Wequaquet Lake Profiling and Long-Term Management Plan

Final Report

Prepared For:
Town of Barnstable
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October 2013

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and
Phosphorus Management Planning

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1.0 INTRODUCTION

1.1 PURPOSE OF STUDY

This report provides an analysis of phosphorous loading from various sources to five basins in Lake Wequaquet: the Main Basin (which includes the most northerly basin and the central basin of the lake); the South Basin of the Lake; Gooseberry Pond; and Bearses Pond. The sources of phosphorous considered included: (1) previously estimated loading from natural areas, impervious surfaces, fertilizers, and wildlife; and (2) revises estimates of loadings from groundwater and rain based on data obtained in this study. The report also provides an analysis of the potential for sediment recycling of phosphorous based on: (1) previous estimates of hydrographic conditions and water column phosphorous concentrations in the lake; and (2) estimates of the depth and areal extent of fine unconsolidated sediments in the lake and the concentrations of phosphorous in the these unconsolidated sediments. The report includes (1) a management plan based on the results of these data analyses and (2) recommendations for further studies to address uncertainties in the assessments and to support the management plan.

1.2 SCOPE OF STUDY

The study included (1) measurement of phosphorous concentrations in shallow groundwater near the shore of the lake along shorelines previously identified as areas of groundwater discharge to the lake over several periods; (2) sampling of phosphorous concentrations in rain falling on the lake over the course of one year; (3) an acoustic bathymetric survey of the lake; (4) an acoustic sub-bottom profile of the thickness of the unconsolidated layer of the lake sediments; (5) sediment coring to sample lake sediments for the analysis of total phosphorous, loosely bound phosphorous, and iron bound phosphorous.

The data analysis and data products included: (1) basin by basin estimates of the loading of phosphorous from shallow groundwater to the five lake basins; (2) basin by basin estimates of the likely contribution of this groundwater load from septic systems within 100 meters of the shoreline under current conditions and at future breakout; (3) an updated and detailed bathymetric map of the Lake; (4) a detailed map of surficial sediment types covering the bottom of the lake; (5) an estimate of the thickness of the uconsolidated sediment layer in each lake basin; (6) a basin by basin estimate of rain water loading of phosphorus; (7) an analysis of the current trophic status of each lake basin based on total phosphorous loading and basin hydrography; (8) an analysis of the potential for phosphorous to release from that fraction of sediments that are occasionally subject to low oxygen conditions.

1.3 CONCLUSIONS OF THE STUDY

The analyses presented in this report suggest that:

1) The phosphorous loading to the lake from the existing septic systems is the largest manageable fraction of the total annual phosphorous load;

2) Some subset of these existing systems are likely to be experiencing breakout currently;
3) Without management actions to control the septic loading, future septic loading will increase sufficiently to drive the trophic status of the lake toward a eutrophic condition;
4) Recycling of phosphorous from sediments may contribute as much as 20% to 30% of the overlying water column phosphorous concentration but only during periods of near bottom anoxia in the Central Basin and Bearses Pond.

Several lines of evidence and analysis indicate that the lake basins, although currently classified as oligotrophic to mesotrophic are susceptible to further eutrophication over the next several decades because:

5) The trophic categorizations based on 95^{th} UCL on the average for groundwater and rainwater measurements of phosphorus indicate that all the basins are at least mesotrophic and Gooseberry may already be eutrophic;
6) The current chlorophyll data indicates that the basins are mesotrophic;
7) Dissolved oxygen data indicate occasional low bottom water oxygen;
8) The maximum and 95^{th} UCL on the mean of measured phosphorous concentrations in groundwater entering the lake suggests some breakout may be occurring;
9) The use of the 95 UCL on the mean in trophic categorizations is often similar to the expected categorization under an assumed condition of phosphorous breakout to the lake.

The general conclusion of these analyses is that Lake Wequaquet is eutrophying and may already be experiencing breakout from near shore septic systems. Although we cannot put a timeframe on the rate of eutrophication or breakout, we do note that the timeframe for breakout from the Otis Air Base plume to Ashumet Pond in Falmouth is on the time scale of decades (recognizing the higher septic loads to that system).

Several observations support the probability of breakout currently occurring, at least on local scales. These include: (1) the water quality data; (2) various aperiodic, but generally late summer qualitative observations of metaphyton blooms along the near shore areas of the lake; and (3) observations of near shore macro-algal blooms at various locations in the lake.

1.4 RECOMMENDATIONS

The report explicitly recognizes various sources of variability and uncertainty in the data and the data analyses, and makes various recommendations to address these. In addition, these recommendations incorporate recent systematic observations made during annual monitoring of the lake and incidental observations regarding transient algal blooms noticed by abutters. The report also describes the manageable loadings of phosphorous and discusses a range of alternatives to address these loadings.

2.0 SAMPLING METHODS

This section describes the methods used to sample near shore shallow groundwater, rainwater, sediments, and to measure lake depths to prepare a bathymetric map of the Lake Wequaquet, Bearses Pond, and Gooseberry Pond. The sampling and measurement program used standard methods, and laboratory analyses followed standard EPA or American Society for Testing and Materials (ASTM) methods for the measurement of chemical and physical parameters.

We assumed that shallow groundwater to Lake Wequaquet enters the lake in the near shore region based on:

- An empirical study in Falmouth (McCobb et al., 2003) demonstrating that phosphorous rich groundwater from a plume entered the Ashumet Pond in the immediate offshore area (within approximately 30 feet of the shoreline);
- Application of an empirically derived model (Pfannkuch et al., 1984) to the various basins of Lake Wequaquet indicating that 74% of the groundwater inflow to the lake occurs within 300 feet of the shoreline.

2.1 SHALLOW GROUNDWATER SAMPLING AND ANALYSIS

Shallow groundwater samples were collected during three separate sampling events in August and October, 2011, and June 2012. This sampling occurred at shorelines that prior studies demonstrated are areas of groundwater discharge to the lake (Eichner et al., 2009). Figure 2.1-1 shows these discharging shorelines.

2.1.1 Sampling Locations and Dates

The sampling stations were located along transects perpendicular to the shore (Figure 2.1-2). Each sample location was labeled with a letter (A through K). In the August, 2011 sampling, a number of locations did not produce groundwater, including location C on the map, on the southern portion of the Lake in the areas of groundwater recharge from the lake. At location B it was very difficult to draw water. No samples were collected at Bearses or Gooseberry Cove at this time. After this initial sampling round the southern areas of the lake that did not have discharging shorelines were not sampled.

The second sampling round took place in October 2011 after the August 2011 results were delivered from the lab. This round of sampling focused on sampling new locations along the discharging shorelines of the western main lake shoreline (locations E, F, and G) and a set of samples was collected from Bearses (location J) and Gooseberry Cove (location H).

The last round of sampling took place in June 2012 results at the locations that were previously sampled. This round of sampling focused on sampling the discharging shorelines of the western main lake shoreline (locations A, E, F, G, and K (formerly D),) and a set of samples was collected from Bearses (location J) and Gooseberry Cove (location H).

2.1.2 Sample Collection Methods and Measurements

These stations were sampled above, at, and below the shoreline using temporary installed piezometers. There is ample precedent for the use of piezometers to measure nutrient concentrations in lake and tidal shores of Cape Cod (e.g. Valiella et al., 1978; Kroeger et al., 2006). Groundwater samples were obtained from depths of one to three feet below the surface of the beach (for those samples above the shoreline) or sediment surface (for those samples at or below the shoreline).

These shallow groundwater samples were collected as pore water samples following the EPA method, Pore Water Sampling, SOP # SESDPROC-513-R0, February 05, 2007.

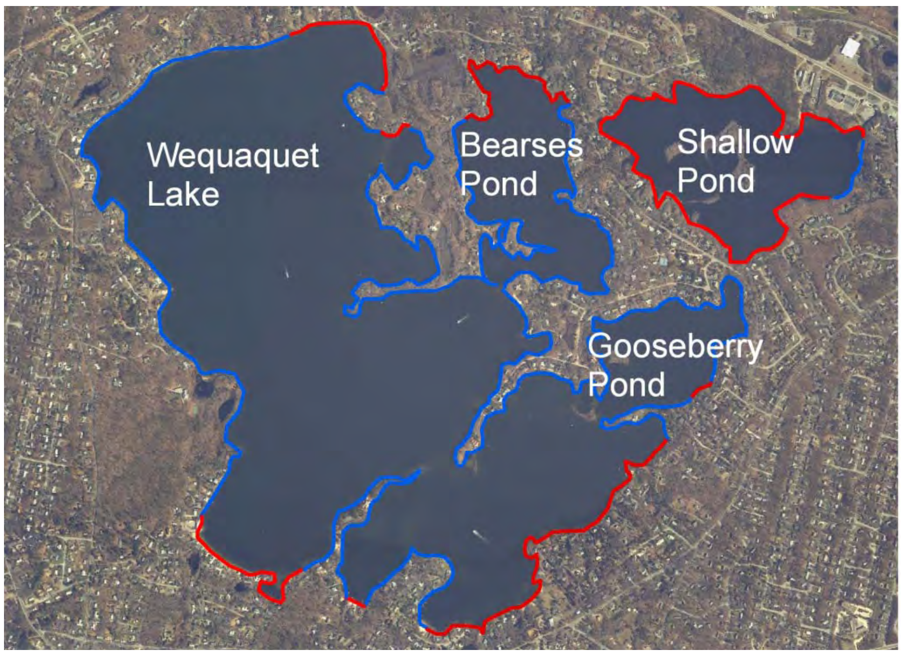


Figure 2.1-1. Shorelines discharging groundwater (blue) to Lake Wequaquet (from Eichner et al., 2009).

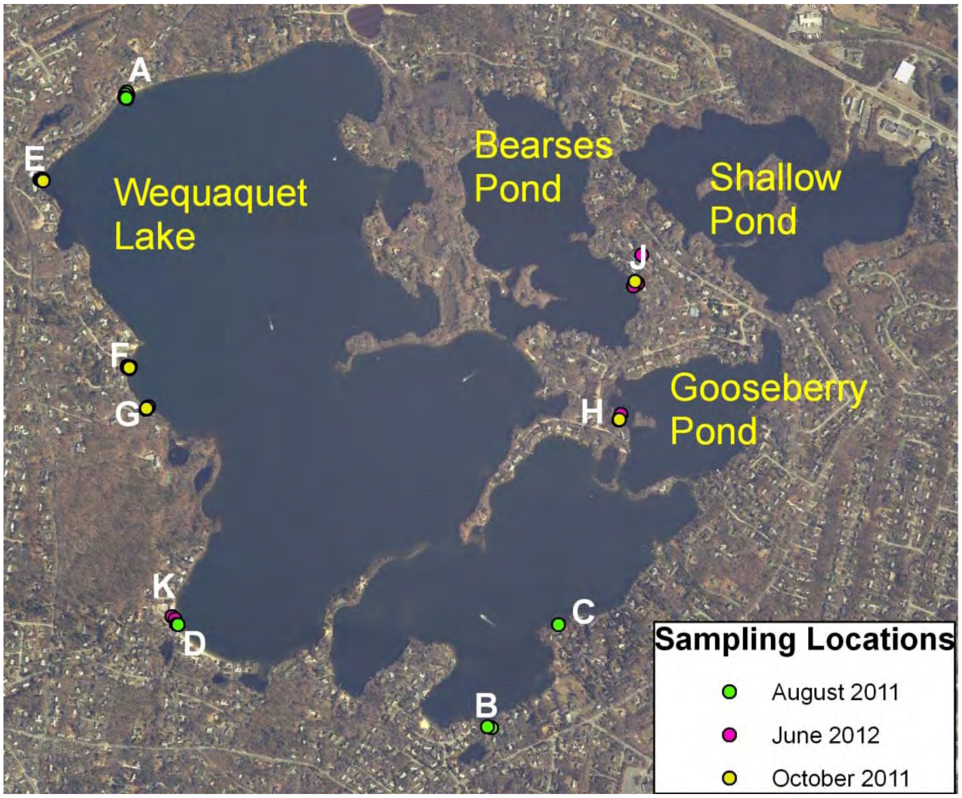


Figure 2.1-2. Shallow groundwater sampling locations for Lake Wequaquet.

The piezometer was a ½ inch hollow iron pipe screened in the bottom 8 inches with a steel point welded on the end. Sampling was initiated by inserting the piezometer sampler into the ground approximately one to three feet deep at the sampling location depending on depth to groundwater or obstructions, such as rocks, present in the ground. The piezometer was hammered into the ground with a slide hammer. Once the piezometer was in the place, an electronic water level meter was used to determine whether water was present in the ground. If water was not present, then the piezometer was hammered further into the ground. If after adjusting the piezometer water was still not found, then the piezometer was pulled from the ground and an additional attempt was made in another location nearby.

Once the water level meter indicated that water was present in the piezometer, ¼ inch polyethylene tubing was inserted down the center of the piezometer to the center of the of the well screen. The other end of the tubing was inserted into a short section of LPDE fitted to a peristaltic pump that was used to draw the groundwater. The effluent end of the peristaltic pump tubing was connected to a flow through cell fitted with a YSI multiparameter sonde to continuously monitor field parameters.

The field parameters included temperature, dissolved oxygen (DO), specific conductance, oxidation reduction potential (ORP), pH, and turbidity.

The YSI was calibrated at the beginning of each field day and the calibration was checked at the end of each day. The groundwater was pumped for several minutes to allow the field parameter readings time to stabilize. These field parameter readings were recorded every 3 to 5 minutes. Once the readings stabilized, the tubing was pulled from the YSI flow through cell and groundwater was discharged directly into the sample container. The time of sample collection was recorded and care was taken not to put the tubing into the bottle or knock debris into the sample container. In addition, several ambient surface water samples were collected and analyzed from each basin during each sampling event to provide a comparison with the groundwater sample results.

The samples were collected in laboratory supplied plastic sample bottles containing a preservative, H2SO4. Each sample was stored in a cooler on ice until delivered to the laboratory. Laboratory analysis of the shallow groundwater samples was performed using method ASTM D515-88(A) for Total Phosphorous and EPA Method 353.2 for Nitrate-Nitrite.

Quality control (QC) samples were collected during the sampling effort included field duplicate samples. Field duplicates are used to evaluate the field sampling procedures and laboratory accuracy and precision in analyzing the samples. Any field equipment such as pumps, tubing, porewater samplers, etc. that was reused between sampling locations was properly decontaminated including bladder pumps and water level meters. The decontamination procedure for equipment involved a deionized water rinse followed by scrubbing with decontamination fluid consisting of a non-phosphate detergent and deionized water mixed in a stainless steel pump sprayer. The decontamination fluid was then rinsed off with deionized water, which was followed by a final rinse with deionized water.

2.2 RAINWATER SAMPLING

Rainwater samples were collected to measure phosphorus concentration in rainwater and to obtain a measure of the variability in this important parameter. A rainfall collection gauge was set on the shores of the lake and collected rain during six rain events over the course of the study.

The samples were collected in plastic containers pre-preserved with H2SO4 provided by Spectrum Analytical, Inc. Each sample was stored in a cooler on ice until delivered to the laboratory. Laboratory analysis of the rain samples was performed using method ASTM D515-88(A) for Total Phosphorous and EPA Method 353.2 for Nitrate-Nitrite.

2.3 SEDIMENT SAMPLING

Sediment sampling occurred in two phases. The first phase of sediment sampling was the collection of surface sediment grab samples at 62 stations, and the second phase was the collection of samples from sediment cores.

2.3.1 Surface Grab Sampling

The surface grab sampling was done to ground-truth bathymetric survey interpretations of the lake bottom.

Surface sediment grabs were collected using a stainless steel Ponar grab sampler deployed from the deck of a small pontoon boat. This Ponar sampler consists of stainless steel jaws which are kept open by a spring-loaded pin. Once the device hits the bottom the tension in the lowering rope is lost, the pin is ejected, and the jaws close, collecting a sample of the top 0.5 feet of bottom sediment. Each grab sample was inspected and physically described for grain size and sediment type. Sixty two samples were collected: 17 in the north basin; 19 in the center basin, and 13 each in Bearses and Goosebury Ponds (Figure 2.3-). A table of sediment grab coordinates and descriptions are in Attachment 1. None of the grab samples underwent chemical analysis because they were used only to ground-truth the bathymetric survey results (section 2.4).

2.3.2 Vibracore Sampling

The second phase of sediment sampling was the collection of cores for (1) chemistry and physical characterization, and (2) to confirm the depth of the unconsolidated layer determined by the subbottom acoustic survey results (subsection 2.4).

Samples were collected using a vibracore. Areas of fine-grain sediment that showed stratification based on sub-bottom sonar data (see subsection 2.4) were selected for sampling. Vibracores were collected by inserting a Lexan polycarbonate core tube into a stainless steel casing, which was fixed to a weighted vibrating head. The vibrating head and core casing were lowered to the bottom using an A-frame and electric winch. Once on the bottom, the vibrating head was engaged to drive the stainless casing into the bottom sediment. Sediment cores were driven to a target depth that penetrated all of the stratigraphy observed in sub-bottom sonar data or to the point of refusal, whichever occurred first. Fourteen (14) sediment vibracores were collected: 4 in the north basin, 3 in the center basin, 3 in the south basin, 2 each in Goosebury and Bearses Ponds (Figure 2.3-2).

Sediment cores were kept upright until processed in the lab. Sediment cores were split lengthwise, and the two halves were rotated 90 degrees away from one another like the pages of a book. One half was used for physical description of grain size, color, and texture; the other half was used for chemical sampling. Analytical samples were collected using a clean stainless steel spoon at defined intervals based on the stratigraphy of each core. Samples were sent to Spectrum Analytical Inc. and analyzed for total phosphorous, loosely bound phosphorous, and iron bound phosphorous. Results of these analyses are presented in section 3.3.

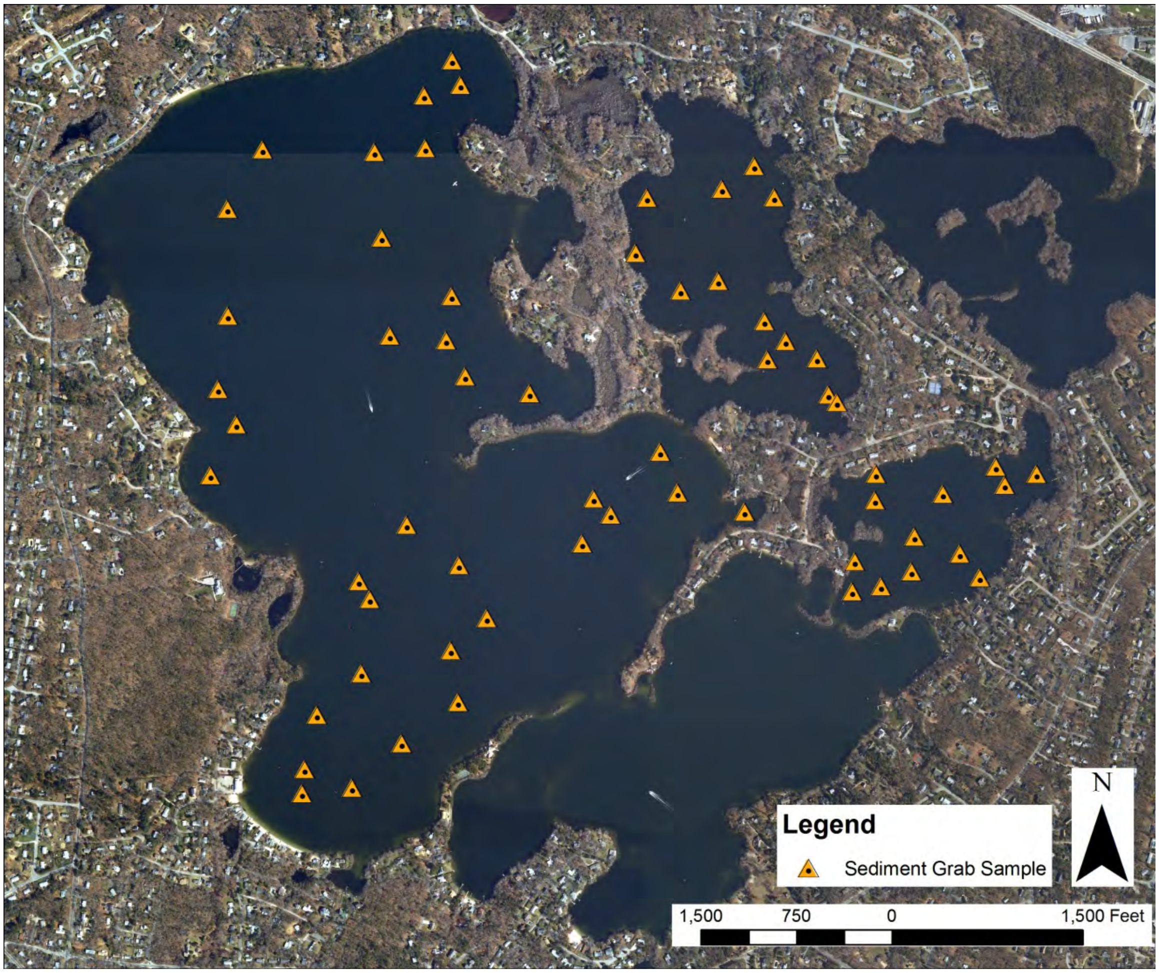


Figure 2.3-1 Sediment grab sample locations.

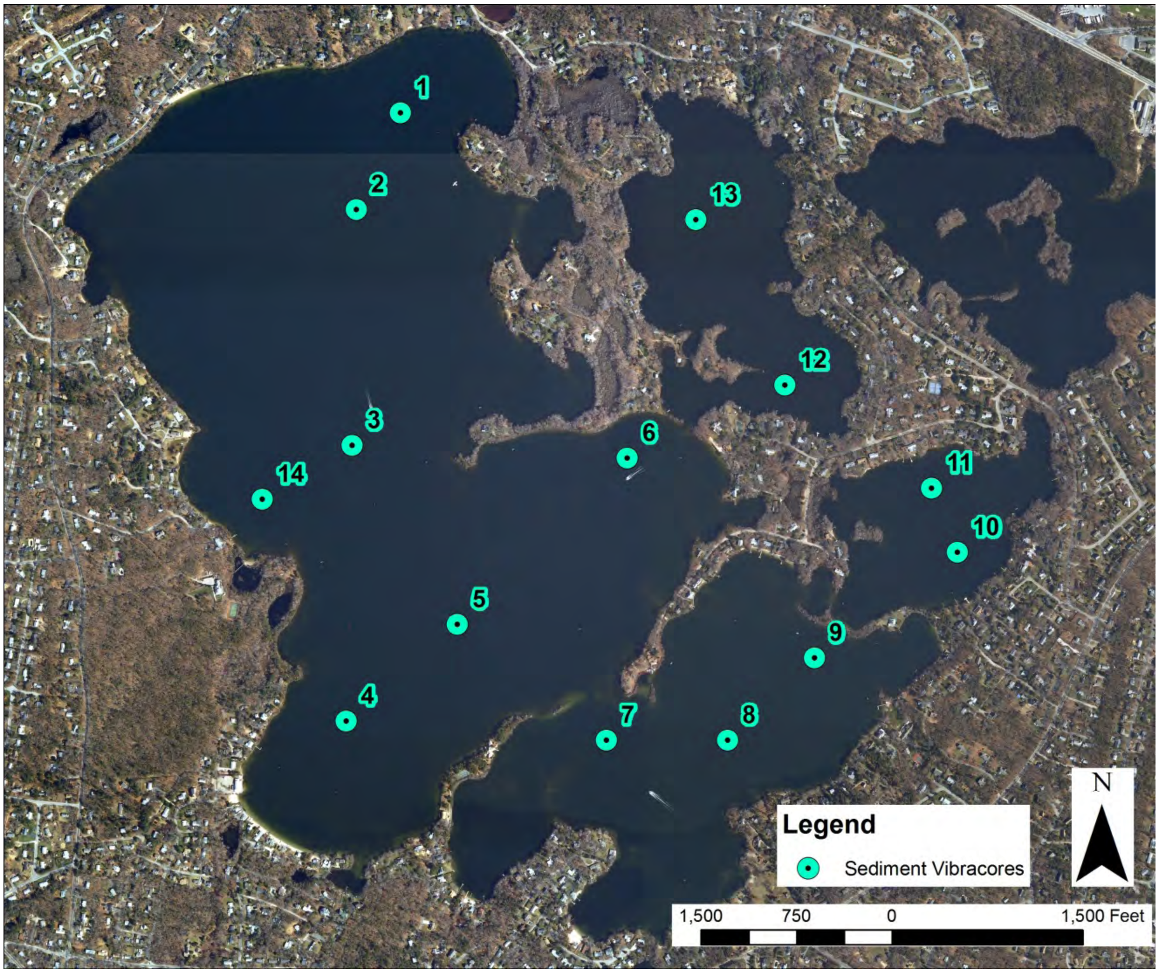


Figure 2.3-2 Sediment vibracore locations.

2.4 BATHYMETRIC AND SEDIMENT MAPPING

Bathymetric and sediment surveys were performed during two surveys. Each survey was performed aboard the *R/V George Hampson*, WHG's 24' pontoon boat, using a differential global positioning system (DGPS) for navigation. All acoustic and navigation data were logged and processed using a PC running hydrographic surveying software.

2.4.1 Bathymetric Survey and Data Processing

The purpose of the bathymetric survey was to provide an updated map of water depths of the lake.

During the first survey, on July 27, 2011, a single-beam echosounder and side-scan sonar were used to map the bathymetric features of the lake bottom. Additional bathymetric data were collected using the echosounder on August 18, 2011.

The bathymetric survey was performed using a 200-kHz SyQuest Hydrobox echosounder system. Over the course of the two surveys, the echosounder system was used to collect >189,000 soundings of the lake's bathymetry.

After post-processing for quality control, the data were filtered with a 1-m spatial buffer to create a data file containing 36,681 soundings; this file was used to subsequently interpolate (via the kriging method) the data into a 10m grid of the lake's bathymetry.

2.4.2 Side Scan Sonar for Surface Sediment Type

The purpose of the side scan sonar survey was to provide an estimate of the areal extent of fine grained sediments in the lake. These data were combined with an estimate of the thickness of the unconsolidated layer (subsection 2.4.2) to calculate the volume of loosely consolidated, organic rich sediments.

The side-scan sonar unit used for this survey was a dual frequency L3-Klein 3900; this instrument provided an acoustic representation of the lake's bottom morphology. The primary objective of using the side-scan sonar was to qualify the sediment type (e.g., fine-grained mud vs. coarser sands and gravel) of the lake bottom. The side-scan sonar can sense the subtle changes in acoustic "backscatter" from these different bottom types; in general, fine-grained sediments attenuate the acoustic signal, whereas coarser grained sediments reflect the acoustic signal. Therefore, analysis of the acoustic backscatter that is recorded by the side-scan sonar can provide a proxy for sediment grain size of the bottom sediments. The side-scan sonar survey covered the entire surface area of the pond in area where the water depth was >1 m.

During post-processing of the side-scan sonar data, the surface area of the lake bottom covered by both low and high acoustic backscatter was quantified using GIS software.

2.4.3 Subbottom Profile Survey for Unconsolidated Sediment Thickness

The purpose of the subottom profile survey was to provide an estimate of the depth of unconsolidated sediments in the lake. These data were combined with an estimate of the area of the fine grained surface sediments (subsection 2.4.2) to calculate the volume of loosely consolidated, organic rich sediments.

The acoustic survey of the subbottom sediments in Lake Wequaquet took place August 17-18, 2011 using an Edgetech 3100p deck unit and SB-424 CHIRP tow fish. The subbottom survey was performed to quantify the thickness of the fine-grained sediment layer that was quantified during the side scan sonar survey. The subbottom survey was focused on the areas interpreted with fine-grained sediment substrate. Previous research has shown that an organic rich fine-grained sediment layer overlays the sand and gravel that makes up the geological framework of the basins in the lake complex (IEP, 1989). Similar to the acoustic principles described for the side-scan sonar, the subbottom sonar will detect sediment layers with different acoustic properties, and therefore, different physical properties. The subbottom CHIRP sonar can detect these acoustic differences between sediment layers and, with processing, determine the thickness of layers. The data collected by the subbottom sonar system is represented as a cross-section, or vertical slice, of the sediment column.

Post-processing of the subbottom data was performed using the Chesapeake Technologies software. During this process, each subbottom cross-section was examined and layers were interpreted and digitized. Sediment core data, which was subsequently collected at strategic locations, were used to confirm ("groundtruth") the subbottom acoustic survey results. The outputs from post-processing were geographic positions (latitude and longitude) and depths below the sediment-water interface for particular sediment layers. Since the objective was to characterize the unconsolidated-loosely consolidated organic-rich surface sediment, the thickness of the first layer represented in the subbottom acoustic data was used for further analysis to quantify the spatial volume of this sediment layer.

3.0 FIELD SAMPLING RESULTS

This section provides the data obtained from the field sampling of the shallow groundwater, rainwater, sediment chemistry, and the sediment type and bathymetric mapping. These data are presented in tabular or graphical form as appropriate. Section 4 provides an analysis of these data as related to lake trophic status and phosphorous management issues.

3.1 SHALLOW GROUNDWATER SAMPLING RESULTS

As indicated in section 2.1, the chemical analysis of shallow groundwater included: field parameters (temperature, dissolved oxygen, specific conductance, oxidation reduction potential, pH, and turbidity) and laboratory analysis of total phosphorous and nitrate-nitrogen.

Table 3.1-1 provides the values of the field parameters from each sampling station after stabilization of the values.

Table 3.1-1. Field Parameters for Shallow Groundwater.

Sample ID	Date	T °C	Conduc-tivity	Dissolved Oxygen	pH	ORP	Turbidity	Air Pressure
			uS/cm @ 25 C	mg/L		mV	NTU	mm Hg
WQ-TA1	8/18/2011	24.8	147	0.45	6.15	9.3	9.1	763.0
WQ-TA2	8/18/2011	24.33	386	0.35	5.42	224.5	4.9	766.0
WQ-TA3	8/18/2011	23.62	303	0.38	4.96	282.8	2.2	765.7
WQ-TA4	8/18/2011	22.13	117	8.16	5.09	335.7	1.7	765.0
WQ-TA4-A	8/18/2011	26.43	131	9.15	7.61	327.2	0.6	765.0
WQ-TA4-B	8/18/2011	22.13	117	8.16	5.09	335.7	1.7	765.0
WQ-TA5	8/18/2011	23.68	120	4.81	5.18	329.1	0.2	765.8
WQ-TB1	8/18/2011	29.73	137	7.52	6.82	122.8	7.3	763.5
WQ-TB1-A	8/18/2011	26.72	128	9.07	8.37	279.1	0.5	764.6
WQ-TD1	8/18/2011	24.18	201	0.34	6.35	-17.0	0.3	761.7
WQ-TD3	8/18/2011	23.56	187	0.35	6.30	27.2	11.7	761.4
WQ-TE1	10/25/2012	24.8	147	0.45	6.15	9.3	9.1	763.0
WQ-TE2	10/25/2012	24.33	386	0.35	5.42	224.5	4.9	766.0
WQ-TE3	10/25/2012	23.62	303	0.38	4.96	282.8	2.2	765.7
WQ-TF1	10/25/2012	22.13	117	8.16	5.09	335.7	1.7	765.0
WQ-TF2	10/25/2012	26.43	131	9.15	7.61	327.2	0.6	765.0
WQ-TF3	10/25/2012	22.13	117	8.16	5.09	335.7	1.7	765.0
WQ-TG1	10/25/2012	23.68	120	4.81	5.18	329.1	0.2	765.8
WQ-TG2	10/25/2012	29.73	137	7.52	6.82	122.8	7.3	763.5
WQ-TG3	10/25/2012	26.72	128	9.07	8.37	279.1	0.5	764.6
WQ-TH1	10/25/2012	15.83	120	7.96	4.22	-220.0	7.5	756.0
WQ-TH1-A	10/25/2012	15.86	107	9.55	5.27	-207.0	1.2	756.0

Sample ID	Date	T °C	Conduc-tivity	Dissolved Oxygen	pH	ORP	Turbidity	Air Pressure
			uS/cm @ 25 C	mg/L		mV	NTU	mm Hg
WQ-TJ1	10/26/2012	16.57	170	1.21	6.00	-172.0	5.8	773.0
WQ-TA1	6/14/2012	17.92	120	0.65	NS	NS	2.4	780.2
WQ-TA2	6/14/2012	18.25	108	0.46	NS	NS	7.5	780.3
WQ-TA3	6/14/2012	18.89	1027	0.48	NS	NS	0.0	780.3
WQ-TA3-A	6/14/2012	19.45	360	7.32	NS	NS	0.0	780.3
WQ-TE1	6/14/2012	15.95	118	0.6	NS	NS	9.0	780.6
WQ-TE2	6/14/2012	16.41	132	7.5	NS	NS	3.1	780.6
WQ-TE3	6/14/2012	18.5	148	0.61	NS	NS	1.8	780.7
WQ-TF1	6/14/2012	17.6	75	6.92	NS	NS	9.4	780.9
WQ-TF2	6/14/2012	16.71	145	0.72	NS	NS	8.6	781.2
WQ-TF3	6/14/2012	17.15	222	8.29	NS	NS	5.1	781.2
WQ-TG1	6/14/2012	16.97	165	0.95	NS	NS	1.0	781.6
WQ-TG2	6/14/2012	17.66	184	0.7	NS	NS	1.8	781.8
WQ-TH1	6/15/2012	20.65	107	0.87	NS	NS	7.6	783.5
WQ-TH1-A	6/15/2012	22	107	8.18	NS	NS	2.8	783.5
WQ-TH2	6/15/2012	20.95	104	5.38	NS	NS	9.2	784.4
WQ-TJ1	6/15/2012	16.13	99	6.34	NS	NS	8.9	782.0
WQ-TJ2	6/15/2012	16.56	112	0.69	NS	NS	16.5	782.5
WQ-TJ3	6/15/2012	21.12	125	0.75	NS	NS	10.8	783.7
WQ-TJ3-A	6/15/2012	22.08	103	8.9	NS	NS	0.0	783.7
WQ-TK1	6/14/2012	17.53	107	0.78	NS	NS	6.7	781.5
WQ-TK2	6/14/2012	20.71	102	7.56	NS	NS	5.4	781.8
WQ-TK2-A	6/14/2012	21.79	108	9.01	NS	NS	7.6	781.8
WQ-TH1	12/12/2012	6.45	98	7.93	5.81	7	NS	778.3
WQ-TH2	12/12/2012	6.58	133	7.32	5.83	22.6	NS	778.3
WQ-TJ1	12/12/2012	5.26	134	12.15	5.19	36.4	NS	778.7
WQ-TL1	12/12/2012	8.26	113	0.3	5.7	-16.2	NS	778.5
WQ-TL2	12/12/2012	7.43	116	0.16	6.02	-62.8	NS	778.6
WQ-TL3	12/12/2012	7.77	111	0.18	6.02	-54	NS	778.6
WQ-TL3-A	12/12/2012	6.83	110	10.67	6.02	-0.5	NS	778.6
WQ-TM1	12/12/2012	7.37	112	0.23	5.5	-8	NS	778.6
WQ-TM1-A	12/12/2012	6.28	114	11.69	5.85	45	NS	778.6
WQ-TM2	12/12/2012	7.07	121	0.2	6.14	53.9	NS	778.6
WQ-TN1	12/12/2012	9.17	91	0.13	5.53	-3.5	NS	777.9
WQ-TN2	12/12/2012	9.32	91	0.07	5.94	-63.9	NS	777.9
WQ-TN3	12/12/2012	8.86	100	0.11	5.11	-21.7	NS	778.1
WQ-TN3-A	12/12/2012	7.32	112	Nov-81	5.73	0.8	NS	778.1
WQ-TO1	12/12/2012	9.83	130	10.45	4.77	89.8	NS	777.6

Sample ID	Date	T ^{O}C	Conduc-tivity	Dissolved Oxygen	pH	ORP	Turbidity	Air Pressure
			uS/cm @ 25 C	mg/L		mV	NTU	mm Hg
WQ-TO2	12/12/2012	8.79	133	10.02	4.96	90.2	NS	777.9
WQ-TO3	12/12/2012	7.78	266	0.3	5.24	61.7	NS	777.9
NS= Not Sampled								

Tables 3.1-2 through 3.1-5 provide the total phosphorous data by station with summary statistics. Figures 3.1-1, 3.1-3, and 3.1-5 show these data plotted as distance from the water's edge at each transect (we do not provide a figure for the South Basin data because the data set was small). Figures 3.1-2, 3.1-4, and 3.1-6 are box and whisker plots that show the average, range, 25th percentile, and 75th percentile values for phosphorous in: (1) shallow groundwater from samples taken at and above the shoreline; (2) shallow groundwater from samples taken below the shoreline; (3) rainfall; (4) in basin surface water. In addition these figures show the Cape Cod regional background for phosphorous in groundwater (Frimpter and Gay, 1979) and the laboratory detection limits. The data tables include field samples designated as FS, and field duplicates designated as FD. Measures below laboratory detection limits were assumed to be half the detection limit and are designated by a star in the tables. For statistical calculations, the field duplicates were considered as separate samples. The statistics in the tables and the individual data points on the figures indicate wide variability in the data regardless of basin. Within each basin, the broad ranges in values, the large standard deviations relative to the mean, and the 95th Upper Confidence Levels[1] for the mean demonstrate the variable nature of these data.

