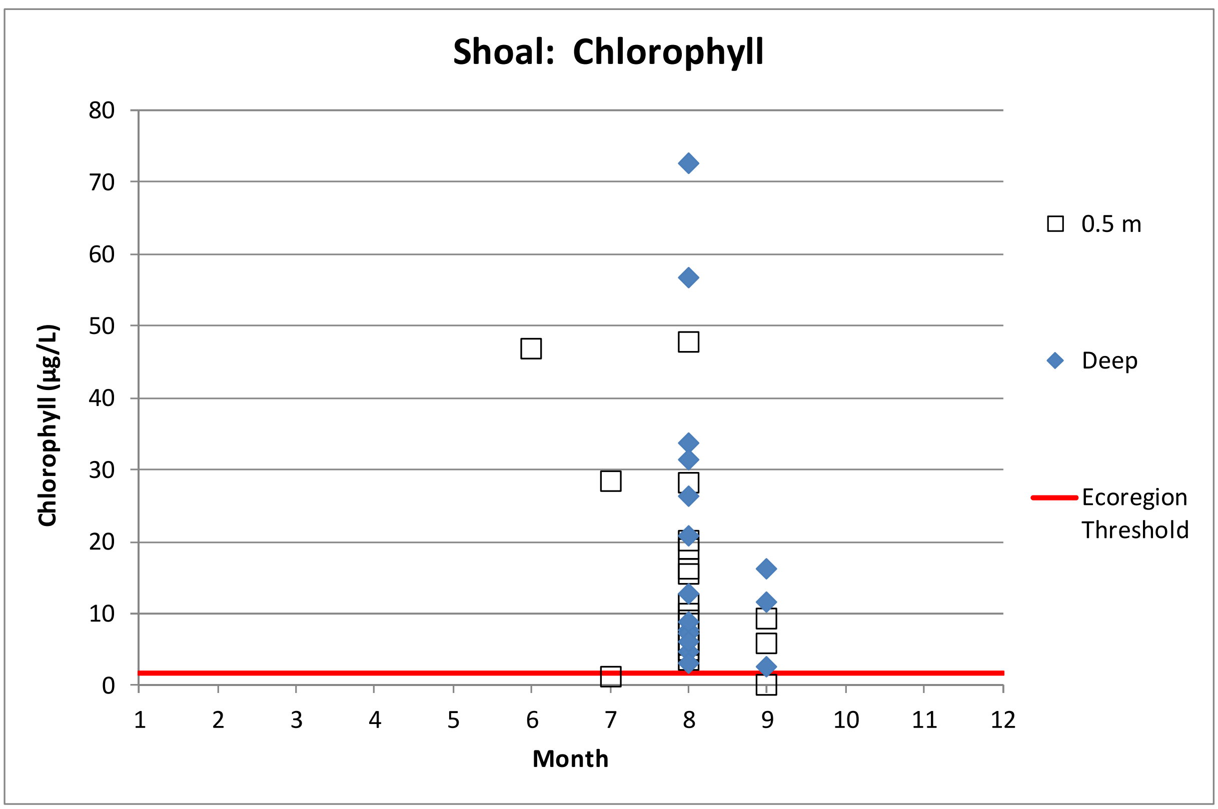

Shoal: Dissolved Oxygen
Dissolved Oxygen (mg/L)
0
2
4
6
8
10
12
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

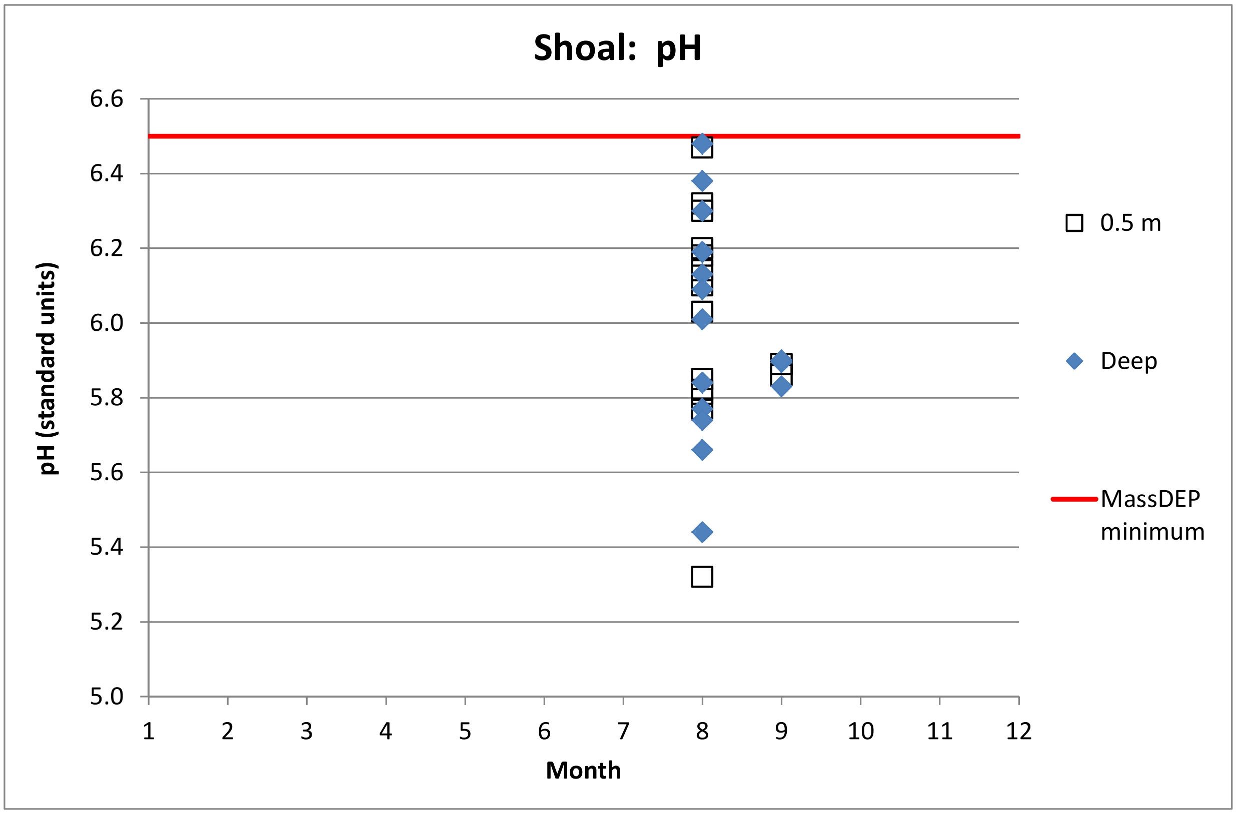

Shoal: Dissolved Oxygen (% sat)
Dissolved Oxygen (% saturation)
0%
20%
40%
60%
80%
100%
120%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium


Shoal: Total Nitrogen
Total Nitrogen (mg/L)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold


Shoal: Total Phosphorus
Total Phosphorus (µg/L)
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

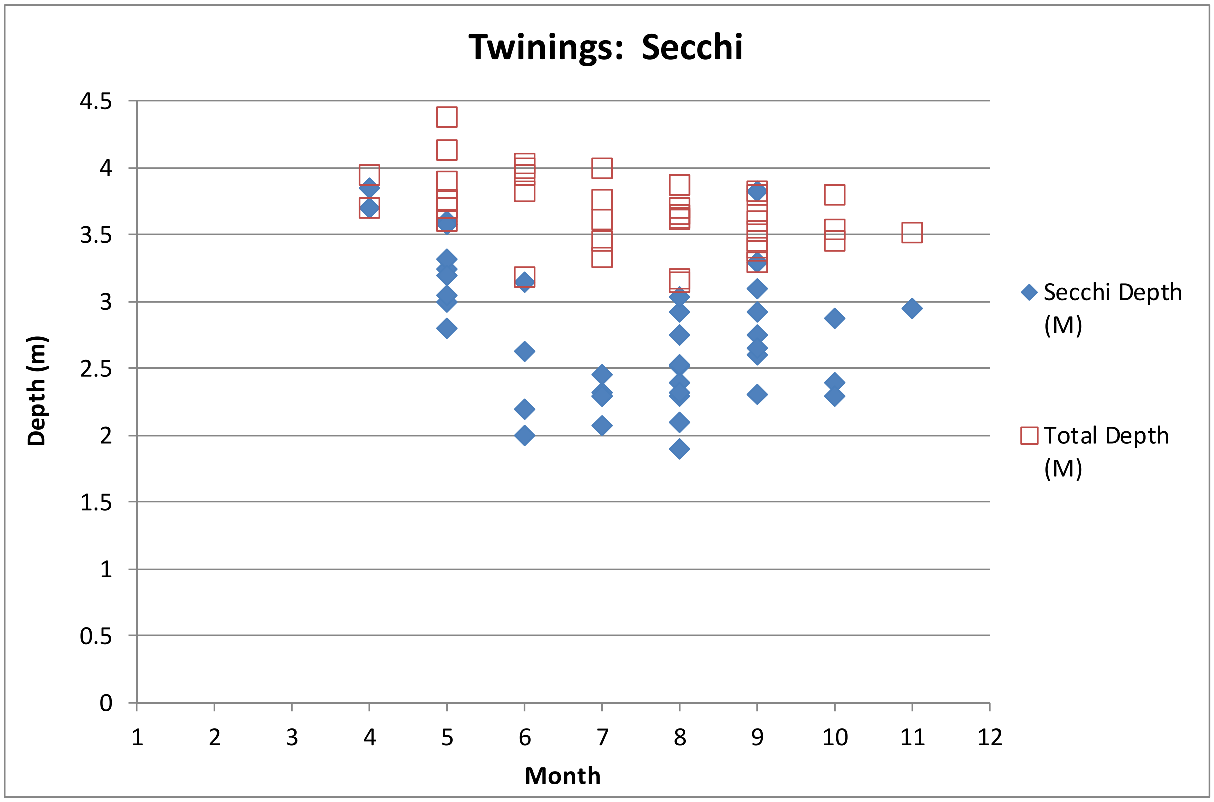

Shoal: N:P ratio
N:P ratio
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield Threshold


Shoal: Chlorophyll
Chlorophyll (µg/L)
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

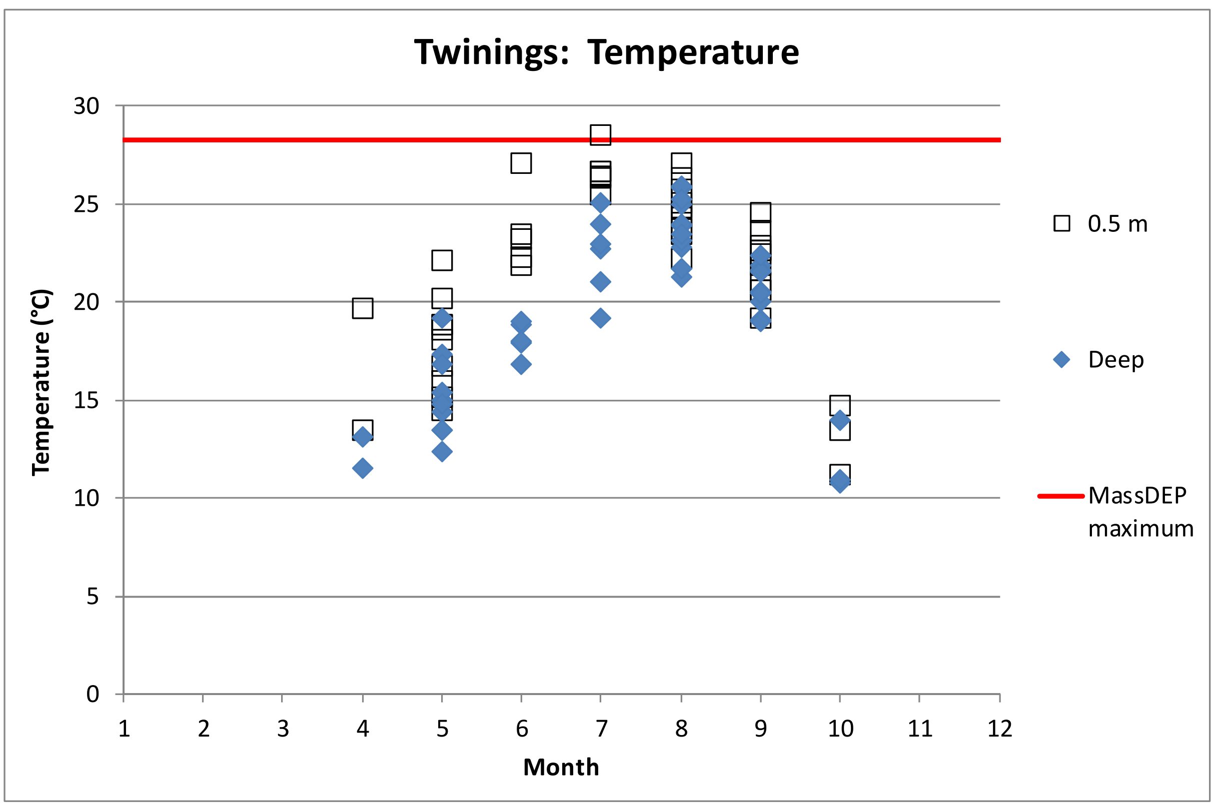


Shoal: pH
pH (standard units)
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
5.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

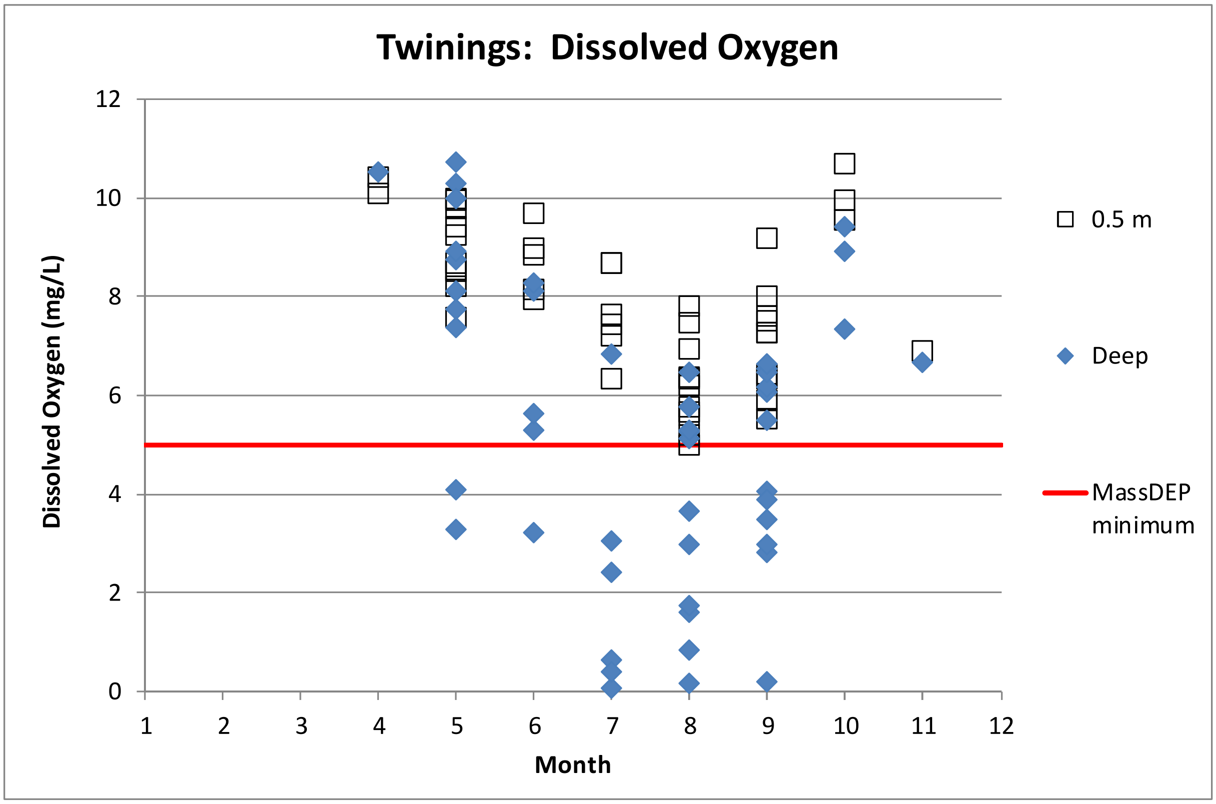
Twinings Pond



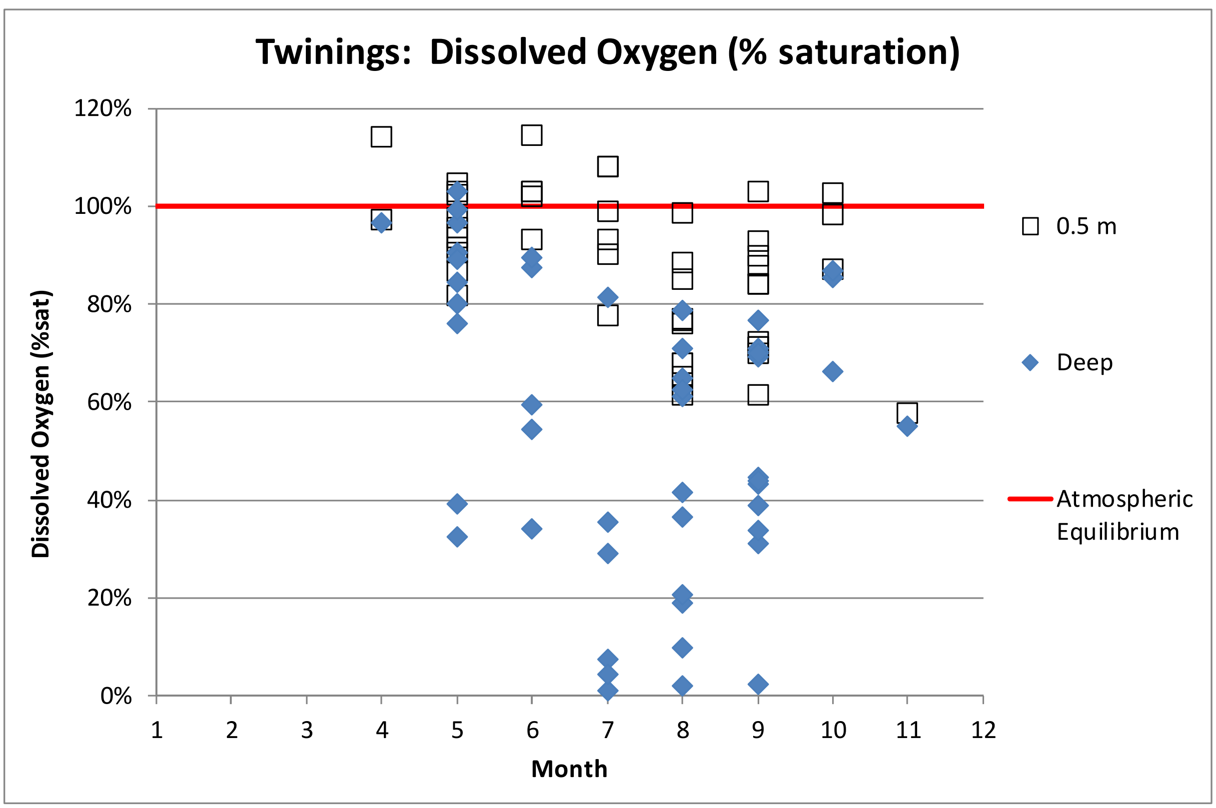
Twinings: Secchi
Depth (m)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)