3.1.1 Main Basin

In the Main Basin (Table 3.1-2) there were 32 individual measurements of phosphorous along the transects ranging from 0.003 (non-detect value) to 0.24 mg/L. Figures 3.1-1 and 3.1-2 show that: (1) the shallow groundwater phosphorous concentrations were generally higher in samples obtained at or above the shoreline relative to the concentrations in groundwater samples obtained from below the shoreline; and (2) both these average concentrations in groundwater exceed the average concentrations in surface water.

[1] The UCL is the value that when calculated for a random data set equals or exceeds the true mean 95% of the time. In subsequent phosphorous loading calculations, we used the 95th UCL as an upper estimate of the mean to account for uncertainty in the measurement.

Table 3.1-2. Main Basin Lake Wequaquet Surface and Groundwater Phosphorous Concentrations

Transect	Sample ID	Type	DATE	Phosphorus as P (mg/L)
Surface Water	WQ-TA3-A		Summer 2012	0.0141
	WQ-TA4-A		Summer 2011	0.028
	WQ-TB1-A		Summer 2011	0.016
	WQ-TF3-A		Fall 2011	0.0139
	WQ-TK2-A		Summer 2012	0.0303
	Average			**0.02**
A	WQ-TA1	FS	Summer 2011	0.24
	WQ-TA1	FS	Summer 2012	0.14
	WQ-TA1-D	FD	Summer 2012	0.13
	WQ-TA2	FS	Summer 2011	0.03
	WQ-TA2	FS	Summer 2012	0.05
	WQ-TA3	FS	Summer 2012	0.01
	WQ-TA4	FS	Summer 2011	0.03
	WQ-TA4-B	FD	Summer 2011	0.02
	WQ-TA3*	FS	Summer 2011	0.005
	WQ-TA5*	FS	Summer 2011	0.005
D	WQ-TD1	FS	Summer 2011	0.16
	WQ-TD2	FS	Summer 2011	0.17
E	WQ-TE1	FS	Fall 2011	0.12
	WQ-TE1	FS	Summer 2012	0.08
	WQ-TE1-B	FD	Fall 2011	0.11
	WQ-TE2	FS	Fall 2011	0.11
	WQ-TE2	FS	Summer 2012	0.09
	WQ-TE3	FS	Fall 2011	0.05
	WQ-TE3	FS	Summer 2012	0.04
F	WQ-TF1	FS	Fall 2011	0.05
	WQ-TF1	FS	Summer 2012	0.01
	WQ-TF2	FS	Fall 2011	0.07
	WQ-TF2	FS	Summer 2012	0.02
	WQ-TF3	FS	Fall 2011	0.01
	WQ-TF3	FS	Summer 2012	0.04
G	WQ-TG1	FS	Fall 2011	0.01

Transect	Sample ID	Type	DATE	Phosphorus as P (mg/L)
	WQ-TG1	FS	Summer 2012	0.01
	WQ-TG2	FS	Fall 2011	0.01
	WQ-TG2	FS	Summer 2012	0.02
	WQ-TG3*	FS	Fall 2011	0.003
K	WQ-TK1	FS	Summer 2012	0.08
	WQ-TK2	FS	Summer 2012	0.02
Statistics for Main Basin				
Mean				**0.061**
Standard Error				0.011
Median				0.042
Mode				0.005
Standard Deviation				0.060
Minimum				0.003
Maximum				0.240
Count				32.000
Confidence Level(95.0%)				0.022
UCL				**0.082**
*** P entered as one-half reporting limit**				

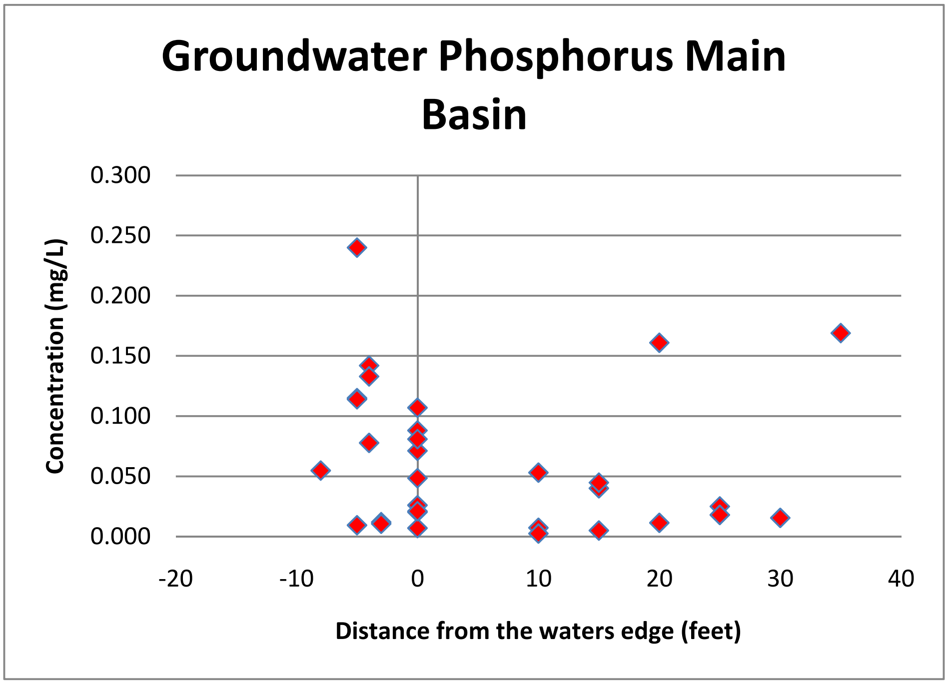


Figure 3.1-1. Main Basin Groundwater Concentrations vs Distance from Water's Edge

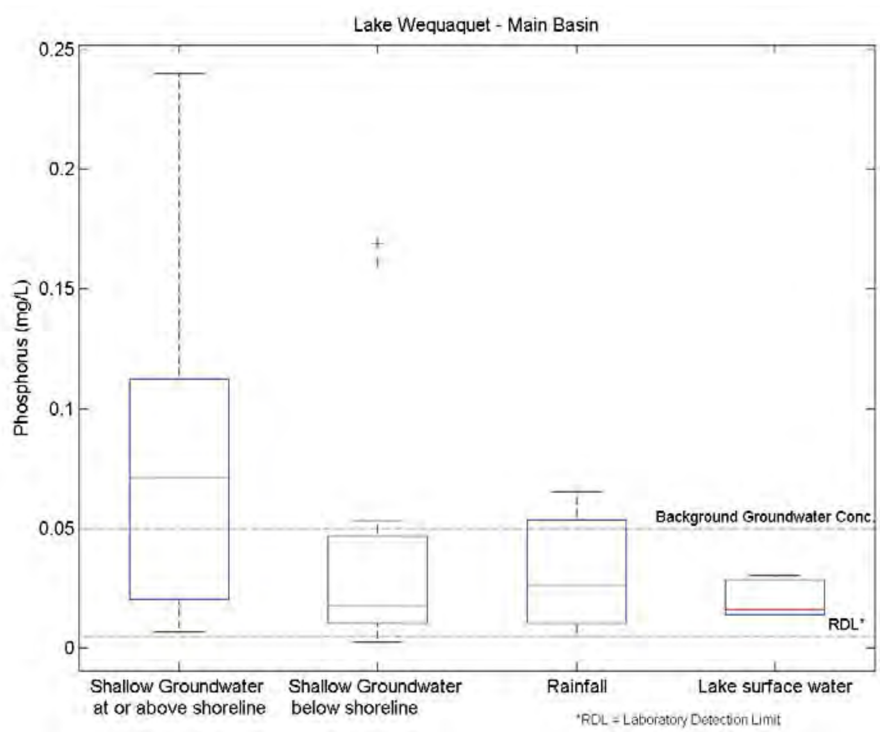


Figure 3.1-2. Box Plots of Phosphorous Concentrations for Main Basin in Shallow Groundwater, Rain, and Lake Surface Water. Background Groundwater Concentration and Analytical Reporting Limits Are Shown.

3.1.2 Gooseberry Pond

In Gooseberry Pond (Table 3.1-3) there were 10 individual measurements of phosphorous along the transects ranging from 0.014 to 0.320 mg/L. Figures 3.1-3 and 3.1-4 show that: (1) the shallow groundwater phosphorous concentrations were generally higher in samples obtained at or above the shoreline relative to the concentrations in groundwater samples obtained from below the shoreline; (2) the average concentrations in groundwater at or above the shoreline exceed the average concentrations in surface water; and (3) the average concentrations in shallow groundwater below the shoreline is similar to the surface water concentrations.

Table 3.1-3. Gooseberry Pond Surface and Groundwater Phosphorous Concentrations

Transect	Sample ID	Type	Date	Phosphorus as P (mg/L)
Surface Water	WQ-TH1-A		Fall 2011	0.01
	WQ-TH1-A		Summer 2012	0.01
	WQ-TL1-A		Winter 2012	0.16
	Average			**0.06**
H	WQ-TH1	FS	Summer 2012	0.07
	WQ-TH1	FS	Winter 2012	0.14
	WQ-TH2	FS	Fall 2011	0.01
	WQ-TH2	FS	Summer 2012	0.25
	WQ-TH2-D	FD	Summer 2012	0.32
	WQ-TH2	FS	Winter 2012	0.04
L	WQ-L1	FS	Winter 2012	0.02
	WQ-L2	FS	Winter 2012	0.06
	WQ-L3	FS	Winter 2012	0.18
	WQ-L3-D	FD	Winter 2012	0.04
	Statistics for Gooseberry			
Mean				**0.114**
Standard Error				0.033
Median				0.066
Mode				#N/A
Standard Deviation				0.105
Minimum				0.014
Maximum				0.320
Count				10.000
Confidence Level(95.0%)				0.08
UCL				**0.19**

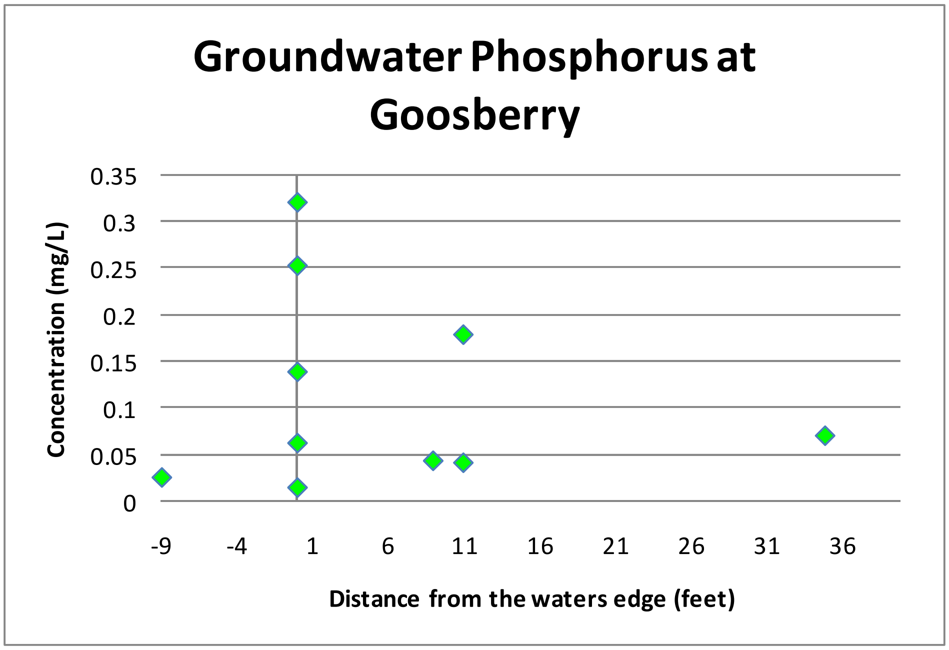


Figure 3.1-3. Gooseberry Pond Groundwater Concentrations vs Distance from Water's Edge

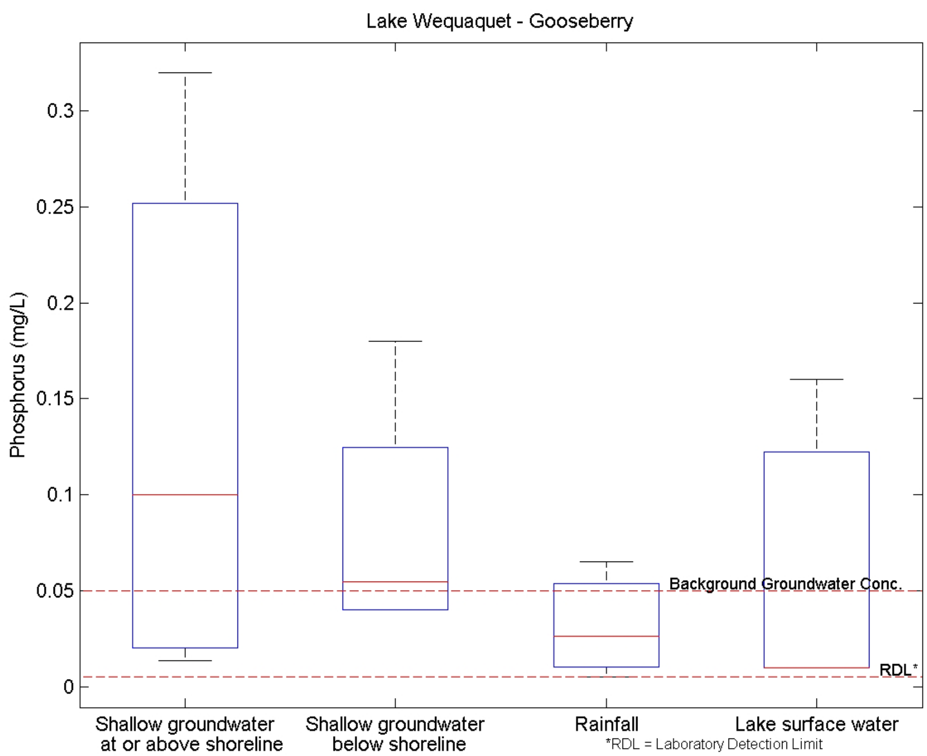


Figure 3.1-4. Box Plots of Phosphorous Concentrations for Gooseberry Pond in Shallow Groundwater, Rain, and Lake Surface Water. Background Groundwater Concentration and Analytical Reporting Limits Are Shown.

3.1.3 Bearses Pond

In Bearses Pond (Table 3.1-4) there were 10 individual measurements of phosphorous along the transects ranging from 0.003 (non-detected value) to 0.112 mg/L. Figures 3.1-5 and 3.1-6 show that: (1) the shallow groundwater phosphorous concentrations were generally lower in samples obtained at or above the shoreline relative to the concentrations in groundwater samples obtained from below the shoreline; (2) the average concentrations in groundwater at or above the shoreline was similar to the average concentrations in surface water; (3) phosphorous concentrations in groundwater at Bearses are below background concentrations for Cape Cod.

Table 3.1-4. Bearses Pond Surface and Groundwater Phosphorous Concentrations

Transect	Sample ID	Type	Date	Phosphorus as P (mg/L)
Surface Water	WQ-TJ3-A		Summer 2012	0.01
	WQ-TI1-A		Fall 2011	0.03
	WQ-TM1-A		Winter 2012	0.01
J	WQ-TJ1	FS	Summer 2012	0.01
	WQ-TJ2	FS	Summer 2012	0.01
	WQ-TJ3	FS	Fall 2011	0.11
	WQ-TJ3	FS	Summer 2012	0.02
	WQ-TJ3*	FS	Winter 2012	0.003
M	WQ-TM1	FS	Winter 2012	0.06
	WQ-TM2	FS	Winter 2012	0.03
O	WQ-TO1	FS	Winter 2012	0.02
	WQ-TO2	FS	Winter 2012	0.02
	WQ-TO3	FS	Winter 2012	0.02
Statistics for Bearses				
Mean				**0.030**
Standard Error				0.010
Median				0.020
Mode				#N/A
Standard Deviation				0.033
Minimum				0.003
Maximum				0.112
Count				10.000
Confidence Level(95.0%)				0.023
UCL				**0.054**
*** P entered as one-half reporting limit**				

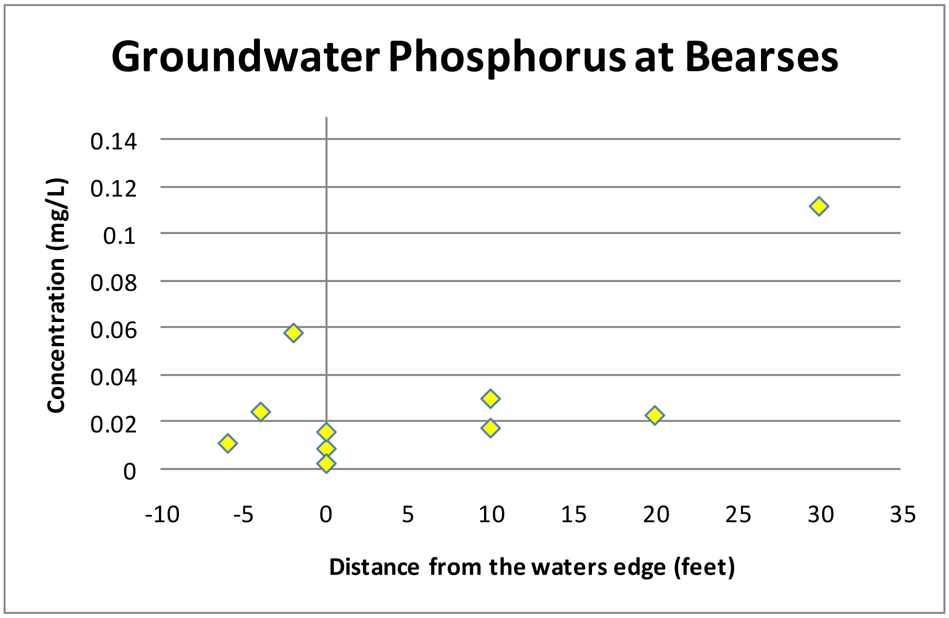


Figure 3.1-5. Bearses Pond Groundwater Concentrations vs Distance from Water's Edge

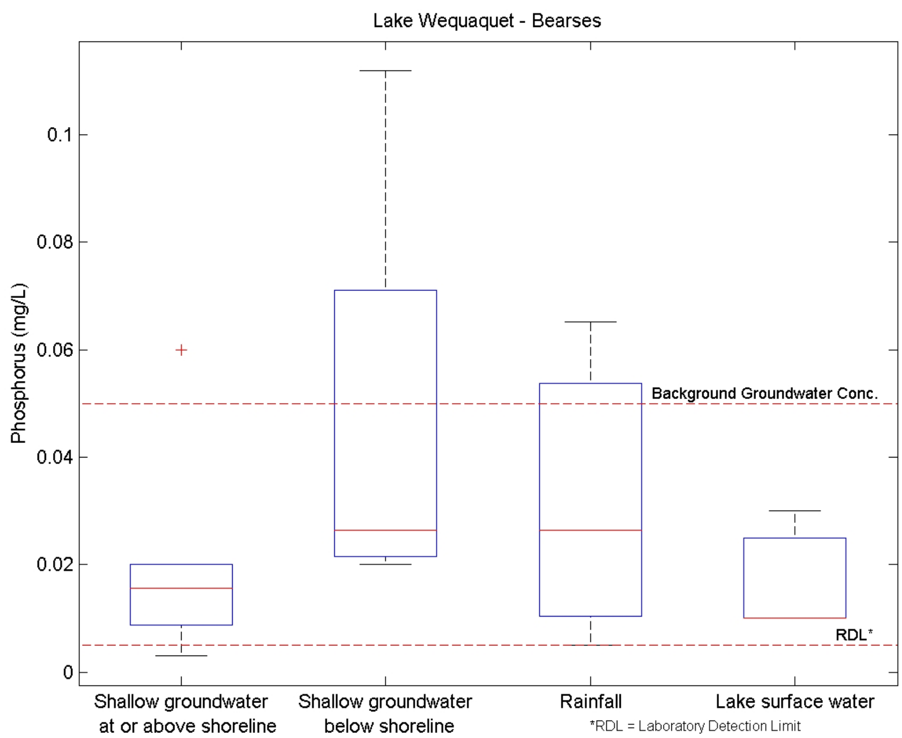


Figure 3.1-6. Box Plots of Phosphorous Concentrations for Bearses Pond in Shallow Groundwater, Rain, and Lake Surface Water. Background Groundwater Concentration and Analytical Reporting Limits Are Shown.

3.1.4 South Basin

In South Basin Pond (Table 3.1-5) there were 3 individual measurements of phosphorous along the transect ranging from 0.05 to 0.08 mg/L.

Table 3.1-5. South Basin Groundwater Phosphorous Concentrations

Transect	Sample ID	Type	Date	Phosphorus as P (mg/L)
N	WQ-TN3-A	Surface Water	Winter 2012	0.17
	WQ-TN1	FS	Winter 2012	0.08
	WQ-TN2	FS	Winter 2012	0.23
	WQ-TN3	FS	Winter 2012	0.05
Statistics for South Basin				
Mean				**0.122**
Median				0.083
Standard Deviation				0.098
Minimum				0.049
Maximum				0.233
Count				3.000
Confidence Level(95.0%)				0.243
UCL				**0.36**

3.2 RAINWATER SAMPLING RESULTS

Table 3.2-1 provides the phosphorous concentrations measured in rain by date. Box and whisker plots of these data (obtained from the analysis of samples obtained from the shore of Bearses Pond) are included on each of Figures 3.1-4 through 3.1-6. These figures show that the concentration of phosphorous in rain is less than the background concentration of phosphorous in Cape Cod groundwater (Frimpter and Gay, 1979) and is less than surface water concentrations (except for Bearses Pond).

3.3 SEDIMENT SAMPLING RESULTS

Previous research has shown that an organic rich fine-grained sediment layer overlays the sand and gravel that makes up the geological framework of the basins in the lake complex (IEP, 1989). The results from the surface grab survey confirm this research. The Lake is spatially heterogeneous in terms of sediment type and no single sediment type or grain size dominates any of the five basins. However, sediment type was strongly correlated with depth, where increased depth often led to increased percentage of fine-grain sediment (silt and mud). The deepest areas of each basin contained the highest percentage of fine-grain material, and the shallower areas contained the most coarse-grained sediment (cobbles, gravel and sand). This is most evident when comparing Figures 3.4-1 (bathymetric map) which shows the depth contours and 3.4-2 which shows the surface sediment type based on side-scan backscatter. The transition from coarser sediment in the shallower flanks to finer sediment in the deeper reaches occurred gradually in most basins, typically over approximately 100 to 300 feet horizontally. However, in Bearses and Gooseberry Ponds, the transition took place much more rapidly, on the order of 50 feet or less in some places.

Table 3.2-1. Lake Wequaquet Rain Phosphorous Concentrations

Date	Total P as P (mg/L)
8/16/2011	0.07
9/7/2011	0.01
10/27/2011	0.03
1/29/2012	0.01
Apr-12	0.05
Statistics for rain data	
Mean	0.03
Standard Error	0.01
Standard Deviation	0.03
Minimum	0.01
Maximum	0.07
Count	5
Confidence Level(95.0%)	0.03
95UCL	0.06

Sediment core locations were obtained in areas of fine-grain sediment. Sediment cores were physically described using ASTM guidelines. In some cores there was a considerable layer of muddy water overlying the loosely consolidated bottom sediments. This layer was up to 0.8 feet thick in some cores. This unconsolidated material was not retained for further analysis during sample processing. This unconsolidated layer was often underlain by a loosely-consolidated layer of organic sediment, with varying percentages of silt and clay. The thickness of the organic silt layer varied among cores from 0.2 – 4.3 feet. Water content of the organic silt layer decreased with increasing depth in each core, leading to increased consolidation. Beneath the upper, fine-grain units were layers of coarser-grained sand or gravel. The transition between these two units was often gradual, with varying dominance between silt and sand (e.g. silty sand vs. sandy silt).

Results from chemical analyses show that in general, phosphorus as P (mg/kg dry) was highest in samples from the top 0.0-0.5 foot interval. The average difference between the upper and lower samples from each core was 303 mg/kg, with a range from 10 – 798 mg/kg. The three largest concentrations came from cores WC-3, WC-7 and WC-12. These data suggest that the more recently deposited sediments are either receiving or transporting a higher phosphorous load than deeper and presumably older sediments.

Table 3.3-1. Phosphorus concentrations (as Total P, iron-bound; loosely-sorbed) of sediment core samples.

Sample ID	% Solids	Total Phosphorus as P (mg/kg)	Iron bound Phosphorus as P (mg/kg dry)	Loosely-sorbed Phosphorus as P (mg/kg dry)	Basin
WC-1A-0-0.5	24.2	997	47.10	BRL	Main
WC-1A-0.5-1	19.5	659	31.80	BRL	Main
WC-2-0-0.5	20.3	1010	50.90	BRL	Main
WC-2-0.5-1	23.1	574	33.90	BRL	Main
WC-3-0-0.5	22.3	1530	59.30	BRL	Main
WC-3-0.5-1	22.9	1340	58.60	BRL	Main
WC-4-0-0.5	23.7	1180	37.10	BRL	Main
WC-4-0.5-1	23.0	1250	41.40	BRL	Main
WC-5-0-0.5	51.0	306	22.70	BRL	Main
WC-5-0.5-1	29.1	296	20.90	BRL	Main
WC-6-0-0.5	25.4	1200	17.90	BRL	Main
WC-6-0.5-1	56.9	402	8.54	BRL	Main
WC-7-0-0.7	39.6	1440	BRL	BRL	South
WC-8-0-0.5	40.6	1160	BRL	BRL	South
WC-8-0.5-1	41.7	552	BRL	BRL	South
WC-9-0-0.5	58.0	963	BRL	BRL	South
WC-9-0.5-1	40.4	742	BRL	BRL	South
WC-10-0-0.5	24.8	750	BRL	BRL	Gooseberry
WC-10-0.5-1	29.0	667	BRL	BRL	Gooseberry
WC-11-0-0.5	24.3	1060	BRL	BRL	Gooseberry
WC-11-0.5-1	29.3	625	BRL	BRL	Gooseberry
WC-12-0-0.5	33.5	1410	BRL	BRL	Bearses
WC-12-0.5-1	16.3	1070	BRL	BRL	Bearses
WC-13-0-0.5	21.7	959	22.50	BRL	Bearses
WC-13-0.5-1	30.5	829	14.60	BRL	Bearses

BRL = Below Reporting Limit
Note: No samples were collected from core WC-14

Iron-bound phosphorus as P (mg/kg) concentrations had a range between below detection limits – 59.3 mg/kg. At all stations, iron bound phosphorous was a small fraction of the total phosphorous. Concentrations varied greatly between basins. Results from the South Basin and Gooseberry Pond were all below reporting limits, and only two samples from Bearses Pond were above reporting limit. The Main Basin had relatively high concentrations, but still as a small portion of the total phosphorous in sediment. The average difference between the upper and lower samples from each core was only 8 mg/kg, with a range from 1 – 15 mg/kg.

All concentrations of loosely-sorbed phosphorus were below the detection limits suggesting that phosphorous recycling from sediments to the water column is unlikely.

3.4 SEDIMENT AND BATHYMETRIC MAPPING

Figure 3.4-1 shows the bathymetric contours based on data return over the survey grid.

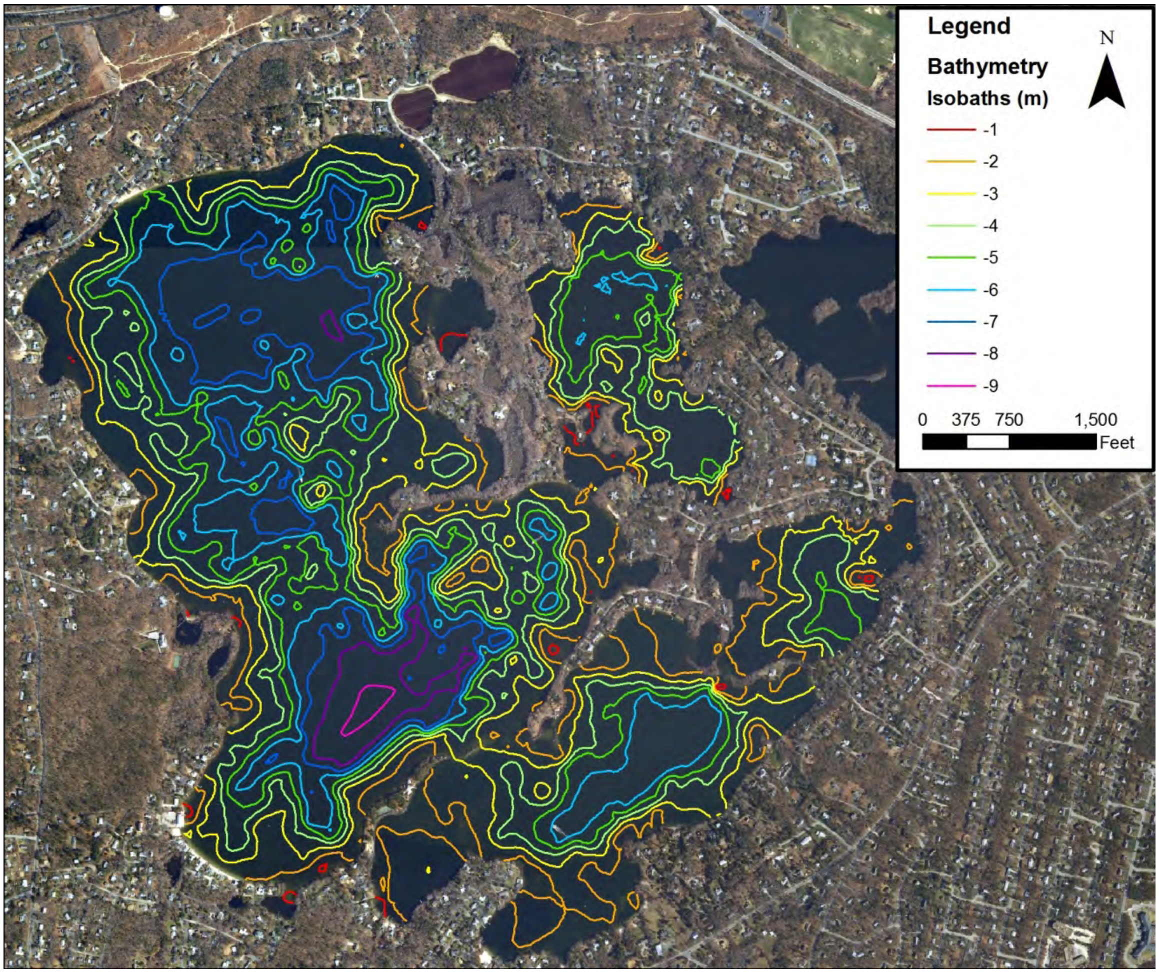


Figure 3.4-1. Bathymetric map produced from acoustic soundings collected during the July-August 2011 survey.

Figure 2-6 provides a map of the side-scan sonar backscatter and interpretation of the low backscatter areas of the lake bottom considered to be covered by fine-grained sediment deposits.

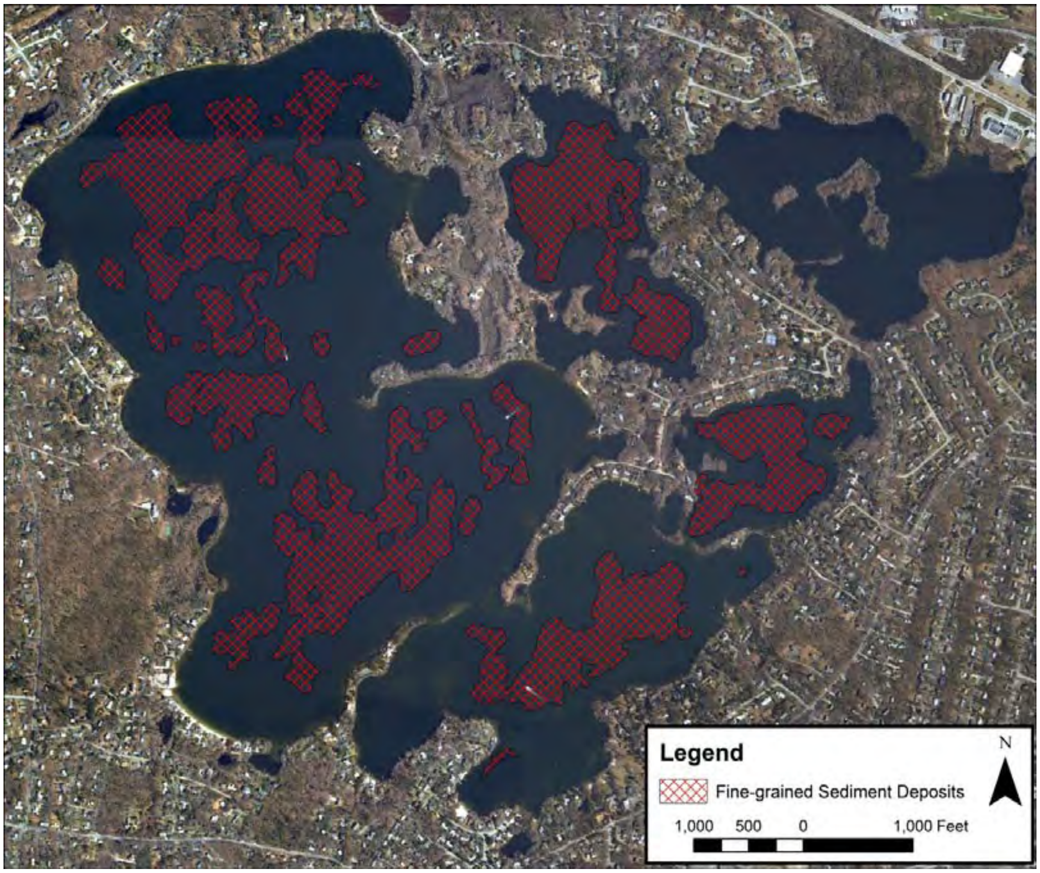


Figure 3.4-2. Map of areas covered by fine-grained sediment deposits, interpreted from side-scan sonar backscatter.