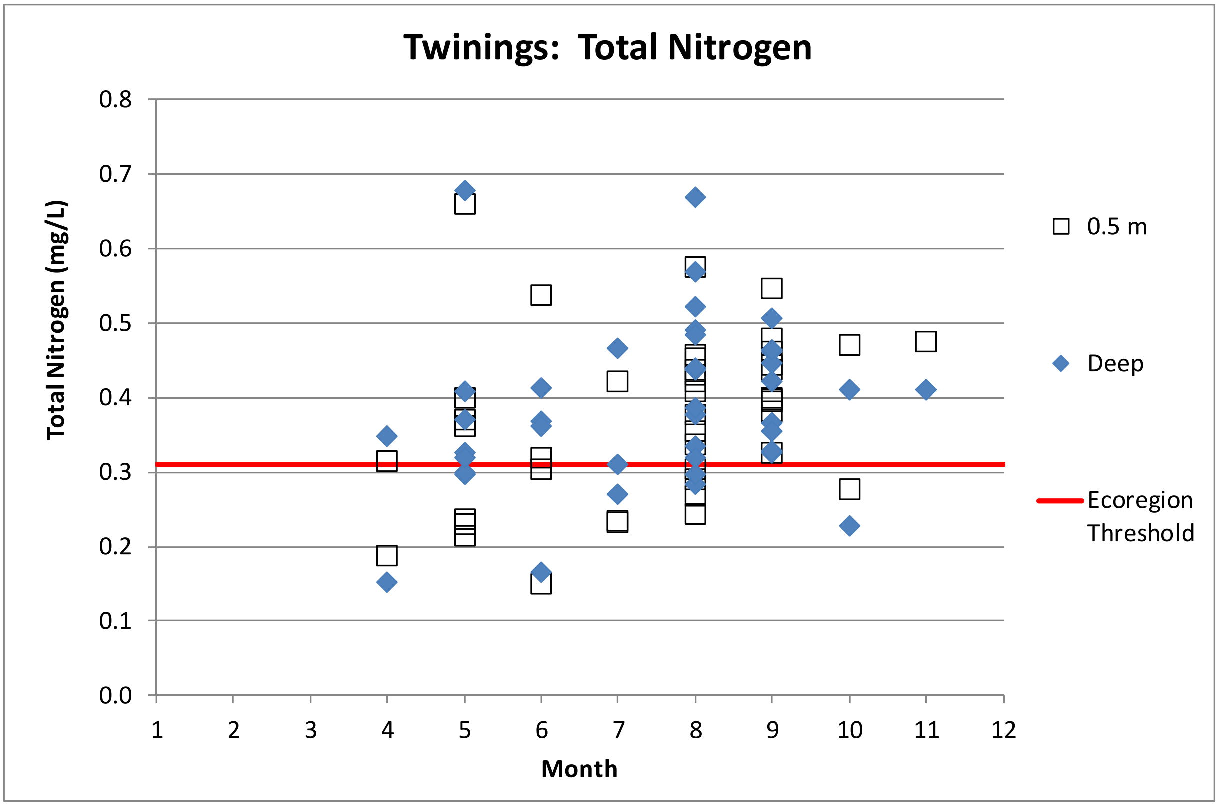
Twinings: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP maximum



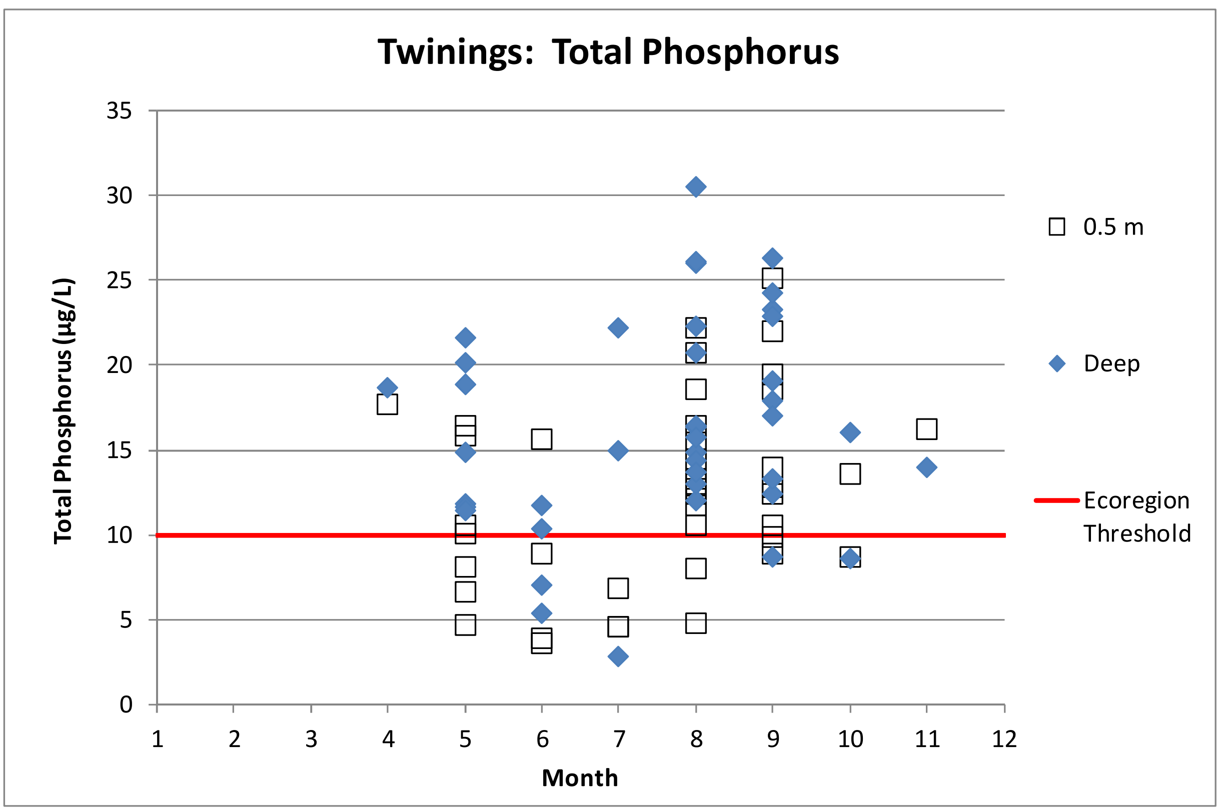
Twinings: Dissolved Oxygen
Dissolved Oxygen (mg/L)
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum



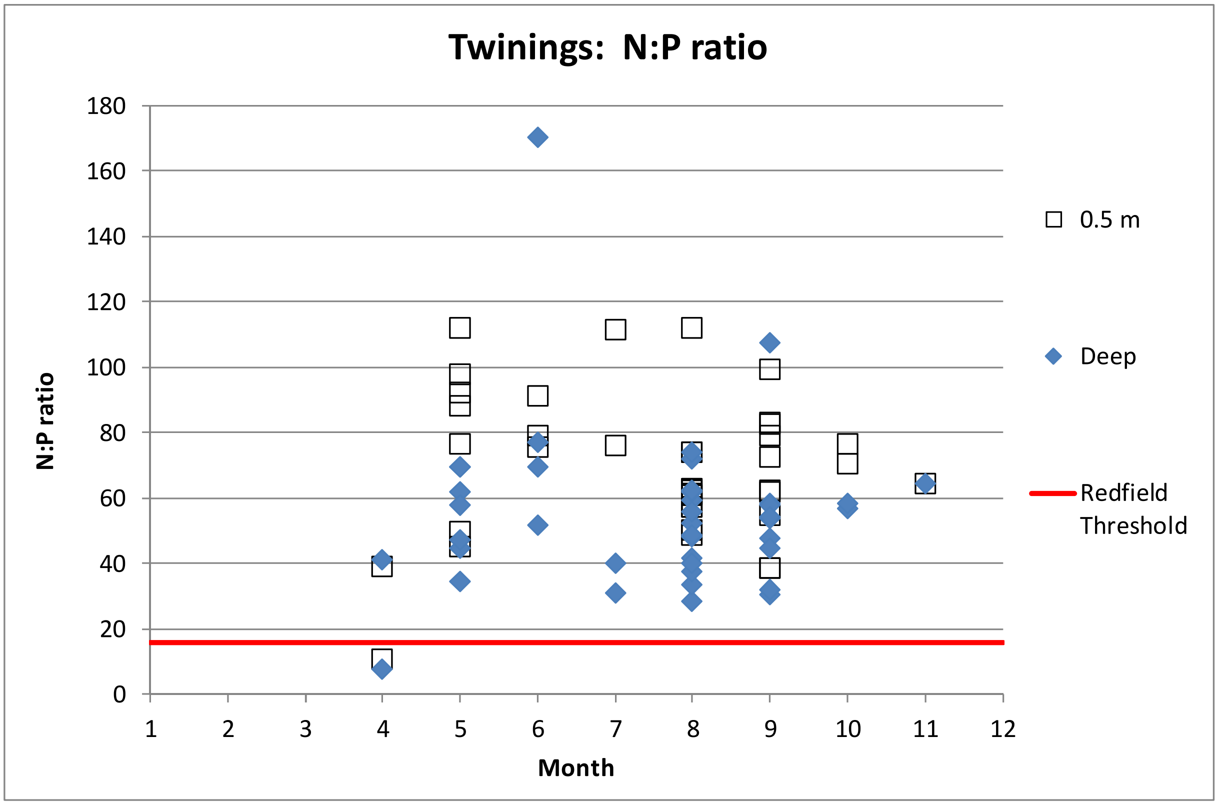
Twinings: Dissolved Oxygen (% saturation)
Dissolved Oxygen (%sat)
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium

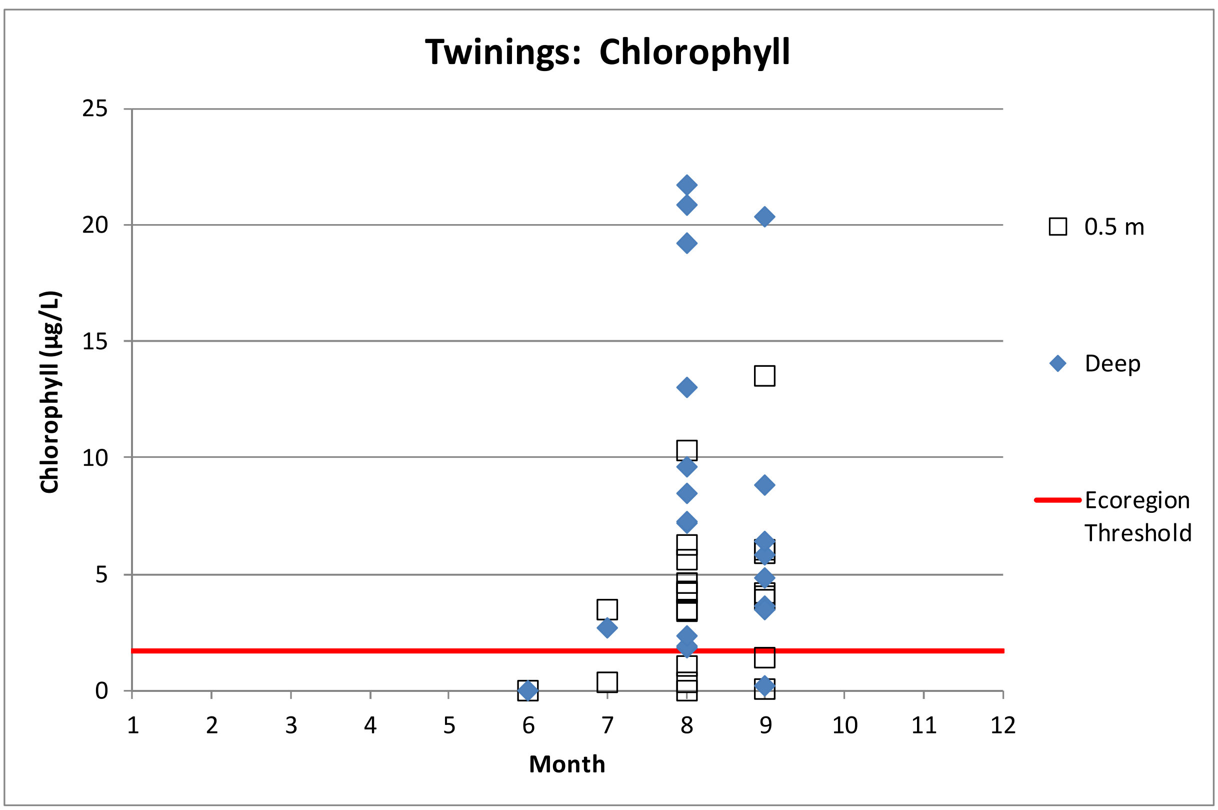


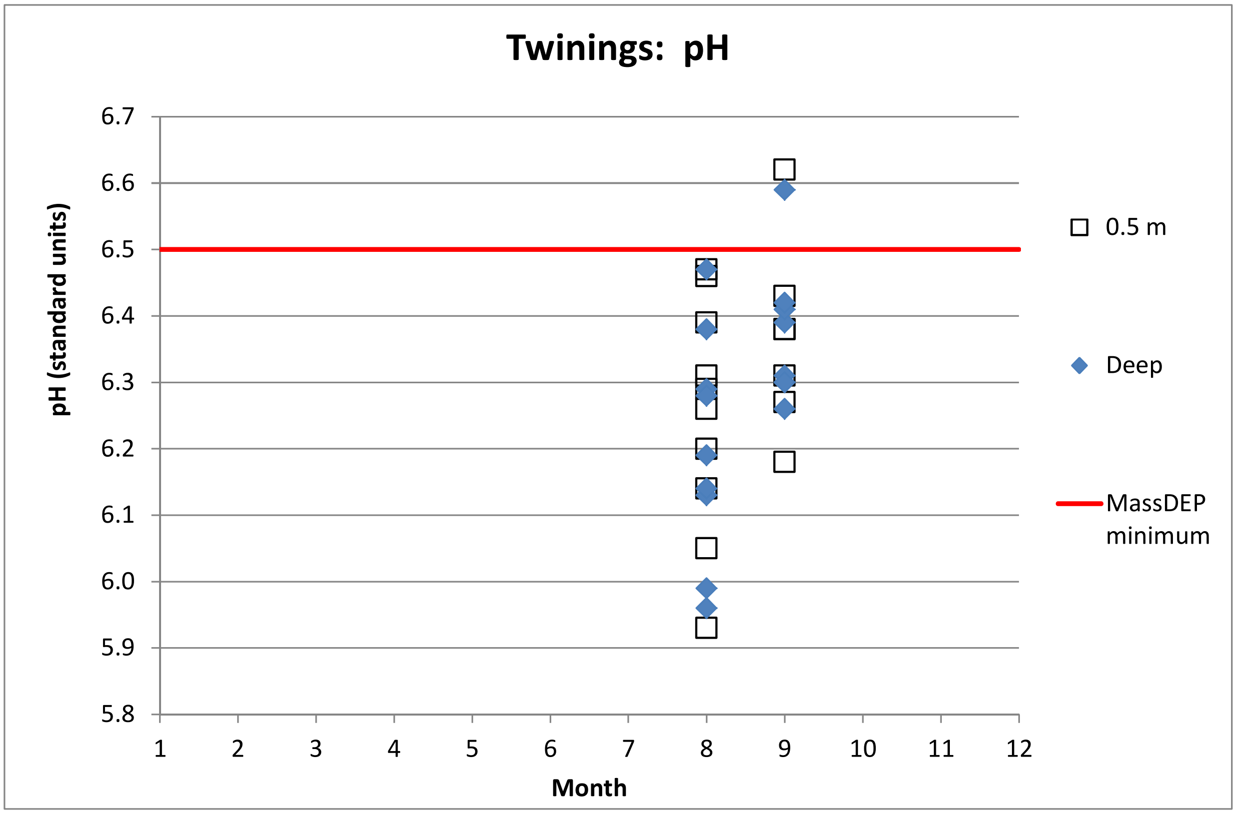
Twinings: Total Nitrogen
Total Nitrogen (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Ecoregion Threshold



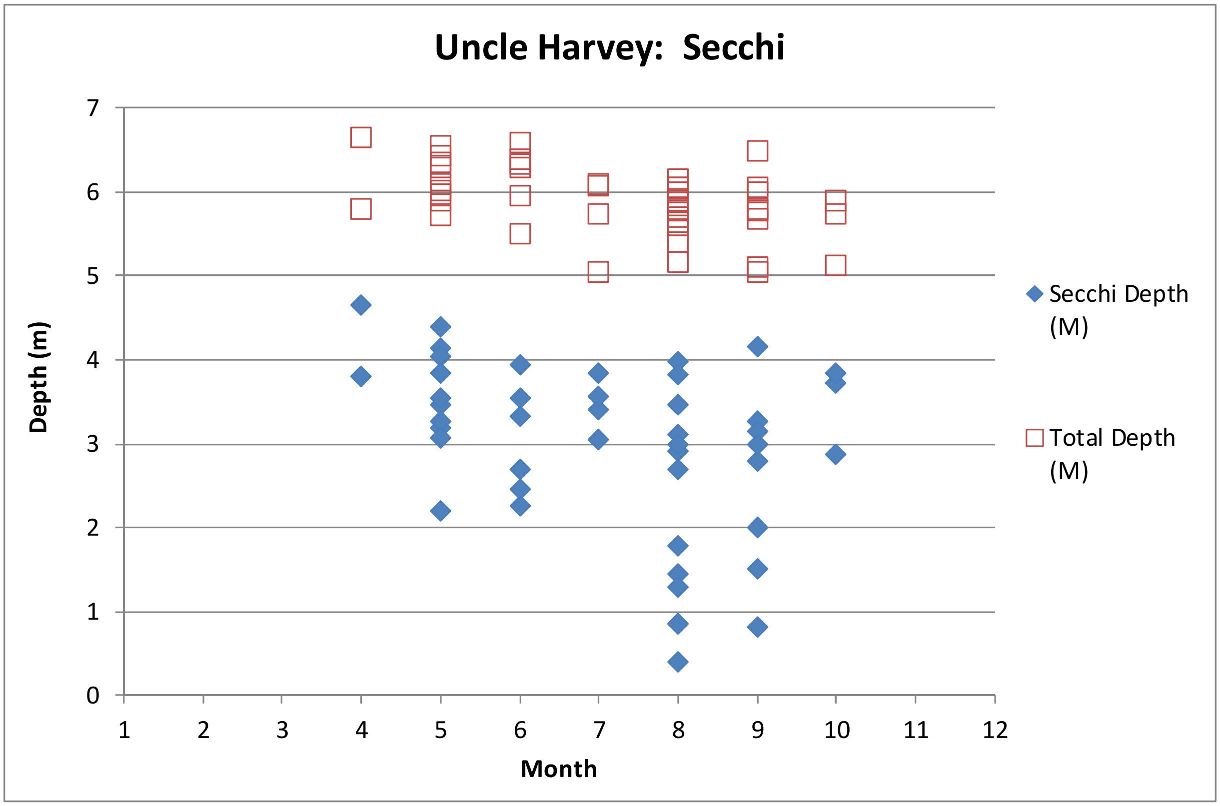
Twinings: Total Phosphorus
Total Phosphorus (µg/L)
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Ecoregion Threshold