Figure 3.4-3 provides an example of the subbottom sonar data. Note the layering present in the depressions, or basins, in the lake's bathymetry.

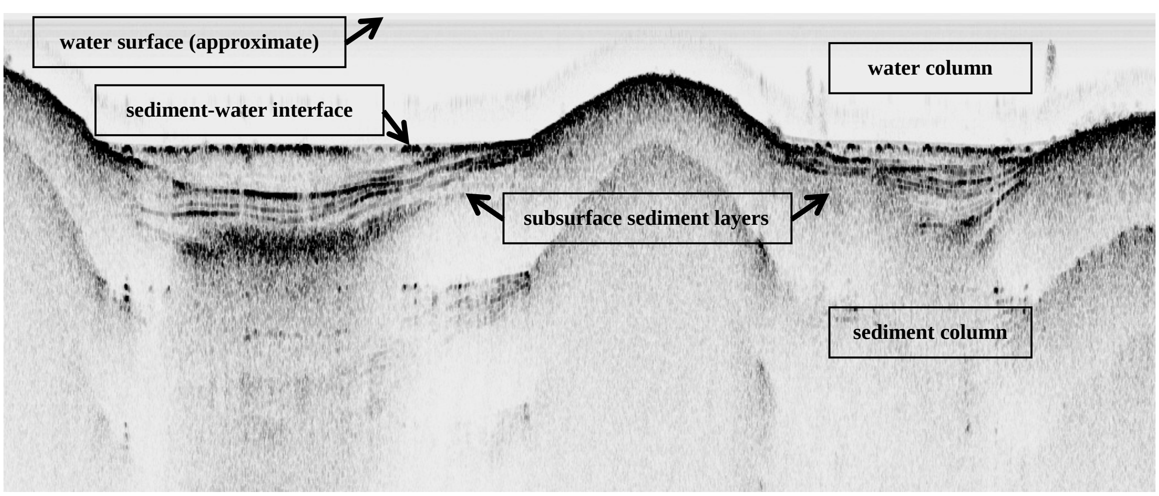


Figure 3.4-3. Subbottom sonar cross-section of sediment column.

A calculation of the volume of unconsolidated-loosely consolidated organic-rich surface sediment was based on the areal extent of fine-grained sediment (Figure 3.4-2) and the thickness of that sediment derived from numerous images as exemplified in Figure 3.4-3 and the cores used to ground-truth the images. Figure 3.4-4 shows the estimated thickness of this loosely consolidated layer. This volume, along with a sediment specific bulk density and phosphorus concentration, was used to determine an estimate of the phosphorus inventory in the lake's bottom sediment.

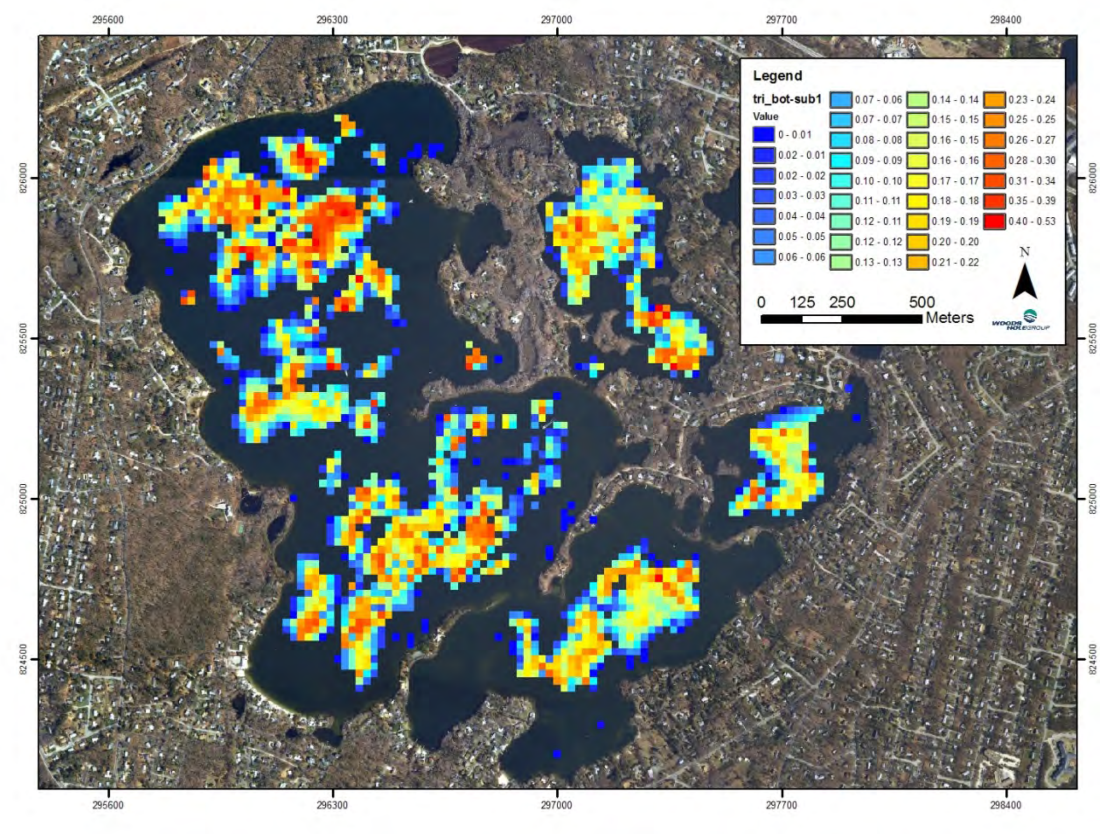


Figure 3.4-4. Map of organic-rich fine grained sediment thickness (in meters) created from the interpretation of the side-scan and subbottom sonar data.

4.0 LAKE MANAGEMENT

For this project, management planning is focused on phosphorus loading and lake trophic status, as that was the focus of this investigation. It should be noted that a comprehensive management plan for the lake, including a full discussion of other issues including recreation, lake access and use, nuisance or exotic species management, fisheries management, local land use, and other issues could be developed, and would be a useful product for lake users. Such a management plan is beyond the scope of this project, so this discussion focuses on lake trophic status and control of phosphorus loads. In the following sections we discuss the steps above as they relate to Lake Wequaquet and its sub-basins. We frame the discussion as a set of direct questions with a set of answers based on the current analysis supplemented with outside information as appropriate.

4.1 WHAT ARE THE GOALS OF THE MANAGEMENT PLAN IN TERMS OF SPECIFIC FUNCTIONAL ASPECTS OF THE LAKE?

For Lake Wequaquet the goal is to maintain the trophic status of the lake as oligotrophic to mesotrophic so that eutrophication due to anthropogenic influence is minimized. This goal recognizes that eutrophication will occur naturally. It also implicitly indicates the goal is to minimize phosphorus loading so that the natural eutrophication process is not accelerated to the point that undesirable changes to water quality and lake benthic habitats occur. Plainly stated, the aim is control phosophorus loading in order to promote good water quality in the lake, and minimize or eliminate the algal blooms that occur periodically during the growing season.

4.2 WHAT CRITERIA ARE USED IN THIS ANALYSIS TO ASSESS THE LAKE RELATIVE TO THE GOALS?

The recommended criteria for assessing the status of Lake Wequaquet include established trophic models and water quality measures that reflect the trophic status of the lake. The Vollenweider model was chosen to indicate the trophic status of each lake basin. This model, coupled with the Town's water quality monitoring data for the lake, is used to define the lake trophic status relative to goals, and to project the future status under different phosphorus loading scenarios.

4.3 WHAT IS THE CURRENT TROPHIC STATUS OF LAKE WEQUAQUET?

Figure 4.3-1 provides estimates of the trophic state of each lake basin based on the Vollenweider model (Vollenweider and Dillon, 1974). The analysis includes two estimates of current trophic status based on the total load of phosphorous from various sources (e.g phosphorous in groundwater and rain, and phosphorous contributed by wildlife, fertilizer, and runoff from impervious surfaces). The two estimates used different estimates of the concentration of phosphorous in groundwater and rain as described in subsection 4.6 including: (1) average measured concentrations of phosphorous in groundwater and rain; and (2) the 95^{th} upper confidence limit on that average (95^{th} UCL). We consider the latter to be an upper estimate of the average potential phosphorous load from these two sources. The analysis indicates (Figure 4.3-1) that under measured average groundwater and rainwater concentrations of phosphorous:

- The Main Basin, South Basin, & Bearses Pond are *Oligotrophic*
- Gooseberry Pond is *Mesotrophic*

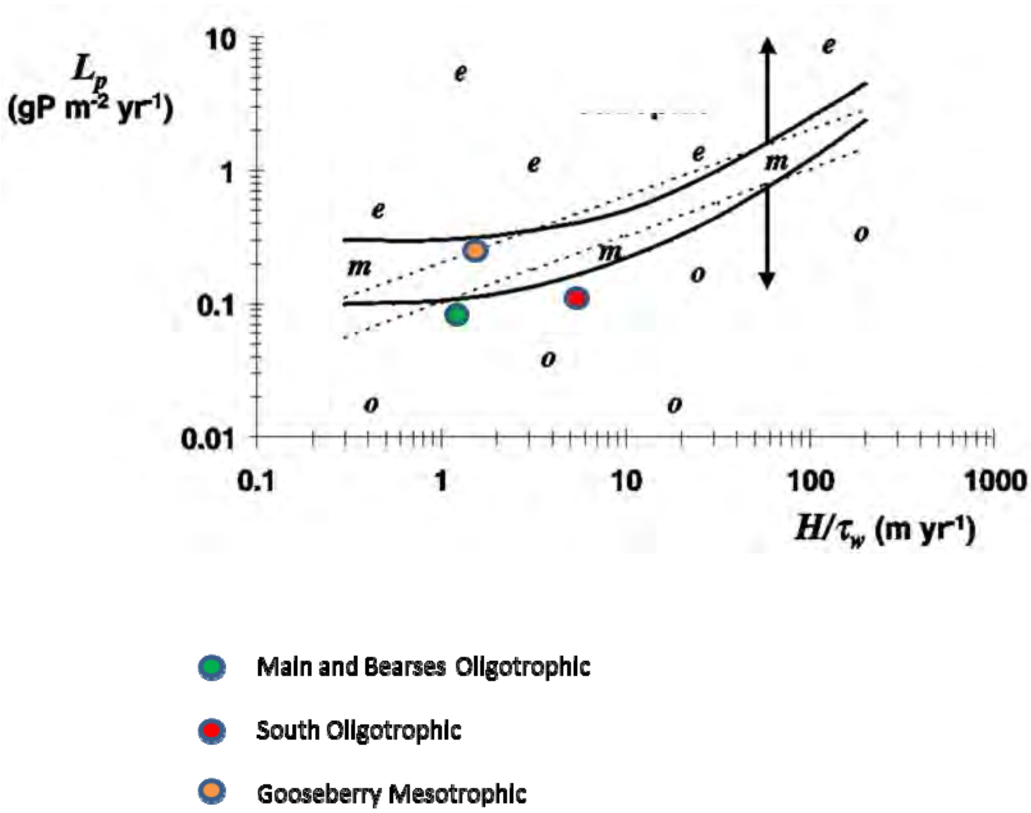


Figure 4.3-1. Vollenweider Classification of Lake Basins Based on Average Measured Groundwater and Rainwater Phosphorus

We provided a second estimate using the 95% UCL values from measured rain and groundwater samples to address the potential uncertainty in the average case. Under this upper estimate case (Figure 4.3-2), the Vollenweider model indicates:

- The Main Basin, South Basin, & Bearses Pond are *Mesotrophic*
- Gooseberry Pond is *Eutrophic*

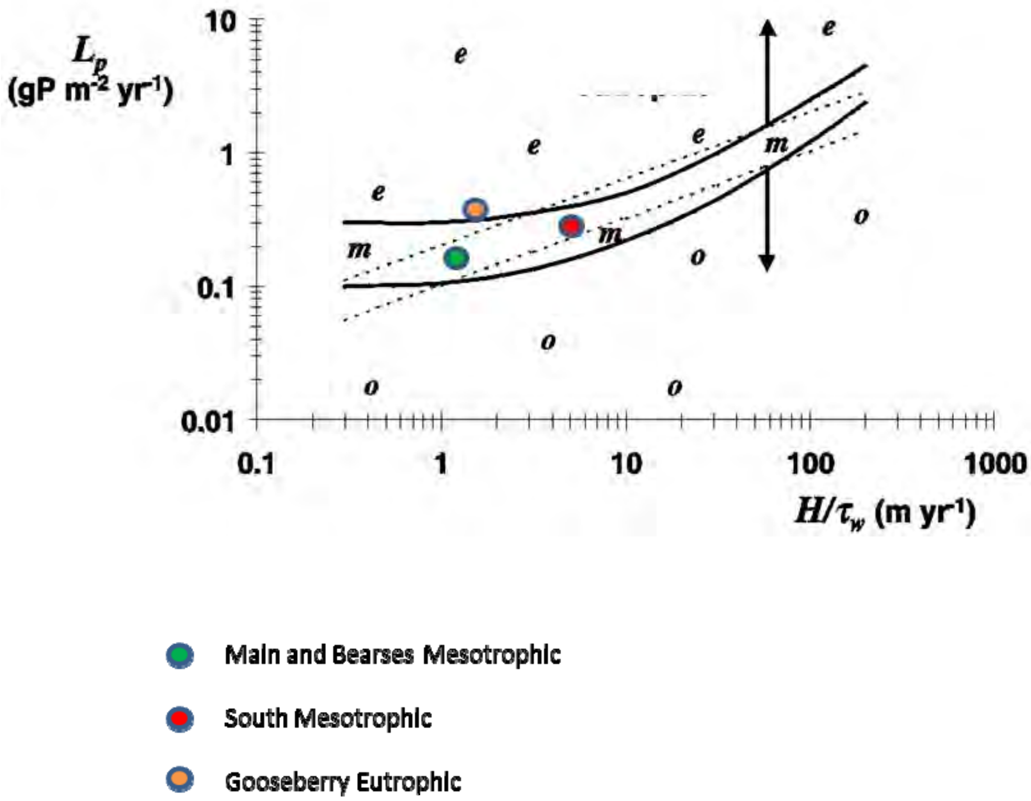


Figure 4.3-2. Vollenweider Classification of Lake Basins Based on 95th UCL Measured Groundwater and Rainwater Phosphorus

Taken together the analyses indicate that the Main Basin, South Basin and Bearses Pond are in the oligotrophic to mesotrophic categories, and Gooseberry Pond is in the mesotrophic to eutrophic category.

4.4 WHAT IS THE CURRENT STATUS OF THE LAKE RELATIVE TO THE SELECTED GOAL?

Table 4.4-1 compares the current trophic state of each lake basin to the selected goal (expressed as a trophic state on the Vollenweider scale). The table shows that all basins except Gooseberry Pond are currently within the range of the selected goal.

Table 4.4-1. Comparison of the trophic status or each lake basin to the selected goal for each basin expressed as a trophic state.

Basin	Current Status	Goal
Main	Oligotrophic to Mesotrophic	Oligotrophic to Mesotrophic
South	Oligotrophic to Mesotrophic	Oligotrophic to Mesotrophic
Gooseberry	Mesotrophic to Eutrophic	Oligotrophic to Mesotrophic
Bearses	Oligotrophic to Mesotrophic	Oligotrophic to Mesotrophic

The question that remains for this management plan is whether over the immediate short term (approximately 25 years) the lake basins will maintain their current trophic status and what management actions can help to assure that the basins maintain, or in the case of Gooseberry Pond, attain the selected goal? The answer to this question lies in an analysis of the sources of phosphorous loading to the lake, whether these sources are manageable, and an estimate of how these loadings may change in the near term.

4.5 WHAT SOURCES OF PHOSPHOROUS TO THE LAKE CAN BE MANAGED TO REACH AND MAINTAIN THE SPECIFIED GOALS?

Management actions that can be used to attain and/or maintain the desired trophic status include those that reduce the phosphorus load to the lake. Figure 4.5-1 shows the various sources of phosphorus, some of which are amenable to management action, while others, such as direct deposition of phosphorus to the lake via rain, are not.

Manageable phosphorus sources include fertilizer application, wastewater contribution to the groundwater discharging to the lake, and impervious runoff. Less manageable are contributions from wildlife and atmospheric deposition.

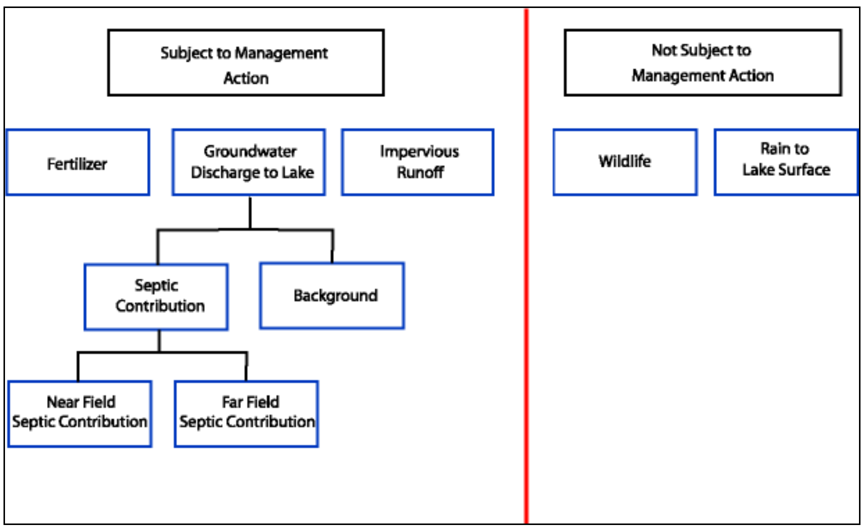


Figure 4.5-1. Sources of Phosphorus to Lake Wequaquet

4.6 HOW MUCH PHOSPHOROUS IS CONTRIBUTED BY EACH OF THESE MANAGEABLE SOURCES?

This subsection provides the phosphorous contribution from various sources to the lake, from three separate Lake Wequaquet studies (IEP, 1989; Eichner et al., 2009; and the present study). Among these studies:

- IEP, 1989 estimated phosphorus loading from groundwater based on average concentrations and groundwater flow as well as a separate estimate based on future breakout of phosphorous from near field and far field septic systems;

- Eichner et al., 2009 estimated groundwater phosphorous loading based on near-field per capita phosphorus load to septic systems and a small contribution from an undefined phosphorus source to groundwater, "natural areas", (which we assumed to mean the phosphorus from dry and wet deposition to the watershed natural areas that moves through the vadose zone and travels with groundwater to the lake);
- The present study included an estimate based on the product of measured phosphorus concentrations in rain and groundwater and estimated rainfall directly to the lake surface and groundwater flow to the lake. These estimates included an average case and an upper estimate based on the 95% UCL on measured phosphorus in rain and groundwater. Tables 4.6-1 and 4.6-2 show the estimated rainfall loadings by basin for the average and 95th UCL phosphorous concentration in rain. Tables 4.6-3 and 4.6-4 show the estimated groundwater loadings by basin for the average and 95th UCL phosphorous concentrations in shallow groundwater. Note that the groundwater phosphorus measured for this study includes contributions from background, septic, and fertilizer phosphorus that travels with groundwater. The present study adopted Eichner et al. 2009 estimates for wildlife and impervious surfaces.

Table 4.6-1. Phosphorous Loadings from Rain Based on Average Concentration

Basin	Annual Rainfall meters	Pond Area m2	Phosphorous Concentration mg/L	Conversion	loading Kg/yr
Main Basin	1.14	1724386.00	0.03	0.001	58.87
Bearses	1.14	267551.00	0.03	0.001	9.13
South	1.14	518621.00	0.03	0.001	17.71
Gooseberry	1.14	165751.00	0.03	0.001	5.66
Total					91.37

Table 4.6-2. Phosphorous Loadings from Rain Based on 95th UCL on Mean of Measured Concentration

Basin	Annual Rainfall meters	Pond Area m2	Phosphorous Concentration mg/L	loading Kg/yr
Main Basin	1.14	1724386.00	0.06	117.74
Bearses	1.14	267551.00	0.06	18.27
South	1.14	518621.00	0.06	35.41
Gooseberry	1.14	165751.00	0.06	11.32
Total				182.74

Table 4.6-3. Phosphorous Loadings from Shallow Groundwater Based on Average Measured Concentration

Basin	Groundwater Recharge m3/yr	Phosphorous Concentration mg/L	**Loading (kg/yr)**
Main Basin	1311097	0.061	**80**
Bearses	238535	0.03	**7**
South	231881	0.122	**28**
Gooseberry	198086	0.114	**23**
Total			**138**

Table 4.6-4. Phosphorous Loadings from Shallow Groundwater Based on 95th UCL on Mean of Measured Concentration

Basin	Groundwater Recharge m3/yr	Phosphorous Concentration mg/L	**Loading**
Main Basin	1311097	0.08	**105**
Bearses	238535	0.05	**12**
South	231881	0.36	**83**
Gooseberry	198086	0.19	**38**
Total			**238**

Table 4.6-5 summarizes the phosphorous loadings from various sources for each study. Among the manageable loadings of phosphorus to the lake, groundwater contributes the largest load. The groundwater load is the sum of background phosphorous in groundwater (assumed to be 0.05 mg/L from Frimpter and Gay, 1979), the contribution from septic systems, and the contribution from fertilizer. Background phosphorous is not vulnerable to management actions. However, the estimates from IEP (1989) and Eichner et al 2009) suggest that septic systems at breakout are a significant contributor to phosphorous entering the lake through the groundwater. Septic contributions, impervious surfaces run-off, and fertilizer are sources subject to management action. Among these, the loading from septic systems is the major contributor.

Given the importance of phosphorous contributions from septic systems, we assessed more closely the fate of phosphorous from septic systems and the implications of this source for Lake Wequaquet's trophic status and management plans.

Importantly, the non-manageable sources including atmospheric deposition and background phosphorus in groundwater represent a substantial fraction of the total load.

Wildlife contribute a negligible part of the load so efforts to control wildlife contributions of phosphorus to the lake would not likely change the lake trophic status.

Table 4.6-5. Contributions of Phosphorous (Kg/year) to Lake Wequaquet from various sources as estimated in three separate studies.

Study	Ground water	Septic Contribution to Groundwater	Natural Areas	Total Groundwater Load	Impervious Surfaces	Fertilizer	Wildlife	Direct Rain to Lake Surface
IEP, 1989 Current (1)	79.7		NA	79.9	3.1	8.1	9	90.4
IEP, 1989 at Breakout (2)	79.7	84.8	NA	164.5	3.1	8.1	9	90.4
Eichner et al., 2009 (3)		114	8	122	26	10	4	38
Current Study Average Case (4)	138	NA	NA	138	26	NA	4	97
Current Study 95th UCL on Average (4)	238	NA	NA	238	26	NA	4	182
(1) Assumed groundwater at background concentrations with no contribution from septic systems (2) Assumed groundwater at background concentrations and breakout of P from septic systems (3) Did not calculate groundwater contribution, only specified a contribution from wastewater assumed to enter as groundwater for this comparison. (4) Groundwater load based on measured P concentration in groundwater entering the lake and assumed to include background, septic, and fertilizer contributions.								

4.7 WHAT IS THE FATE OF PHOSPHOROUS FROM SEPTIC SYSTEMS?

Lombardo (2006) provides a review of the fate of phosphorous in septic systems. He indicates that the fraction removal of wastewater phosphorous entering septic systems includes:

- 20% to 30% removal in septic tanks due to particle settling and chemical precipitation;
- 23% to 99% reduction in groundwater relative to effluent concentrations (i.e 23% to 99% mass removal assuming no immediate down gradient dilution in the soil adsorption systems (soils below the septic tank and above the ground water table) as iron and aluminum precipitates;
- Further attenuation in groundwater due to adsorption to soils

That fraction of the phosphorous neither retained in the septic system nor attenuated in groundwater is available to migrate in groundwater away from the septic system sites as dissolved or very small particulate fraction. This fraction may enter down gradient surface water bodies and contribute to the overall phosphorous load. Lombardo's review indicates that the septic system contribution to surface water bodies ranged from 4% to 55% of the total load during Total Maximum Daily Load estimates for various lakes in the United States and Canada.

The migration of phosphorous from septic systems and their associated soil adsorption systems through groundwater depends on the geochemistry of the surrounding soil. Acidic groundwater flowing through non-calcareous sands tends to enhance phosphorous retention as a result of precipitation with aluminum (Lombardo, 2006). The pH in Cape Cod groundwater tends to be acidic with an average pH of 6.1 (Frimpter and Gay, 1979). Lake Wequaquet lies in a glacial outwash plain (Soil Conservation Service, 1984) which tend to have non-calcareous sands (e.g. Godfrey et al., 1999). These conditions suggest that phosphorous in groundwater is largely attenuated down gradient of the septic systems. The length scales of this attenuation are likely to be on the order of two meters or less in sandy, non-calcareous soil, and on the order of tens of meters in calcareous sand at higher pH (Table 4.7-1).

Table 4.7-1. Measured migration of phosphorous from septic systems in soils with various properties.

Study	Location	Phosphorous Migration from Septic System (m)	Soil Type	pH
Harman et al., 1996	Ontario, Canada	75 meters	Calcareous Sand	7.1 to 8
Robertson et al., 1998	Ontario, Canada	1 meters	Non Calcareous Sand	6.1
Minnesota Pollution Control, 1999	Minnesota	12 meters	Fine Sand	7.3 to 8.2
Robertson et al., 1998	Ontario, Canada	3	Non Calcareous Sand	4.5
McCobb et al., 2003	Otis Air Base, Cape Cod	600 meters	Calcareous Sand	5.5

These data suggest that septic systems more than 100 meters upgradient of Lake Wequaquet are unlikely to contribute phosphorous from septic systems to groundwater entering the lake because the low pH and non-calcareous soils of the watershed are likely to attenuate phosphorous in the immediate (less than 100 meters) down gradient soils. Note that Table 4.7-1 also indicates that under certain conditions phosphorous may migrate as far as 600 meters as in the plume from Otis Air Base to Ashumet Pond in Falmouth, Massachusetts. Although residential systems do not receive the substantial loading that occurs at Otis Air Base, the study demonstrates that phosphorous adsorption sites in soil may become saturated and result in the breakout of dissolved phosphorous and subsequent transport to down gradient water bodies even in the sandy, low pH, calcareous soils of Cape Cod.

4.8 WHAT IS THE ESTIMATED SEPTIC SYSTEM CONTRIBUTION TO GROUNDWATER LOADING IN LAKE WEQUAQUET?

Groundwater contributes a large fraction of the phosphorous load to Lake Wequaquet. The concentration of phosphorous in groundwater includes the "background concentration" that is typical of groundwater on Cape Cod (the concentration occurring as a result of rainfall, dry deposition to the watershed, and application of fertilizes in the watershed), and any additional phosphorous contributed to groundwater from septic systems. As noted above, there are three estimates of annual loading of phosphorous from groundwater to Lake Wequaquet (Table 4.6-1):

- IEP (IEP, 1989) assumed that the current groundwater loading of phosphorous to be the product of a background concentration in groundwater (0.05 mg/L from Frimpter and Gay, 1979) and an estimated groundwater flow (1,456,518 m^3/year);
- Eichner et al. (2009) essentially ignored background concentrations of phosphorous (except possibly for a small contribution from "natural areas") and assumed that all the phosphorous entering the lake through groundwater was from septic systems within 300 feet of the lake shore;
- The current study assumed that the current groundwater load to be the product of basin by basin measurements of phosphorous concentration in near shore groundwater and the most recent estimate of groundwater flow for each basin (from Eichner et al., 2009).

The differences in these estimates reflect varying assumptions and data availability. The critical question is what fraction of the phosphorous entering the Lake through groundwater is due to septic systems. The answer is critical to lake management because the septic system fraction is the portion of the load most vulnerable to management action.

4.8.1 How Much Phosphorous is Entering Lake Wequaquet from Septic Systems under Current Conditions?

Unfortunately we cannot provide an answer to this question for the current conditions because of the uncertainties surrounding any estimate of septic system contributions. Specifically:

- The septic system phosphorous loading is most likely confined to the systems nearest the lake shore (within 100 meters) because the scientific literature indicates that individual septic systems in soils such as are found on Cape Cod are likely to bind phosphorous and retard any down gradient distant migration to the lake (Table 4.7-1);
- Even these near shore systems may not be contributing very much phosphorous to the lake because the measured length scales of down gradient migration in soils similar to Cape Cod are on the order of 1 to 3 meters (Table 4.7-1);
- This phosphorous attenuation in soil is dependent on the specific mineralogical characteristics (especially aluminum and iron) of the soils underlying and immediately down gradient of residential septic systems (Table 4.7-1);
- The potential for breakout (the saturation of soil binding sites with phosphorous to the extent that the soils no longer attenuate phosphorous and allow migration to the lake) depends on soil mineralogy, conditions of the septic system, and duration of phosphorous discharge from these systems (as summarized in Lombardo, 2006).

However, the results of long term studies in Falmouth, Massachusetts (McCobb et al., 2003) demonstrate that under conditions of high septic loading and long duration of loading to soils, breakout does occur and does affect the concentration of phosphorus in groundwater entering down gradient water bodies.

4.8.2 How Much Phosphorous may Enter Lake Wequaquet from Septic Systems under Future Conditions?

We can answer the question of how much phosphorus may enter Lake Wequaquet under future conditions with somewhat more certainty by calculating per capita or per residence phosphorous discharge to septic systems and assuming breakout conditions. For example:

- IEP (1986) assumed that there is some future state of what they referred to as "equilibrium conditions" when the soil phosphorous binding sites will be saturated and the phosphorous used in lakeshore residences (near-field residences within 100 meters of shore) and, to a lesser extent, far-field residences will contribute as much phosphorous (84.8 Kg/year) as is now contributed by background concentrations (75.5 kg/year) in groundwater.
- Eichner et al. (2009) assumed that the major load from groundwater was the septic system contribution from residences within 100 meters of the shoreline (wastewater load of 114 kg/year).

Both these estimates depended upon an assumption of either a per capita or per residence loading of phosphorous to the septic system. The current study used an alternative method based on recent measurements of phosphorous concentrations in septic systems (Idaho DEQ, 2012).

This method estimated the potential annual load of phosphorous to the lake from septic systems within 100 meters of the shoreline for each basin as:

Pl = Ce x Uw x H x 365 days/year

- Pl = annual phosphorous loading by basin
- Ce = concentration of phosphorous in septic effluent = 7.6 mg/L (Idaho DEQ, 2012)
- Uw = daily water use per home = 524 L/day (Howes et al., 2004)
- H = number of homes within 100 meters of discharging shoreline (estimated from overflight images).

Table 4.8-1 provides this potential additional annual phosphorous load from septic systems to each basin at breakout.

Table 4.8-1. Estimated Contribution of Phosphorous to Lake Basins at Breakout

Basin	Septic Effluent Concentration (mg/L) (1)	Water Use (L/day) (2)	Number of Homes (3)	Days/ year	Conversion mg to Kg	Annual Load Kg/year
Main Basin	7.6	524	103	365	0.000001	150
South Basin	7.6	524	45	365	0.000001	65
Bearses	7.6	524	53	365	0.000001	77
Gooseberry	7.6	524	69	365	0.000001	100
Total						392
(1) Value from Idaho DEQ, 2012						
(2) Value from Howes et al., 2004 with total water use multiplied by 0.9 to correct for wastewater as suggested by Howes et al., 2004						
(3) Homes within 100 meters of shorelines where groundwater recharges the lake based on over flight images						

The estimated loading at break-out from near-field septic systems in Table 4.8-1 is approximately four times prior estimates. We regard this current estimate of phosphorous loading at breakout as more certain because it depends on measured concentrations of phosphorous in the effluent of a large number of septic systems (118 samples) and probably therefore provides a more rigorous estimate of phosphorous emanating from septic systems than the "usage" factors applied in prior estimates.

The potential future groundwater load of phosphorous is equal to the estimates in Table 4.8-1 plus the continuing background contribution (the product of the background concentration, 0.05 mg/L, and the groundwater flow to each basin). Table 4.8-2 provides these total future loadings of phosphorous.

Table 4.8-2. Total Future Phosphorous Load at Breakout by Basin and Source

Basin	Groundwater(1)	Rain	Impervious	Birds	Total
Main	215	62	10	1	289
Bearses	89	10	6	1	106
Gooseberry	77	6	5	1	89
South	110	19	5	1	135
Total	491	97	26	4	618
(1) Groundwater annual load is the sum of background load and near field septic contribution at breakout.					

4.9 WOULD SUCH A FUTURE INCREASE IN THE CONTRIBUTION FROM GROUNDWATER AFFECT THE TROPHIC STATUS OF THE LAKE?

We answer this question by revising the Vollenwieder plots for each basin (Chapter 3) to account for the increased annual loading of phosphorous at breakout from Table 4.8-2.

That future loading assumes no change in all sources except groundwater. Figure 4.9-1 provides the revised plot.