Twinings: N:P ratio
180
160
140
120
100
80
60
40
20
0
N:P ratio
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield Threshold

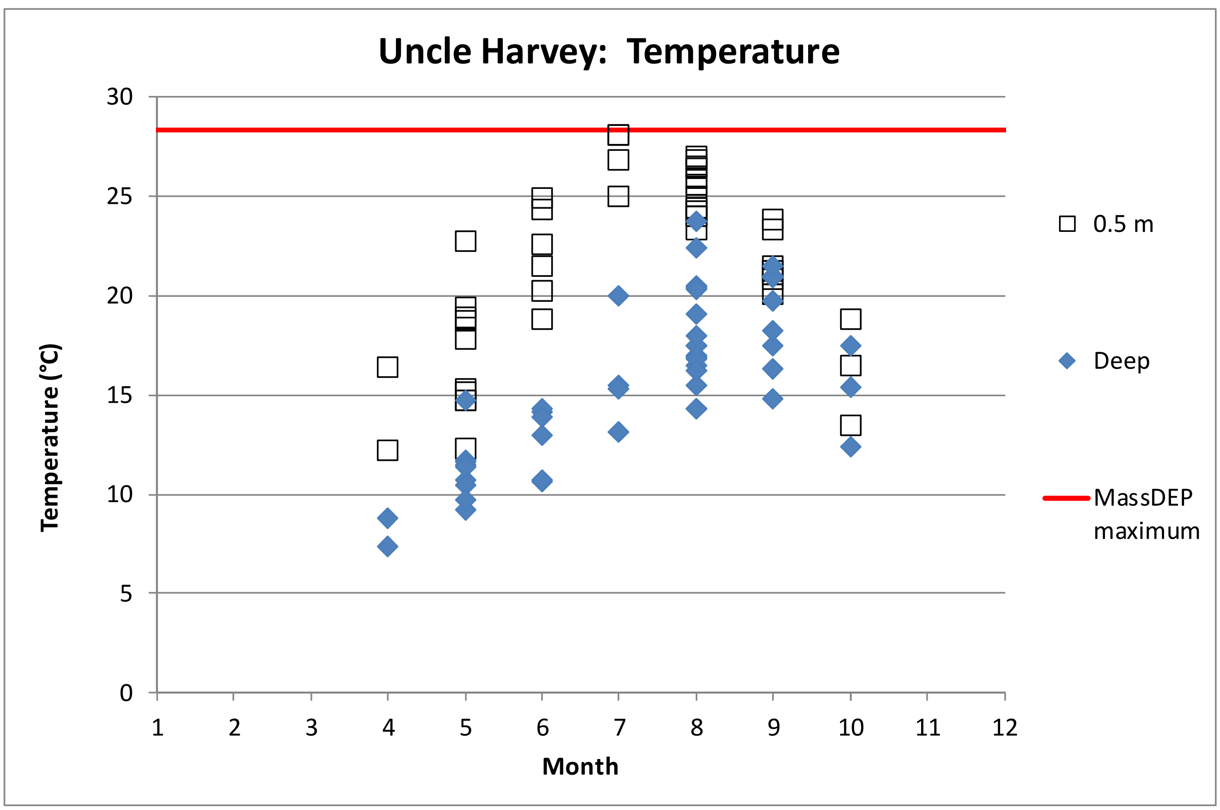

Twinings: Chlorophyll
25
20
15
10
5
0
Chlorophyll (µg/L)
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold


Twinings: pH
pH (standard units)
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6.0
5.9
5.8
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

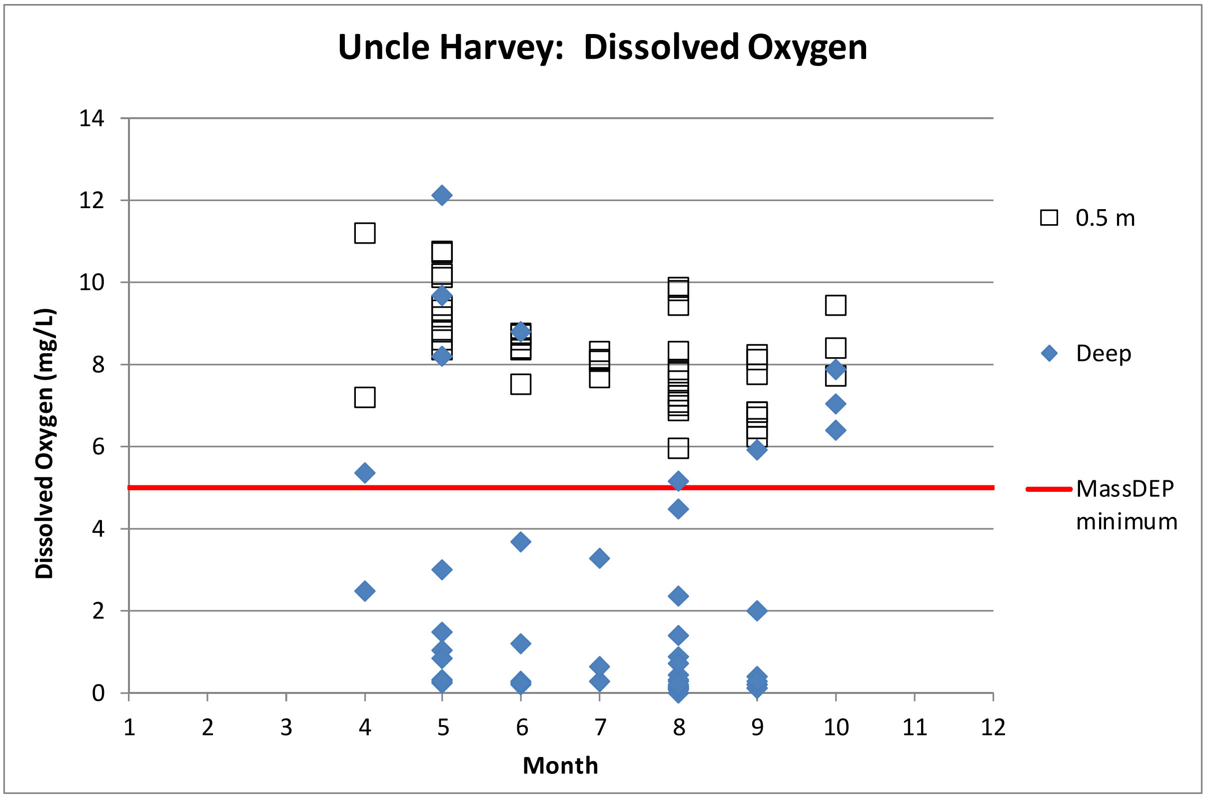
Uncle Harveys Pond

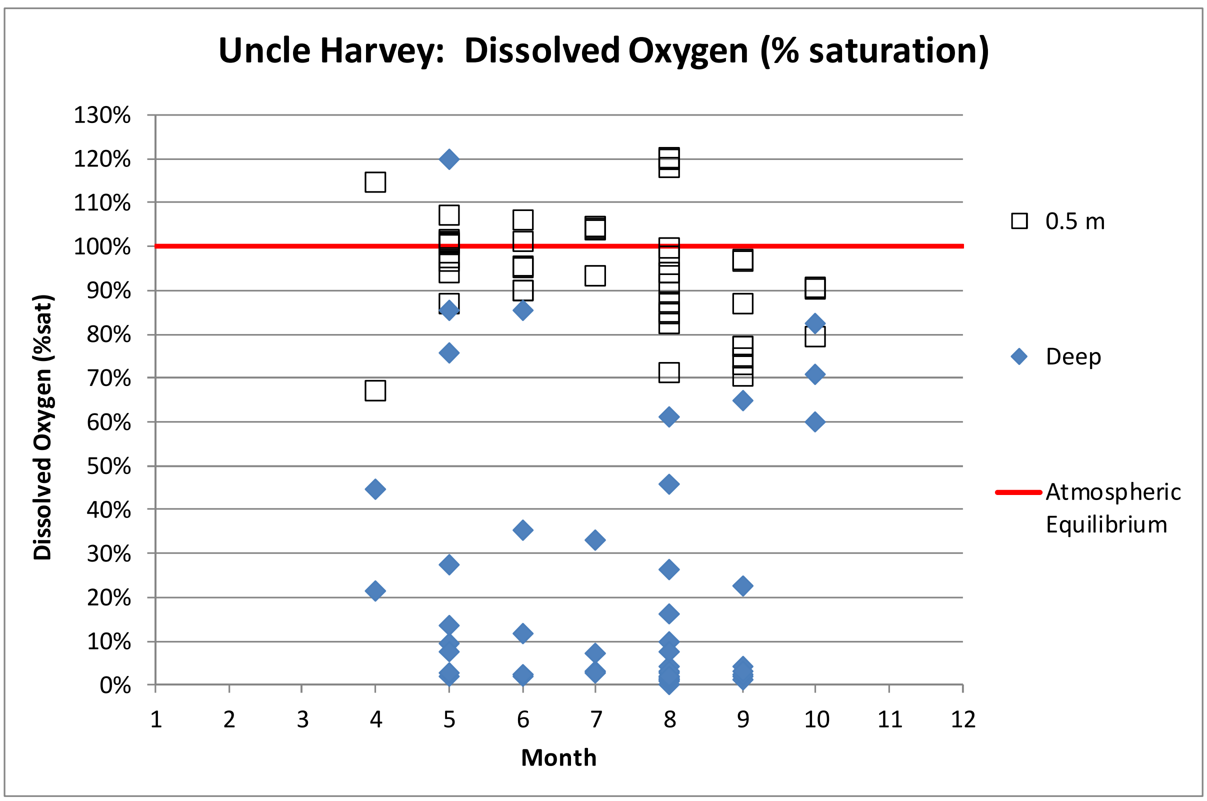


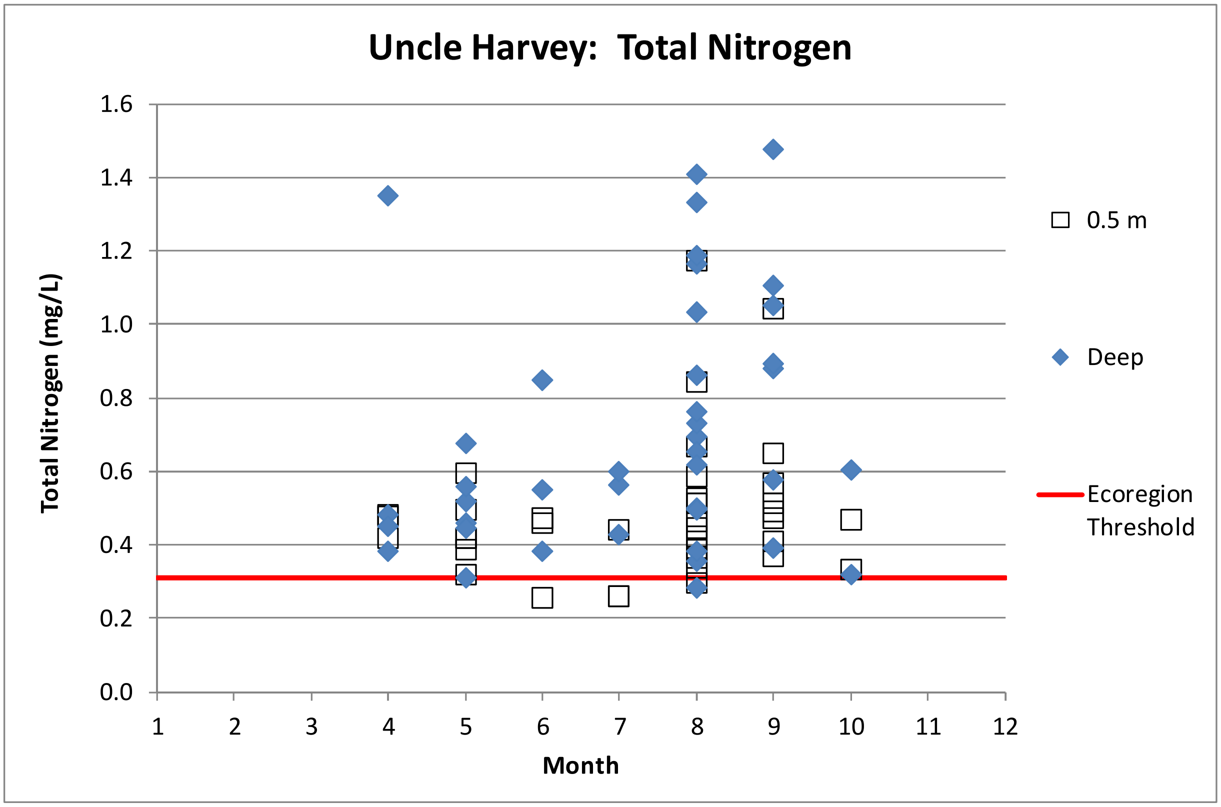
Uncle Harvey: Secchi
Depth (m)
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)

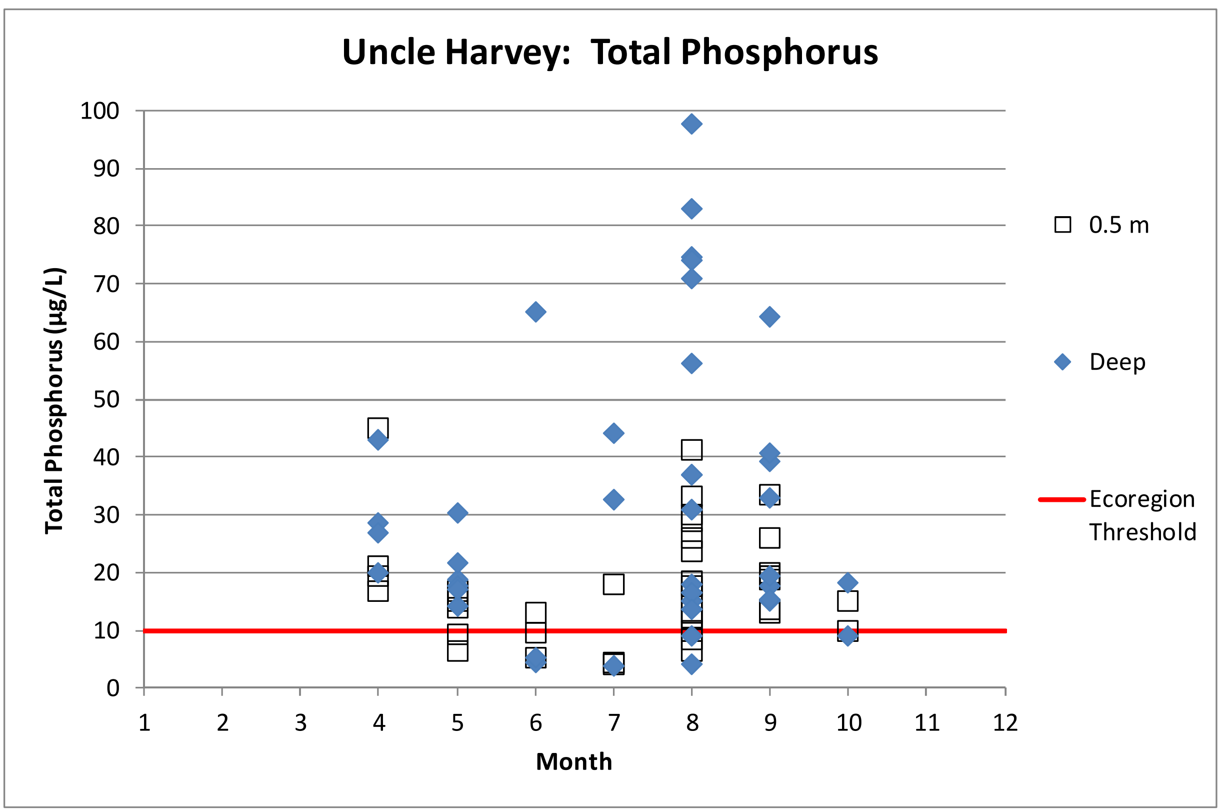


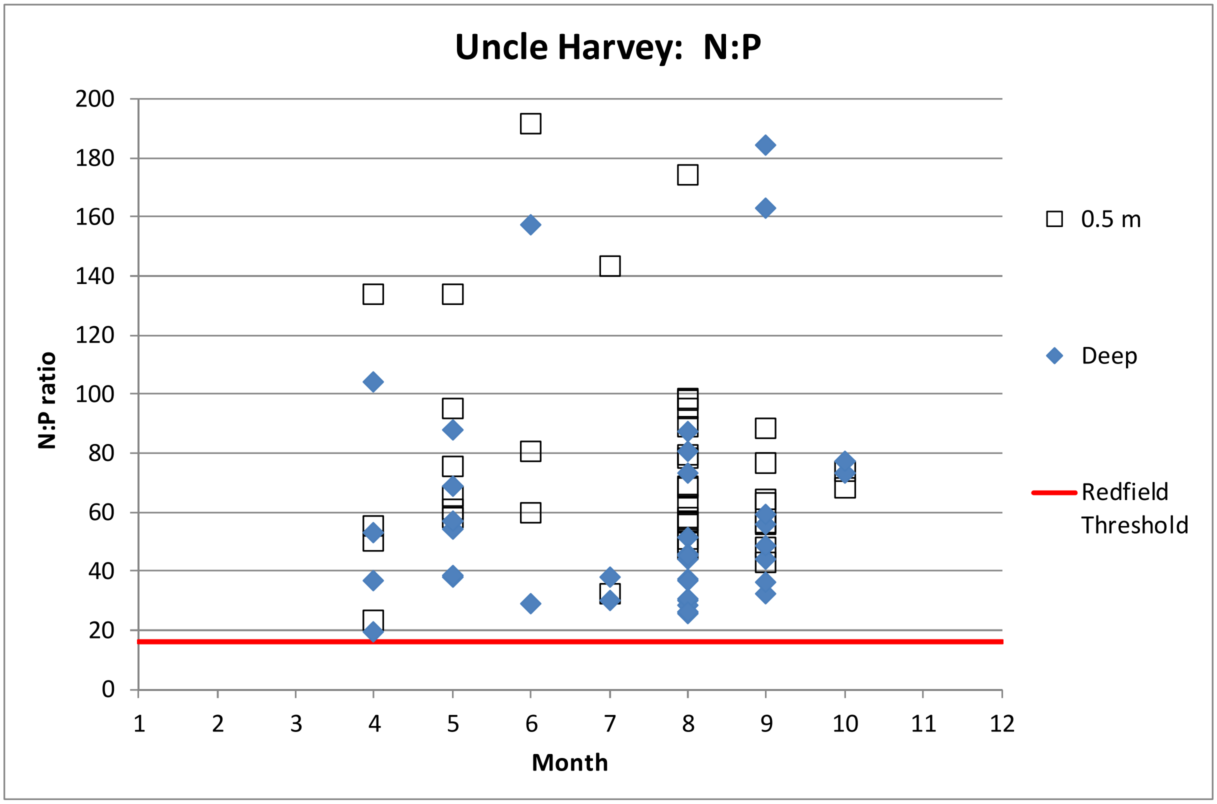
Uncle Harvey: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP maximum