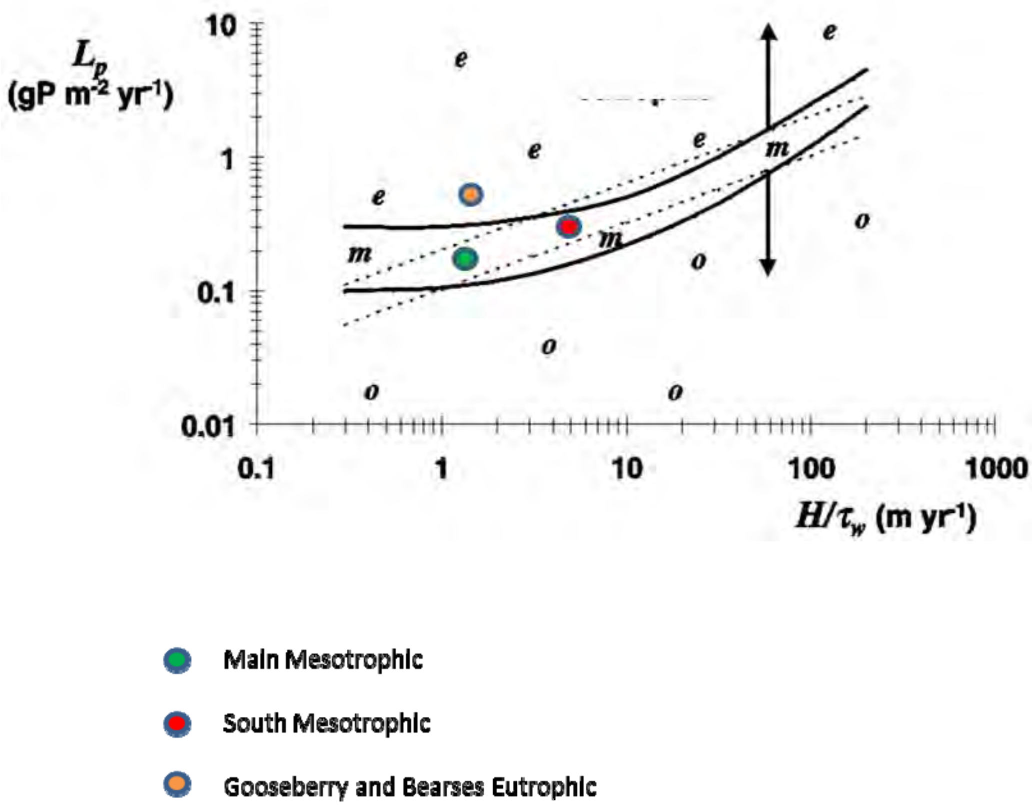


Figure 4.9-1. Vollenweider Classification of Lake Basins Based on Estimated Future Phosphorus Load (Septic Breakout plus Groundwater Background)

Figure 4.9-1 demonstrates that at breakout, the basins move either well into the mesotrophic category or even into the eutrophic category (e.g. Bearses and Gooseberry). Note that this indicates a significant change from current estimates of trophic characterization under current measured average conditions (compare to Figure 4.3-1 above) and is more similar to the current conditions using the 95th UCL on the averages (compare to Figure 4.3-2). The immediacy of this potential for eutrophication of the ponds depends upon the potential that breakout is currently occurring.

4.10 IS BREAKOUT CURRENTLY OCCURRING?

We answer this question from two perspectives by comparing:

- The trophic characterization of each lake basin under currently measured average and 95th UCL estimated conditions to the projected status of each basin at breakout of phosphorous from septic systems within 100 meters of the lake shore;

- The measured average and upper estimate concentrations of phosphorous in groundwater to the projected concentration in groundwater at breakout of phosphorous from septic systems within 100 meters of the lake shore.

4.10.1 The comparison of basin trophic status under current and projected conditions indicates that breakout may be currently occurring.

The above trophic analyses indicate that breakout may be occurring currently. Table 4.10-1 compares the trophic status of each lake basin under three assumptions: current average conditions, current upper estimate conditions, and future breakout conditions.

Table 4.10-1. Comparison of lake basin trophic status under various assumed conditions of phosphorous loading

Assumed Conditions			
Basin	**Average Measured Phosphorous in Groundwater and Rain**	**95th UCL Estimate Measured Phosphorous in Groundwater and Rain**	**Estimated Phosphorous in Groundwater at Breakout (all other conditions at average measured value)**
Main Basin	Oligotrophic	Mesotrophic	Mesotrophic
South Basin	Oligotrophic	Mesotrophic	Mesotrophic
Bearses	Oligotrophic	Mesotrophic	Eutrophic
Gooseberry	Mesotrophic	Eutrophic	Eutrophic

Table 4.10-1 shows that if we assume that the average measured phosphorous concentration in groundwater and rain adequately reflects the current condition, then the septic systems along the lakeshore have probably not reached breakout. However, examination of only the average conditions does not account for uncertainty in the measured data sets. To address the potential uncertainty in the data, we also compared the trophic status of the lake basins using the 95th Upper Confidence Limit on the average to the estimated trophic status at breakout. This analysis indicated that:

- The Main Basin trophic status under upper estimate assumptions for current loading is similar to the projected trophic status at breakout of phosphorous from septic systems within 100 meters of the lake shore. The similarity between the 95th UCL loading estimate and the future loading estimate assuming breakout suggests that septic phosphorous breakout may be occurring along the shoreline of the Main Basin.
- The South Basin trophic status under upper estimate assumptions for current loading is similar to the projected trophic status at breakout of phosphorous from septic systems within 100 meters of the lake shore. The similarity between the 95th UCL loading estimate and the future loading estimate assuming breakout suggests that septic phosphorous breakout may be occurring along the shoreline of the South Basin.

- The Gooseberry Pond trophic status under upper estimate assumptions for current loading is similar to the projected trophic status at breakout of phosphorous from septic systems within 100 meters of the lake shore. The similarity between the 95th UCL loading estimate and the future loading estimate assuming breakout suggests that septic phosphorous breakout may be occurring along the shoreline of Gooseberry Pond;
- The Bearses Pond trophic status under upper estimate assumptions for current loading is mesotrophic while the breakout conditions suggest that the pond will be eutrophic. This suggests that Bearses Pond, although susceptible to eutrophication at breakout, may not be as immediately vulnerable to a trophic change as the other basins.

In general, these comparisons suggest that there may be some degree of breakout currently occurring in the 100 meter zone adjacent to the lake.

4.10.2 The comparison of measured concentration of phosphorous in lake shore groundwater to projected concentrations suggest that breakout may be currently occurring.

We estimated the concentrations of phosphorus in groundwater entering the lake at the shore if breakout is occurring from septic systems within 100 meters of the shoreline. If such breakout is actually occurring, we would expect the measured phosphorous concentration in groundwater at the lake shore to reflect the contribution from septic systems.

Under assumed breakout, the concentration of phosphorous entering the lake basins would be:

Cl = Ce x fs +Cb x fb

Where,

- Cl = concentration in groundwater entering the basin
- Ce = as defined above
- Fs = fraction of groundwater flow entering the lake from septic systems
- Cb = background concentration of phosphorous in groundwater (0.05 mg/l from Frimpter and Gay, 1979)
- Fb = fraction of groundwater flow entering the lake from the watershed

We calculated the fraction flows by estimating the septic flow to each basin as the product of the average water use 524 L/day (as described in Table 4.8-1) and the number of houses within 100 meters of the shoreline (estimated) divided by this contribution plus the watershed groundwater flow (from Eichner et al., 2009). Table 4.10-2 provides the basin specific estimates of projected phosphorus in groundwater discharging to the lake.

Table 4.10-2. Projected Concentrations of Phosphorous in Groundwater at Breakout

Basin	Septic Effluent Conc. (mg/L) (1)	Water Use (L per day) (2)	No. of Homes (3)	Days per year	GW Flow (m3/year) (4)	Septic flow (m3/year)	Fraction Septic Flow	Fraction GW Flow	Background Conc. (mg/L) (5)	Projected Conc. (mg/L)
Main Basin	7.6	524	103	365	1.31E+06	1.97E+04	0.01	0.99	0.05	0.16
South Basin	7.6	524	45	365	2.33E+05	8.61E+03	0.04	0.96	0.05	0.32
Bearses	7.6	524	53	365	2.39E+05	1.01E+04	0.04	0.96	0.05	0.36
Gooseberry	7.6	524	69	365	1.98E+05	1.32E+04	0.06	0.94	0.05	0.52
(1) from Idaho DEQ, 2012 (2) Value from Howes et al., 2004 with 0.9 correction factor to correct for wastewater										
(3) homes within 100 meters of shoreline where groundwater recharges lake										
(4) from Eichner et al. , 2009										
(5) from Frimpter and Gay, 1979										

Table 4.10-3 compares these projected concentrations to the range of measured concentrations by basin.

Table 4.10-3. Comparison of Projected Concentrations of Phosphorous in Groundwater at Breakout to Measured Values (mg/L)

Basin	Projected Conc. (mg/L)	Measured Average	Measured 95th UCL	Measured Minimum	Measured Maximum
Main Basin	0.16	0.061	0.08	0.003	0.24
South Basin	0.32	0.122	0.36	0.049	0.233
Bearses	0.36	0.03	0.05	0.003	0.112
Gooseberry	0.52	0.114	0.19	0.014	0.32

Table 4.10-3 demonstrates that:

- In the Main Basin, measured average and upper estimate concentrations of phosphorous in groundwater along the lake shore exceed Cape Cod background and maximum measured concentrations are similar to projected concentrations at breakout. These observations suggest that there may be breakout of phosphorous from septic systems along the shoreline of the Main Basin;
- In the South Basin, measured average and upper estimate concentrations of phosphorous in groundwater along the lake shore exceed Cape Cod background and maximum measured concentrations approach projected concentrations at breakout. These observations suggest that there may be breakout of phosphorous from septic systems along the shoreline of the South Basin;
- In Gooseberry Pond, measured average and upper estimate concentrations of phosphorous in groundwater along the lake shore exceed Cape Cod background and maximum measured concentrations approach projected concentrations at breakout. These observations suggest that there may be breakout of phosphorous from septic systems along the shoreline of Gooseberry Pond;
- In Bearses Pond, measured average and upper estimate concentrations of phosphorous in groundwater along the lake shore are less than or similar to Cape Cod background and maximum measured concentrations approach projected concentrations at breakout. These data suggest that breakout may not be occurring at Bearses Pond.

In general, these comparisons suggest that there may be some degree of breakout currently occurring in the 100 meter zone adjacent to the lake.

4.11 WHAT IS THE POTENTIAL FOR PHOSPHOROUS RELEASE FROM SEDIMENT

Phosphorus release from sediments generally requires: (1) anoxic (no oxygen) conditions in the bottom waters of the lake; and (2) concentrations of phosphorous as either loosely bound or iron bound phosphorous that are available for release during anoxic periods in the overlying water column (e.g Sondergaard, 2007).

Attachment 2 shows the temperature stratification, oxygen profiles, and total water column phosphorous data in the various basins of the lake based on available data from the years 1986 (IEP, 1989); 2010 (Eichner and Howes, 2011), 2011 (data base provided by the Town of Barnstable) and 2012 (data base provided by the Town of Barnstable). There are additional data from 2007 not included in Attachment 2 because the data are provided as graphical profiles but not raw data (Eichner, 2009).

Note that these prior studies reference five basins within the lake. These include:

- North Main Basin which is the most northerly basin in the Main portion of the lake;
- Central Basin which lies between North Main Basin and South Basin;
- South Basin which is the most southerly basin in the Main portion of the lake;

- Gooseberry Pond; and,
- Bearses Pond.

This subsection references these five basins. Attachment 2 provides the historical water quality data in graphical form by date and basin along with the synoptically obtained concentrations of surface and bottom total phosphorous in the water. We defined anoxic conditions as periods when near bottom oxygen concentrations fell to below 1 mg/L. Figure 4.11-1 and 4.11-2 provide examples of a period when a basin was completely mixed and a period when the basin was stratified (defined as a greater than 1 degree Centigrade difference between surface and bottom temperatures) and had near bottom oxygen concentrations below 1 mg/L).

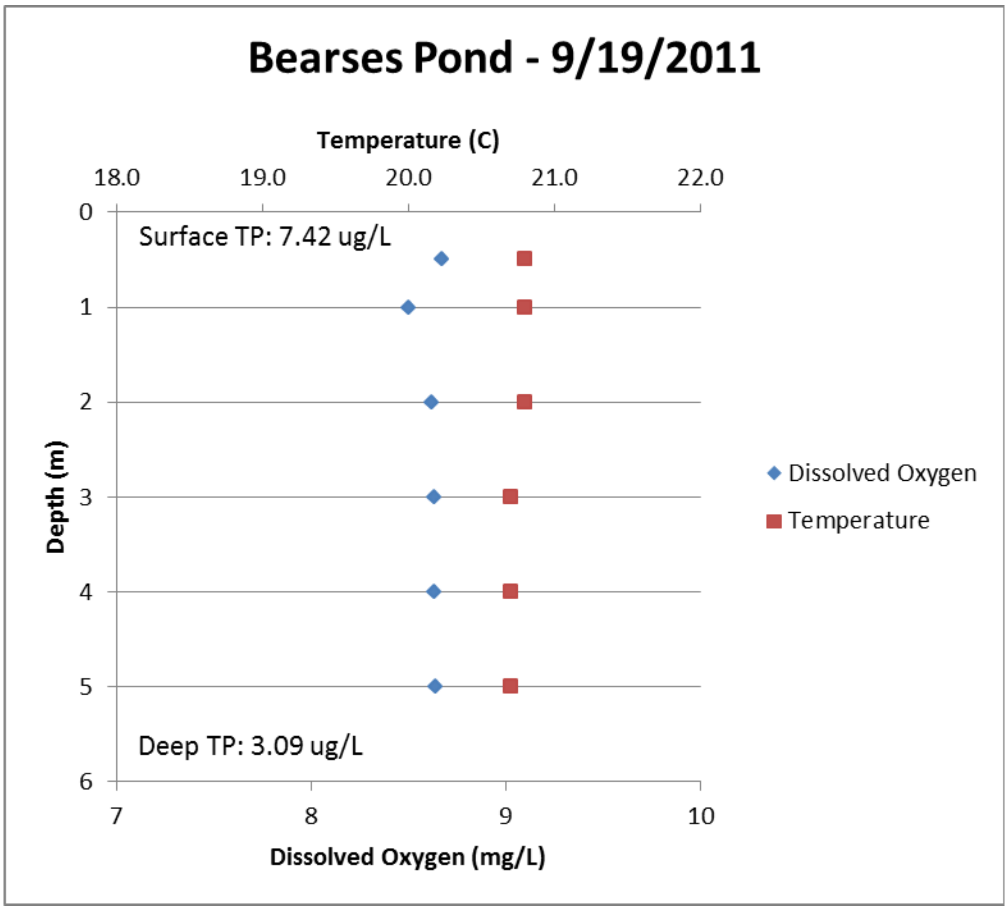


Figure 4.11-1. Temperature and Oxygen Profiles and Surface and Bottom Phosphorous Concentrations (TP) during Well Mixed Period in Bearses Pond

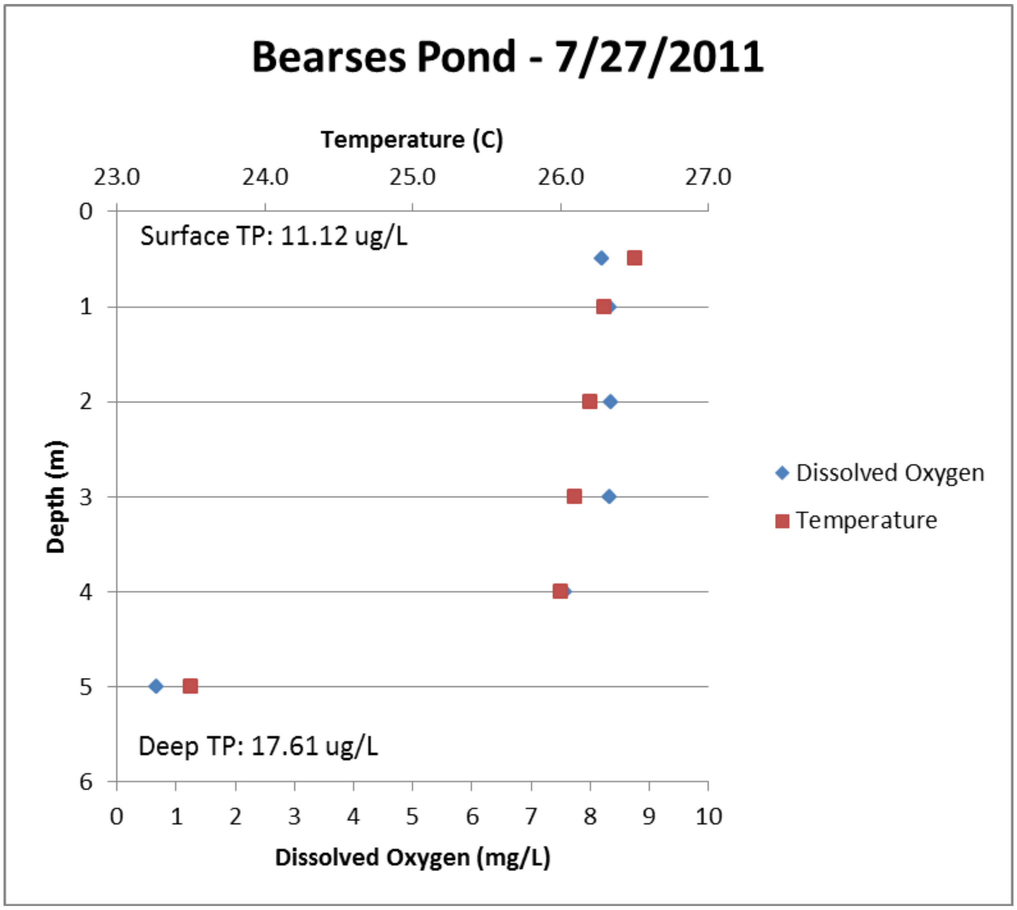


Figure 4.11-2. Temperature and Oxygen Profiles and Surface and Bottom Phosphorous Concentrations (TP) during a Stratified and Near Bottom Anoxic Period in Bearses Pond

The data in Attachment 2 and in Eichner et al. (2009) include approximately monthly temperature and oxygen profiles from June to October for four years (2007, 2010 to 2012). These data show that there are very few periods when any of the basins of the lake are stratified (defined here as a greater than one degree temperature difference between the temperature at one meter and the temperature at the bottom) and are anoxic (defined here as near bottom oxygen concentrations less than 1 mg/L). Specifically:

- Gooseberry Pond waters did not exhibit anoxia on any sampling date, and were stratified only during one sampling day in June, 2011;
- South Basin waters did not exhibit anoxia on any sampling date, and were stratified only during one sampling day in June, 2011;
- North Basin waters did not exhibit anoxia on any sampling date and were stratified during one sampling day in June, 2011 and one sampling day in May, 2007;
- Central Basin exhibited anoxic conditions below 8 to 8.5 meters during three of four sampling dates in 2011 (June, July, and August) and one sampling date in

July, 2007, and was stratified on these sampling dates and in one sampling date in May, 2007;

- Bearses Pond exhibited stratification and anoxic conditions below 5 meters during two sampling dates, July, 2010 and July, 2011, and was stratified below 5m in June 2012, May, 2007, and on two dates in June, 2007.

These data indicate that:

- Gooseberry Pond, South Basin, and North Basin remain sufficiently mixed and oxygenated during the late Spring to Autumn. These conditions are not conducive to the recycling of phosphorous from bottom sediments.
- Bearses Pond and Central Basin may experience anoxia in near bottom waters (below 5 meters in Bearses Pond and below 8 meters in Central Basin) to allow recycling of phosphorous from bottom sediments in some years.

The fraction of total phosphorus in the sediments that is available for release during these periods is that fraction that is either loosely bound or iron bound phosphorous.

In general, the reservoir of excess phosphorus in freshwater systems is largely in the sediments. Therefore, we calculated the mass of phosphorus in the lake sediments for each basin as:

$$M_p = V_b \text{ x } F_s \text{ x } D_b \text{ x } [P]$$

Where:

M_p = Mass of phosphorus (kg) in a given basin

V_b = Volume of the unconsolidated layer of fine sediments in the basin ($L_{sediment}$)

F_s = Average Fraction Solids in the unconsolidated layer ($Kg_{solids}/Kg_{sediment}$)

D_b = bulk density ($Kg_{sediment}/L_{sediment}$)

[P] = average basin dry weight phosphorus concentration (mg P/Kg_{solid})

The volume term in this equation was determined based on the area of the fine surface sediments as estimated using side scan sonar and the depth of the fine grained layer based on subbottom acoustic profiles and cores used for verification. The fraction solids, sediment phosphorous concentrations (total phosphorous, iron bound phosphorus, and loosely bound phosphorous), and bulk density were measured as part of the sediment measurement program. Tables 4.11-1 and 4.11-2 show the total phosphorous and iron bound phosphorous inventory by basin (all measurements of loosely bound phosphorous were below detection limits).

Table 4.11-1. Inventory of Mass of Total Phosphorous in Sediments by Basin

	Volume m^3	**Sediment Solids Kg_{dw}/Kg**	**Bulk Density Kg/L**	**Total [P] mg/Kg**	**Mass of Total P Kg**
North Basin	52389	0.2	1.10	1018	12,962.66
Central Basin	36237	0.4	1.25	1240	19,583.08
South Basin	17679	0.5	1.43	828	9,399.93
Bearses	20396	0.3	1.08	1067	6,135.82
Gooseberry	8382	0.3	1.54	776	2,696.52
Total					50,778.01

Table 4.11-2. Inventory of Mass of Iron Bound Phosphorous in Sediments by Basin

	Volume m^3	**Sediment Solids Kg_{dw}/Kg**	**Bulk Density Kg/L**	**Iron Bound [P] mg/Kg**	**Mass of P Kg**
North Basin	52389	0.2	1.10	46.93	597.58
Central Basin	36237	0.4	1.25	24.76	391.03
South Basin	17679	0.5	1.43	0	0.00
Bearses	20396	0.3	1.08	9.28	53.36
Gooseberry	8382	0.3	1.54	0	0.00
Total					1,041.98

A comparison of the total mass of phosphorous and the mass of iron bound phosphorus shows that the iron bound phosphorous is a small fraction of the total phosphorous in all basins.

We estimated the maximum contribution that iron bound phosphorous recycled from the bottom sediments of Bearses Pond and Central Basin could make to the overlying water column assuming:

- All iron bound phosphorous in the top 3 cm of the sediment layer (the approximate depth of bioturbation in soft lake sediments) was released;
- The release is instantaneous; and,
- The entire released mass mixed completely into the overlying water column in each basin.

Table 4.11-3 shows that the potential incremental phosphorous concentration in the water columns of the Central Basin and Bearses Pond from sediment recycling during periods of anoxia is about 6.1 ug/L and 5.4 ug/L respectively. A comparison of these incremental concentrations to the long-term (data in Attachment 2) average water column phosphorous concentrations during the spring to autumn in each basin shows that the potential incremental increase in phosphorous is approximately 21.9% in the Central Basin and 26% in Bearses Pond. Note that these conservatively derived incremental phosphorous concentrations apply only during and shortly after periods of stratification and anoxia. During these periods of anoxia, there is no consistent pattern of phosphorous build up in near bottom water as exhibited by phosphorous concentrations measured at the surface and bottom (see data in Attachment 2).

Table 4.11-3. Potential Incremental Phosphorous Concentration in the Water Colums of the Central Basin and Bearses Pond

	Pond Basin Area m^2	**Depth of Bioturbation m**	**Sediment Solids Kg$_{dw}$/Kg**	**Bulk Density Kg/L**	**[P] mg/Kg**	**Mass of P Kg**	**Water Volume m3**	**Incremental Concentration ug/L**
Central Basin	60678	0.03	0.35	1.25	24.76	19.72	3253669	6.1
Bearses	58579	0.03	0.26	1	9.28	4.24	780586	5.4

4.12 WHAT ARE THE GENERAL CONCLUSIONS?

In general these data suggest that: (1) the phosphorous loading to the lake from the existing septic systems is the largest manageable fraction of the total annual phosphorous load; (2) some subset of these existing systems are likely to be experiencing breakout currently; (3) without management actions to control the septic loading, future septic loading will increase sufficiently to drive the trophic status of the lake toward a eutrophic condition; (4) recycling of phosphorous from sediments may contribute as much as 20% to 30% of the overlying water column phosphorous concentration but only during periods of near bottom anoxia in the Central Basin and Bearses Pond. These generalizations are subject to various sources of uncertainty including:

- Limited spatial distribution of the groundwater phosphorous concentrations especially for the smaller basins (e.g. Bearses Pond);
- Limited temporal distribution of the groundwater data (largely summer to fall);
- Dependence on assumed septic concentrations of phosphorous from a non-site specific source;
- Lack of knowledge of the site-specific mineralogy of the soil surrounding the near field septic systems;

- Dependence on the assumption that the Vollenweider model accurately reflects the trophic conditions in the basins;
- Limited temporal distribution of surface and bottom water phosphorous concentrations;
- No pattern in the differences between surface and bottom water phosphorous that would indicate near bottom phosphorous build up during periods of anoxia.

However, there are several lines of evidence and analysis indicating that the lake basins, although currently classified as oligotrophic to mesotrophic are susceptible to further eutrophication over the next several decades because:

1) The trophic categorizations based on 95th UCL on the average for groundwater and rainwater measurements of phosphorus indicate that all the basins are at least mesotrophic and Gooseberry may already be eutrophic;
2) The current chlorophyll data (e.g Eichner et al., 2009) indicate that the basins are mesotrophic;
3) Dissolved oxygen data indicate occasional low bottom water oxygen;
4) The maximum and 95th UCL on the mean of measured phosphorous concentrations in groundwater entering the lake suggests some breakout may be occurring;
5) The use of the 95 UCL on the mean in trophic categorizations is often similar to the expected categorization under an assumed condition of phosphorous breakout to the lake;

The general conclusion of these analyses is that Lake Wequaquet is eutrophying and may already be experiencing breakout from near shore septic systems. Although we cannot put a timeframe on the rate of eutrophication or breakout, we do note that the timeframe for breakout from the Otis Air Base plume to Ashumet Pond in Falmouth is on the time scale of decades (recognizing the higher septic loads to that system).

Several observations support the probability of breakout currently occurring, at least on local scales. These include: (1) the water quality data; (2) various aperiodic, but generally late summer qualitative observations of metaphyton blooms along the near shore areas of the lake; and (3) observations of near shore macro-algal blooms at various locations in the lake. Therefore, some phosphorous control actions should be taken to meet the stated management goals.

4.13 WHAT SAMPLING AND ANALYSIS CAN BE DONE TO ADDRESS THE UNCERTAINTIES IN THE GENERAL CONCLUSION?

Monitoring Program: To refine the estimates of phosphorus loading from groundwater to the lake basins

Monitoring Program 1a: Obtain More Spatially Dense Data Sets for Groundwater Phosphorous Along the Shoreline of the Lake

The analysis relies heavily on the calculated average and 95th UCL of phosphorous concentrations in near shore groundwater and the data indicate that the concentrations are highly variable. Therefore, we recommend:

- Doubling the number of transects for groundwater phosphorous measurements in each basin (transect locations are dependent upon land owner permission);
- Measuring phosphorous concentration over three seasons (late winter, summer, and late autumn) along each of these transects;
- Revising the estimates of groundwater loading based on this more robust data set.

Monitoring Program 1b: Watershed Specific Background Phosphorous Concentrations in Groundwater

Resolving the different contributions of phosphorous from nearfield septic systems and watershed background would improve the estimate of septic contribution to lake phosphorous loading. Toward this end we recommend:

- Sampling groundwater in ten installed groundwater sampling wells in the watershed of the main basin of Lake Wequaquet and three installed groundwater wells in each of the smaller basins (South, Bearses, and Gooseberry).
- Analyze samples for total phosphorous quarterly for one year.
- Estimate the background loading using phosphorous data and estimates of groundwater flow to the lake.
- Estimate phosphorus loading from near field septic systems by subtracting background groundwater phosphorus concentration from the concentration measured at the edge of the lake, then multiplying the P concentration by groundwater flow volume.

Estimated Cost:

Monitoring Program 2: Assess the temporal and spatial occurrence of blue green algal blooms in nearshore waters.

Monitoring Program 2a: Assess the Local Loading of Phosphorous from the Johnson Road Culvert and Direct Deposition During Six Rain Storms Over one Hydrological Year

There have been various qualitative observations of blue-green algal blooms originating in near shore areas. These blooms may be initiated by local inputs of phosphorous due to storm water runoff such as occurs at the Johnson Lane culvert. Direct deposition to the lake also serves as an important source of phosphorous, so we recommend sampling during and just after rain events. Specifically we recommend

- Collect either time or flow weighted water samples at the culvert during rain storms (at a target minimum duration of at least 2 hours) and analyze for total phosphorus.
- Estimate runoff volume at the culvert.
- Use phosphorous concentrations and runoff volume estimates to calculate phosphorous loading to the lake via the culvert.
- Measure real-time (using water quality monitoring probes) in-lake surface water phosphorous and chlorophyll offshore of the culvert during the sampled rainstorms, and every 24 hours following a storm for a 72 hour period.
- If the chlorophyll doubles between sampling periods, initiate sampling of water samples for analysis of phytoplankton abundance and dominant species.
- Evaluate data to assess whether any differences in chlorophyll concentration in surface water after a rain storm lead to blooms.

Monitoring Program 2b: In Addition to the Johnston Lane Monitoring, Conduct Nearshore High Frequency Sampling In "Real-Time" to assess the spatial and temporal patterns of the recently observed blue-green algal blooms. We recommend:

- Sampling ten to twenty shallow stations along the perimeter of the lake basins
- Sampling twice weekly at all stations around the perimeter of the lake basins;
- analyze samples for chlorophyll, phyocyanin, phytoplankton and metaphyton;
- Whenever chlorophyll doubles at a sampling station, collect water samples and perform phytoplankton and metaphyton counts to describe algal concentrations and document any blooms.

Monitoring Program 3: Build Upon Current Water Quality Progam to Assess More Closely the Frequency and Effects of Stratification on Bottom Oxygen and Bottom Phosphorous and Assess the Trends in Trophic Status of the Lake.

- Collect water quality data (including surface and bottom phosphorous concentrations) every other week during late winter/early spring (March and April) and weekly throughout the growing season (May-September).
- Use a YSI or other real-time data collection system to monitor dissolved oxygen, turbidity, temperature, chlorophyll (phytoplankton indicator), and phycocyanin (blue-green algae indicator).
- Compile data in brief data summary reports after each monitoring event in order to provide timely dissemination of water quality conditions to interested parties.

4.14 WHAT CAN BE DONE TO MAINTAIN THE CURRENT TROPHIC STATUS OF MAIN BASIN, SOUTH BASIN, AND GOOSEBERRY POND?

Various management actions can aid in decreasing the future phosphorus load to the lake. Phosphorus sources that are locally manageable include wastewater, impervious surface runoff, and fertilizers.

4.14.1 Wastewater

Wastewater phosphorus loading can be reduced by 1) reducing the use of phosphate detergents, 2) diverting wastewater from the watershed for treatment elsewhere using traditional sewering; or 3) reducing the phosphorus concentration in septic effluent using on-site septic systems.

Reducing Phosphte-rich Detergents

Detergent, is estimated to account for up to 10-12% of phosphorus in wastewater (MA EEA, 2013). In an effort to reduce phosphorus in groundwater, Massachusetts recently passed regulations that prohibit the sale of high-phosphate detergents. In February 2008, the State passed legislation that made it illegal for retailers to offer dishwashing detergents containing more than 0.5% or phosphate by weight. The rule became effective July 1, 2010 (MA EEA, 2013). The reduction in phosphate detergent may be helping to reduce the phosphorus load to groundwater, though additional measures are necessary in that even a complete removal of phosphorus from detergent would cause at most a 12% reduction in the total wastewater phosphorus load.

Sewering

Traditional sewer systems could be used to remove septic effluent from area in the vicinity of the lake for treatment elsewhere, essentially preventing all of the septic-related phosphorus from entering the groundwater flowing to the lake. If sewering is the selected alternative, our analysis indicates that initially the system should at least include those septic systems within 100 meters of the lake shore, in order to remove the wastewater-derived phosphorus from the near field watershed area.

"Alternative" On-site Septic Systems

There are several types of onsite septic systems designed for nutrient removal, and they vary in phosphorus reduction (Heufelder and Mroczka 2006). Interestingly, a comparison of phosphorus removal from traditional septic systems vs. phosphorus removal systems showed that the phosphorus removal systems had higher retention of phosphorus in the septic tank, but when the soil adsorption system in the leachfield and vadose zone[2] was considered, the standard septic system out-performed the systems designed to remove phosphorus. This illustrates the importance of the soil in the vicinity of the septic system. In particular, Heufelder and Mroczka (2006) note that phosphorus retention is enhanced by maximizing the distribution area of the effluent, maintaining a maximum vadose zone, locating dispersal pipes in the upper soil horizons and selecting soils with redder hues and higher iron content.

4.14.2 Impervious Surfaces

Impervious surface runoff can be managed by collecting and re-using or treating the water. Runoff from roads can be captured in storm drains designed to capture solids and nutrients. Runoff from roofs can be captured in rain barrels and used to create rain gardens. Vegetative buffers and wetlands can be created to capture runoff and/or groundwater nutrients.

4.14.3 Fertilizer

Phosphorus in fertilizer can be managed by following best practices, reducing overall use in areas adjacent to water bodies, or by using no-phosphate brands of fertilizer. Recommendations for fertilizer use in lawns and gardens near waterbodies include:

- Have your soil tested to determine how much fertilizer to apply.
- Water your lawn after fertilizing, but do not allow excess water to run off into surface waters.
- Sweep up any fertilizer which is spilled on hard surfaces such as walks and driveways.
- Do not spread fertilizer within 75 feet of surface waters or wetlands.
- Use a "drop" spreader and not a "cyclone" spreader to reduce the chances of getting fertilizer in the water.

Massachusetts currently does not have fertilizer use regulations, though other states do. Seventeen states ban the use of phosphate fertilizers, except for certain purposes such as turf management, agriculture, lawn creation/repair, or if a phosphorus deficiency is documented in a growing area (Miller, 2012).

[2] The vadose zone is a subsurface zone of soil or rock containing fluid under pressure that is less than that of the atmosphere. Pore spaces in the vadose zone are partly filled with water and partly filled with air. In the vadose zone phosphorus from land-based sources such as rain on the watershed or septic system effluent can be retained rather than transferred to groundwater.

4.15 USE ADAPTIVE MANAGEMENT TO REVISE ACTIONS IF ADDITIONAL INFORMATION SUGGESTS CHANGES ARE NECESSARY

Adaptive management is a structured, iterative process of decision making in the face of uncertainty, with an aim of reducing uncertainty over time. In this way decision making simultaneously meets one or more resource management objectives and accrues information needed to improve future management. In the case of lake management this is an important framework, as there is considerable uncertainty in predicting the trophic status and how it may change with changes in phosphorus loading. The lake water quality monitoring can be used to update information on the lake trophic status and should be pursued.

5.0 REFERENCES

Eichner, E., X. Wu, D. McCaffery, and G. Prahm. 2009. Lake Wequaquet Water Quality Assessment, Final Report, January 2009. Prepared for the Town of Barnstable.

Eichner, E. and B. Howes. 2011. Technical Memorandum, Lake Wequaquet Summer 2010 Water Quality Monitoring. March 23, 2011.

Frimpter, M.H. and F.B. Gay. 1979. Chemical Quality of Ground Water on Cape Cod, Massachusetts. USGS Investigation 79-65.

Godfrey, P.J., K. Galluzzo, N. Price & J.W. Portnoy. 1999. Water Resources Management Plan for Cape Cod National Seashore. National Park Service 251 pp.

Harman, J., W.D. Robertson, J.A. Cherry and L. Zanini. 1996. "Impacts on a sand aquifer from an old septic system: nitrate and phosphate." *Ground Water* 34:1105-1114.

Howes, B., Kelley, S., Ramsey, J., Samimy, R., Eichner, E., Schlezinger, D., and Wood, J. 2004. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Popponesset Bay, Mashpee and Barnstable, Massachusetts. Commonwealth of Massachusetts, Department of Environmental Protection, Massachusetts Estuaries Project, 138 pp. + Executive Summary, 10 pp.