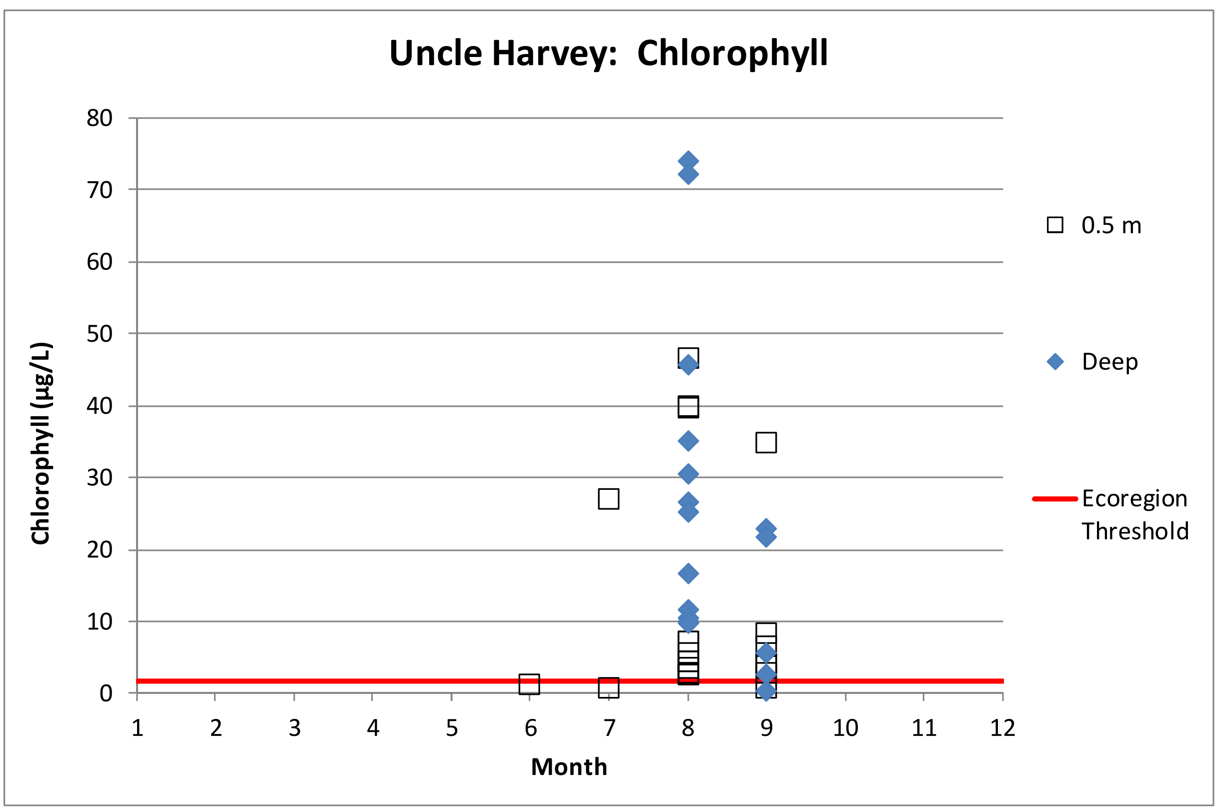

Uncle Harvey: Dissolved Oxygen
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

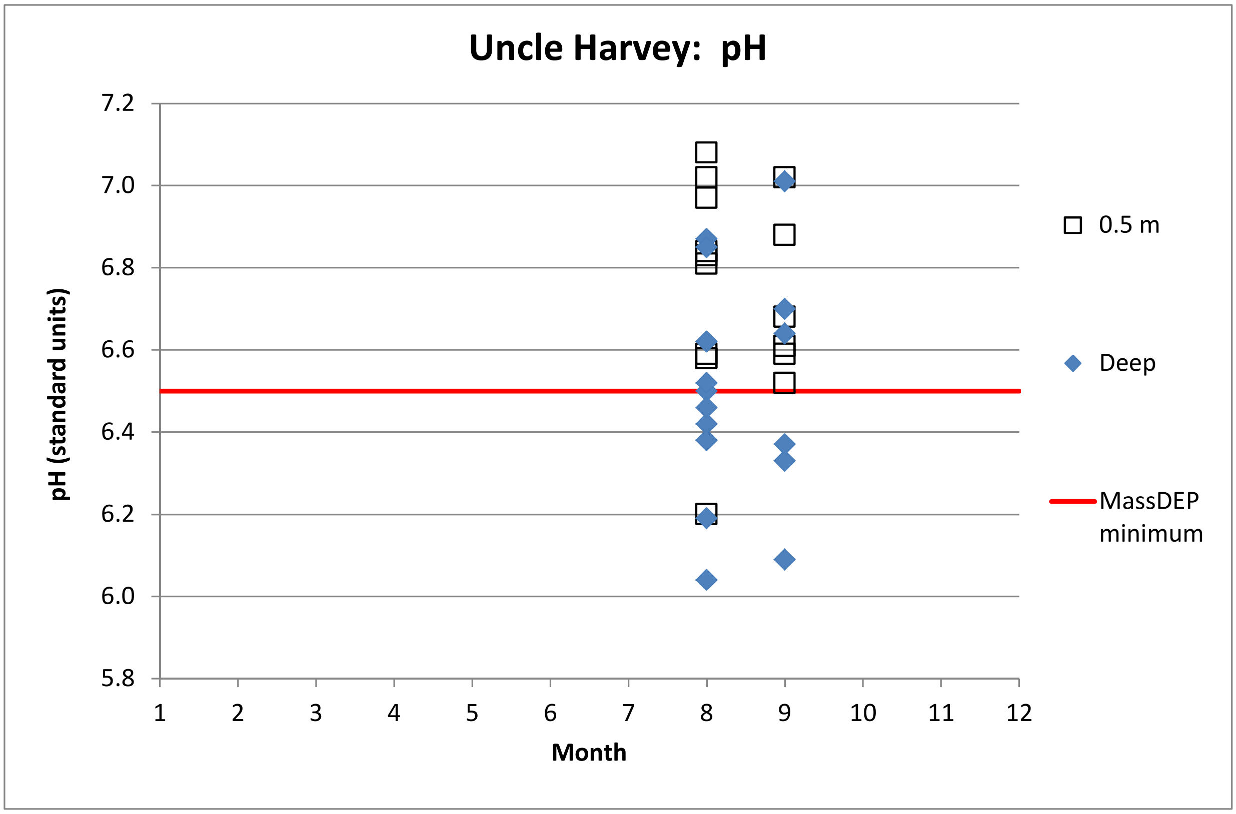

Uncle Harvey: Dissolved Oxygen (% saturation)
Dissolved Oxygen (%sat)
130%
120%
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium


Uncle Harvey: Total Nitrogen
Total Nitrogen (mg/L)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold


Uncle Harvey: Total Phosphorus
Total Phosphorus (µg/L)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

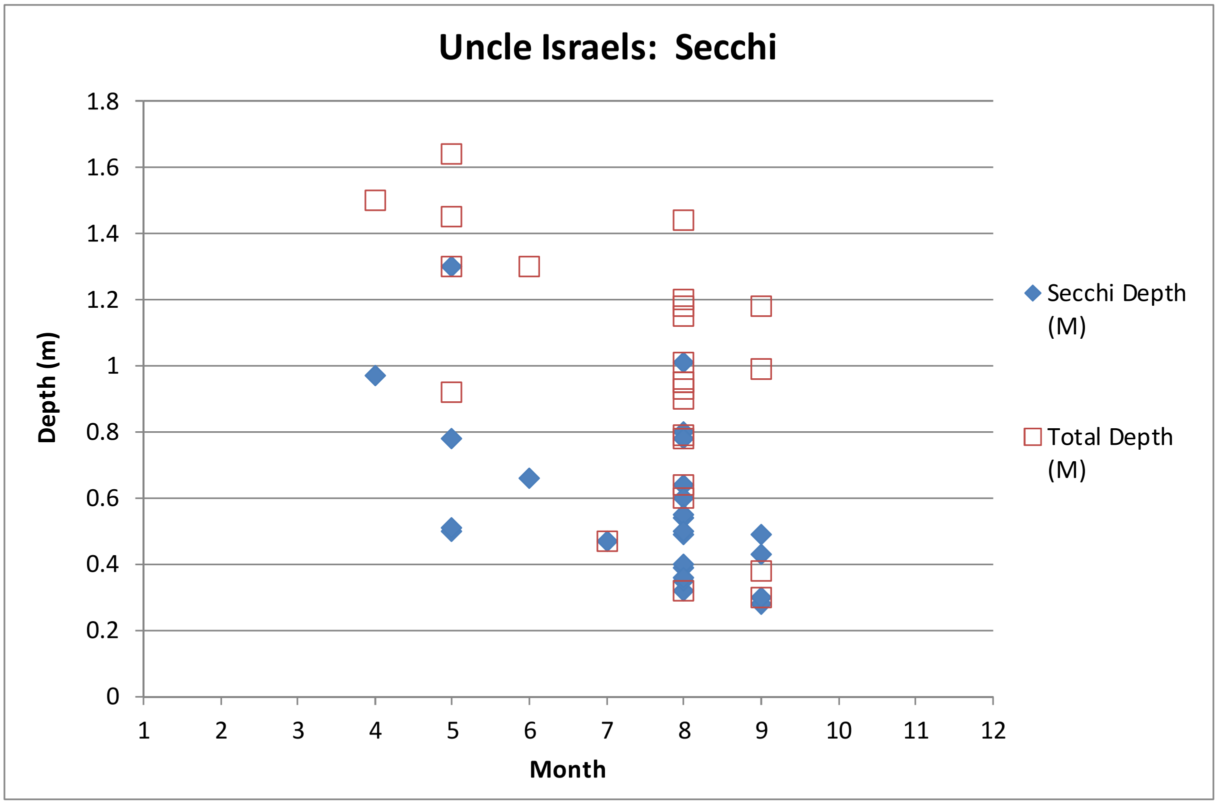

Uncle Harvey: N:P
N:P ratio
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield Threshold


Uncle Harvey: Chlorophyll
Chlorophyll (µg/L)
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

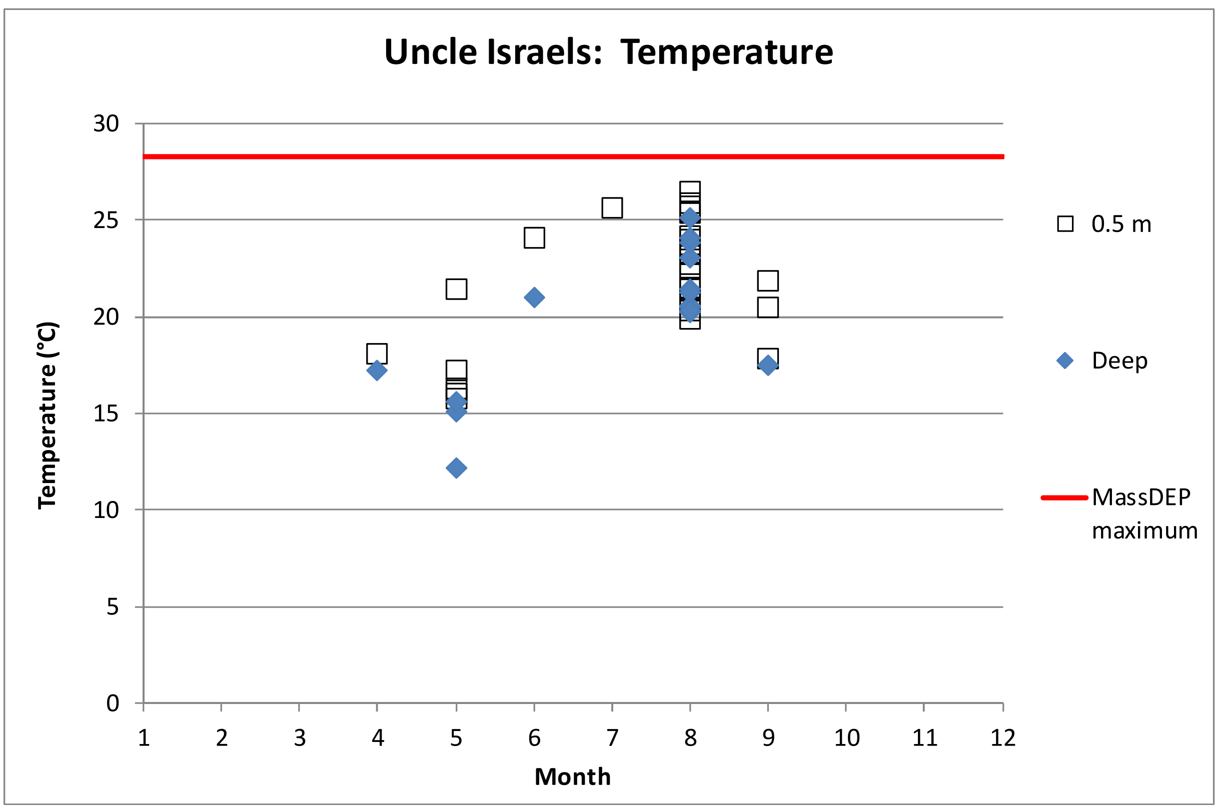


Uncle Harvey: pH
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
pH (standard units)
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

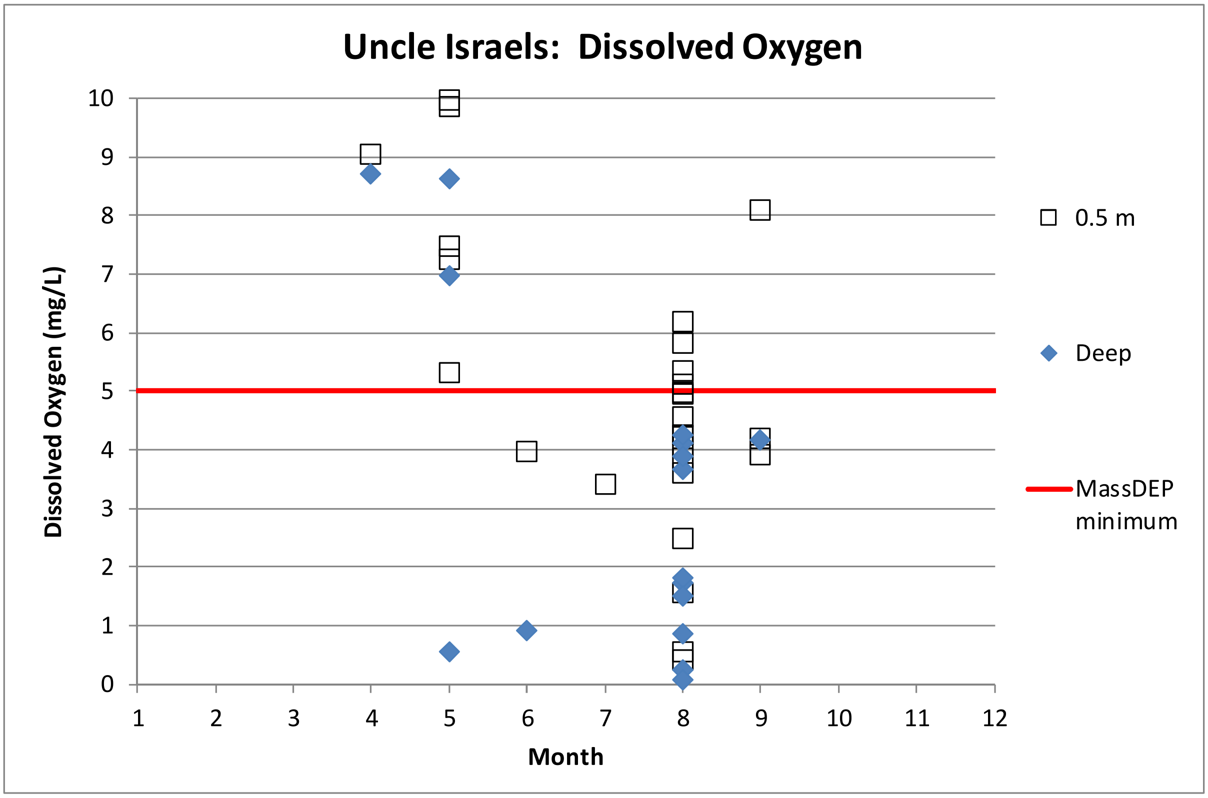
Uncle Israels Pond

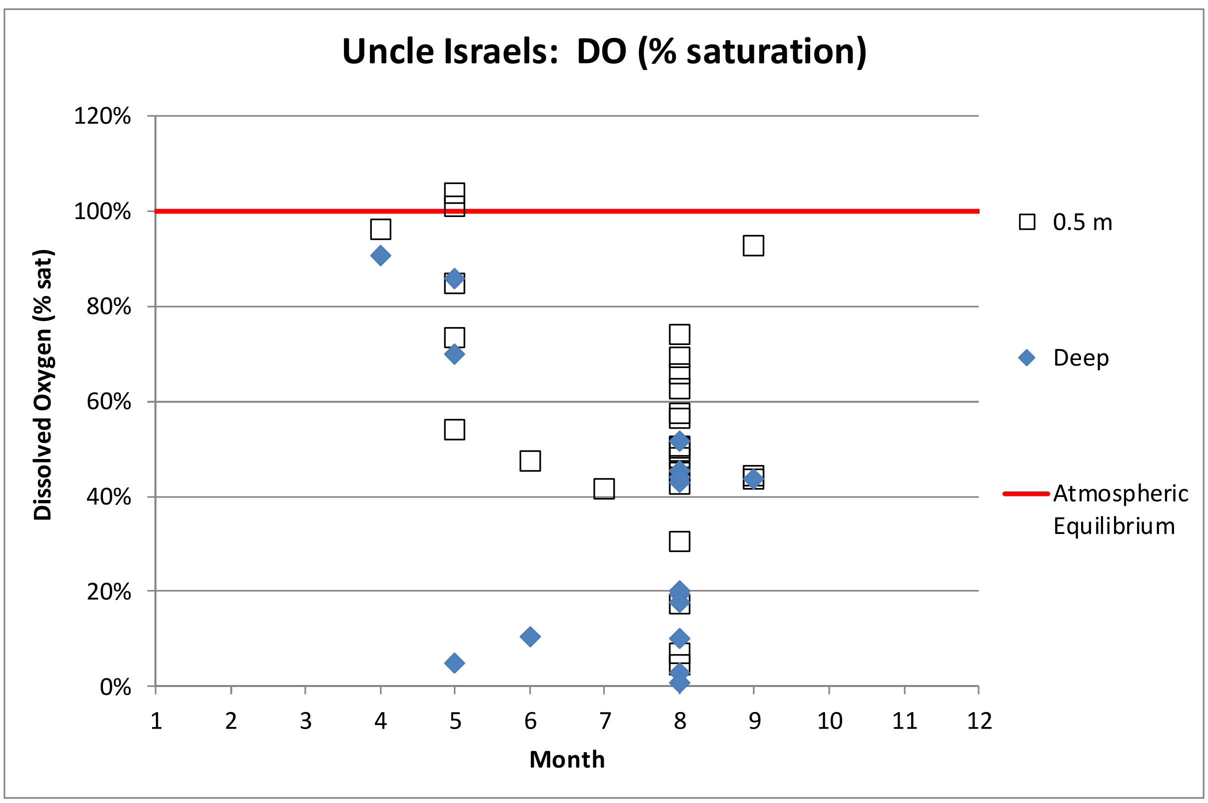


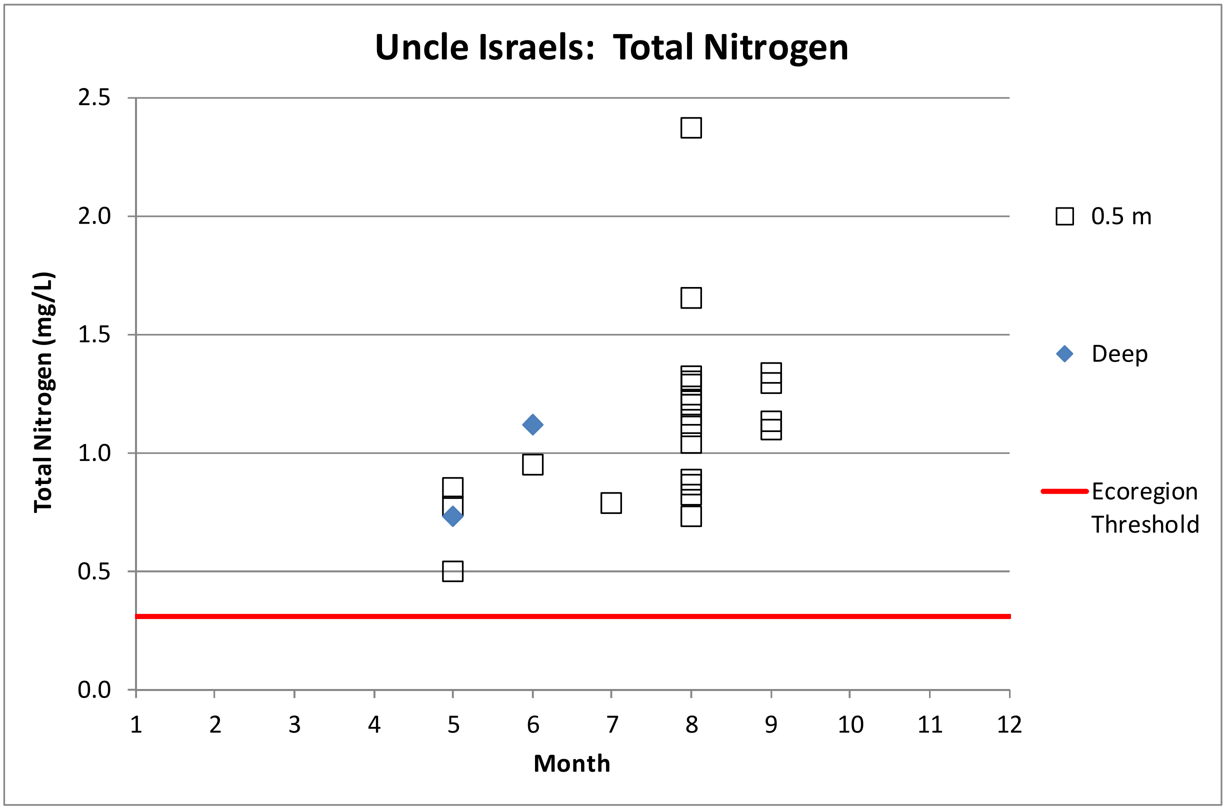
Uncle Israels: Secchi
Depth (m)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Secchi Depth (M)
Total Depth (M)



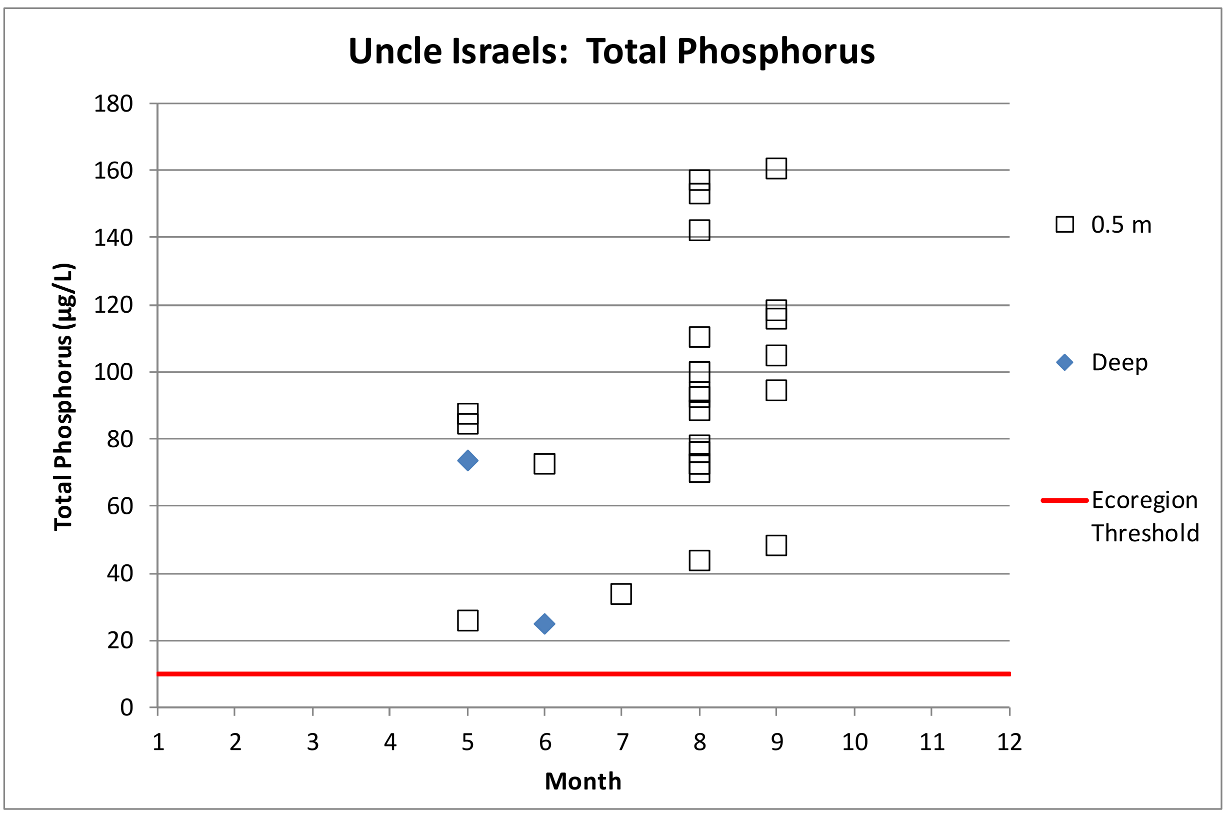
Uncle Israels: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
MassDEP maximum


Uncle Israels: Dissolved Oxygen
Dissolved Oxygen (mg/L)
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

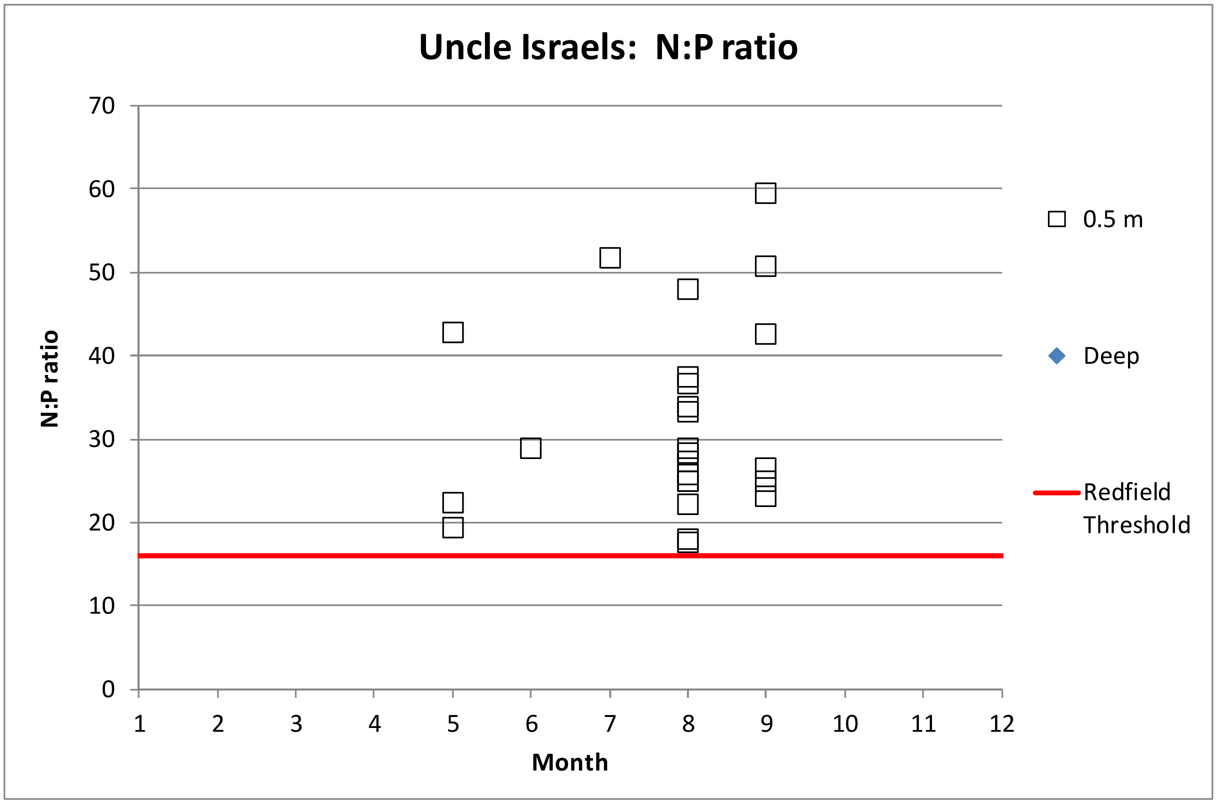

Uncle Israels: DO (% saturation)
Dissolved Oxygen (% sat)
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium



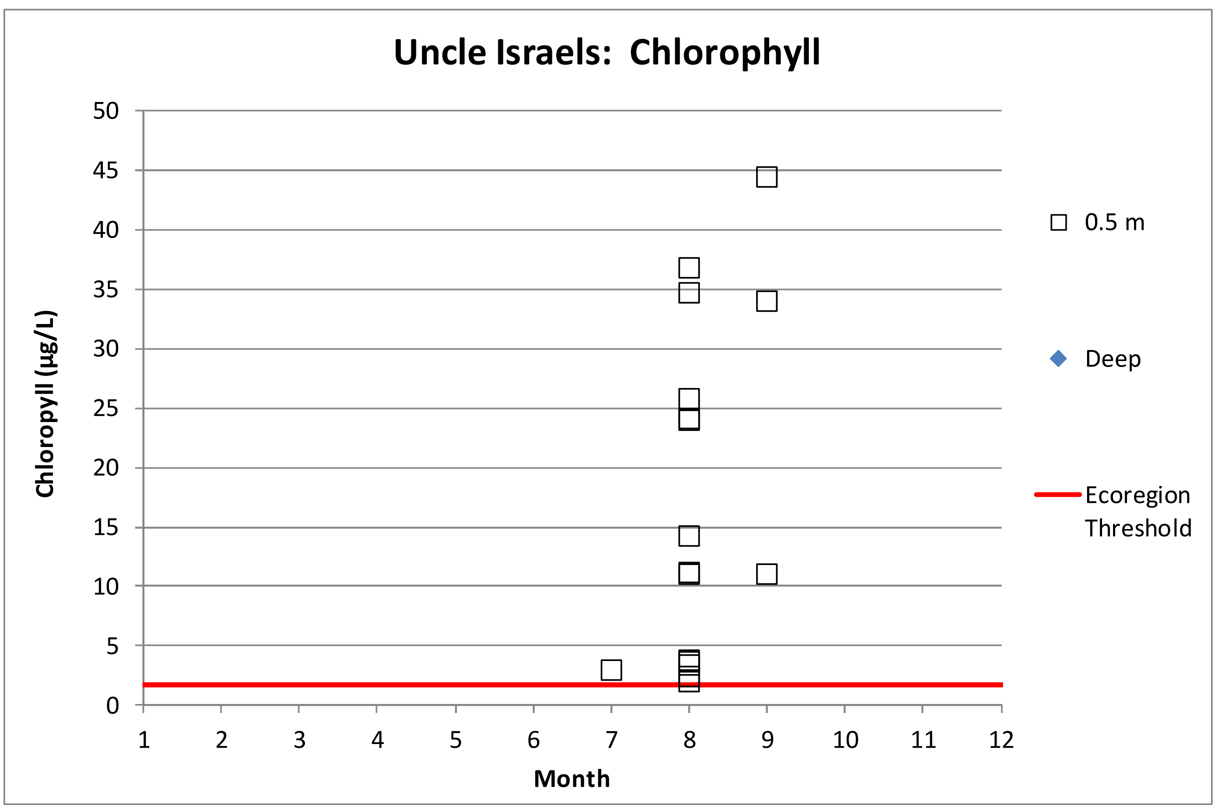
Uncle Israels: Total Nitrogen
Total Nitrogen (mg/L)
2.5
2.0
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Ecoregion Threshold



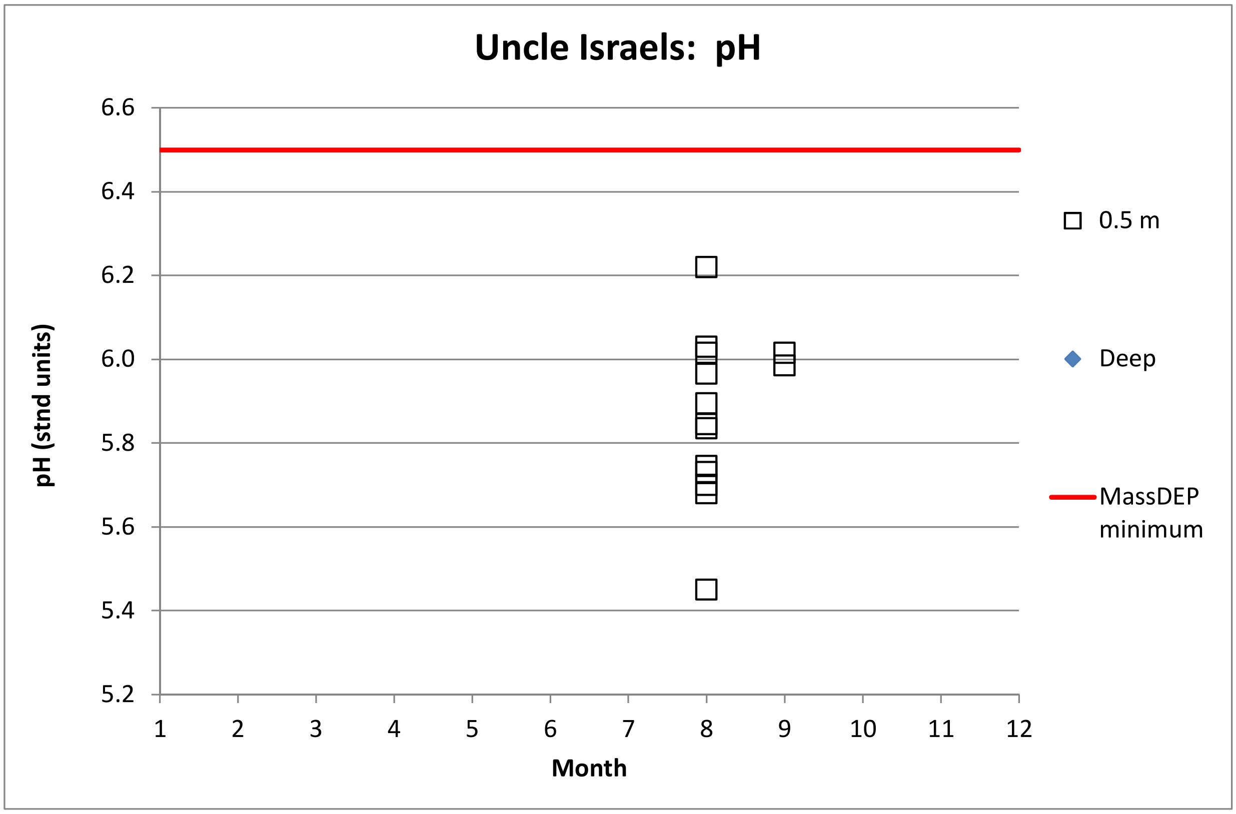
Uncle Israels: Total Phosphorus
Total Phosphorus (µg/L)
180
160
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Ecoregion Threshold



Uncle Israels: N:P ratio
N:P ratio
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield Threshold