Heufelder, G. and K. Mroczka. 2006. Evaluation of Methods to Control Phosphorous in Areas Served by Onsite Septic Systems. A Special Issue of Environment Cape Cod. County of Barnstable Massachusetts. June 2006.

Idaho DEQ. 2012. Domestic Wastewater Phosphorus Report, Phosphorus Concentration of Residential Clarified Effluent. State of Idaho, Department of Environmental Quality. PID OSWW, CA 82541, Water Quality Division, Boise ID.

IEP. 1989. Final Report, Diagnostic/Feasibility Study Wequaquet Lake, Bearse, and Long Pond.

Kroeger, K.D. et al., Groundwater-transported dissolved organic nitrogen exports from coastal watersheds. Limnol. Oceanogr., 51(5), 2006, 2248–2261

Lombardo, P. 2006. Phosphorus geochemistry in septic tanks, soil absorption systems, and groundwater. Lombardo Associates, Inc., 4 Edge Hill road, Newton, Massachusetts.

MA EE. 2013. Massachusetts Nutrient Management Report 2013. Online at http://www.mass.gov/eea/agencies/massdep/water/watersheds/massachusetts-nutrient-management-report-2013.html.

Mccobb, T.D., D. R. Leblanc, D. A. Walter, K. M. Hess, D. B. Kent, and R. L. Smith. 2003. Phosphorus in a Ground-Water Contaminant Plume Discharging toAshumet Pond, Cape Cod,Massachusetts, 1999. U.S. Geological Survey, Water-Resources Investigations Report 02-4306.

Miller, KL. 2012. State Laws Banning Phosphorus Fertilizer Use. State of CT General Assembly report available online at http://www.cga.ct.gov/2012/rpt/2012-R-0076.htm

Minnesota Pollution Control Agency. 1999. Effects of Septic Systems on Ground Water Quality - Baxter, Minnesota, May 1999 Published by Minnesota Pollution Control Agency, Ground Water and Toxics Monitoring Unit, Environmental Monitoring and Analysis Section, Environmental Outcomes Division, 520 Lafayette Road North, St. Paul, Minnesota 55155-4194.

Pfannkuch, H.O. and T.S. Winter. 1984. Effect of anisotropy and groundwater system geometry on seepage through lakebeds, 1. Analog and dimensional analysis. J. Hydrol., 75: 213--237.

Robertson, W.D., S.L. Schiff, C.J. Ptacek. 1998. Review of phosphate mobility and persistence in ten septic system plumes. Ground Water, 36: 1000-1010.

Sondergaard, M. Nutrient Dynamics in Lakes, with Emphasis on Phosphorous, Sediment and Lake Restoration. Doctors Dissertation, National Environmental Research Institute, University of Aarhus, Denmark.

Soil Conservation Service. 1984. Soil Survey or Barnstable County, Massachusetts. United States Department of Agriculture.

Valiela et al. 1978. Nutrient and particulate fluxes in a salt marsh ecosystem. Tidal exchanges and inputs by precipitation and groundwater. *Limnology and Oceanography*. 23: 798-812.

Vollenweider, R.A. and P.J. Dillon. 1974. The application of the phosphorus loading concept to eutrophication research. National Research Council Canada, NRCC 13690.

ATTACHMENT 1. WEQUAQUET LAKE SEDIMENT GRABS

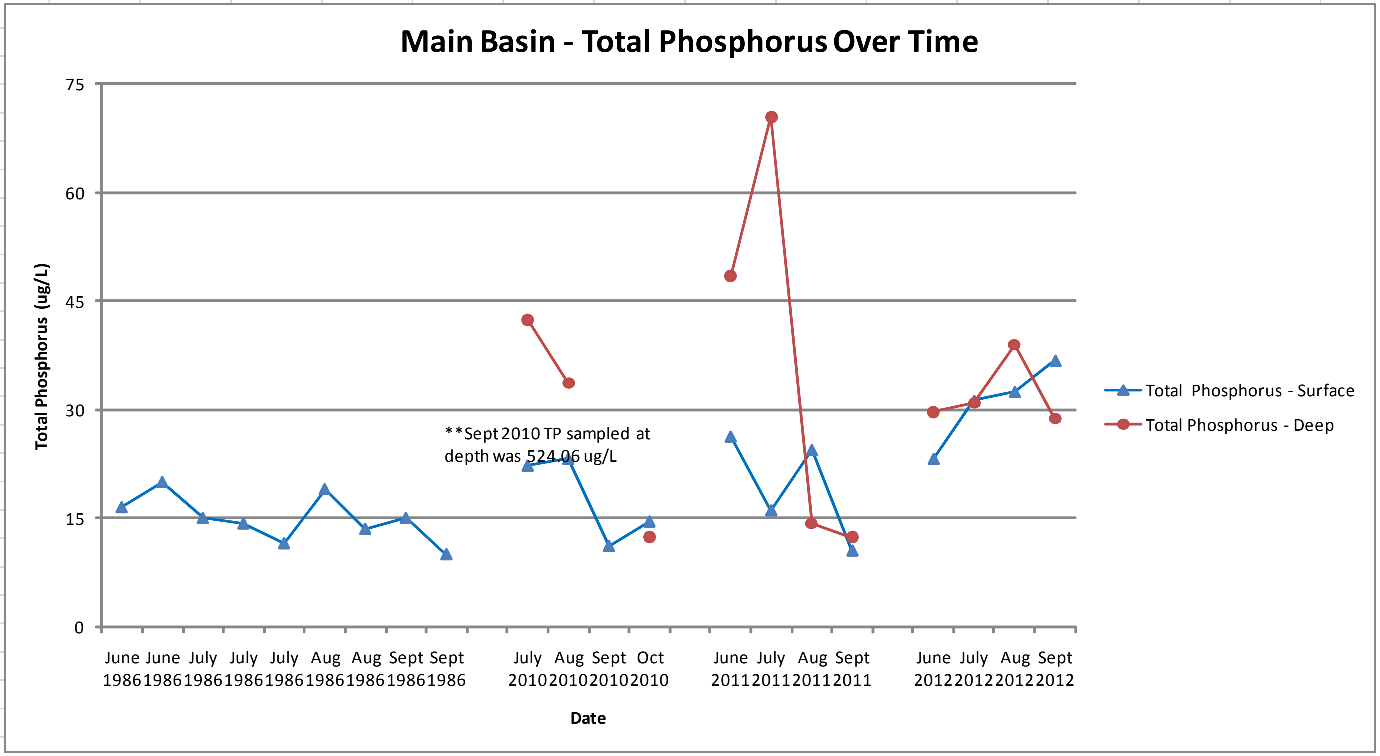
Table A1-1. Wequaquet Lake Sediment Grabs – Ground Truthing

			Latitude		Longitude								
Sample ID	**Date**	**Time**	**D**	**MIN**	**D**	**MIN**	**Depth (ft)**	**Description**		**Longitude**	**Latitude**	**X MASPMm**	**Y MASPMm**
WN-22	8/16/2011	11:49	41	40.389	70	20.309	15.7	fine/mud		-70.33848333	41.67315	296721.079	825425.085
WN-21	8/16/2011	12:00	41	40.412	70	20.420	11.5	coarse/gravel		-70.34033333	41.67353333	296566.457	825465.561
WN-20	8/16/2011	12:13	41	40.459	70	20.452	23.0	fine sand		-70.34086667	41.67431667	296520.867	825551.952
WN-19	8/16/2011	12:20	41	40.516	70	20.441	21.7	fine sand		-70.34068333	41.67526667	296534.698	825657.664
WN-18	8/16/2011	12:26	41	40.466	70	20.549	16.5	fine-med sand		-70.34248333	41.67443333	296386.08	825563.081
WN-08	8/16/2011	12:31	41	40.593	70	20.561	26.5	mud - very fine/soft		-70.34268333	41.67655	296366.237	825797.926
WN-09	8/16/2011	12:38	41	40.704	70	20.571	17.0	very coarse - cobble, mussel shells, coarse sand		-70.34285	41.6784	296349.573	826003.194
WN-13	8/16/2011	12:48	41	40.708	70	20.483	20.0	No Sample - two attempts one grab came up with small amount of coarse sand		-70.34138333	41.67846667	296471.586	826012.256
WN-15	8/16/2011	12:54	41	40.776	70	20.484	27.0	fine-mud		-70.3414	41.6796	296468.488	826138.102
WN-14	8/16/2011	13:01	41	40.821	70	20.435	14.0	med sand w/gravel, mussel shell & organic debris		-70.34058333	41.68035	296535.35	826222.319
WN-17	8/16/2011	13:08	41	40.789	70	20.421	20.0	mud w/fine sand		-70.34035	41.67981667	296555.582	826163.353
WN-11	8/16/2011	13:23	41	40.709	70	20.764	21.0	silty sand w/mussel shells		-70.34606667	41.67848333	296081.629	826008.821
WN-05	8/16/2011	13:31	41	40.776	70	20.484	27.0	fine-mud		-70.3414	41.6796	296468.488	826138.102
WN-07	8/16/2011	13:39	41	40.495	70	20.828	21.0	muddy sand & gravel		-70.34713333	41.67491667	295998.173	825611.515
WN-24	8/16/2011	13:46	41	40.400	70	20.847	18.5	mud		-70.34745	41.67333333	295974.183	825435.317
WN-23	8/16/2011	13:51	41	40.354	70	20.816	11.0	gravel (small sample, hard bottom, 2 attempts)		-70.34693333	41.67256667	296018.355	825350.754
WN-27	8/16/2011	13:56	41	40.289	70	20.862	14.0	sand w/veg. (2 attempts)		-70.3477	41.67148333	295956.142	825229.579
WC-26	8/16/2011	14:05	41	40.221	70	20.524	18.5	muddy sand/gravel w/live mussel		-70.34206667	41.67035	296426.93	825110.067
WC-31	8/16/2011	14:13	41	40.149	70	20.608	18.0	cobble & gravel w/mussel shell		-70.34346667	41.66915	296312.159	824975.216
WC-29	8/16/2011	14:17	41	40.126	70	20.590	23.0	sandy mud (fine sand) - lower portion of grab becomes coarser		-70.34316667	41.66876667	296337.718	824932.983
WC-59	8/16/2011	14:27	41	40.168	70	20.435	21.0	2nd attempt - muddy sand w/mussel shells, sand is med-coarse 1st attempt - a wash out, coarse sand & shells		-70.34058333	41.66946667	296551.78	825013.644
WC-43	8/16/2011	14:39	41	40.030	70	20.606	15.0	gravel & cobbles 3 attempts - 1st gravel, 2nd nothing, 3rd - large cobble		-70.34343333	41.66716667	296317.922	824754.99
WC-39	8/16/2011	14:46	41	39.977	70	20.684	22.0	sandy mud		-70.34473333	41.66628333	296210.994	824655.422
WC-40	8/16/2011	14:53	41	39.907	70	20.706	17.0	sandy mud (fine-coarse sand)		-70.3451	41.66511667	296182.214	824525.442
WC-41	8/16/2011	15:00	41	39.876	70	20.711	17.0	sand, 2-live mussels		-70.34518333	41.6646	296176.051	824467.968
WC-42	8/16/2011	15:10	41	39.882	70	20.625	10-14	gravel/cobble - 4 attempts		-70.34375	41.6647	296295.265	824480.691
WC-35	8/16/2011	15:18	41	39.939	70	20.538	16.0	gravel & shells		-70.3423	41.66565	296414.585	824587.833
WC-33	8/16/2011	15:30	41	39.991	70	20.440	21.0	gravel - 4 attempts		-70.34066667	41.66651667	296549.294	824685.931
WC-36	8/16/2011	15:41	41	40.058	70	20.451	32.0	mud/sandy mud		-70.34085	41.66763333	296532.342	824809.737
WC-58	8/16/2011	16:31	41	40.099	70	20.388	21.0	cobble (1 large cobble)		-70.3398	41.66831667	296618.747	824886.815
WC-49	8/16/2011	16:39	41	40.194	70	20.222	12.5	gravel, shells & SAV		-70.33703333	41.6699	296846.736	825065.794
WC-53	8/16/2011	16:45	41	40.231	70	20.172	18.5	mud w/low % sand		-70.3362	41.67051667	296915.194	825135.226
WC-52	8/16/2011	16:51	41	40.252	70	20.201	16.0	mud w/SAV, coarser down at bottom of grab w/sand		-70.33668333	41.67086667	296874.417	825173.547
WC-55	8/16/2011	16:57	41	40.232	70	19.941	6.5	muddy sand w/SAV		-70.33235	41.67053333	297235.756	825141.458
WC-54	8/16/2011	17:05	41	40.258	70	20.056	6.0	gravel/cobbles - 3 attempts		-70.33426667	41.67096667	297075.499	825187.4
WC-50	8/16/2011	17:22	41	40.311	70	20.085	13.0	gravel, cobbles, mussels - 5 attempts		-70.33475	41.67185	297033.912	825284.951
B-144	8/18/2011	14:05	41	40.679	70	19.916	15.0	gravel/cobbles		-70.33193333	41.67798333	297259.121	825969.31
B-143	8/18/2011	14:10	41	40.638	70	19.882	18.0	mud/organic mud		-70.33136667	41.6773	297307.341	825894.067
B-140	8/18/2011	14:15	41	40.650	70	19.972	20.0	mud/organic mud		-70.33286667	41.6775	297182.146	825914.569
B-138	8/18/2011	14:20	41	40.640	70	20.102	12.0	mud		-70.33503333	41.67733333	297002.001	825893.593
B-145	8/18/2011	14:24	41	40.569	70	20.123	7.0	gravel & cobble		-70.33538333	41.67615	296974.655	825761.777
B-137	8/18/2011	14:29	41	40.519	70	20.046	17.7	organic mud		-70.3341	41.67531667	297082.773	825670.689
B-134	8/18/2011	14:33	41	40.531	70	19.981	6.7	gravel		-70.33301667	41.67551667	297172.671	825694.134
B-130	8/18/2011	14:40	41	40.429	70	19.898	9.8	gravel		-70.33163333	41.67381667	297290.438	825506.914
B-131	8/18/2011	14:45	41	40.478	70	19.902	8.5	1 large cobble - sample not saved		-70.3317	41.67463333	297283.645	825597.534
B-133	8/18/2011	14:47	41	40.452	70	19.866	15.0	mud		-70.3311	41.6742	297334.263	825550.094
B-128	8/18/2011	14:52	41	40.429	70	19.812	15.8	organic mud		-70.3302	41.67381667	297409.785	825508.55
B-127	8/18/2011	14:58	41	40.382	70	19.793	17.0	organic mud		-70.32988333	41.67303333	297437.346	825421.916
B-126	8/18/2011	15:08	41	40.372	70	19.779	8.0	6 attempts made		-70.32965	41.67286667	297457.028	825403.673
G-123	8/18/2011	15:45	41	40.133	70	19.707	10.8	sandy mud w/gravel		-70.32845	41.66888333	297563.025	824962.667
G-125	8/18/2011	15:50	41	40.166	70	19.752	6.5	sandy mud w/gravel		-70.3292	41.66943333	297499.732	825022.891
G-124	8/18/2011	15:57	41	40.127	70	19.757	8.3	Organic mud w/SAV, 2 attempts - both with heavy % SAV		-70.32928333	41.66878333	297493.784	824950.609
G-113	8/18/2011	16:04	41	40.152	70	19.654	16.0	sandy mud w/organics		-70.32756667	41.6692	297636.098	824998.846
G-112	8/18/2011	16:10	41	40.174	70	19.570	18.0	organic mud		-70.32616667	41.66956667	297752.117	825041.171
G-114	8/18/2011	16:17	41	40.197	70	19.648	9.0	gravel & 1 large cobble		-70.32746667	41.66995	297643.28	825082.254
G-115	8/18/2011	16:23	41	40.252	70	19.598	16.5	mud w/organics		-70.32663333	41.67086667	297711.271	825185.01
G-117	8/18/2011	16:30	41	40.245	70	19.715	7.4	mud w/organics/rhizomes		-70.32858333	41.67075	297549.074	825169.822
G-147	8/18/2011	16:35	41	40.279	70	19.713	7.0	sand, muddy sand, sand if fine-coarse		-70.32855	41.67131667	297550.986	825232.792
G-118	8/18/2011	16:43	41	40.286	70	19.506	9.0	sand and gravel		-70.3251	41.67143333	297838.083	825249.7
G-121	8/18/2011	16:48	41	40.262	70	19.491	11.8	muddy w/SAV		-70.32485	41.67103333	297859.513	825205.564
G-148	8/18/2011	16:53	41	40.276	70	19.436	9.5	muddy SAND w/SAV		-70.32393333	41.67126667	297935.485	825232.53
G-122*	8/18/2011	17:01	41	40.143	70	19.536	17.0	sand & gravel (*As-built position not recorded, but collection location was very near the proposed sample position. Therefore, the proposed position is listed here.)		-70.3256	41.66905	297799.7383	824984.2719

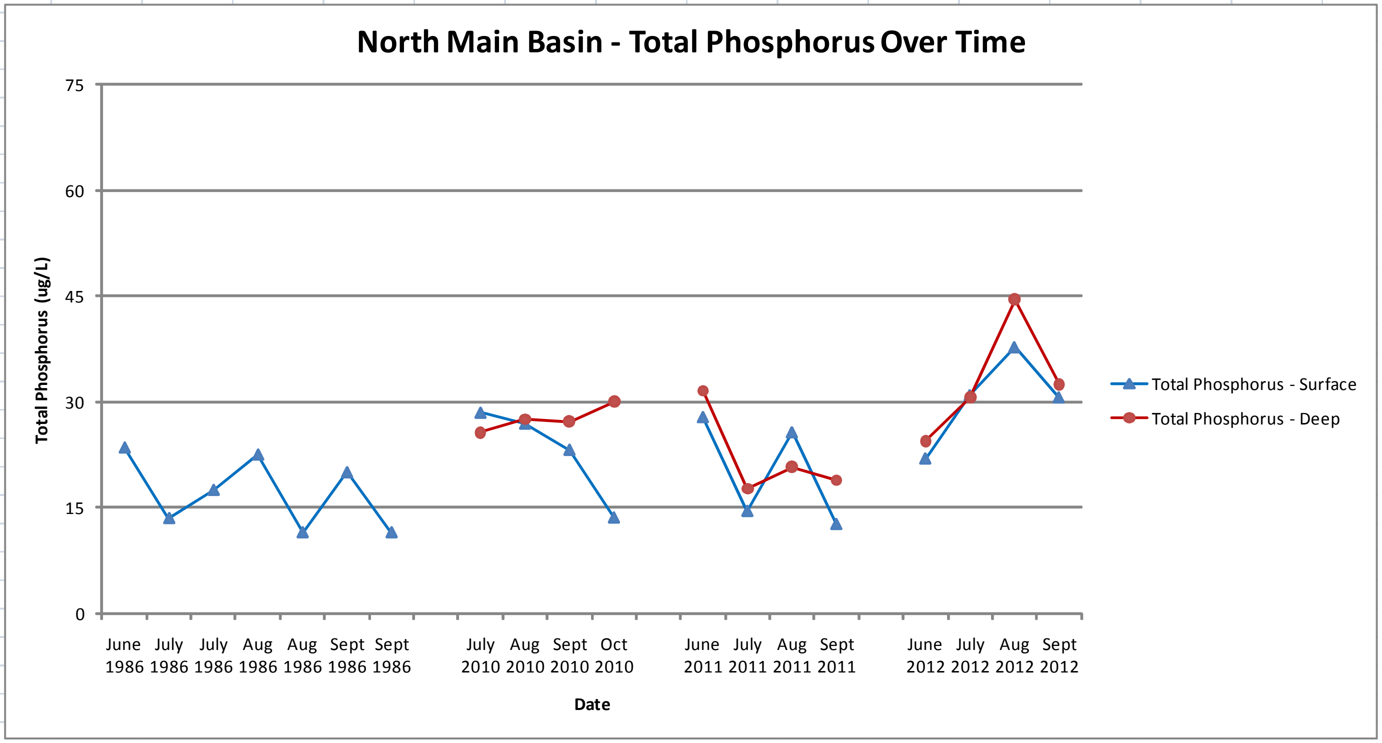
ATTACHMENT 2. WATER QUALITY DATA OVER TIME

ATTACHMENT 2-1 TOTAL PHOSPHORUS

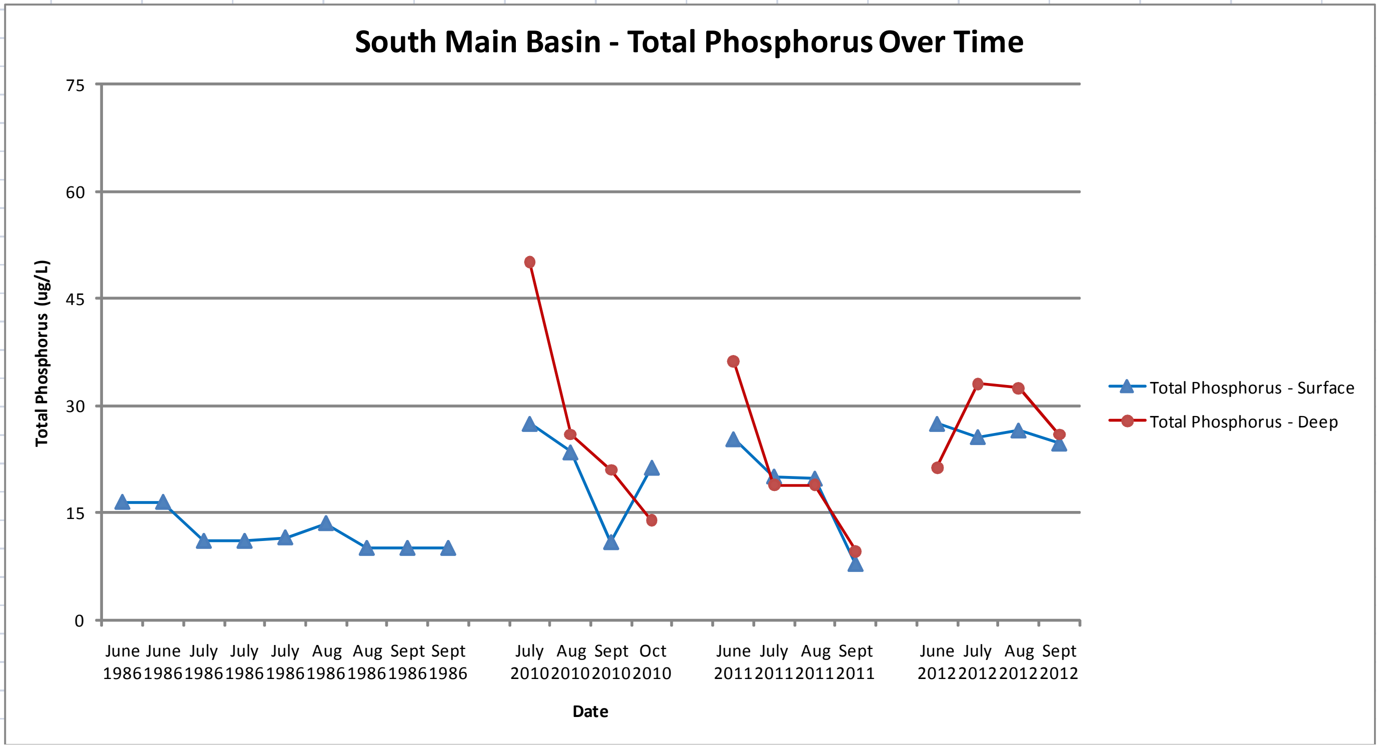
Main Basin		
	TP Surface	TP Deep
June 1986	16.5	
June 1986	20	
July 1986	15	
July 1986	14.25	
July 1986	11.5	
Aug 1986	19	
Aug 1986	13.5	
Sept 1986	15	
Sept 1986	10	
July 2010	22.25	42.33
Aug 2010	23.18	33.68
Sept 2010	11.12	
Oct 2010	14.52	12.36
June 2011	26.27	48.51
July 2011	16.07	70.45
Aug 2011	24.41	14.21
Sept 2011	10.51	12.36
June 2012	23.175	29.664
July 2012	31.209	30.9
Aug 2012	32.445	38.934
Sept 2012	36.771	28.737
Average	**27.57**	



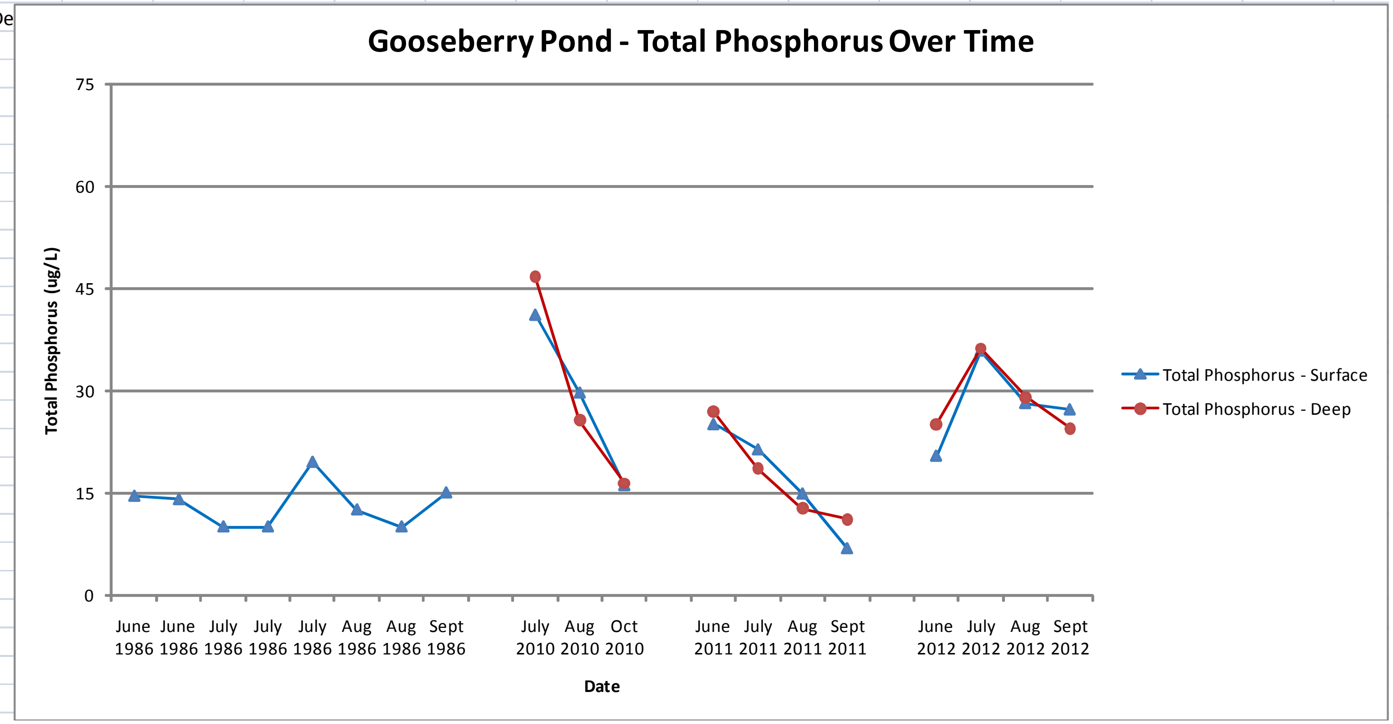
North Main Basin		
	TP Surface	TP Deep
June 1986	23.50	
July 1986	13.50	
July 1986	17.50	
Aug 1986	22.50	
Aug 1986	11.50	
Sept 1986	20.00	
Sept 1986	11.50	
July 2010	28.43	25.65
Aug 2010	26.88	27.50
Sept 2010	23.18	27.19
Oct 2010	13.60	29.97
June 2011	27.81	31.52
July 2011	14.52	17.61
Aug 2011	25.65	20.70
Sept 2011	12.67	18.85
June 2012	21.939	24.411
July 2012	30.9	30.591
Aug 2012	37.698	44.496
Sept 2012	30.591	32.445
Average	**26.03**	



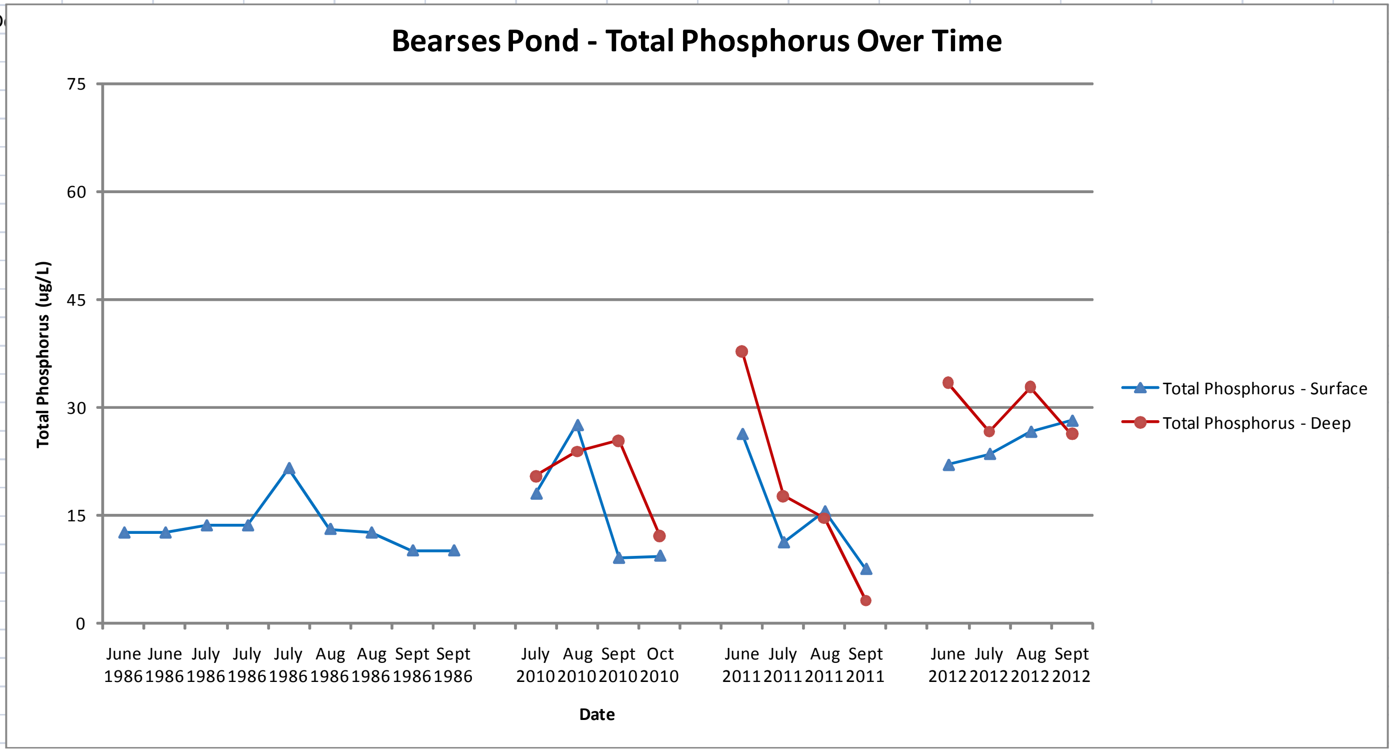
South Main Basin		
	TP Surface	TP Deep
June 1986	16.50	
June 1986	16.50	
July 1986	11.00	
July 1986	11.00	
July 1986	11.50	
Aug 1986	13.50	
Aug 1986	10.00	
Sept 1986	10.00	
Sept 1986	10.00	
July 2010	27.50	50.06
Aug 2010	23.48	25.96
Sept 2010	10.82	21.01
Oct 2010	21.32	13.91
June 2011	25.34	36.15
July 2011	20.09	18.85
Aug 2011	19.78	18.85
Sept 2011	7.73	9.58
June 2012	27.501	21.321
July 2012	25.647	33.063
Aug 2012	26.574	32.445
Sept 2012	24.72	25.956
Average	**23.65**	



Gooseberry Pond		
	Total Phosphorus -	ıosphorus - De
June 1986	14.50	
June 1986	14.00	
July 1986	10.00	
July 1986	10.00	
July 1986	19.50	
Aug 1986	12.50	
Aug 1986	10.00	
Sept 1986	15.00	
July 2010	41.10	46.66
Aug 2010	29.66	25.65
Oct 2010	16.07	16.38
June 2011	25.03	26.88
July 2011	21.32	18.54
Aug 2011	14.83	12.67
Sept 2011	6.80	11.12
June 2012	20.394	25.029
July 2012	35.844	36.153
Aug 2012	28.119	29.046
Sept 2012	27.192	24.411
Average	**24.50**	



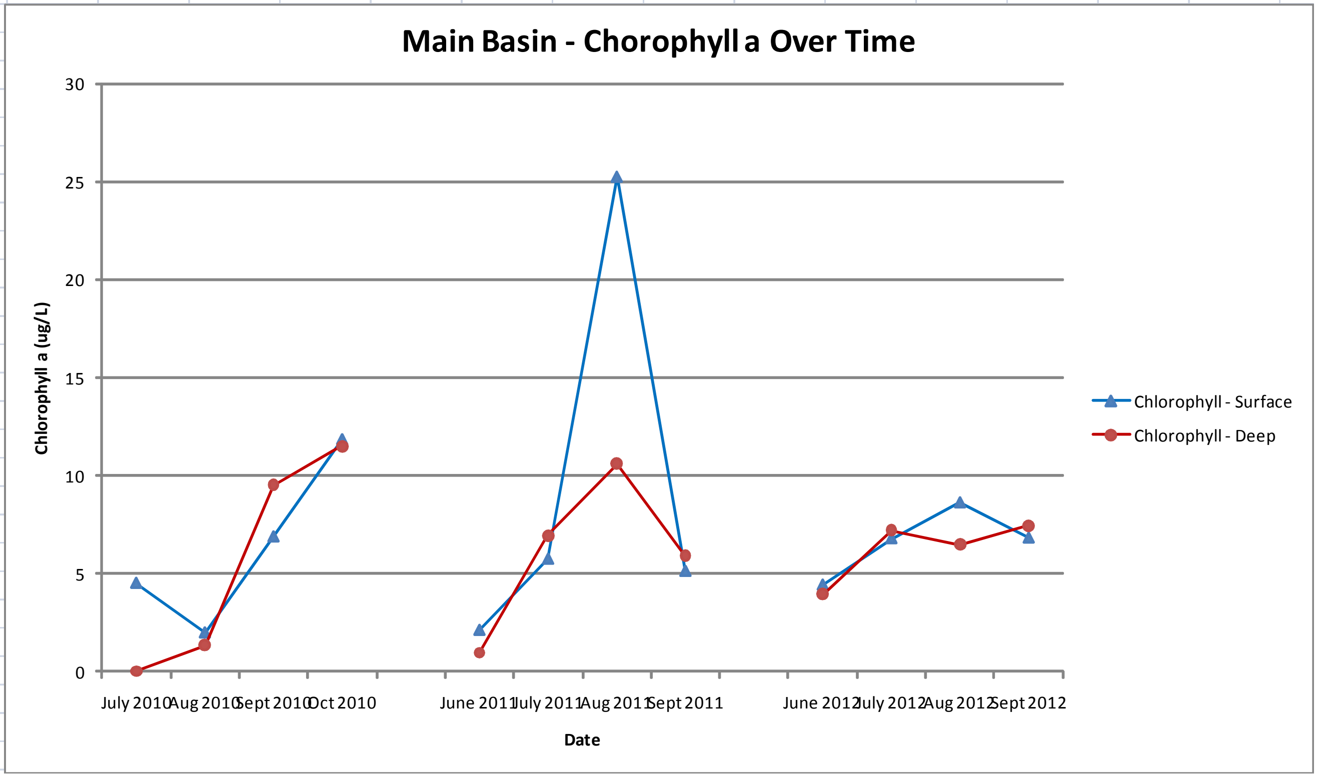
Beares Pond		
	Total Phosphorus -	ıosphorus - D
June 1986	12.50	
June 1986	12.50	
July 1986	13.50	
July 1986	13.50	
July 1986	21.50	
Aug 1986	13.00	
Aug 1986	12.50	
Sept 1986	10.00	
Sept 1986	10.00	
July 2010	17.92	20.394
Aug 2010	27.50	23.793
Sept 2010	8.96	25.338
Oct 2010	9.27	12.051
June 2011	26.27	37.698
July 2011	11.12	17.613
Aug 2011	15.45	14.523
Sept 2011	7.42	3.09
June 2012	21.939	33.372
July 2012	23.484	26.574
Aug 2012	26.574	32.754
Sept 2012	28.119	26.265
Average	**20.73**	