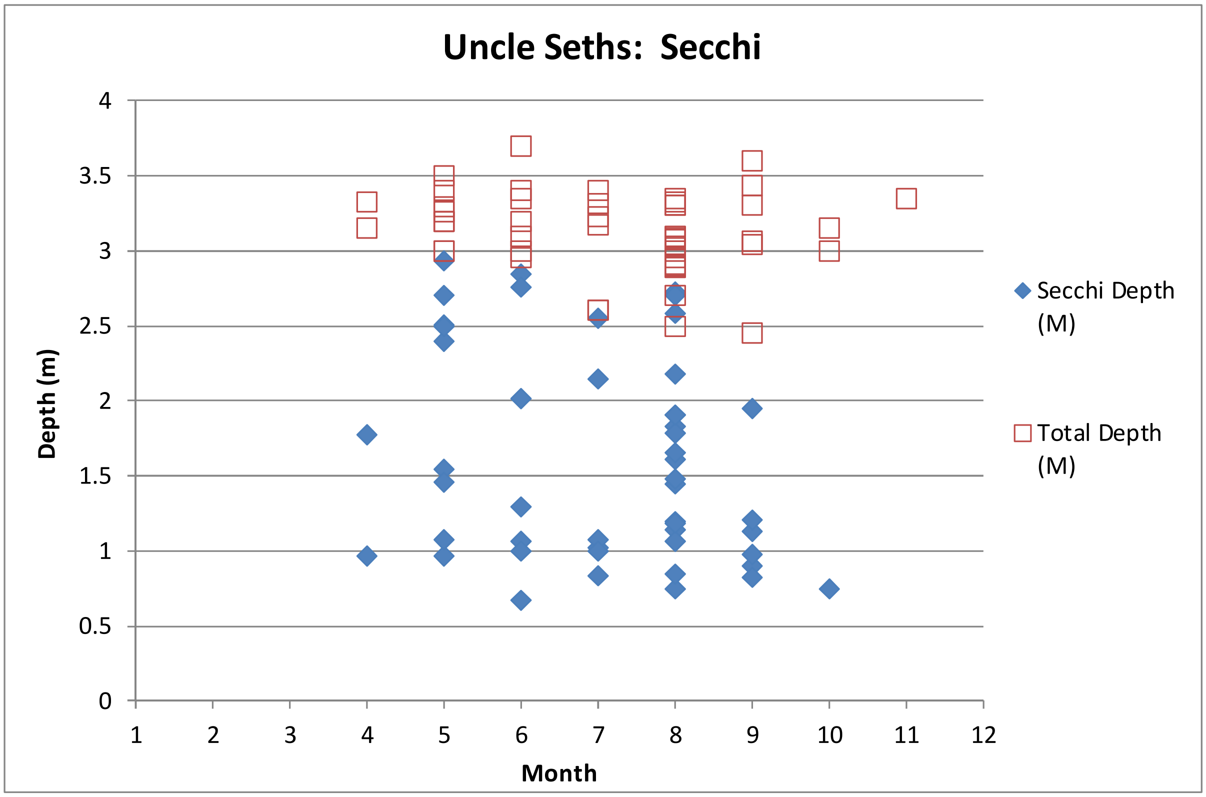


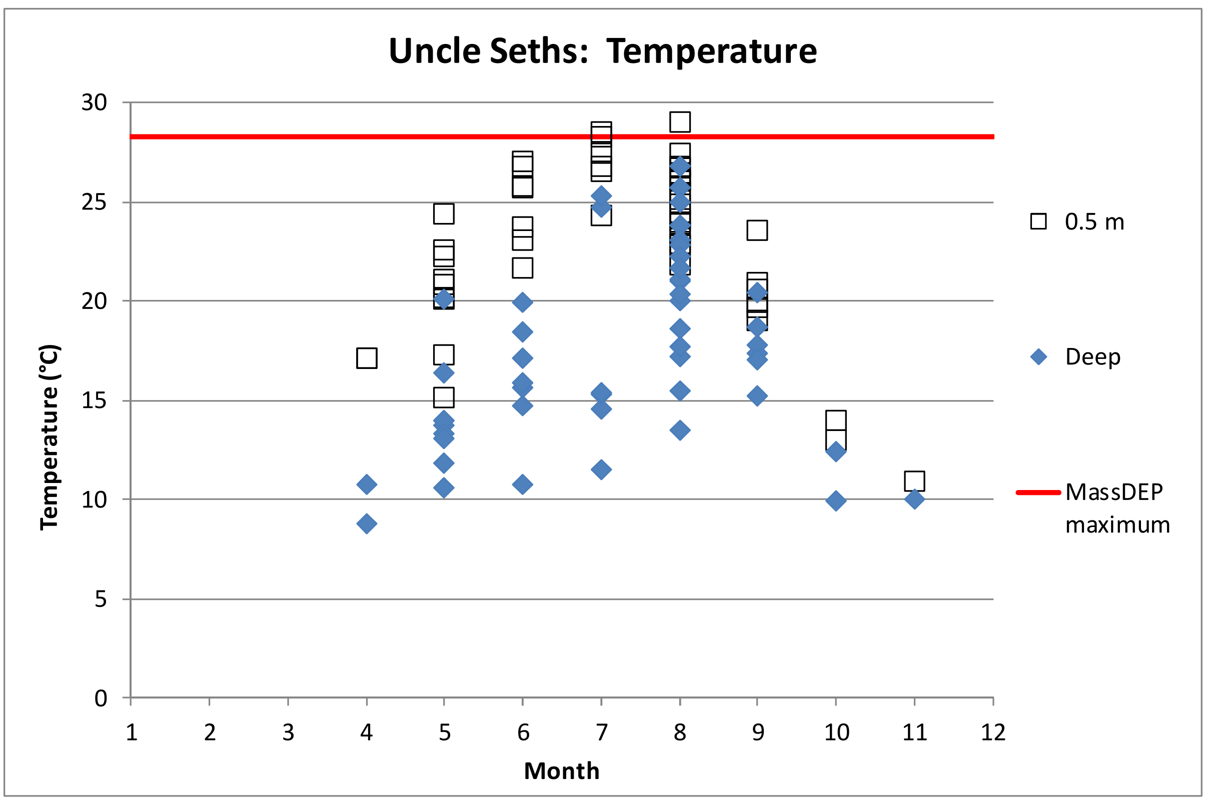
Uncle Israels: Chlorophyll
Chloropyll (µg/L)
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

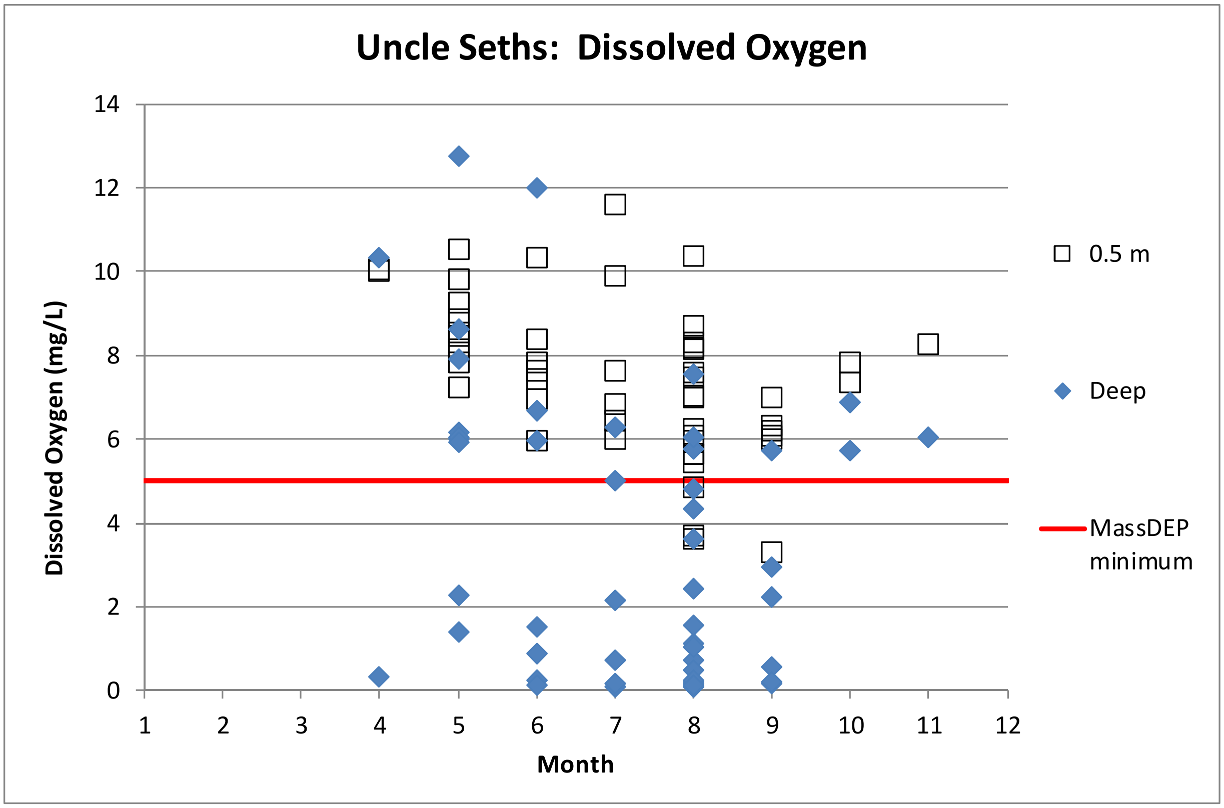


Uncle Israels: pH
pH (stnd units)
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

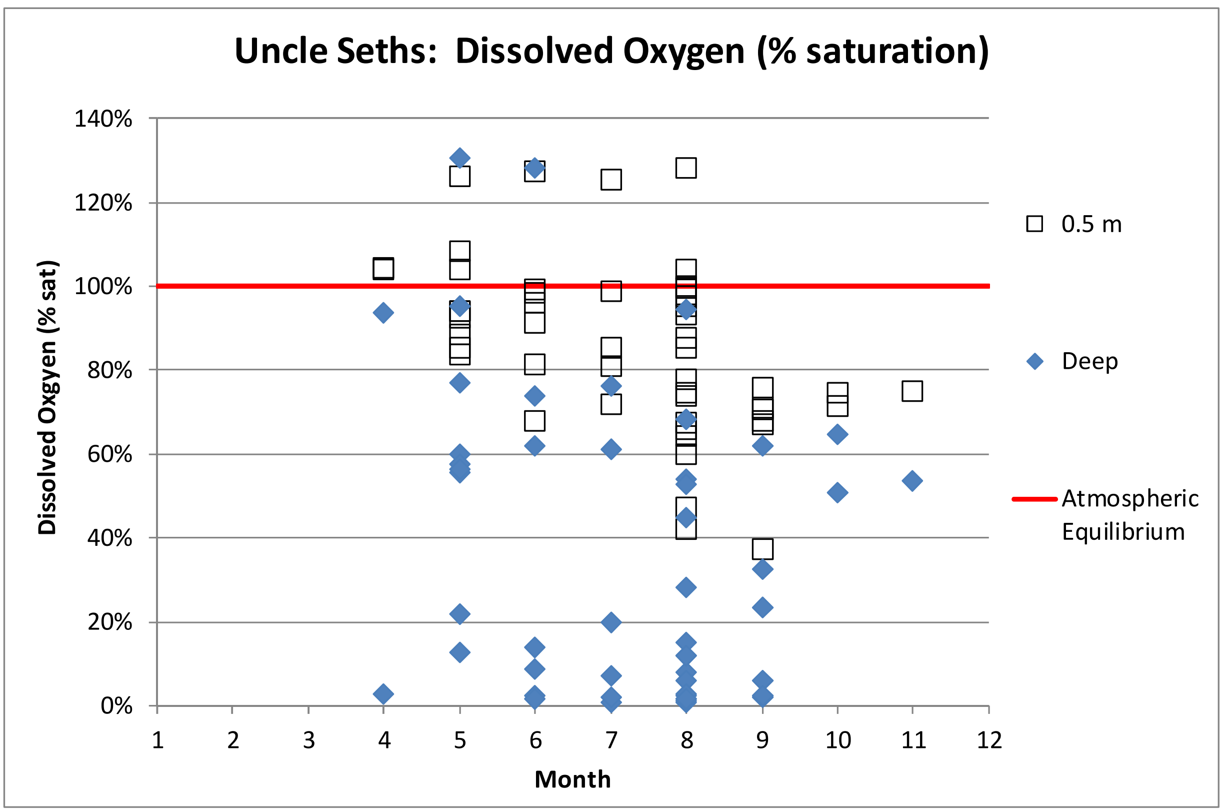
Uncle Seths Pond


Uncle Seths: Secchi
Depth (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)

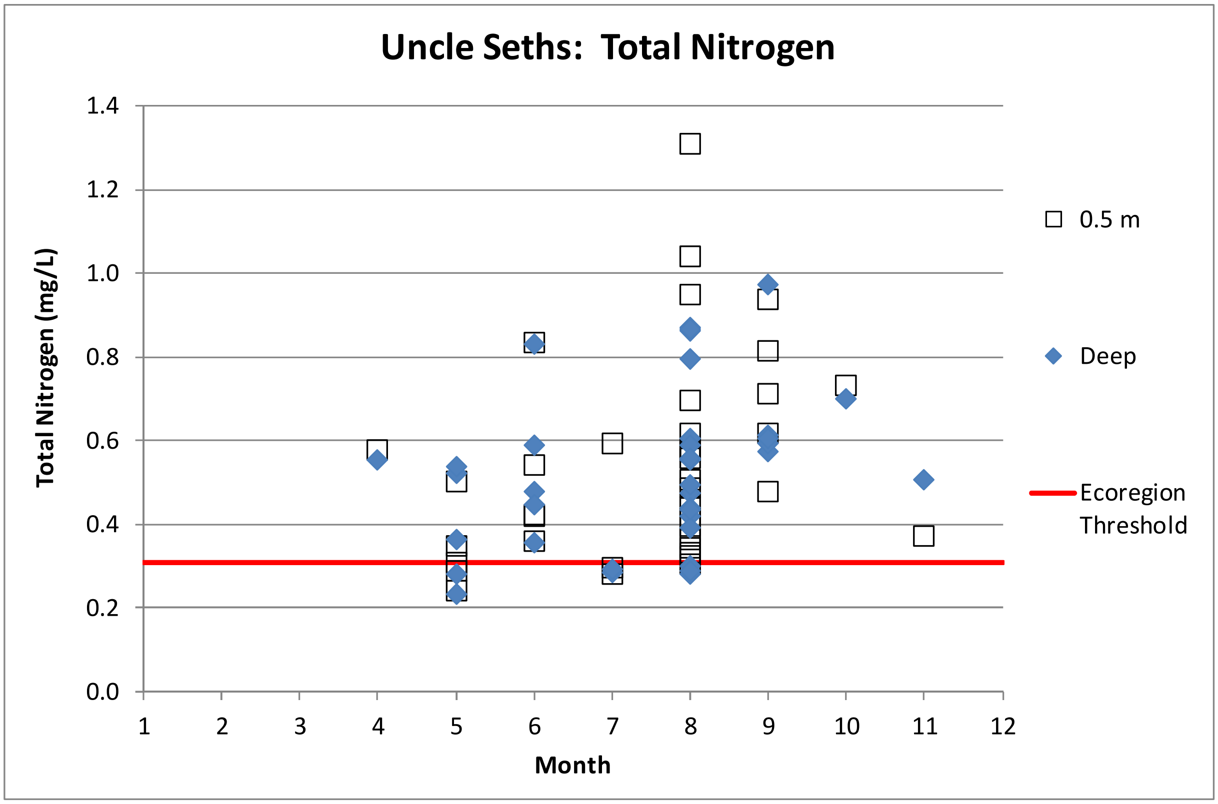

Uncle Seths: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP maximum

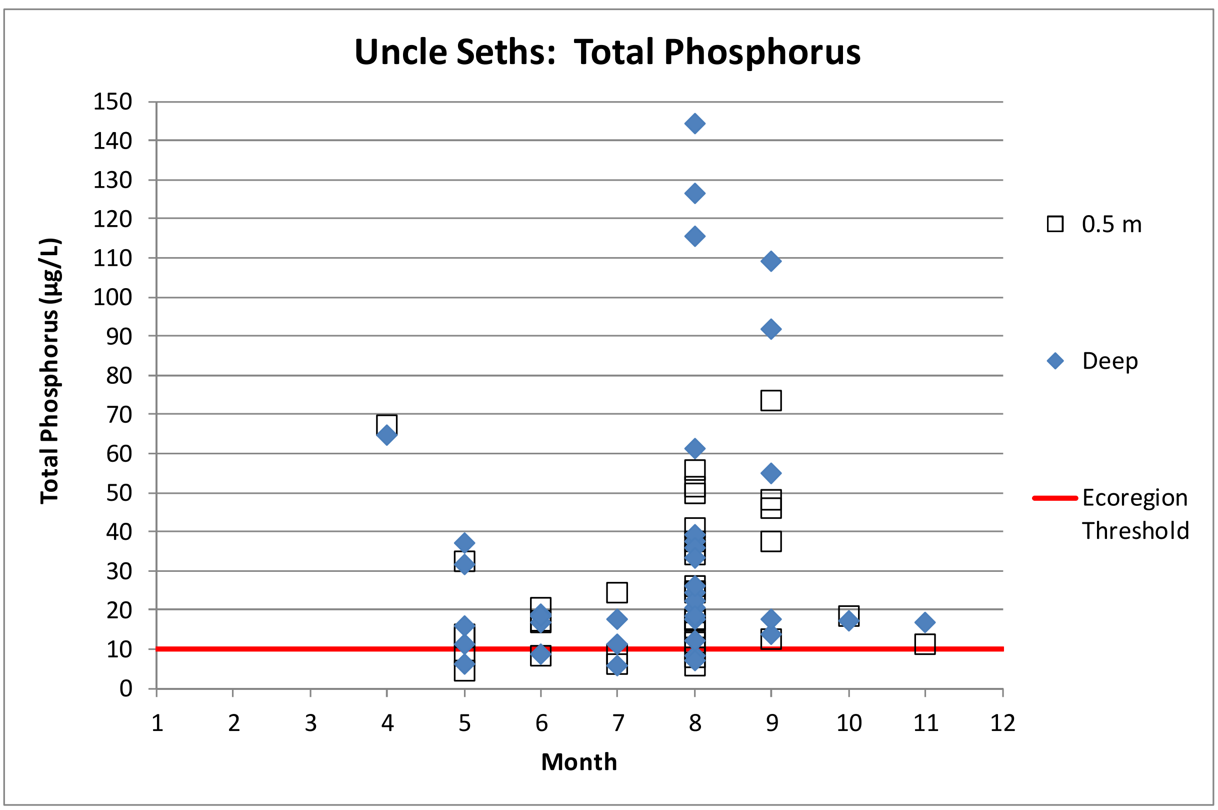


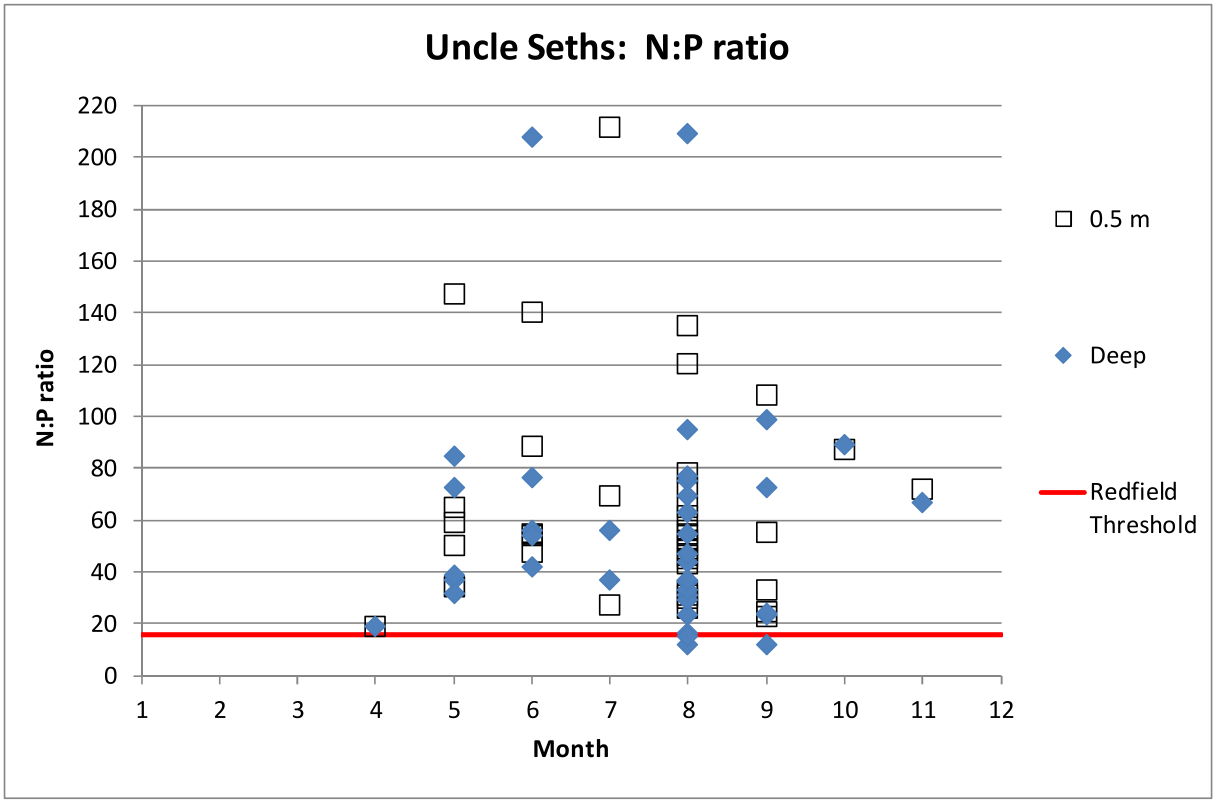
Uncle Seths: Dissolved Oxygen
Dissolved Oxygen (mg/L)
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