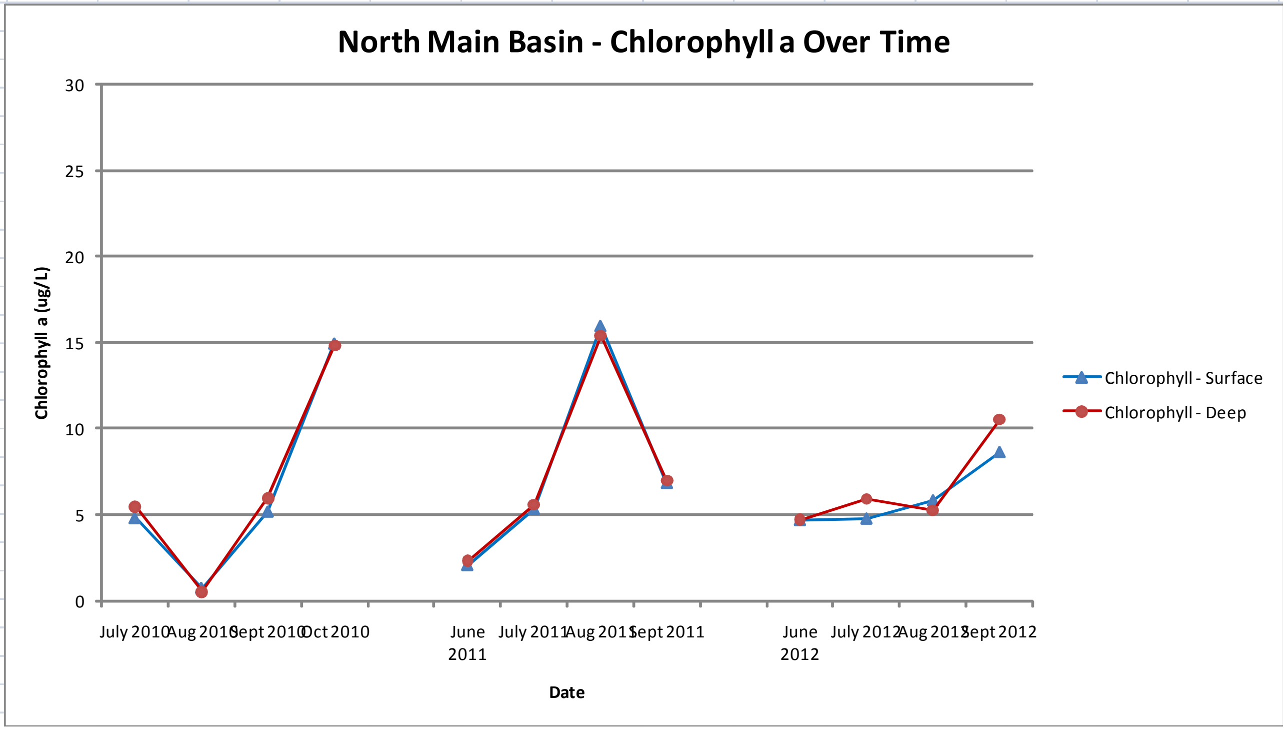
ATTACHMENT 2-2 CHLOROPHYLL A

Main Basin		
	Chlorophyll - Surface	Chlorophyll - Deep
July 2010	4.51	0.03
Aug 2010	1.98	1.36
Sept 2010	6.88	9.52
Oct 2010	11.84	11.51
June 2011	2.11	0.98
July 2011	5.74	6.94
Aug 2011	25.24	10.61
Sept 2011	5.12	5.92
June 2012	4.42	3.95
July 2012	6.79	7.22
Aug 2012	8.62	6.5
Sept 2012	6.82	7.45

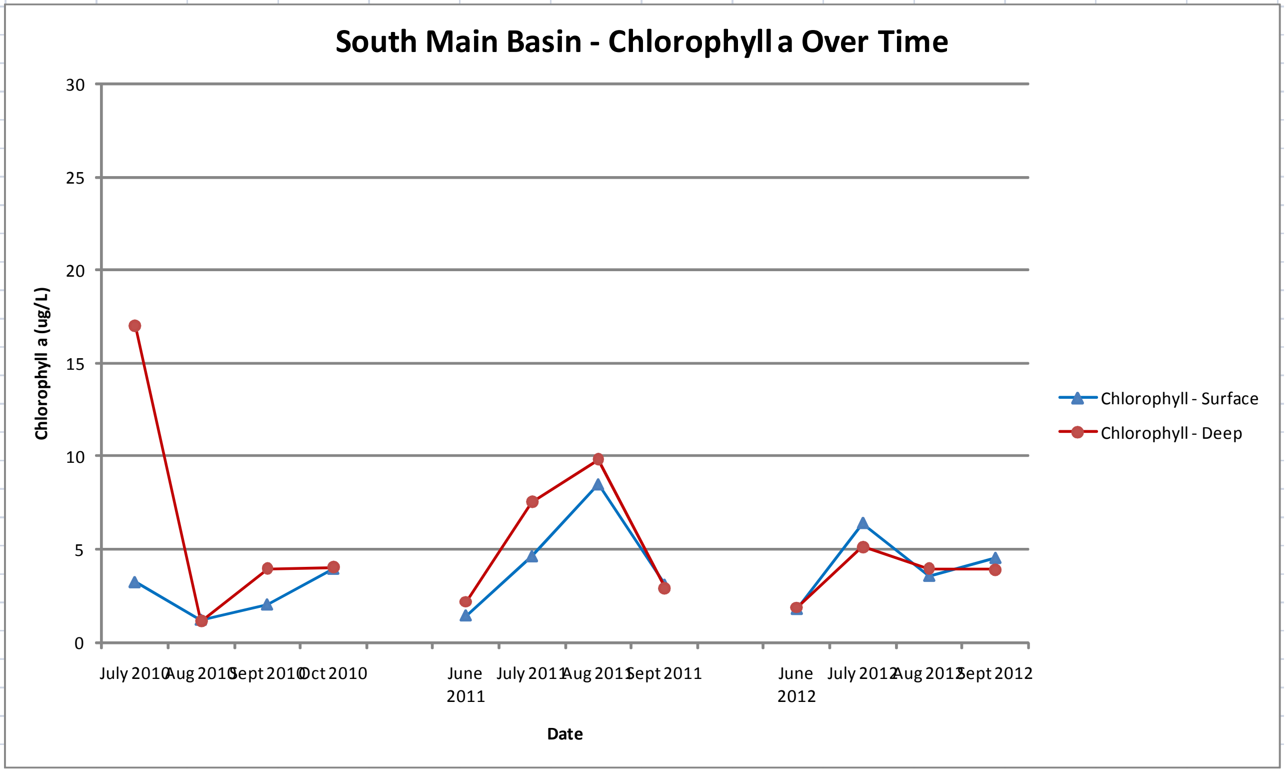
6.8 Average



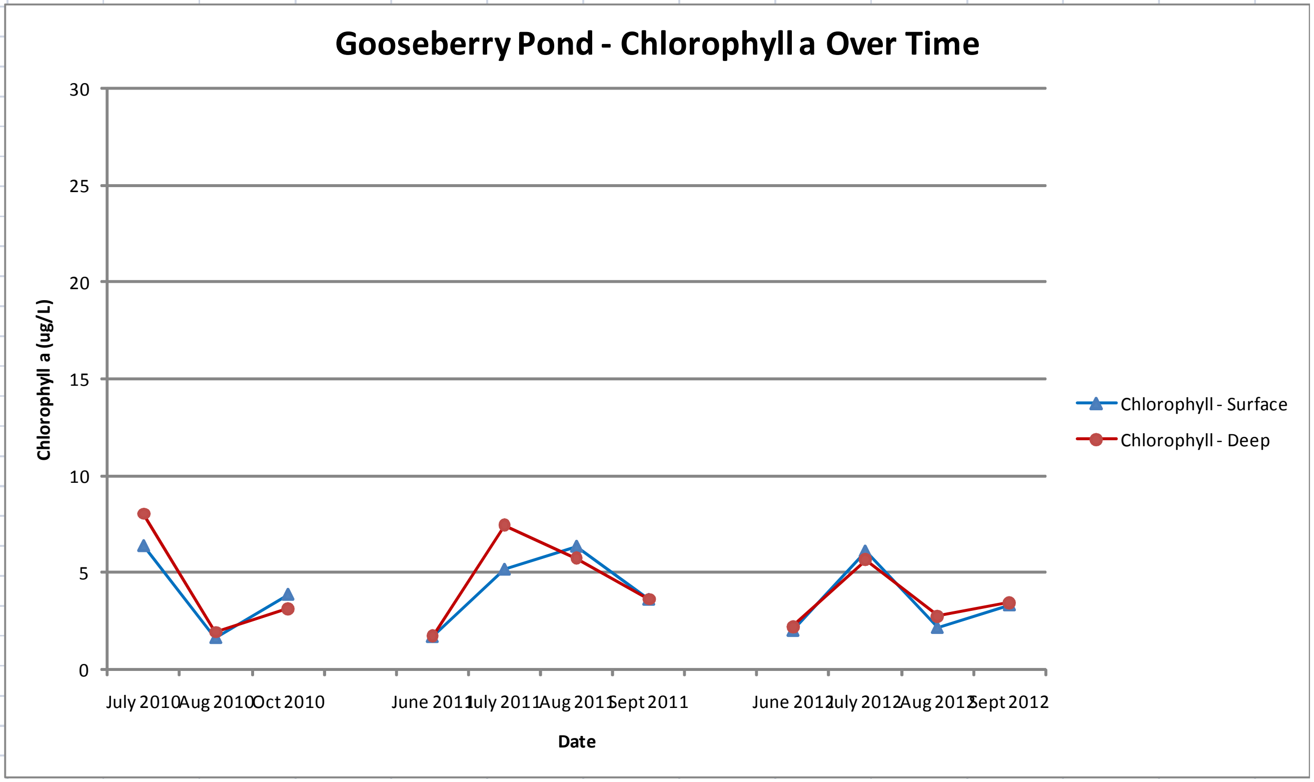
North Main Basin		
	Chlorophyll - Surface	Chlorophyll - Deep
July 2010	4.80	5.46
Aug 2010	0.74	0.51
Sept 2010	5.18	5.98
Oct 2010	14.96	14.82
June 2011	2.07	2.30
July 2011	5.34	5.59
Aug 2011	15.98	15.39
Sept 2011	6.85	6.99
June 2012	4.69	4.69
July 2012	4.78	5.91
Aug 2012	5.84	5.25
Sept 2012	8.65	10.52
		6.8 Average



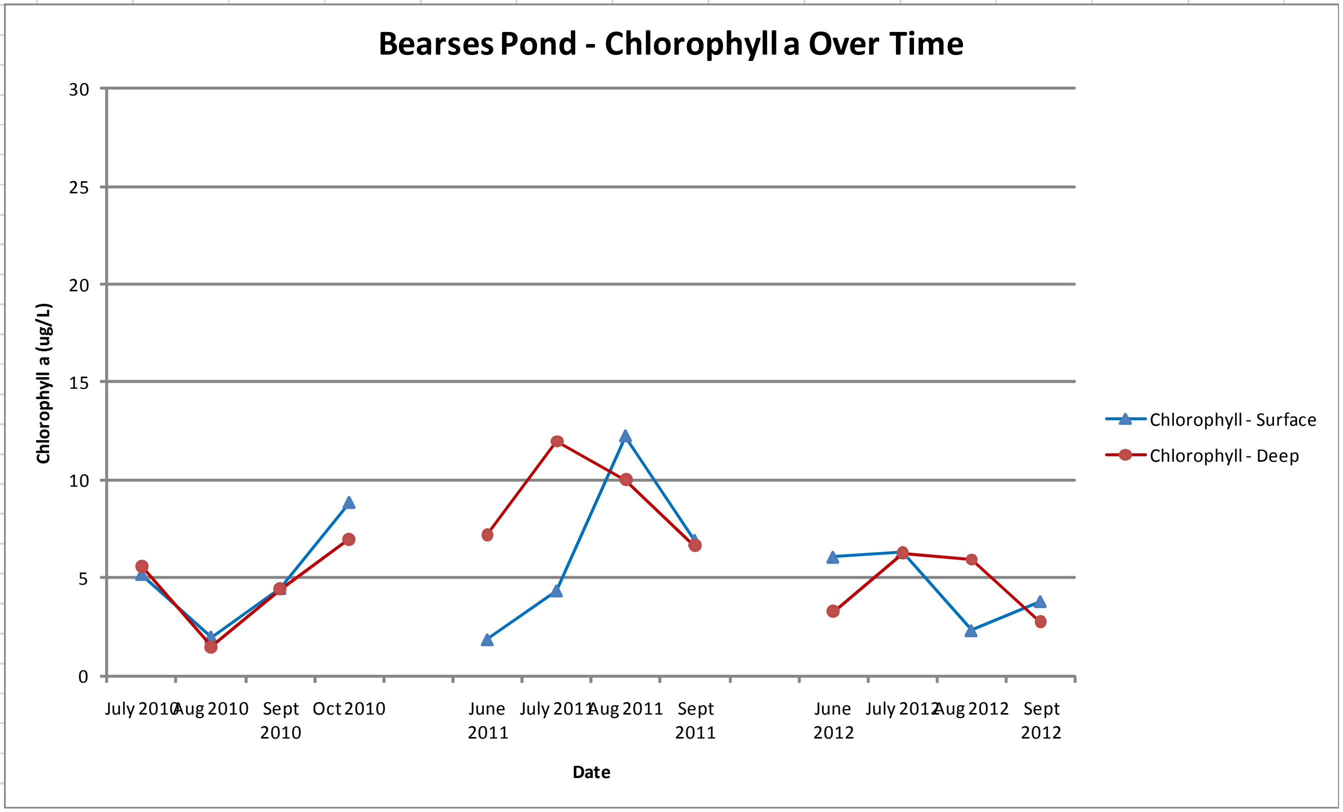
South Main Basin		
	Chlorophyll - Surophyll - Deep	
July 2010	3.23	16.99
Aug 2010	1.21	1.13
Sept 2010	2.03	3.97
Oct 2010	3.95	4.04
June 2011	1.44	2.19
July 2011	4.62	7.54
Aug 2011	8.48	9.83
Sept 2011	3.09	2.92
June 2012	1.79	1.87
July 2012	6.41	5.14
Aug 2012	3.57	3.95
Sept 2012	4.53	3.92
		4.5 Average



Gooseberry Pond		
	Chlorophyll - Surface	Chlorophyll - Deep
July 2010	6.40	8.04
Aug 2010	1.64	1.94
Oct 2010	3.88	3.13
June 2011	1.69	1.73
July 2011	5.18	7.45
Aug 2011	6.37	5.74
Sept 2011	3.62	3.62
June 2012	2.01	2.21
July 2012	6.12	5.66
Aug 2012	2.16	2.75
Sept 2012	3.33	3.46
	4.0	Average

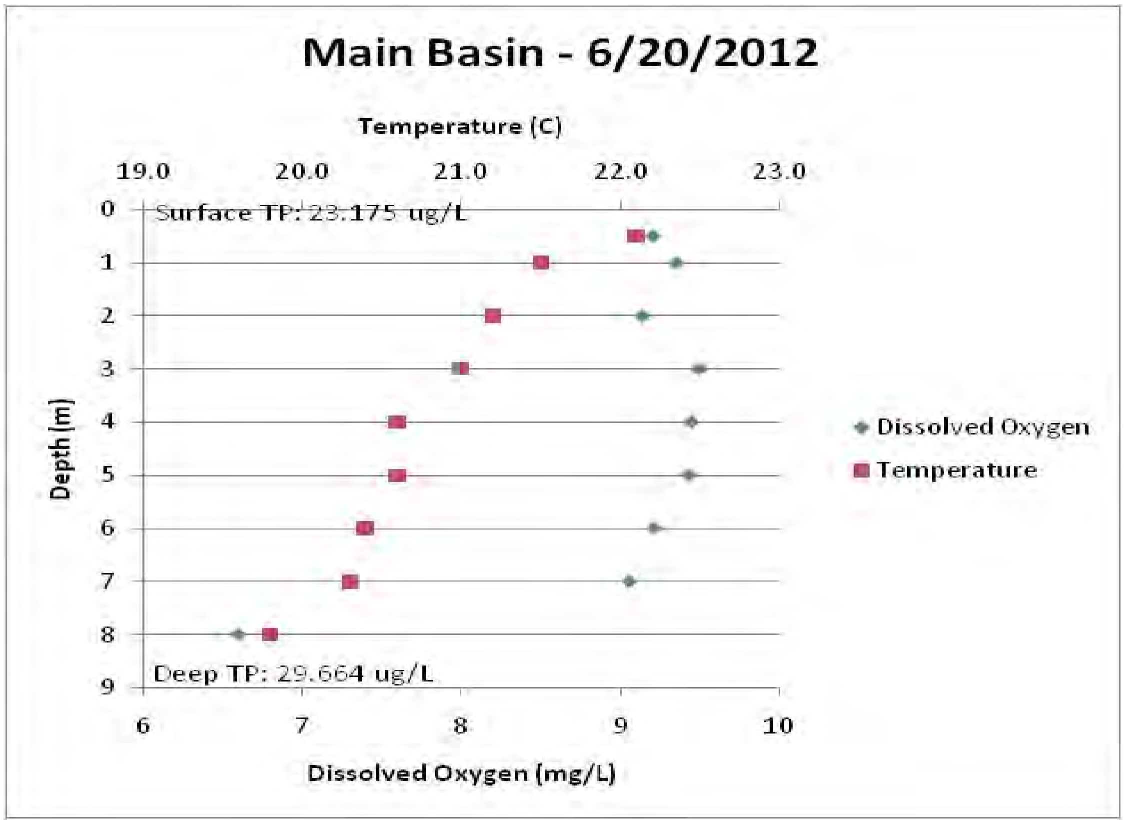


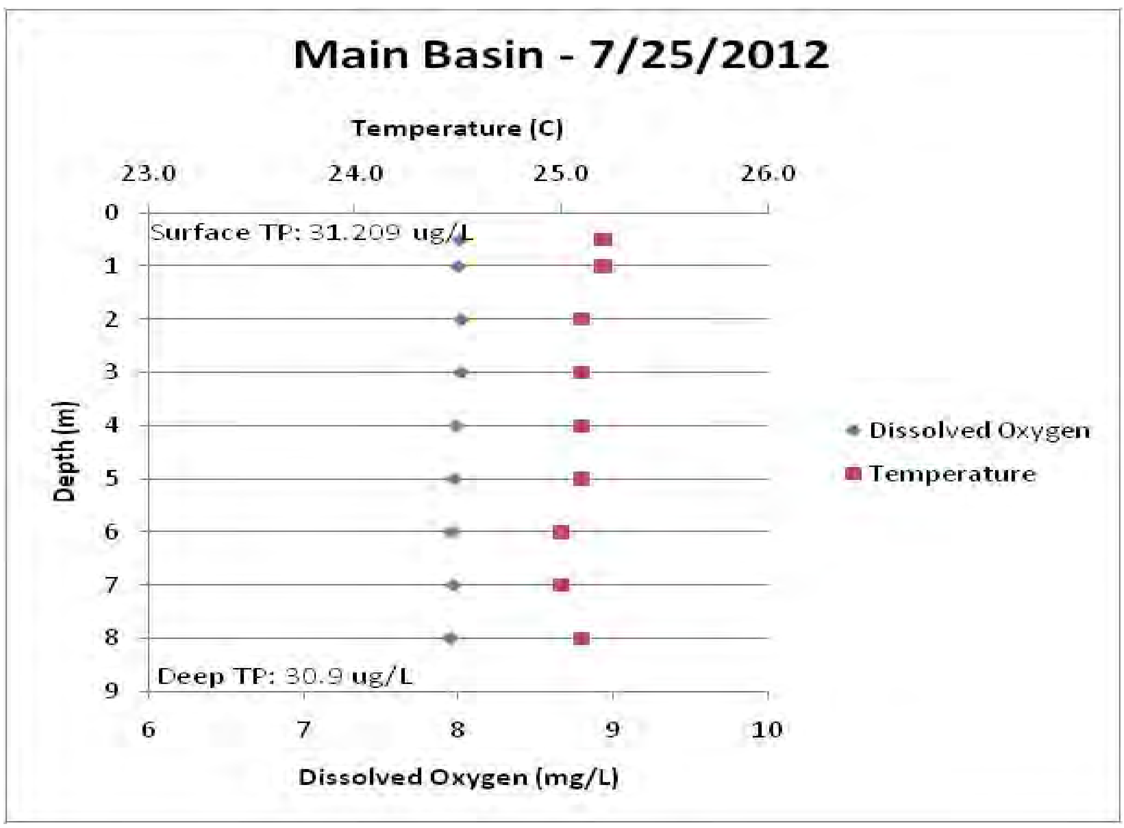
Beares Pond		
	Chlorophyll - Su	rophyll - Deep
July 2010	5.18	5.6
Aug 2010	1.99	1.47
Sept 2010	4.46	4.44
Oct 2010	8.84	6.97
June 2011	1.85	7.2
July 2011	4.34	11.98
Aug 2011	12.23	10.01
Sept 2011	6.91	6.66
June 2012	6.05	3.28
July 2012	6.29	6.27
Aug 2012	2.31	5.94
Sept 2012	3.79	2.75
	5.7	Average

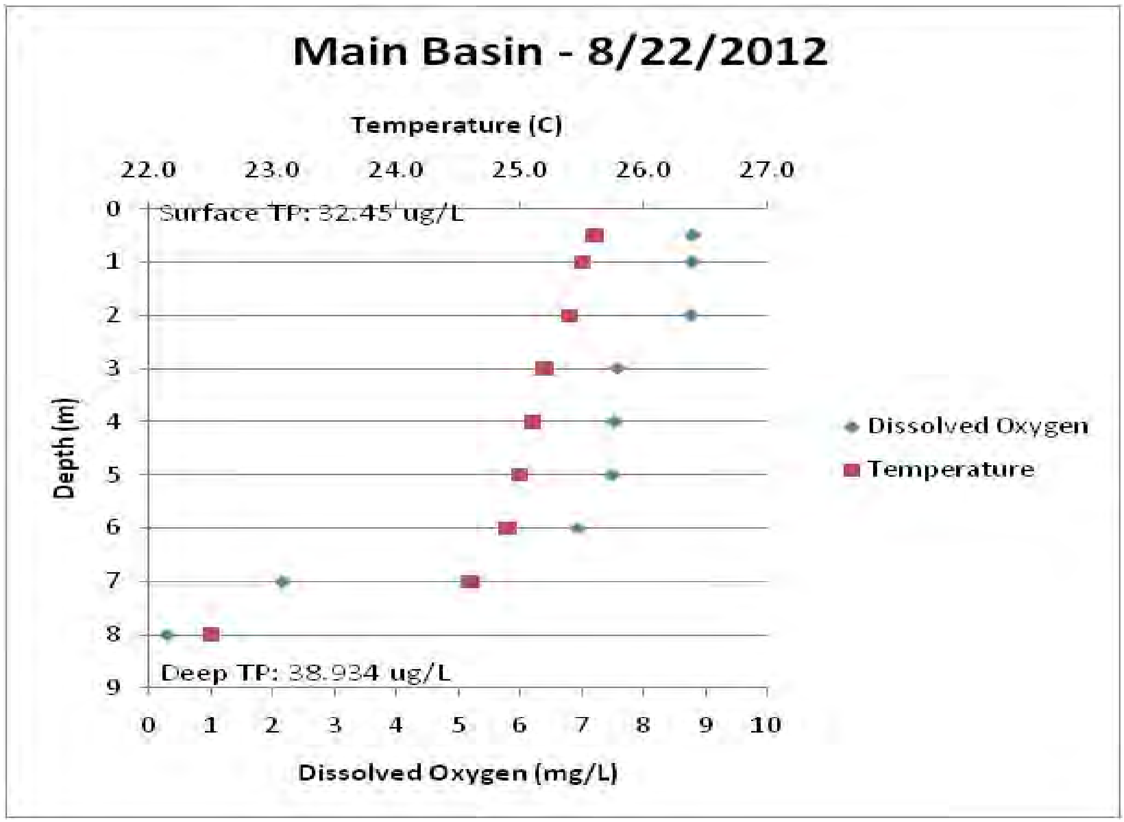


ATTACHMENT 2-3 2012 TEMP OXYGEN PROFILES

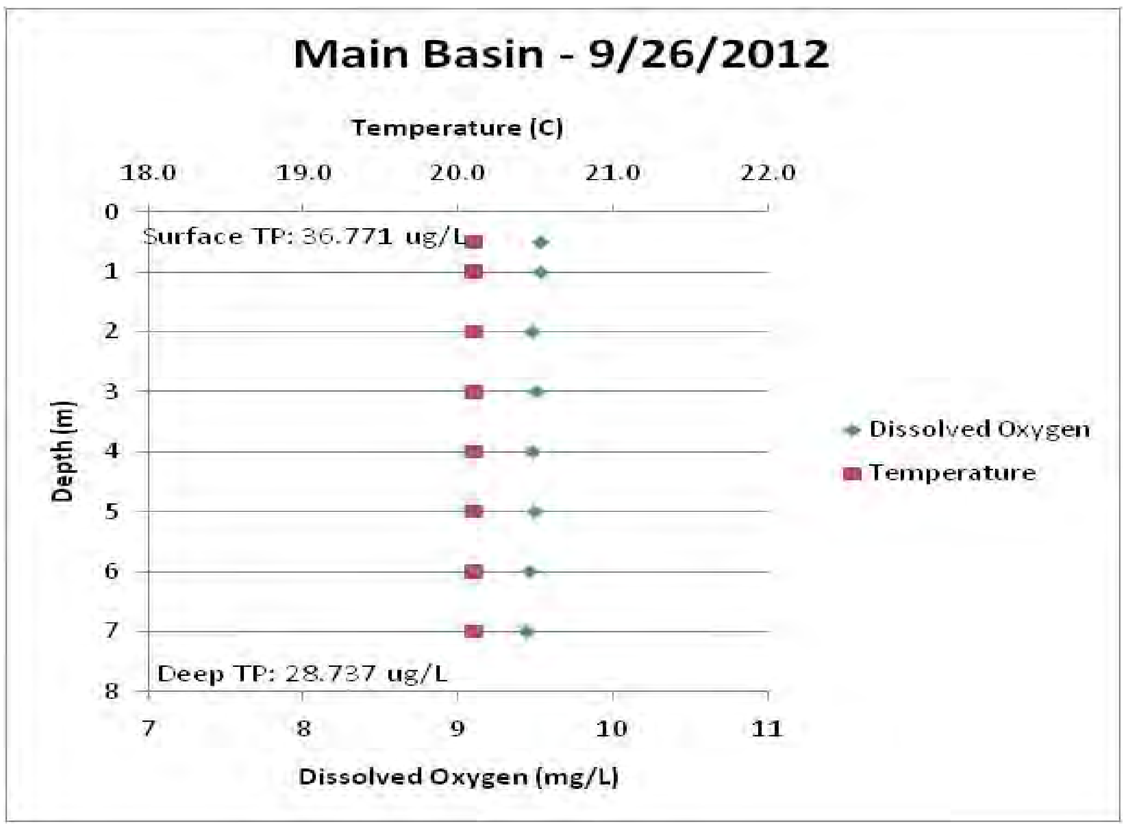
Main Basin (STA 1)												
DO				Temp						TP Surface	TP Bottom	
6/20/2012	7/25/2012	8/22/2012	9/26/2012	6/20/2012	7/25/2012	8/22/2012	9/26/2012			ug/L		
9.21	8.01	8.80	9.53	22.1	25.2	25.6	20.1		June	23.175	29.664	
9.36	8.00	8.79	9.53	21.5	25.2	25.5	20.1		July	31.209	30.9	
9.14	8.02	8.77	9.48	21.2	25.1	25.4	20.1		Aug	32.445	38.934	
9.50	8.02	7.58	9.50	21.0	25.1	25.2	20.1		Sept	36.771	28.737	
9.45	7.99	7.53	9.48	20.6	25.1	25.1	20.1					
9.44	7.97	7.50	9.49	20.6	25.1	25.0	20.1					
9.22	7.96	6.93	9.46	20.4	25.0	24.9	20.1					
9.06	7.97	2.16	9.44	20.3	25.0	24.6	20.1					
6.60	7.95	0.30		19.8	25.1	22.5						


Main Basin - 6/20/2012
Temperature (C)
19.0
20.0
21.0
22.0
23.0
Surface TP: 23.175 ug/L
Deep TP: 29.664 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
9
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature


Main Basin - 7/25/2012
Temperature (C)
23.0
24.0
25.0
26.0
Surface TP: 31.209 ug/L
Deep TP: 30.9 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
9
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

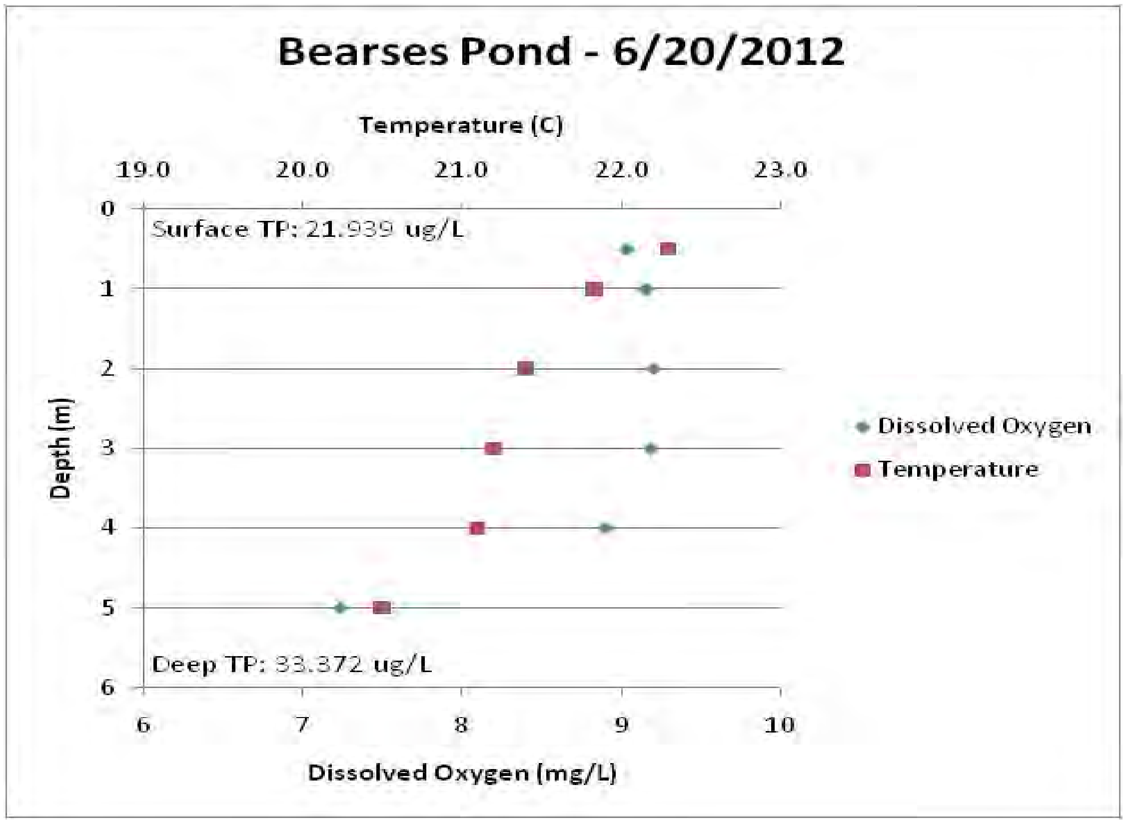


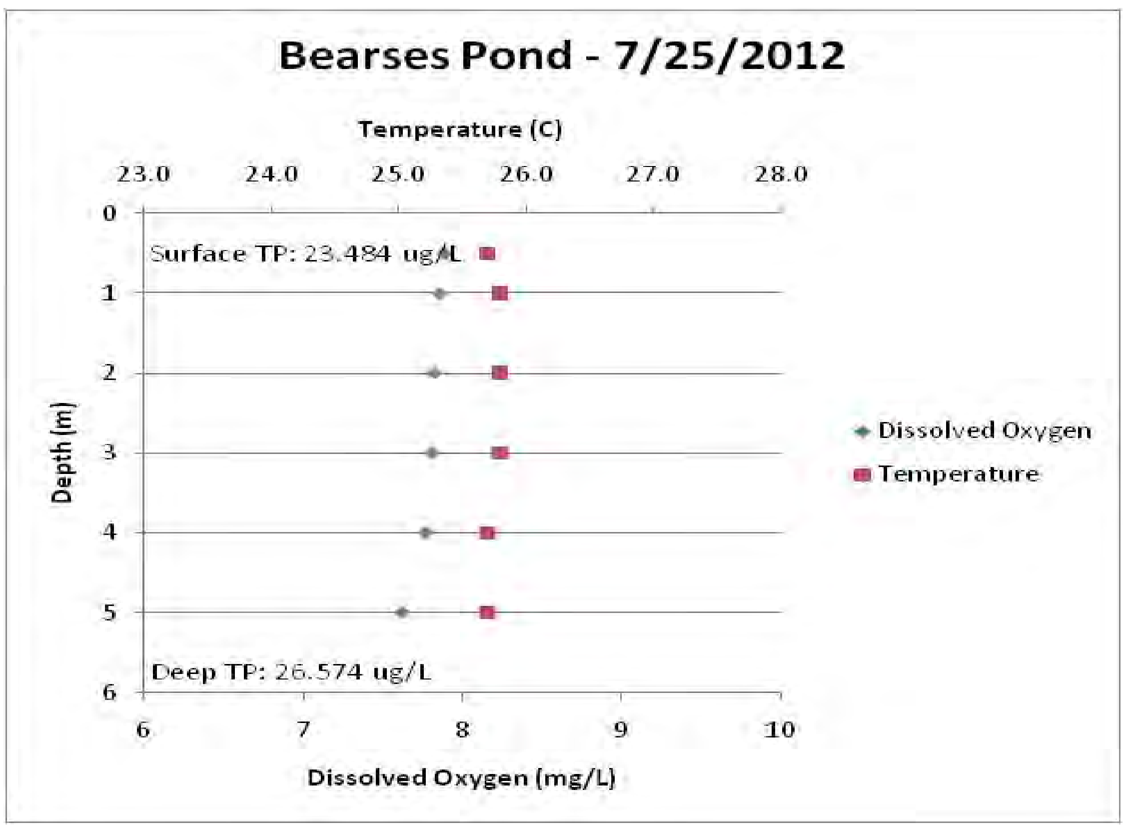
Main Basin - 8/22/2012
Temperature (C)
22.0
23.0
24.0
25.0
26.0
27.0
Surface TP: 32.45 ug/L
Deep TP: 38.934 ug/L
Depth (m)
Dissolved Oxygen
Temperature
Dissolved Oxygen (mg/L)