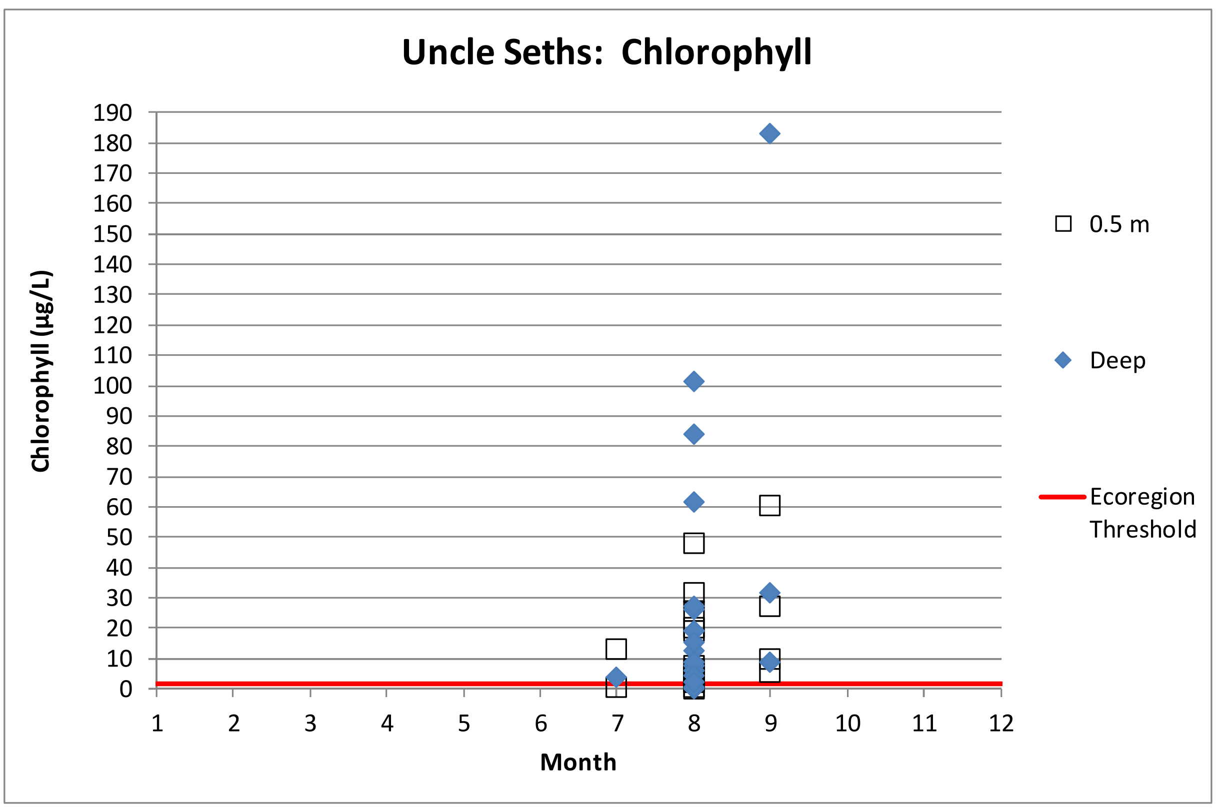


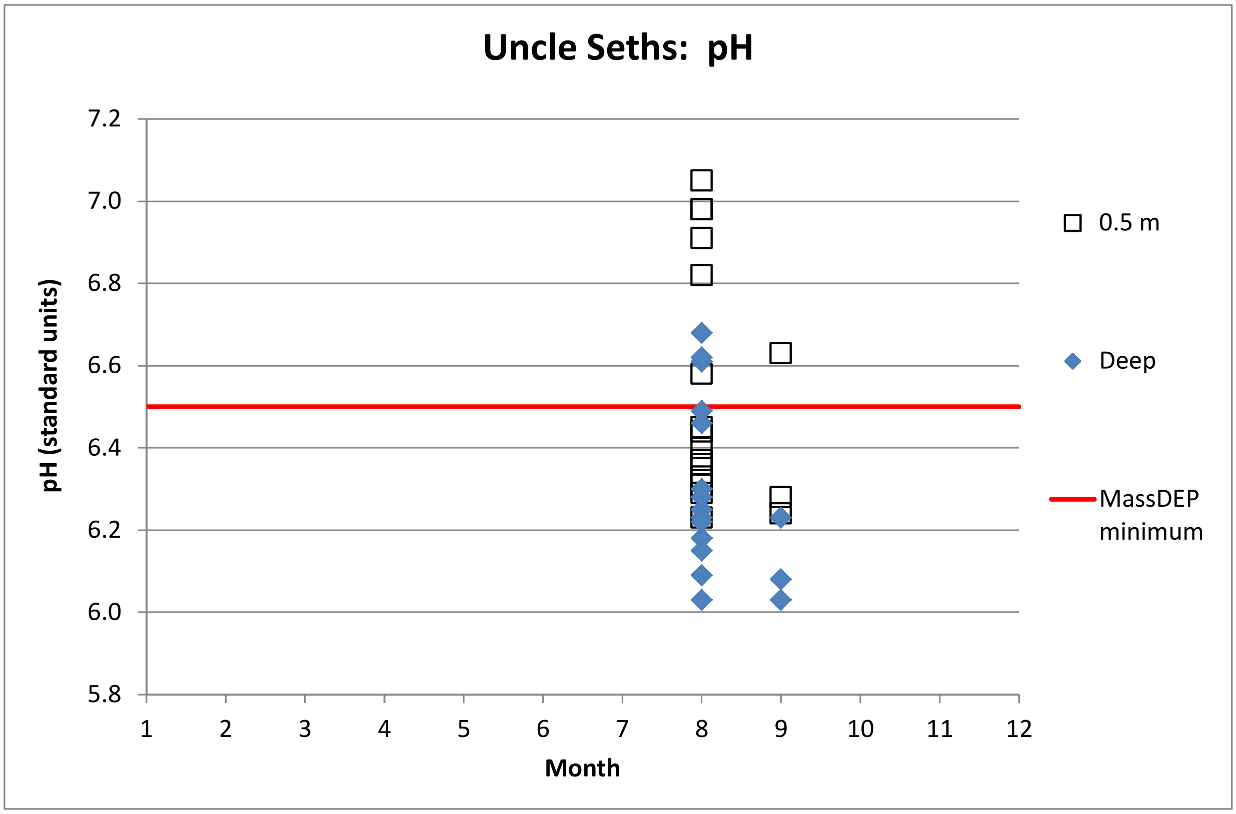
Uncle Seths: Dissolved Oxygen (% saturation)
Dissolved Oxgyen (% sat)
140%
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium


Uncle Seths: Total Nitrogen
Total Nitrogen (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Ecoregion Threshold


Uncle Seths: Total Phosphorus
Total Phosphorus (µg/L)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
0.5 m
Deep
Ecoregion Threshold

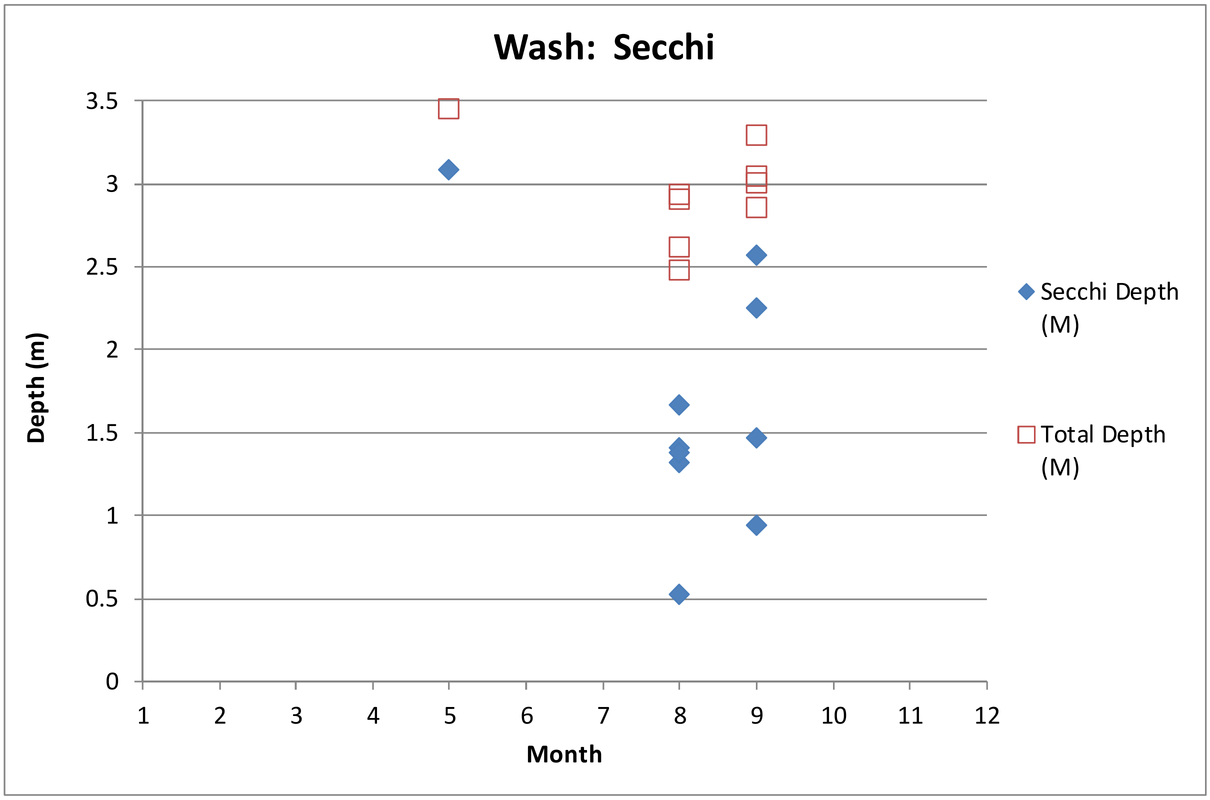

Uncle Seths: N:P ratio
N:P ratio
220
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Redfield Threshold

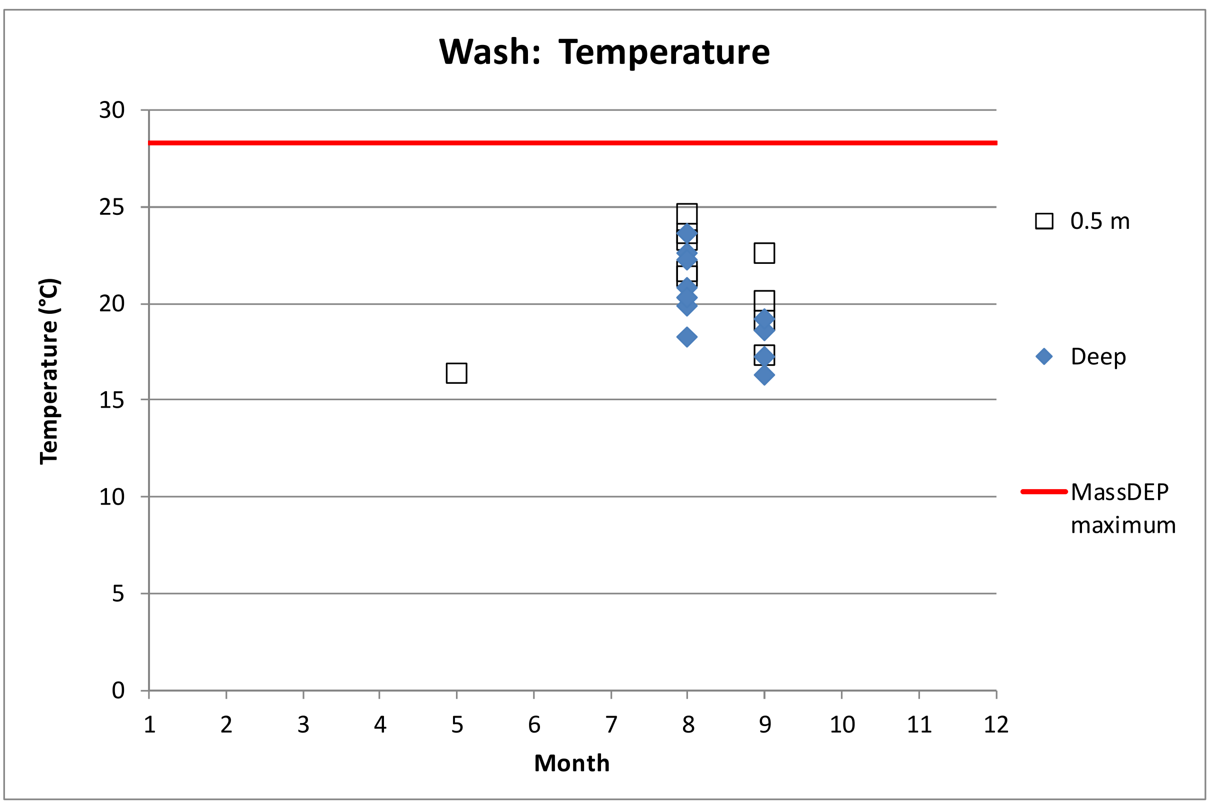

Uncle Seths: Chlorophyll
Chlorophyll (µg/L)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold

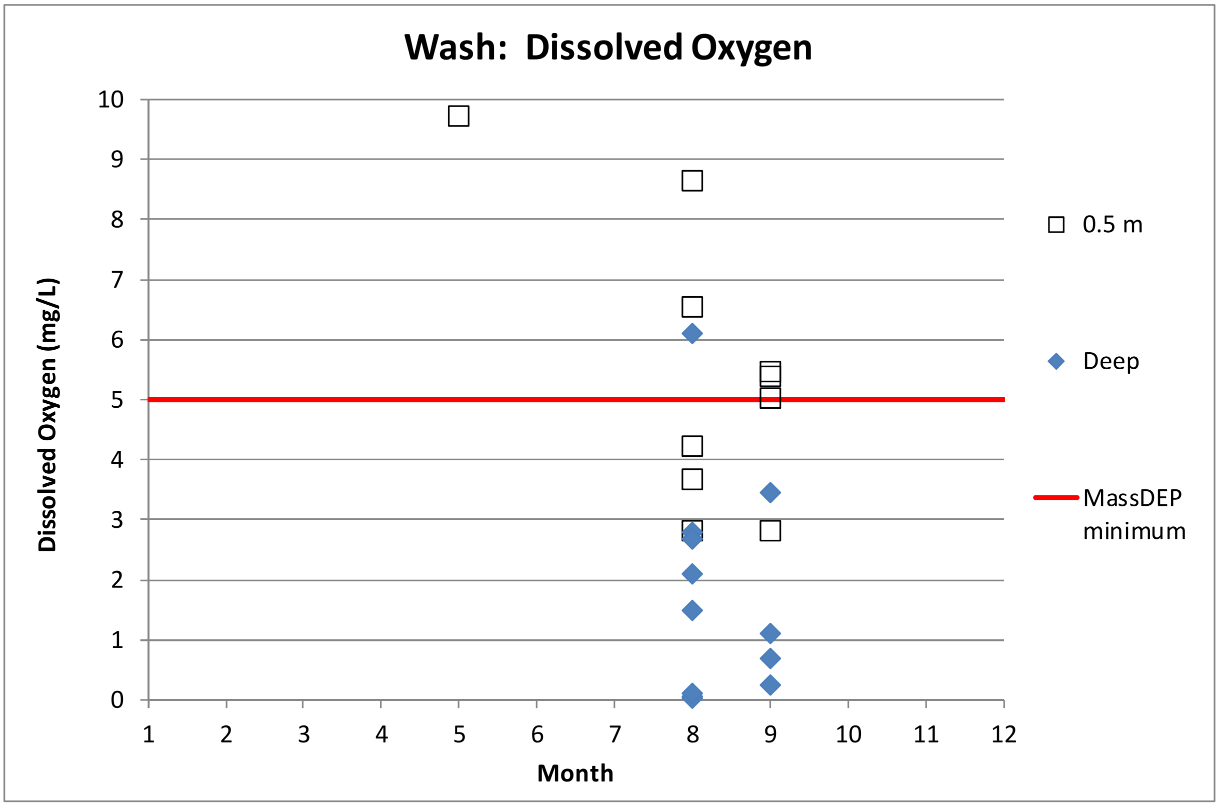


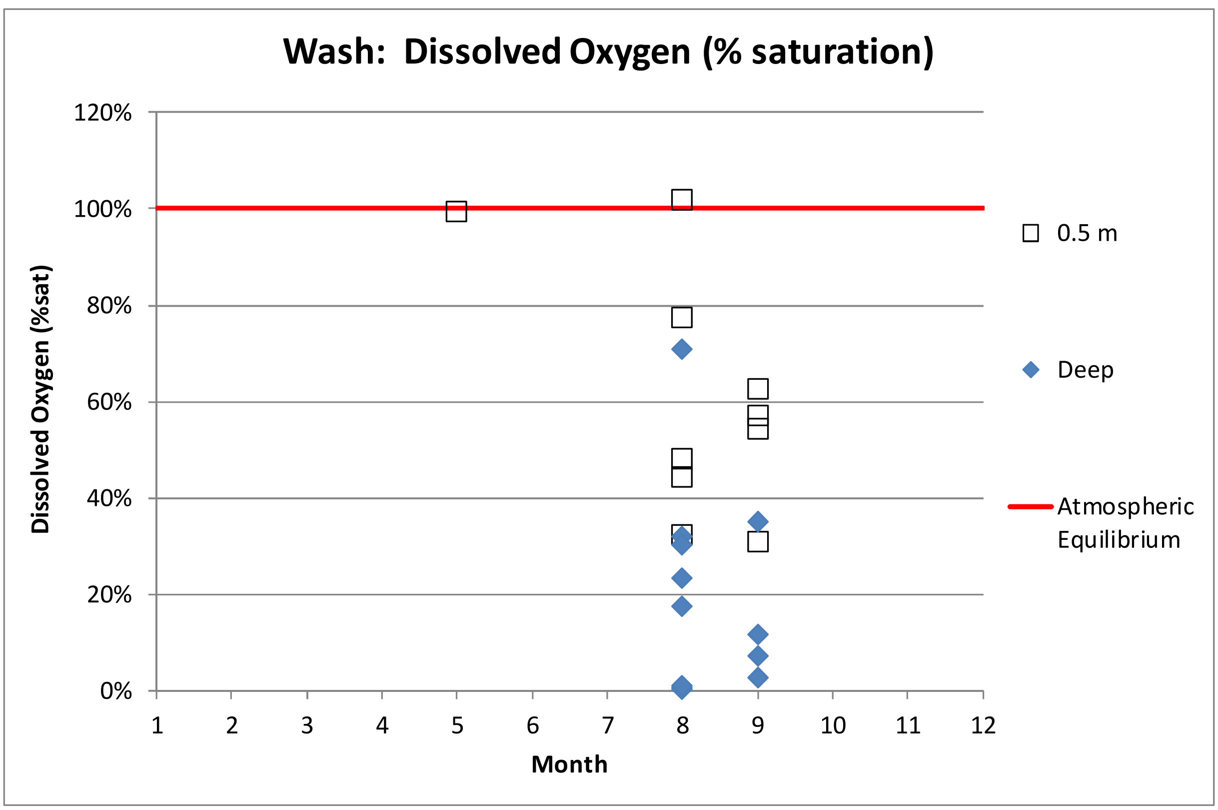
Uncle Seths: pH
pH (standard units)
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