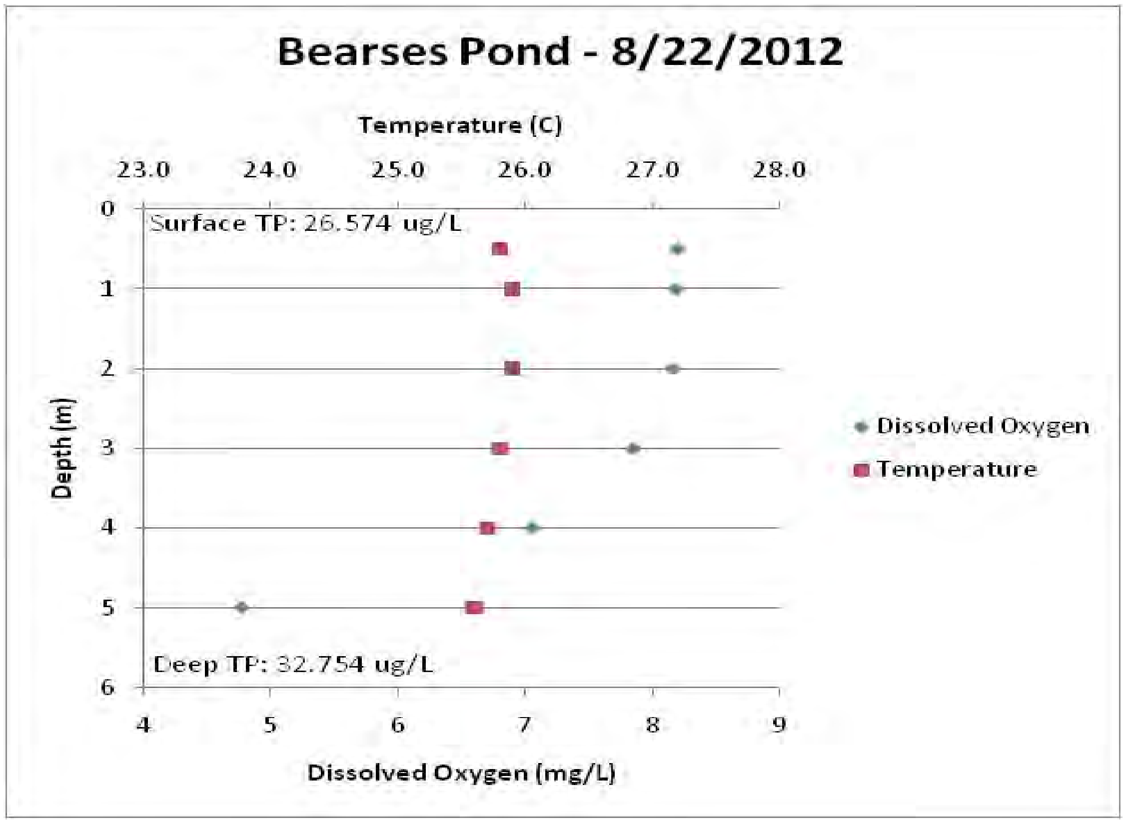


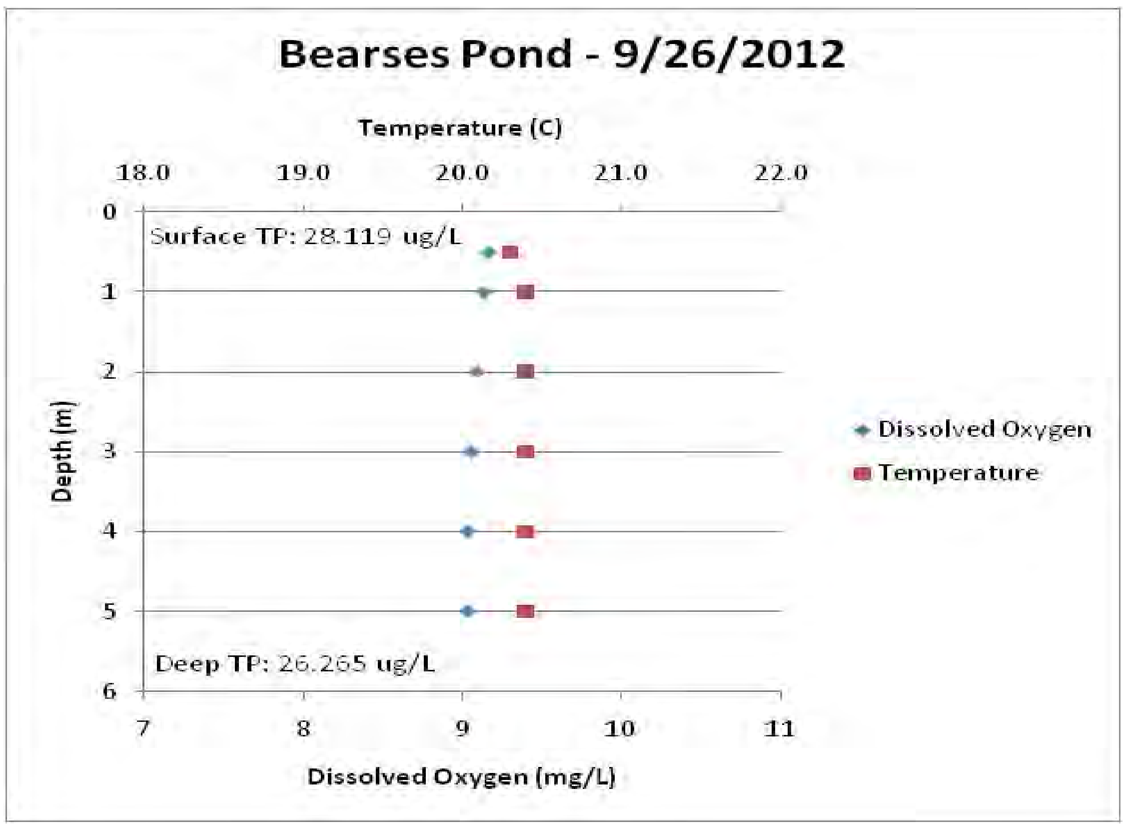
Main Basin - 9/26/2012
Temperature (C)
18.0
19.0
20.0
21.0
22.0
Surface TP: 36.771 ug/L
Deep TP: 28.737 ug/L
Depth (m)
Dissolved Oxygen
Temperature
Dissolved Oxygen (mg/L)

	Beares Pond (STA 5)										
	DO				Temp						
Depth (m)	6/20/2012	7/25/2012	8/22/2012	9/26/2012	6/20/2012	7/25/2012	8/22/2012	9/26/2012		**TP Surface**	**TP Bottom**
0.5	9.03	7.89	8.20	9.17	22.3	25.7	25.8	20.3		**ug/L**	
1	9.15	7.86	8.19	9.14	21.8	25.8	25.9	20.4	June	21.939	33.372
2	9.20	7.83	8.16	9.10	21.4	25.8	25.9	20.4	July	23.484	26.574
3	9.18	7.81	7.85	9.06	21.2	25.8	25.8	20.4	Aug	26.574	32.754
4	8.90	7.77	7.06	9.04	21.1	25.7	25.7	20.4	Sept	28.119	26.265
5	7.24	7.62	4.77	9.04	20.5	25.7	25.6	20.4			

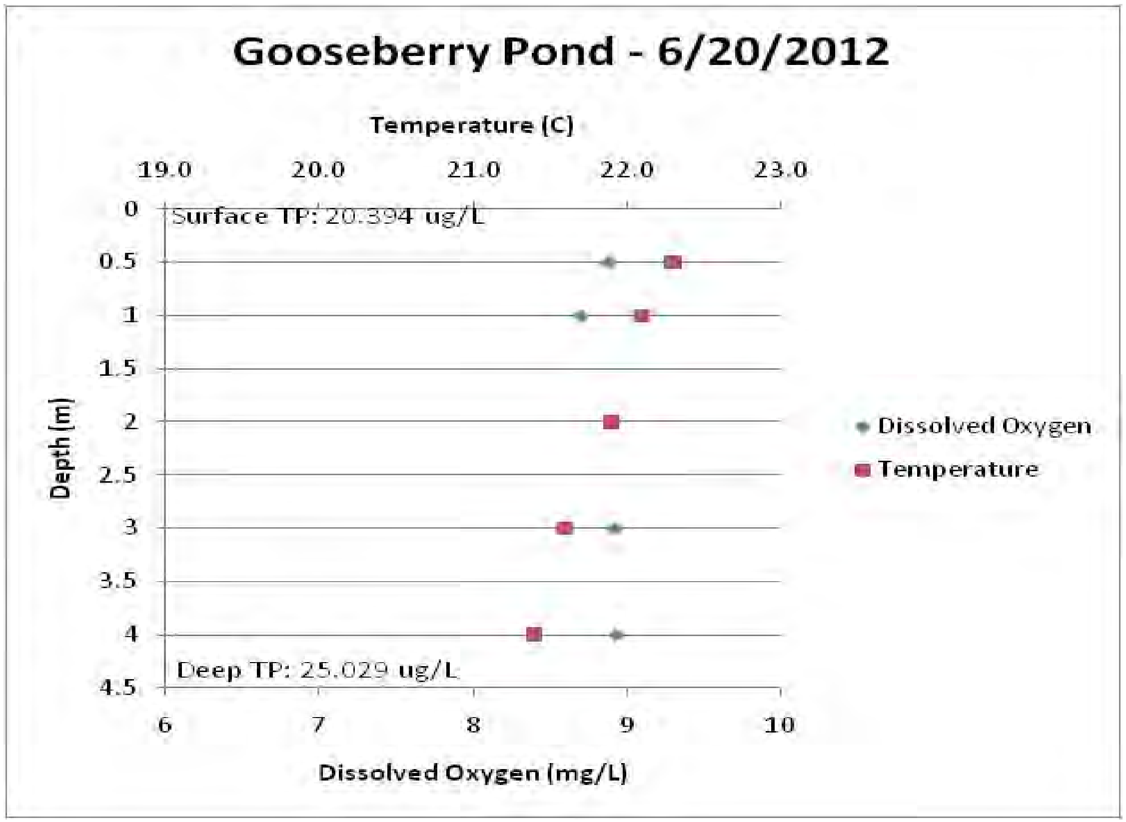

Bearses Pond - 6/20/2012
Temperature (C)
19.0
20.0
21.0
22.0
23.0
Surface TP: 21.939 ug/L
Deep TP: 33.372 ug/L
Depth (m)
0
1
2
3
4
5
6
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

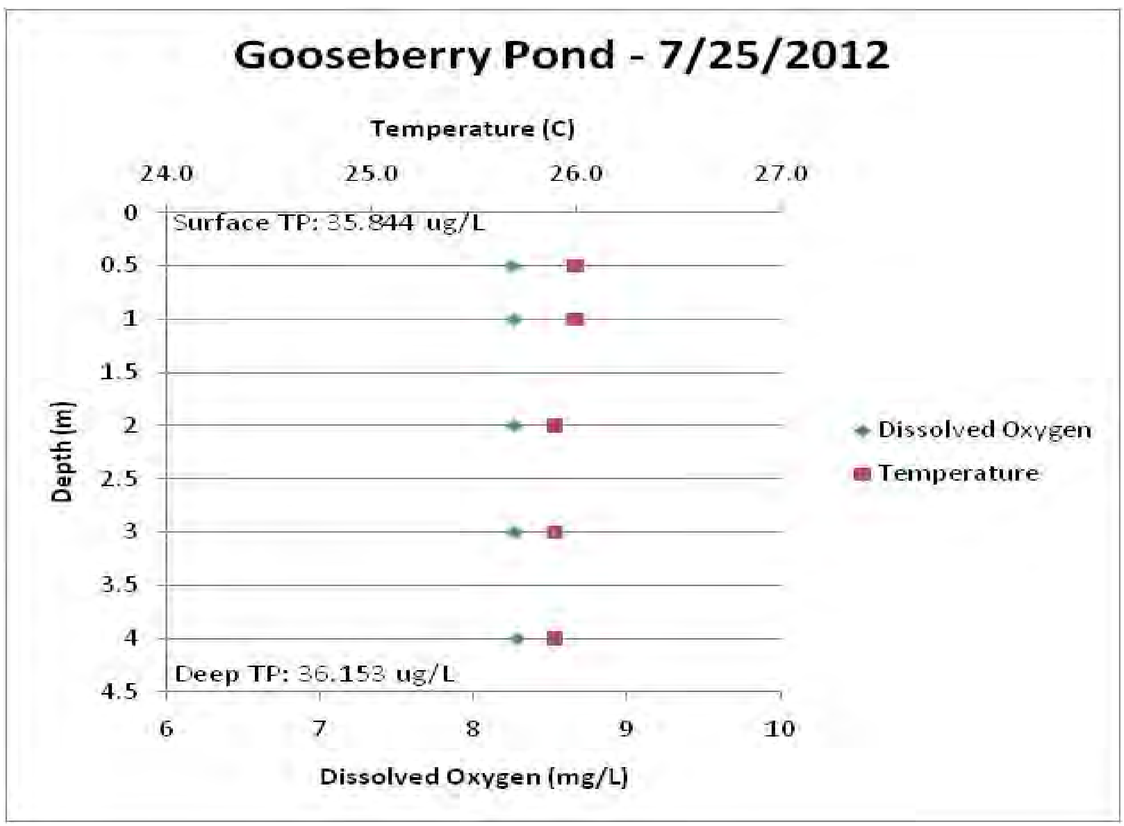

Bearses Pond - 7/25/2012
Temperature (C)
23.0
24.0
25.0
26.0
27.0
28.0
Surface TP: 23.484 ug/L
Deep TP: 26.574 ug/L
Depth (m)
0
1
2
3
4
5
6
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

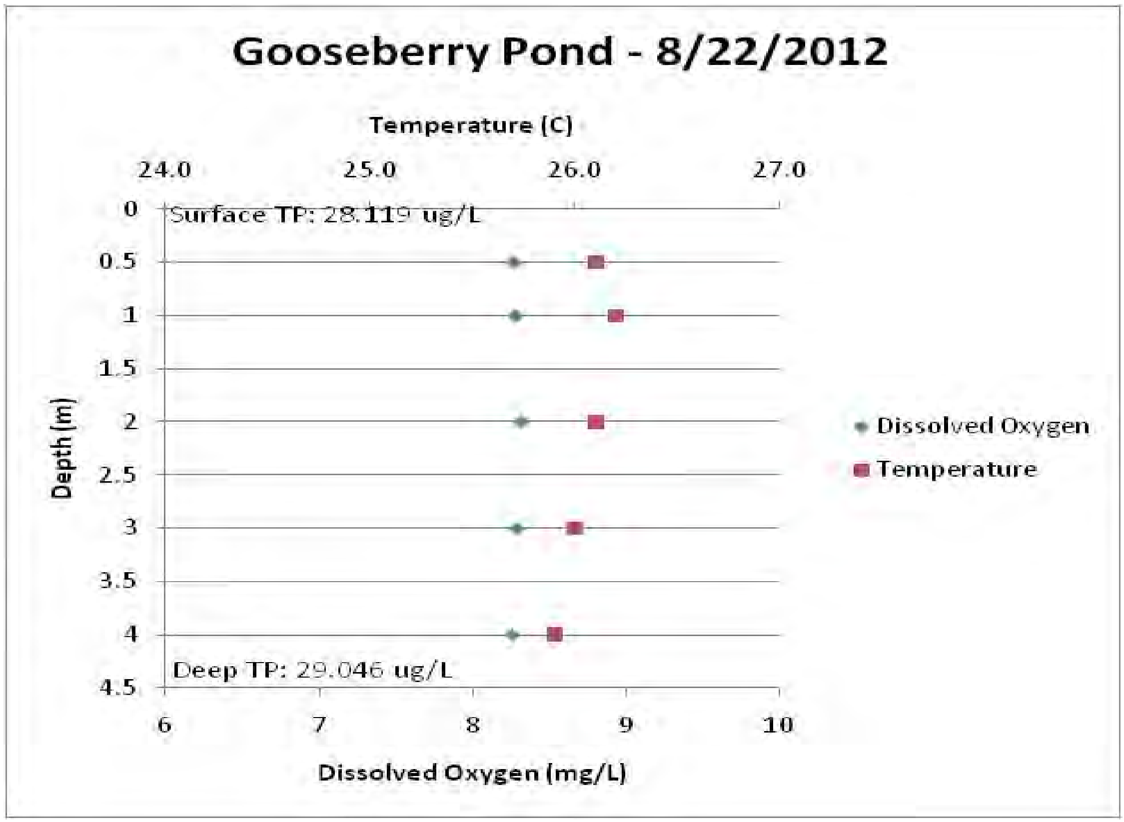

Bearses Pond - 8/22/2012
Temperature (C)
23.0
24.0
25.0
26.0
27.0
28.0
Surface TP: 26.574 ug/L
Deep TP: 32.754 ug/L
Depth (m)
0
1
2
3
4
5
6
4
5
6
7
8
9
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature


Bearses Pond - 9/26/2012
Temperature (C)
18.0
19.0
20.0
21.0
22.0
Surface TP: 28.119 ug/L
Deep TP: 26.265 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
11
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

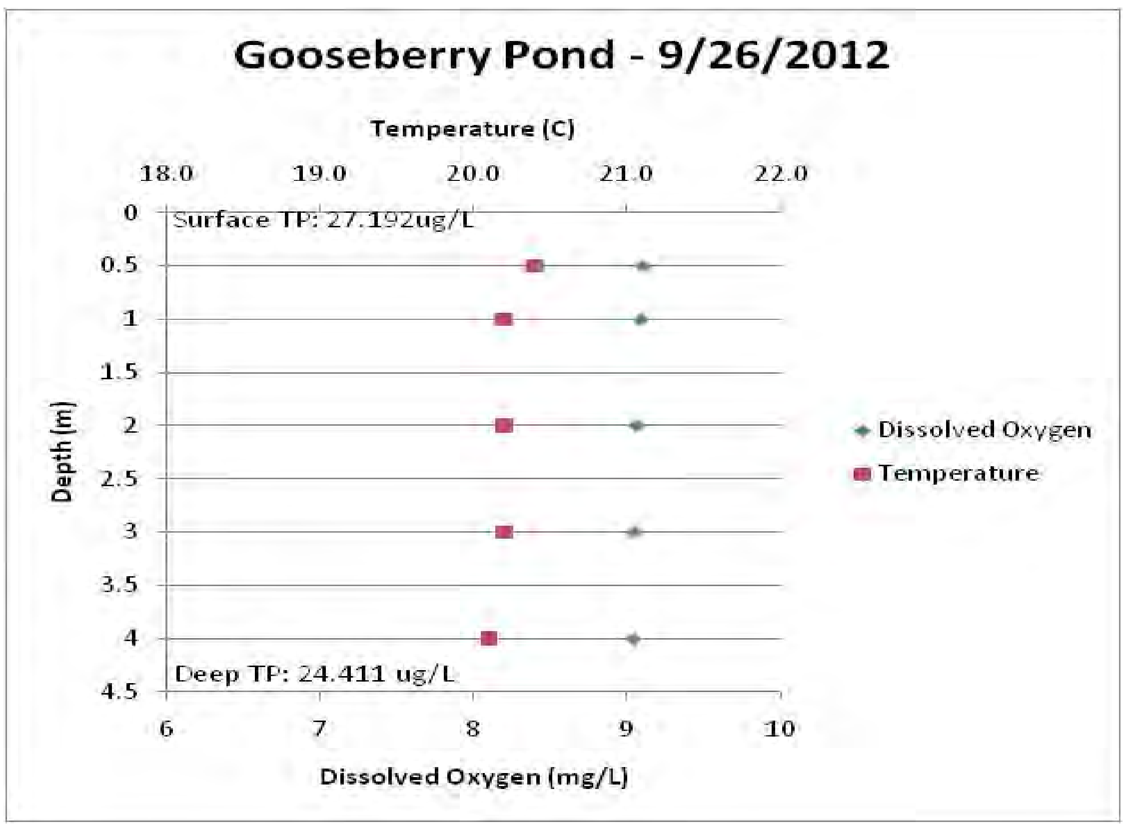
	Gooseberry Pond (STA 4)												
	DO				Temp							TP Surface	TP Bottom
Depth (m)	6/20/2012	7/25/2012	8/22/2012	9/26/2012	6/20/2012	7/25/2012	8/22/2012	9/26/2012				ug/L	
0.5	8.88	8.26	8.27	9.10	22.3	26.0	26.1	20.4			June	20.394	25.029
1	8.70	8.27	8.28	9.09	22.1	26.0	26.2	20.2			July	35.844	36.153
2	8.91	8.27	8.32	9.06	21.9	25.9	26.1	20.2			Aug	28.119	29.046
3	8.92	8.27	8.29	9.05	21.6	25.9	26.0	20.2			Sept	27.192	24.411
4	8.93	8.29	8.26	9.04	21.4	25.9	25.9	20.1					


Gooseberry Pond - 6/20/2012
Temperature (C)
19.0
20.0
21.0
22.0
23.0
Surface TP: 20.394 ug/L
Deep TP: 25.029 ug/L
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature


Gooseberry Pond - 7/25/2012
Temperature (C)
24.0
25.0
26.0
27.0
Surface TP: 35.844 ug/L
Deep TP: 36.153 ug/L
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature



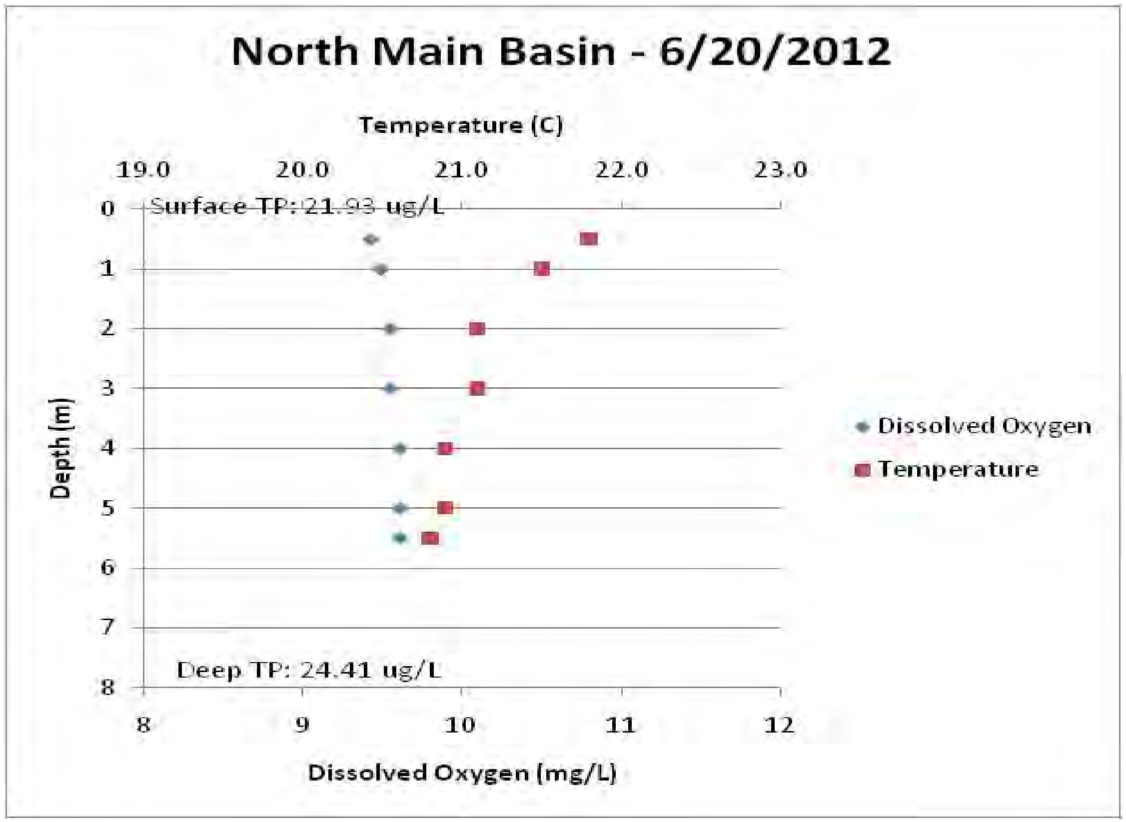
Gooseberry Pond - 8/22/2012
Temperature (C)
24.0
25.0
26.0
27.0
Surface TP: 28.119 ug/L
Deep TP: 29.046 ug/L
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

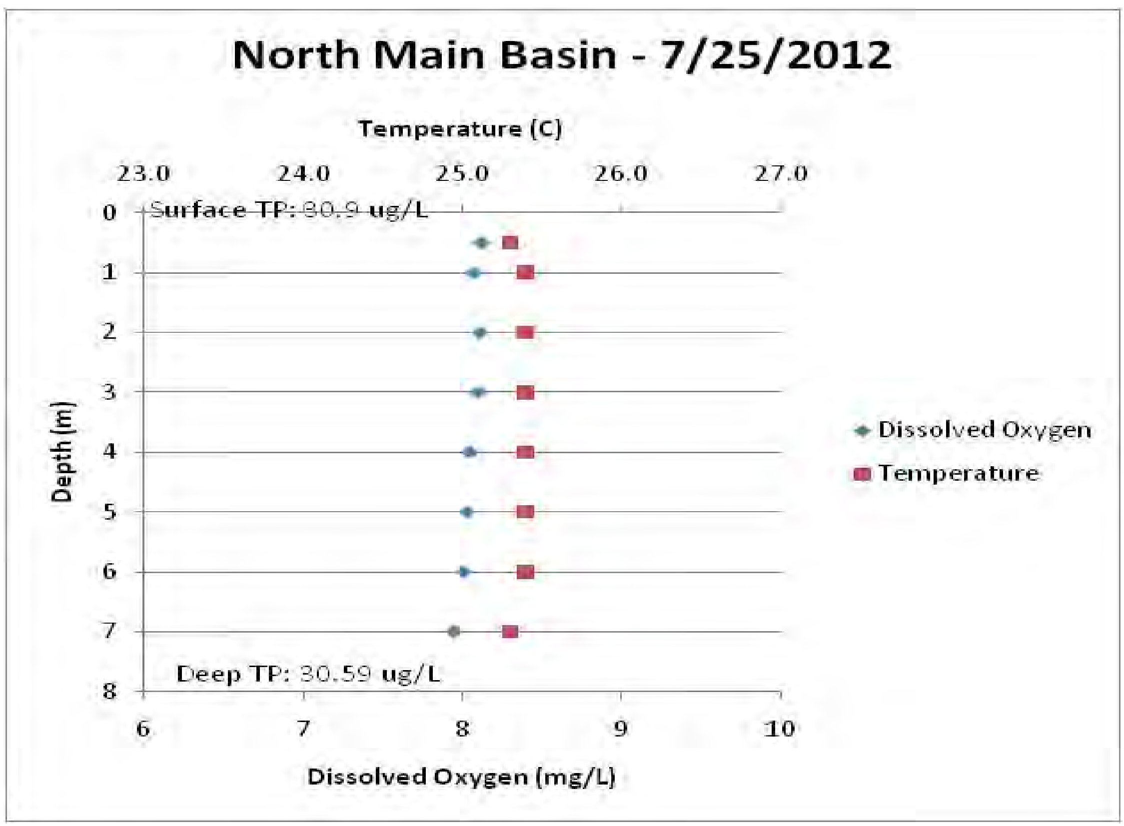


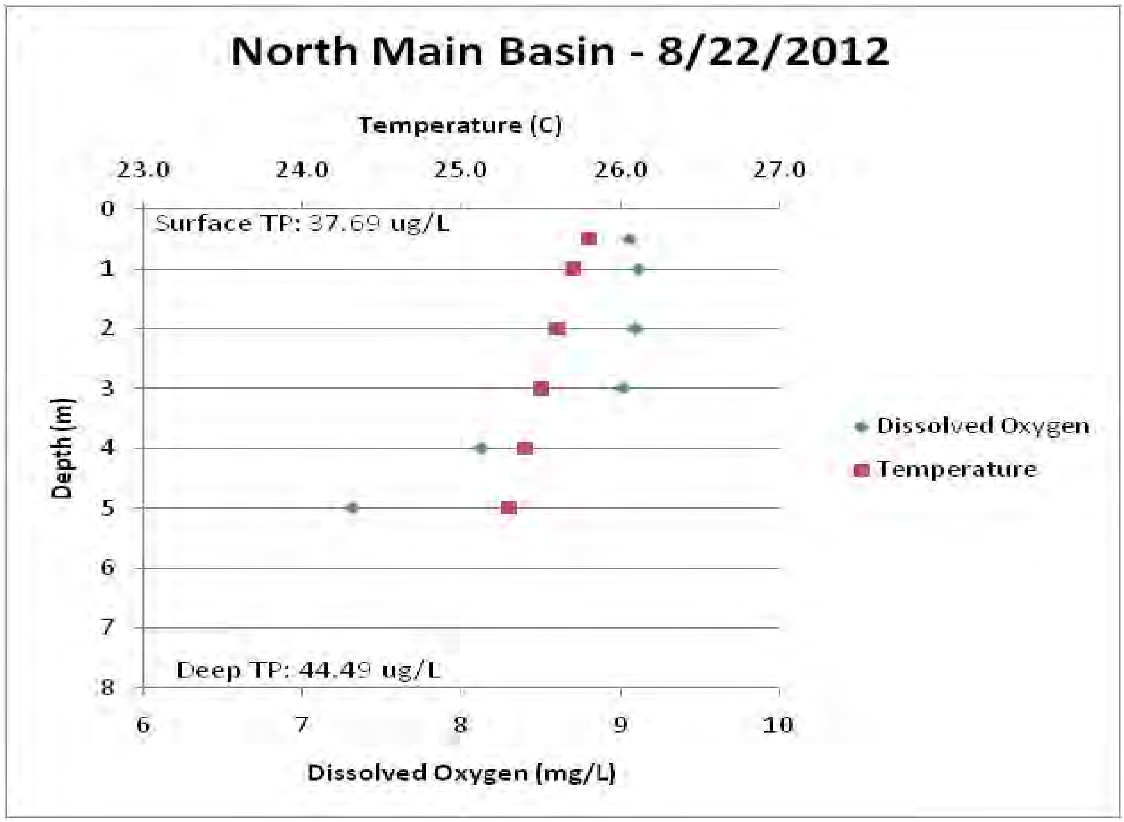
Gooseberry Pond - 9/26/2012
Temperature (C)
18.0
19.0
20.0
21.0
22.0
Surface TP: 27.192ug/L
Deep TP: 24.411 ug/L
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

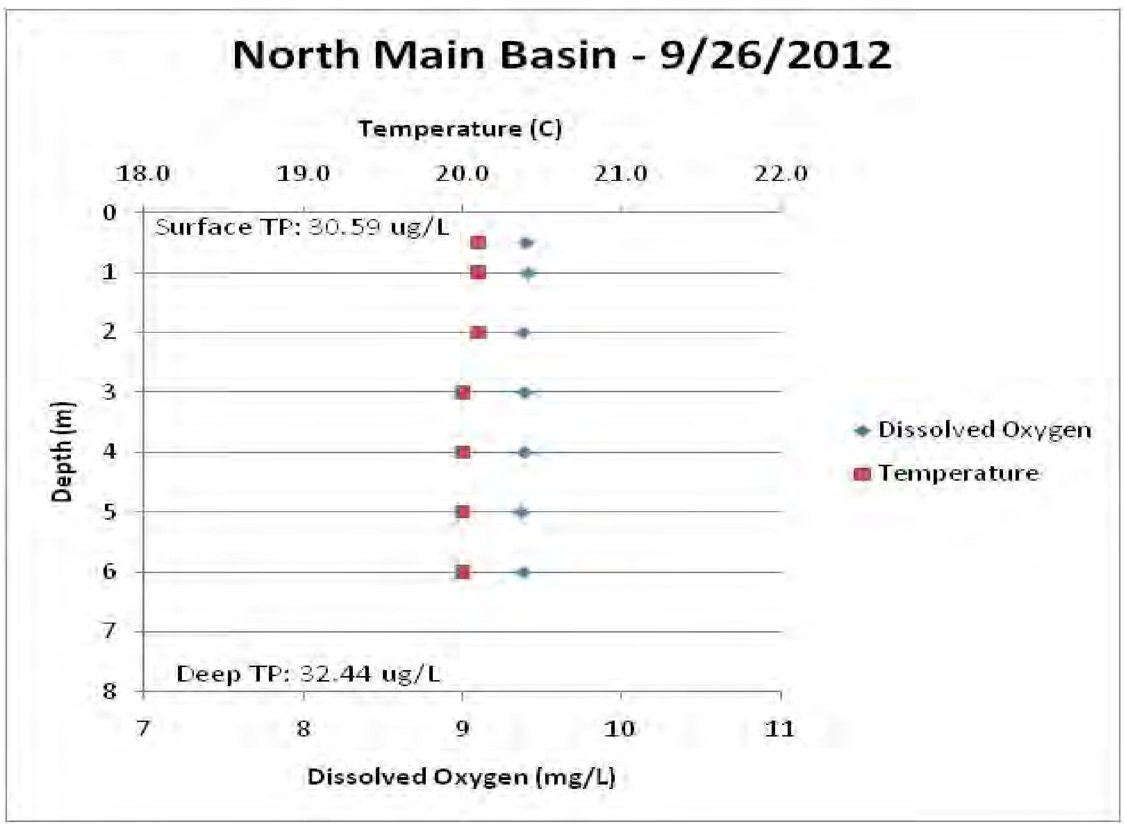
	North Main Basin (STA 2)							
	DO				Temp			
Depth (m)	6/20/2012	7/25/2012	8/22/2012	9/26/2012	6/20/2012	7/25/2012	8/22/2012	9/26/2012
0.5	9.43	8.12	9.05	9.40	21.8	25.3	25.8	20.1
1	9.49	8.07	9.11	9.41	21.5	25.4	25.7	20.1
2	9.55	8.11	9.09	9.38	21.1	25.4	25.6	20.1
3	9.55	8.10	9.01	9.39	21.1	25.4	25.5	20.0
4	9.61	8.05	8.12	9.39	20.9	25.4	25.4	20.0
5	9.61	8.03	7.31	9.37	20.9	25.4	25.3	20.0
5.5	9.61				20.8			
6		8.01		9.38		25.4		20.0
7		7.95				25.3		