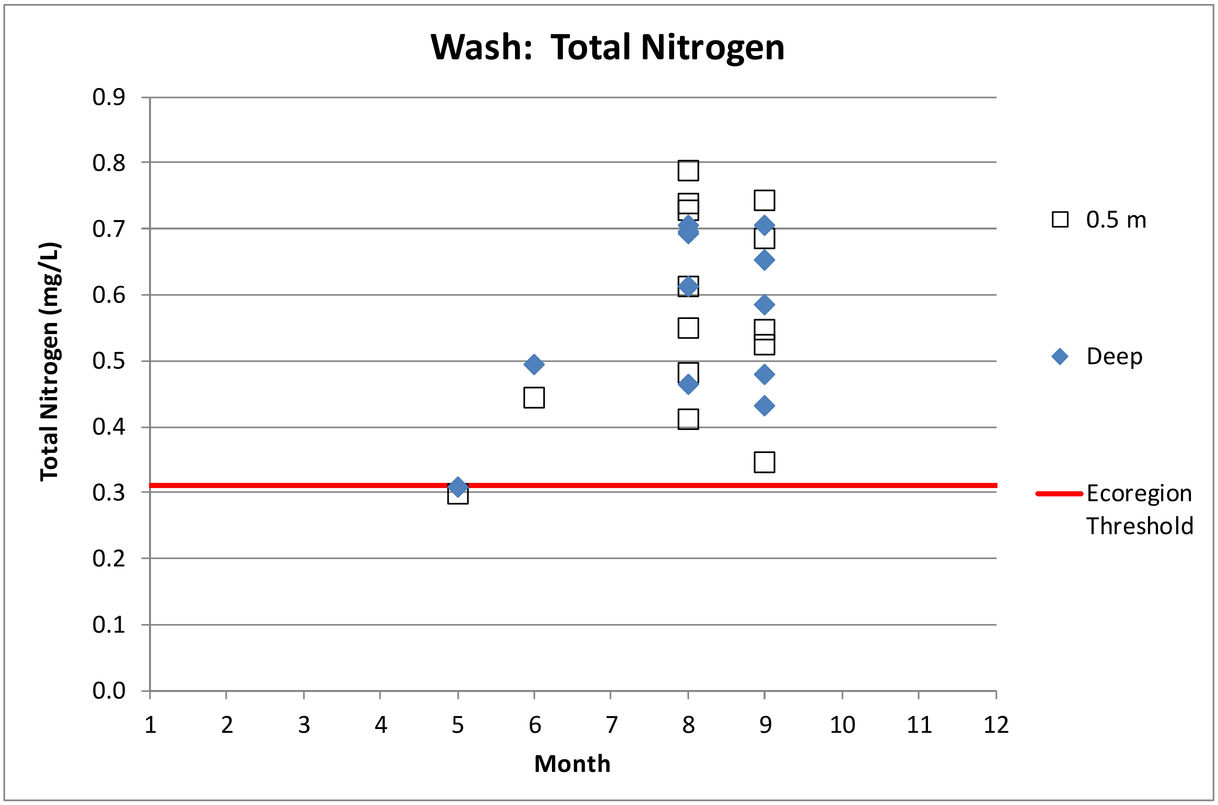
Wash Pond


Wash: Secchi
Depth (m)
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Secchi Depth (M)
Total Depth (M)

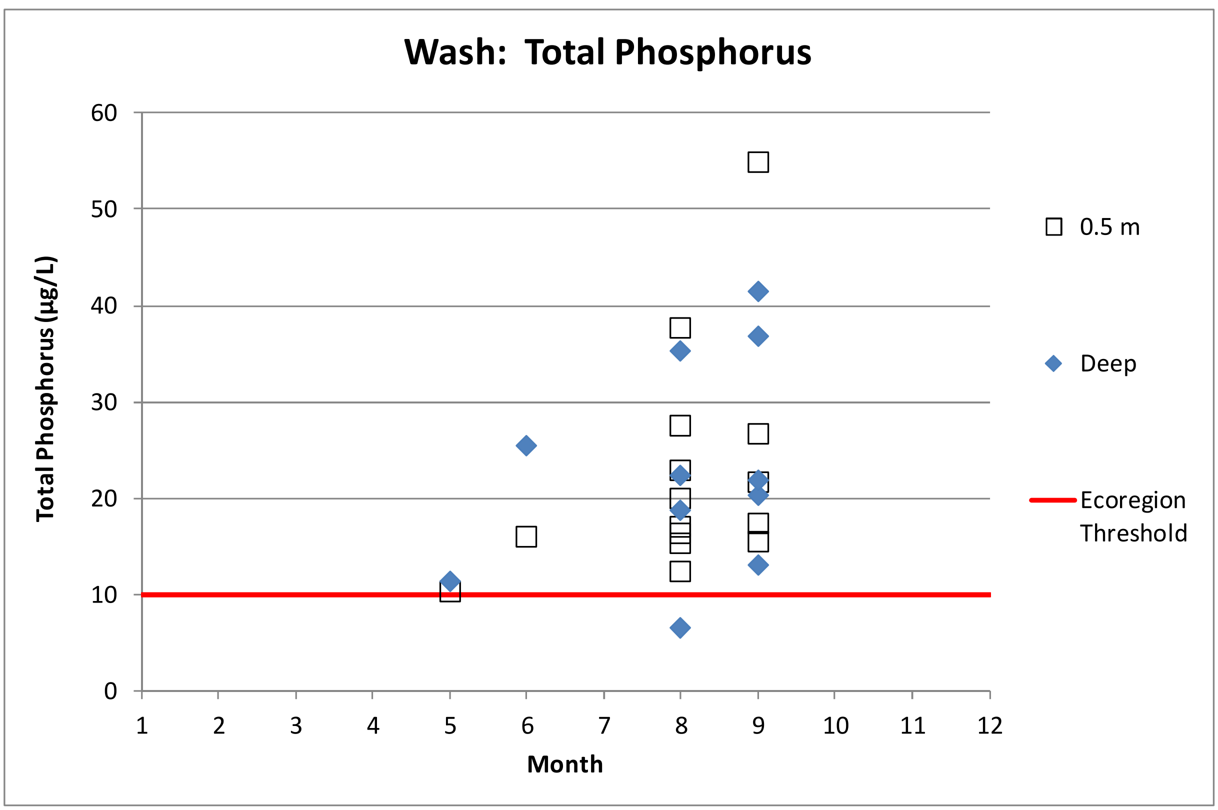

Wash: Temperature
Temperature (°C)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP maximum


Wash: Dissolved Oxygen
Dissolved Oxygen (mg/L)
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDEP minimum

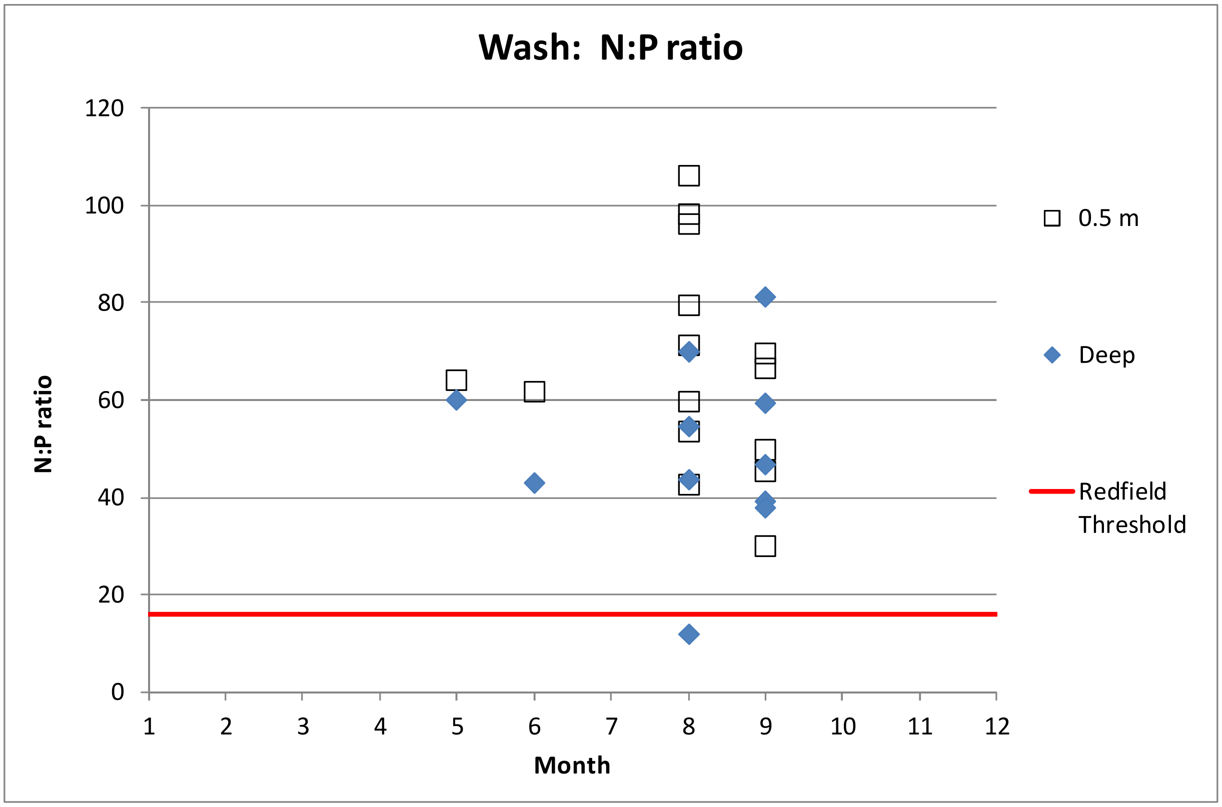

Wash: Dissolved Oxygen (% saturation)
Dissolved Oxygen (%sat)
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Atmospheric Equilibrium



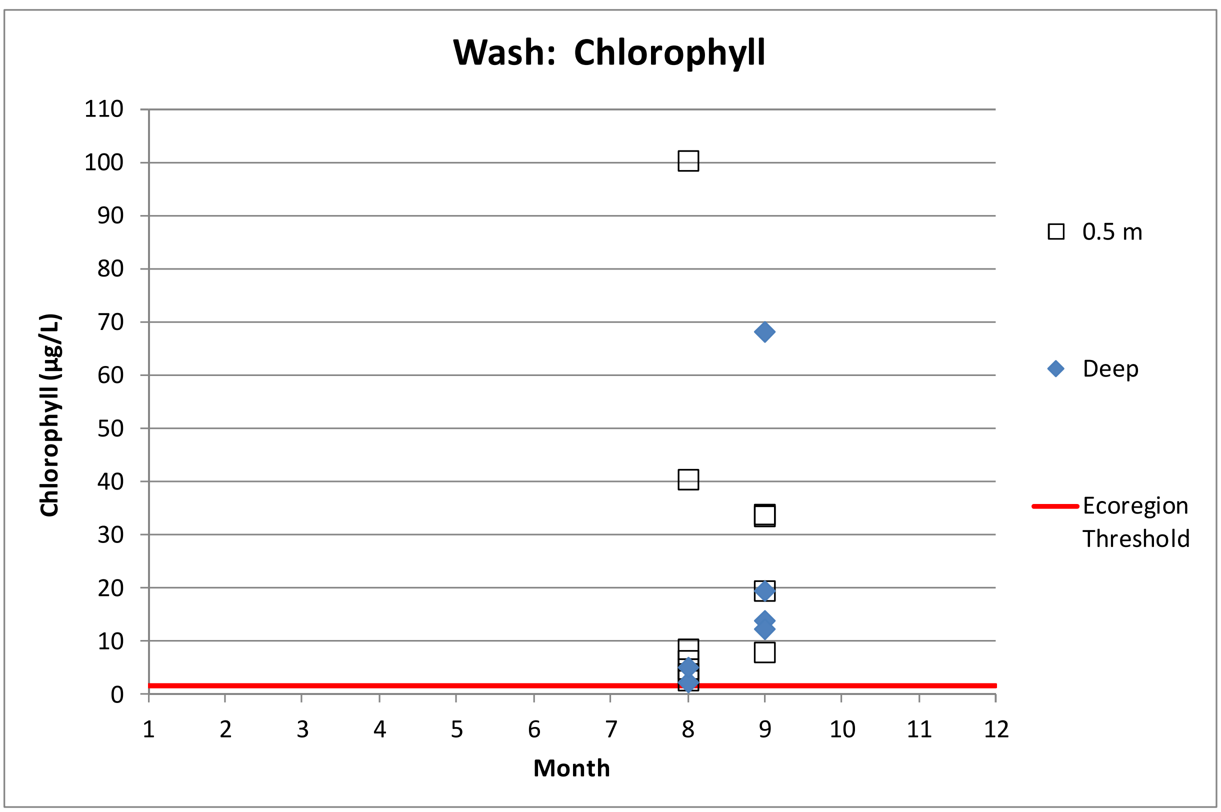
Wash: Total Nitrogen
Total Nitrogen (mg/L)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold



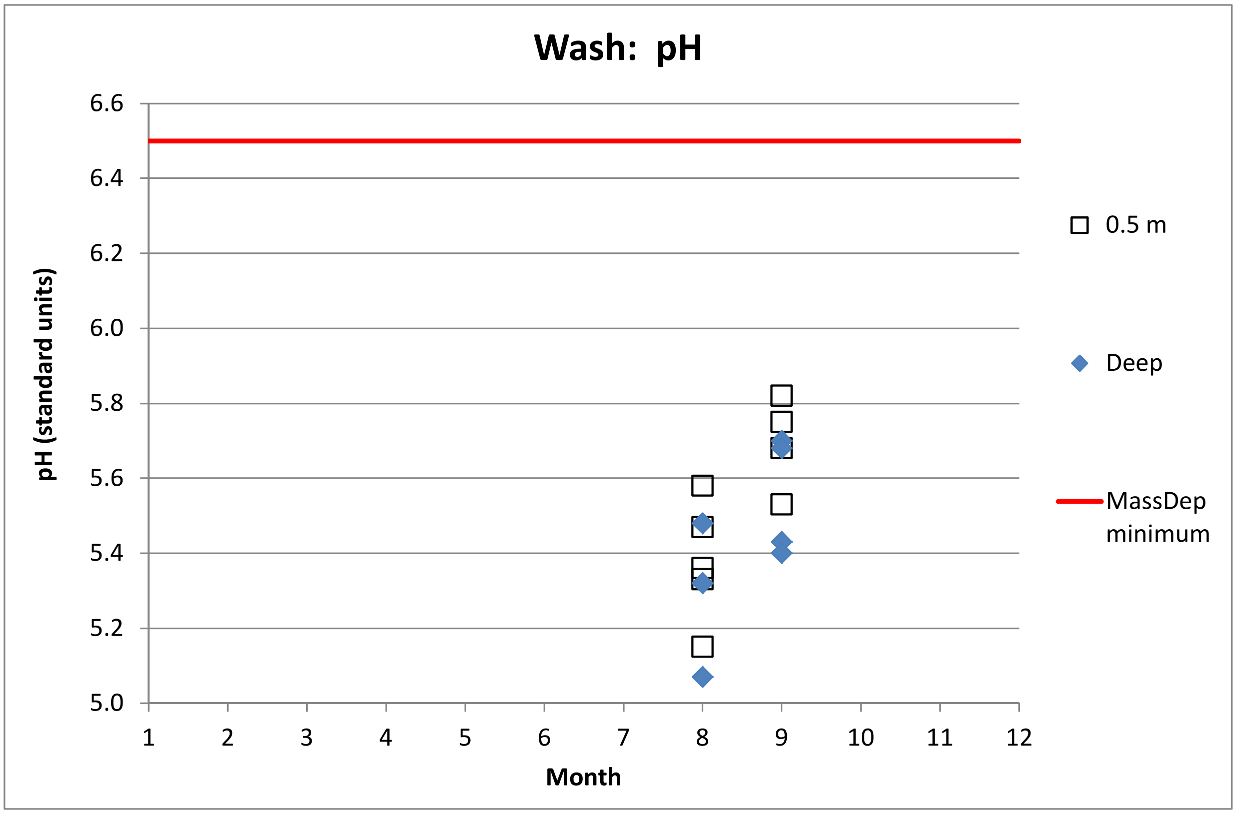
Wash: Total Phosphorus
Total Phosphorus (µg/L)
0
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
Ecoregion Threshold



Wash: N:P ratio
N:P ratio
Month
0.5 m
Deep
Redfield Threshold



Wash: Chlorophyll
Chlorophyll (µg/L)
Month
0.5 m
Deep
Ecoregion Threshold


Wash: pH
pH (standard units)
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
5.0
1
2
3
4
5
6
7
8
9
10
11
12
Month
0.5 m
Deep
MassDep minimum