	TP Surface	**TP Bottom**
	ug/L	
June	21.939	24.411
July	30.9	30.591
Aug	37.698	44.496
Sept	30.591	32.445

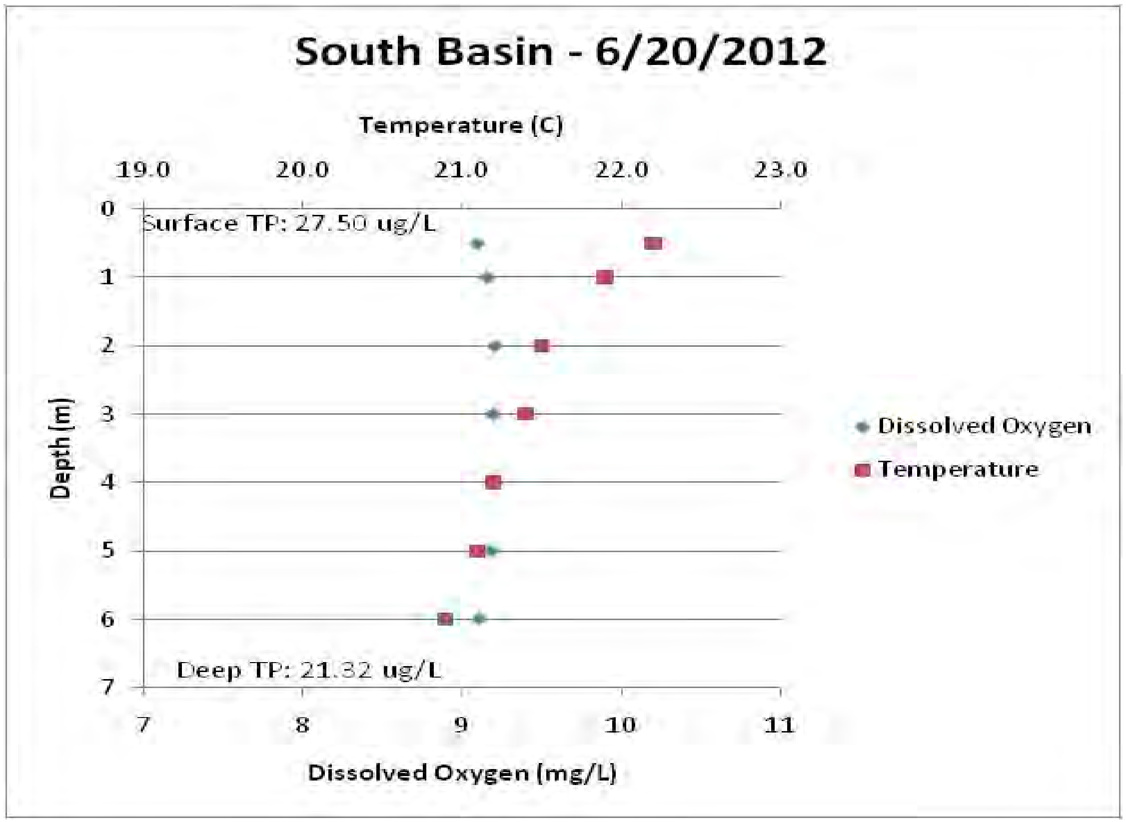

North Main Basin - 6/20/2012
Temperature (C)
19.0
20.0
21.0
22.0
23.0
Surface TP: 21.93 ug/L
Deep TP: 24.41 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
Dissolved Oxygen
Temperature
8
9
10
11
12
Dissolved Oxygen (mg/L)

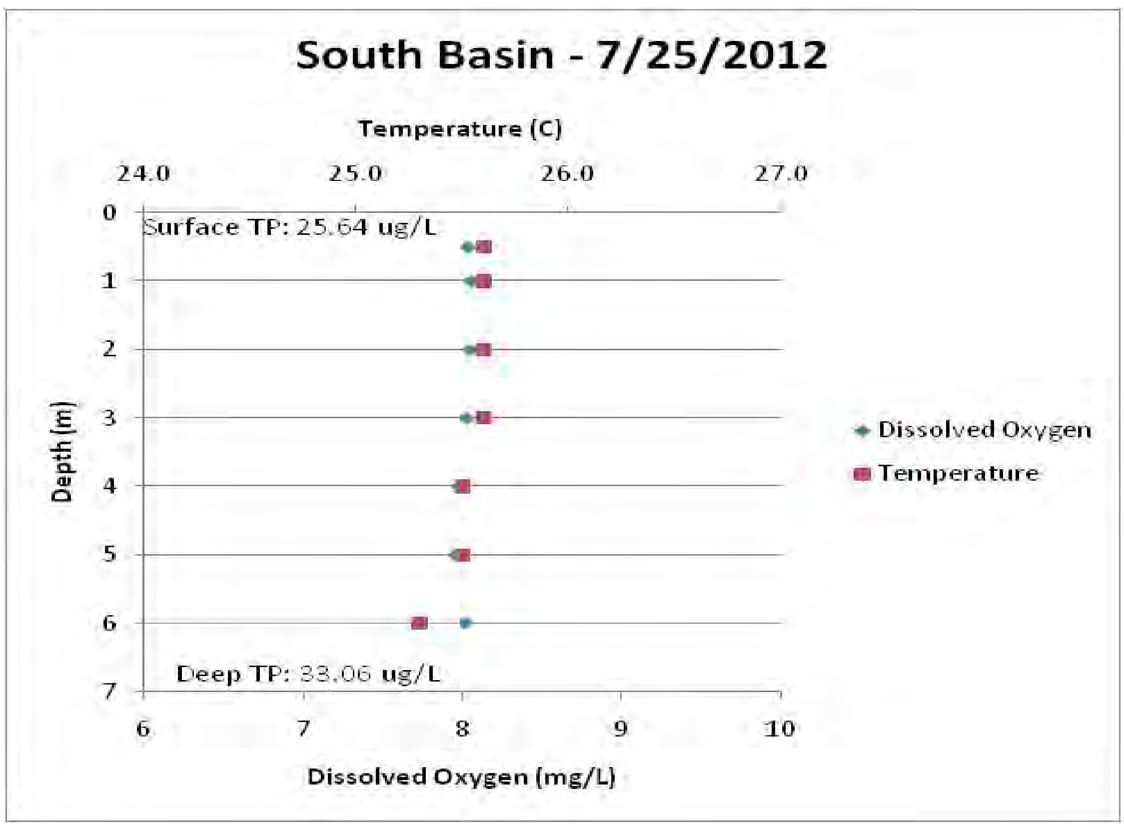

North Main Basin - 7/25/2012
Temperature (C)
23.0
24.0
25.0
26.0
27.0
Surface TP: 30.9 ug/L
Deep TP: 30.59 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
Dissolved Oxygen
Temperature
6
7
8
9
10
Dissolved Oxygen (mg/L)

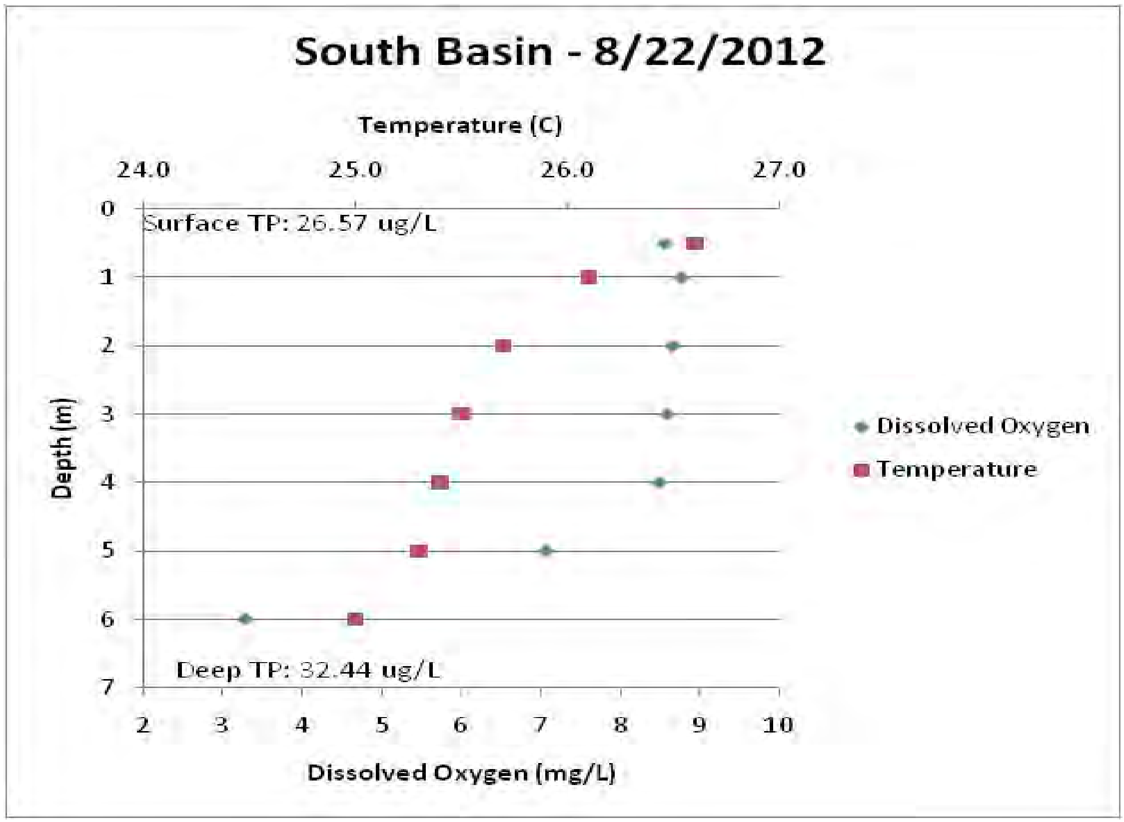

North Main Basin - 8/22/2012
Temperature (C)
23.0
24.0
25.0
26.0
27.0
Surface TP: 37.69 ug/L
Deep TP: 44.49 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

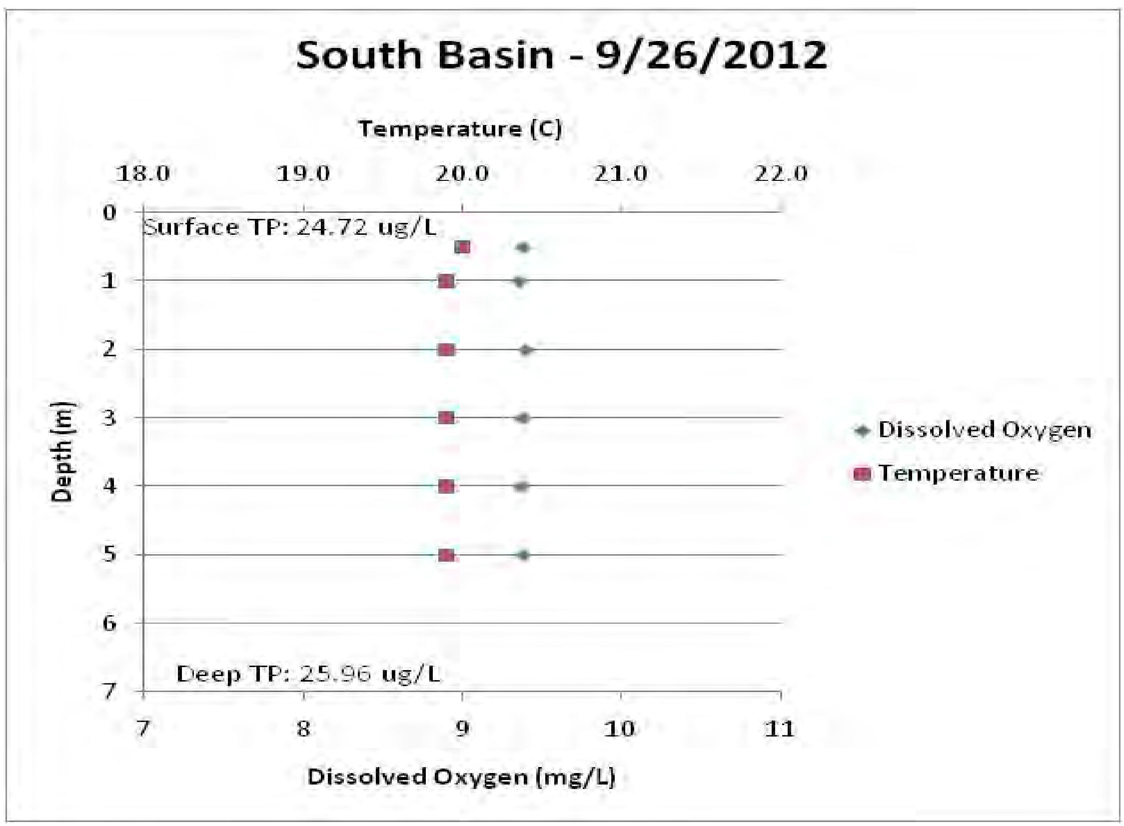

North Main Basin - 9/26/2012
Temperature (C)
18.0
19.0
20.0
21.0
22.0
Surface TP: 30.59 ug/L
Deep TP: 32.44 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
7
8
9
10
11
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

	South Basin (STA 3)											
	DO				Temp							
Depth (m)	6/20/2012	7/25/2012	8/22/2012	9/26/2012	6/20/2012	7/25/2012	8/22/2012	9/26/2012			**TP Surface**	**TP Bottom**
0.5	9.10	8.04	8.55	9.38	22.2	25.6	26.6	20.0			**ug/L**	
1	9.16	8.06	8.76	9.36	21.9	25.6	26.1	19.9		June	27.501	21.321
2	9.21	8.05	8.65	9.40	21.5	25.6	25.7	19.9		July	25.647	33.063
3	9.20	8.03	8.58	9.38	21.4	25.6	25.5	19.9		Aug	26.574	32.445
4	9.21	7.98	8.48	9.37	21.2	25.5	25.4	19.9		Sept	24.72	25.956
5	9.19	7.96	7.06	9.38	21.1	25.5	25.3	19.9				
6	9.11	8.02	3.28		20.9	25.3	25.0					


South Basin - 6/20/2012
Temperature (C)
19.0
20.0
21.0
22.0
23.0
Surface TP: 27.50 ug/L
Deep TP: 21.32 ug/L
Depth (m)
0
1
2
3
4
5
6
7
Dissolved Oxygen
Temperature
7
8
9
10
11
Dissolved Oxygen (mg/L)


South Basin - 7/25/2012
Temperature (C)
24.0
25.0
26.0
27.0
Surface TP: 25.64 ug/L
Deep TP: 33.06 ug/L
Depth (m)
0
1
2
3
4
5
6
7
Dissolved Oxygen
Temperature
6
7
8
9
10
Dissolved Oxygen (mg/L)

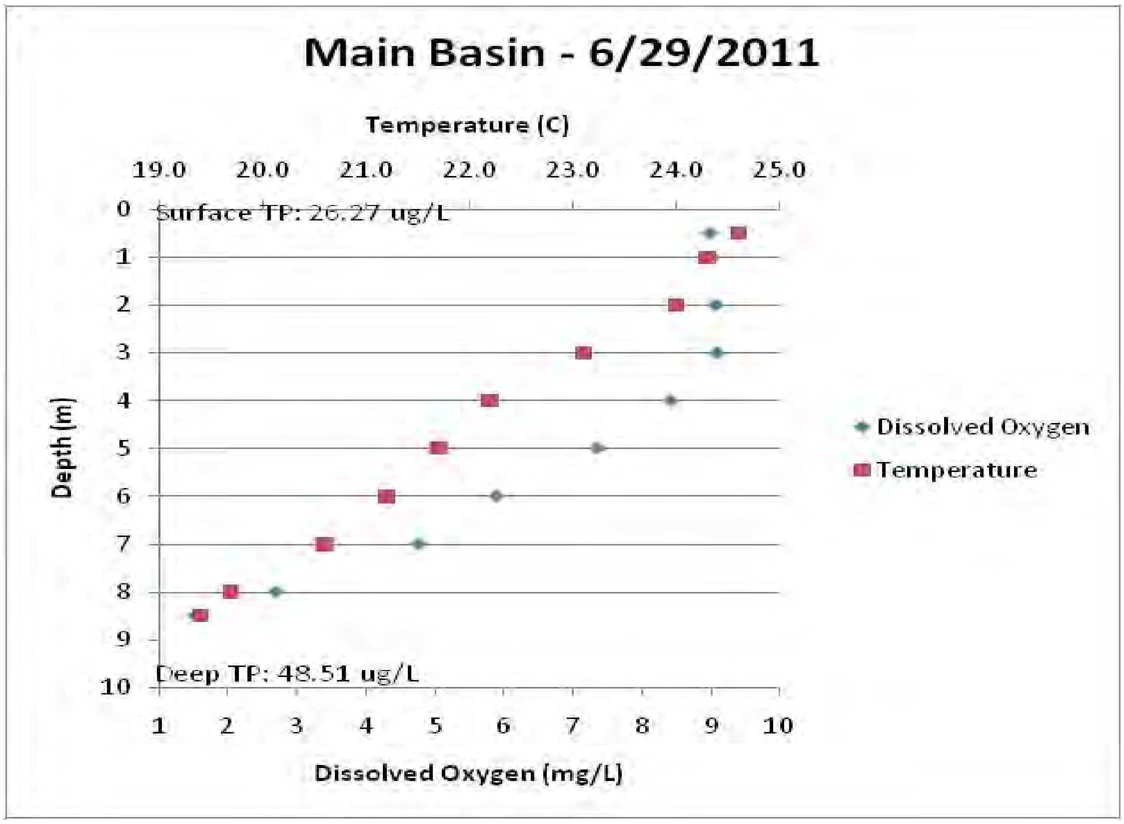

South Basin - 8/22/2012
Temperature (C)
24.0
25.0
26.0
27.0
Surface TP: 26.57 ug/L
Deep TP: 32.44 ug/L
Depth (m)
0
1
2
3
4
5
6
7
2
3
4
5
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature


South Basin - 9/26/2012
Temperature (C)
18.0
19.0
20.0
21.0
22.0
Surface TP: 24.72 ug/L
Deep TP: 25.96 ug/L
Depth (m)
0
1
2
3
4
5
6
7
7
8
9
10
11
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

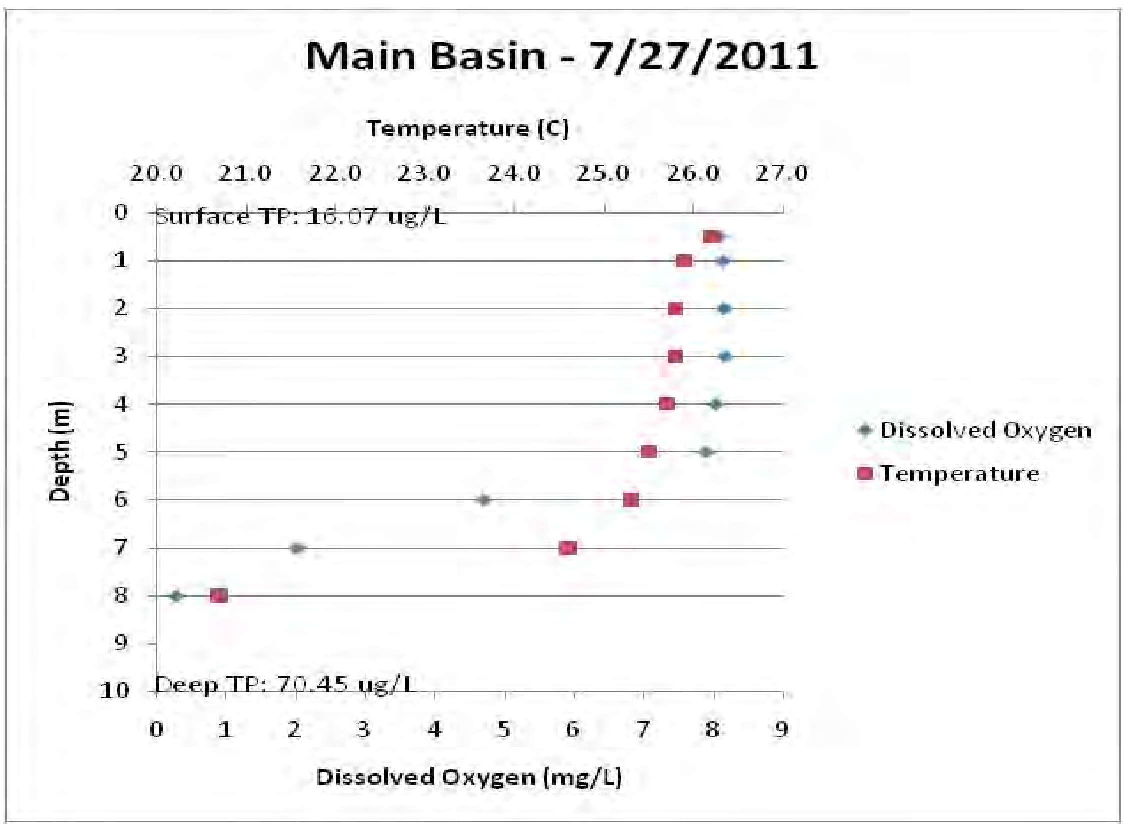
ATTACHMENT 2-4 2011 TEMP OXYGEN PROFILES

	Main Basin (STA 1)							
	DO				Temp			
Depth (m)	6/29/2011	7/27/2011	8/24/2011	9/19/2011	6/29/2011	7/27/2011	8/24/2011	9/19/2011
0.5	8.98	8.09	8.45	8.98	24.6	26.2	25.5	20.8
1	9.01	8.14	8.53	9.04	24.3	25.9	25.1	20.5
2	9.06	8.16	8.52	9.06	24.0	25.8	25.1	20.4
3	9.08	8.17	8.53	9.02	23.1	25.8	25.0	20.4
4	8.41	8.04	8.36	9.00	22.2	25.7	24.9	20.4
5	7.35	7.90	8.26	9.03	21.7	25.5	24.9	20.3
6	5.89	4.70	7.82	9.01	21.2	25.3	24.8	20.3
7	4.77	2.02	5.00	8.99	20.6	24.6	24.3	20.3
8	2.70	0.28	1.39		19.7	20.7	23.9	
8.5	1.53		0.27		19.4		23.3	

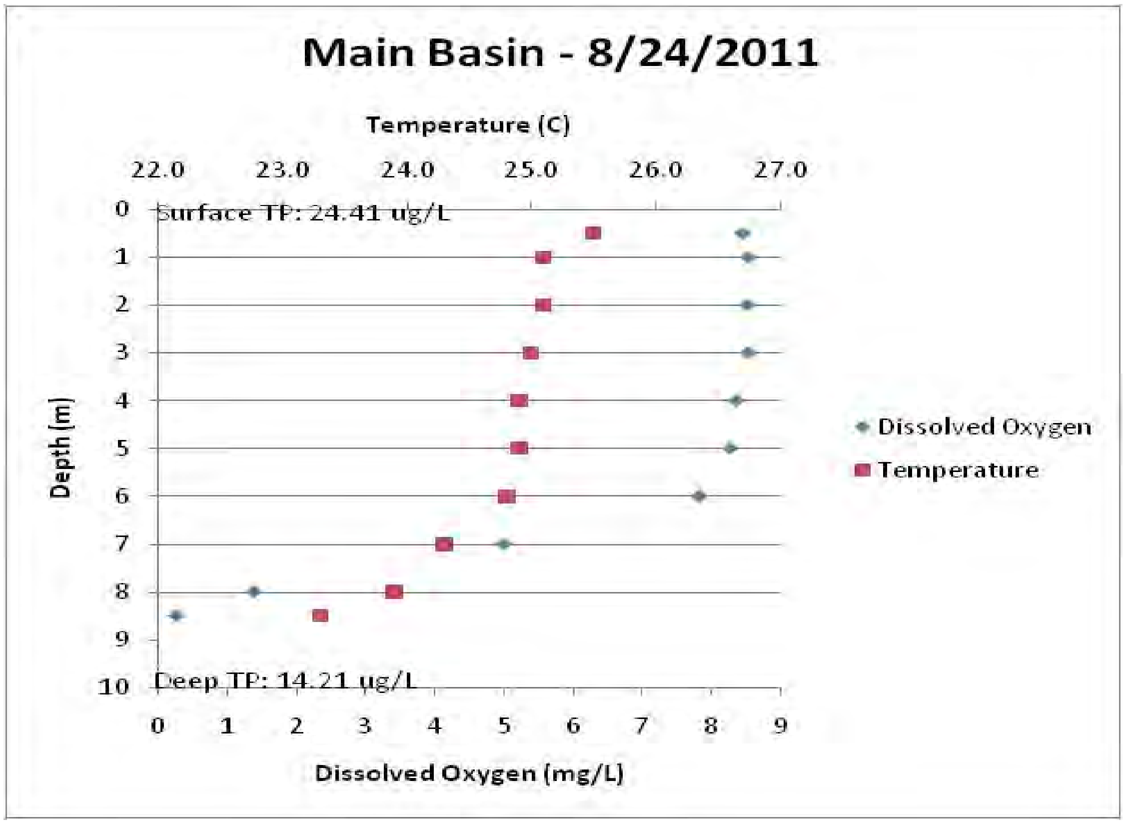
	TP Surface	**TP Bottom**
	ug/L	
6/29/2011	26.27	48.51
7/27/2011	16.07	70.45
8/24/2011	24.41	14.21
9/19/2011	10.51	12.36

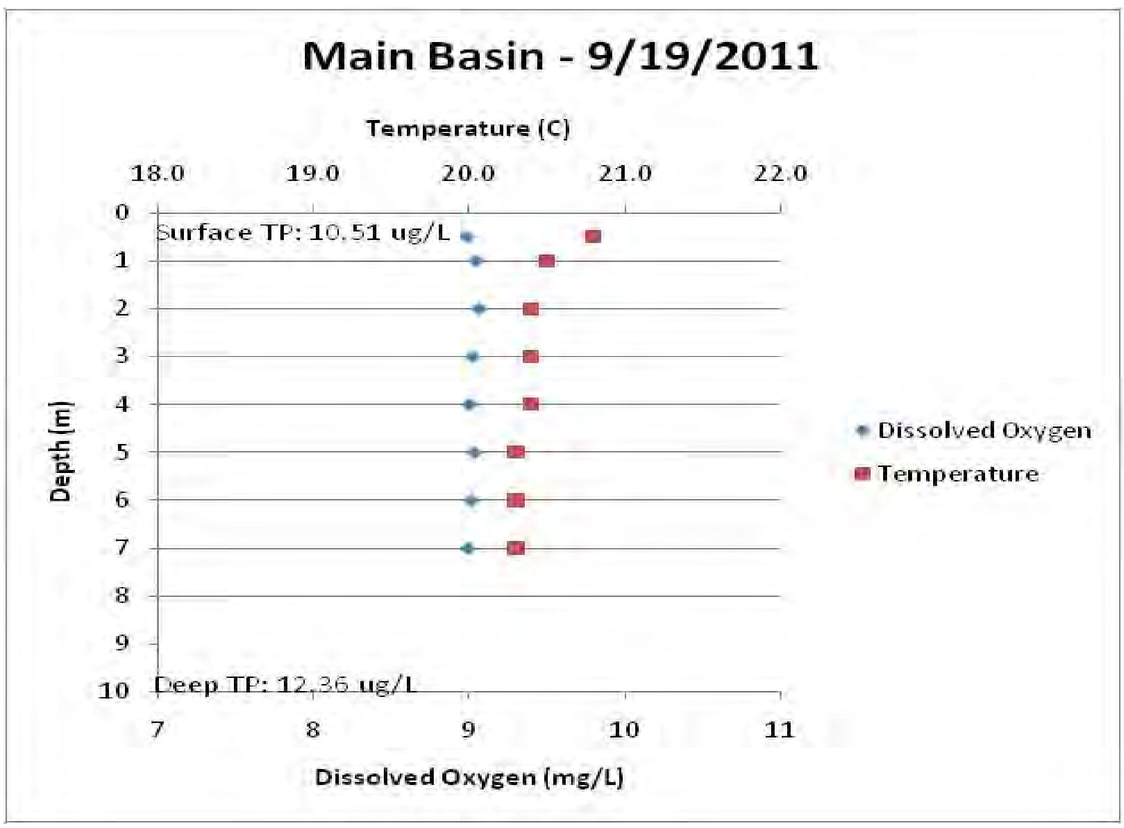


Main Basin - 6/29/2011
Temperature (C)
19.0 20.0 21.0 22.0 23.0 24.0 25.0
Surface TP: 26.27 ug/L
Deep TP: 48.51 ug/L
Depth (m)
0 1 2 3 4 5 6 7 8 9 10
1 2 3 4 5 6 7 8 9 10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature



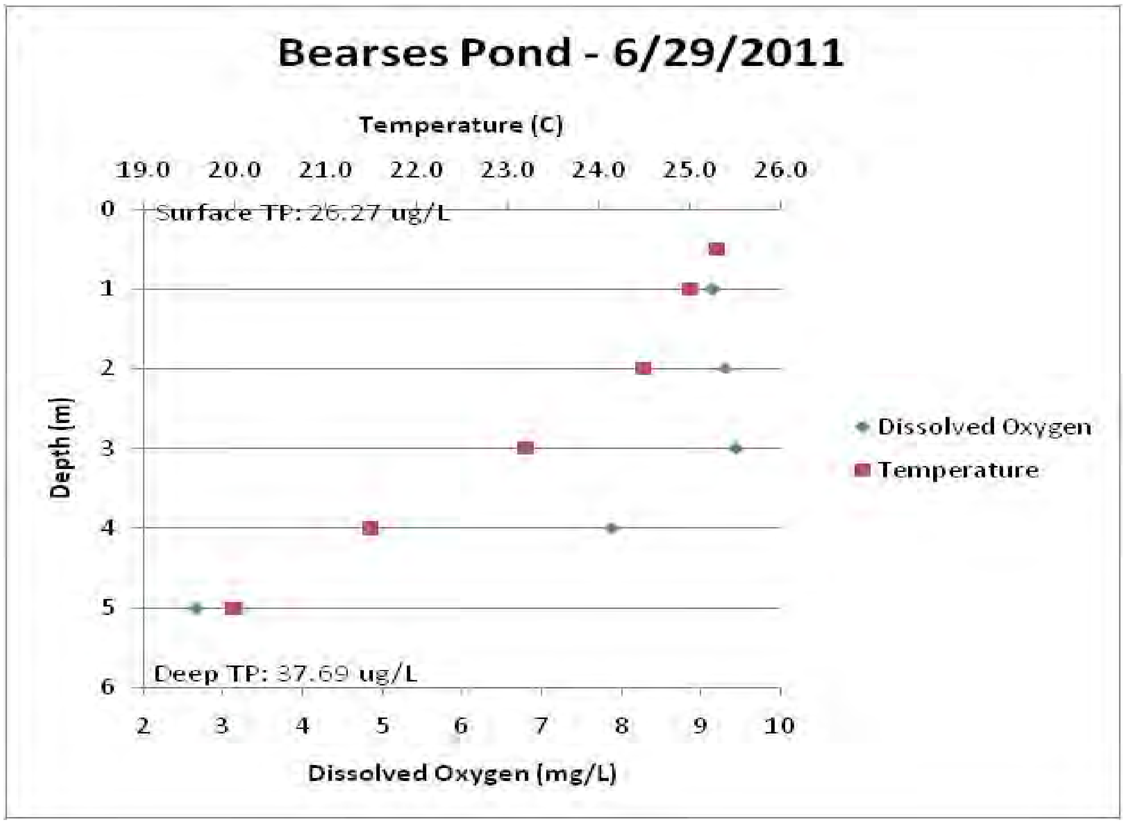
Main Basin - 7/27/2011
Temperature (C)
20.0 21.0 22.0 23.0 24.0 25.0 26.0 27.0
Surface TP: 16.07 ug/L
Deep TP: 70.45 ug/L
Depth (m)
0 1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

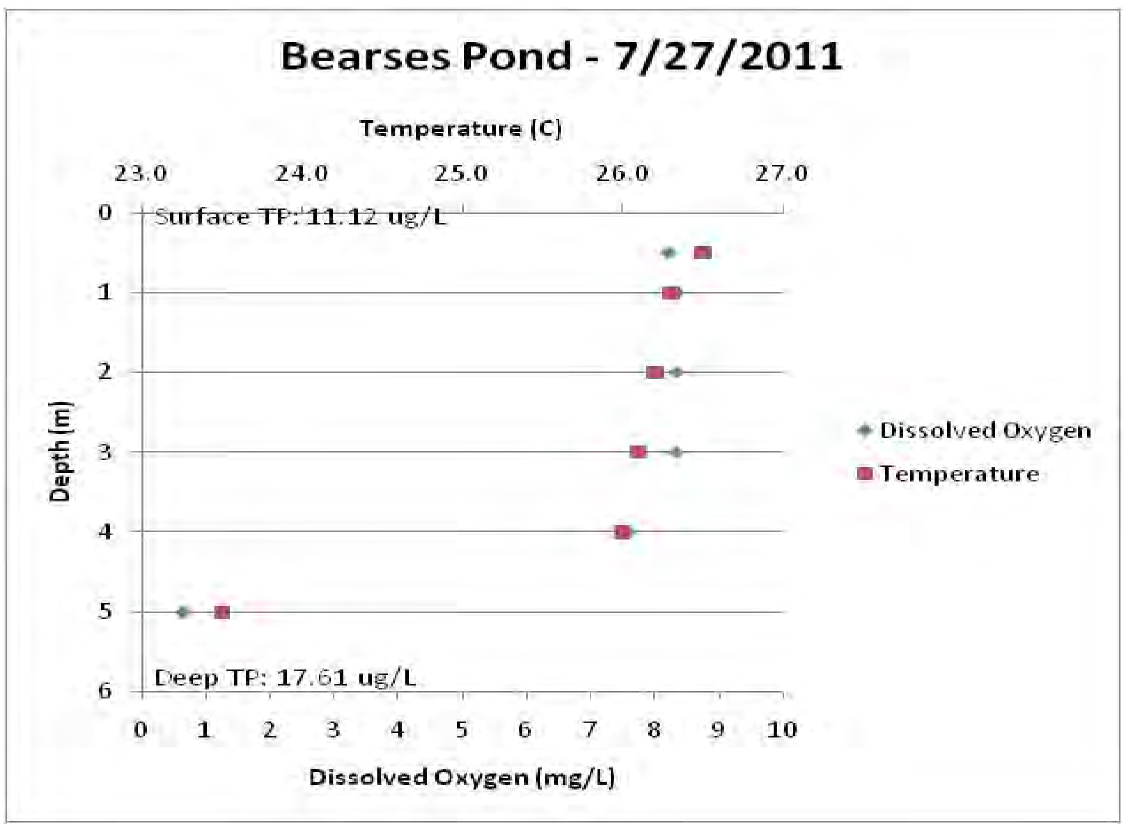

Main Basin - 8/24/2011
Temperature (C)
22.0
23.0
24.0
25.0
26.0
27.0
Surface TP: 24.41 ug/L
Deep TP: 14.21 ug/L
Depth (m)
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

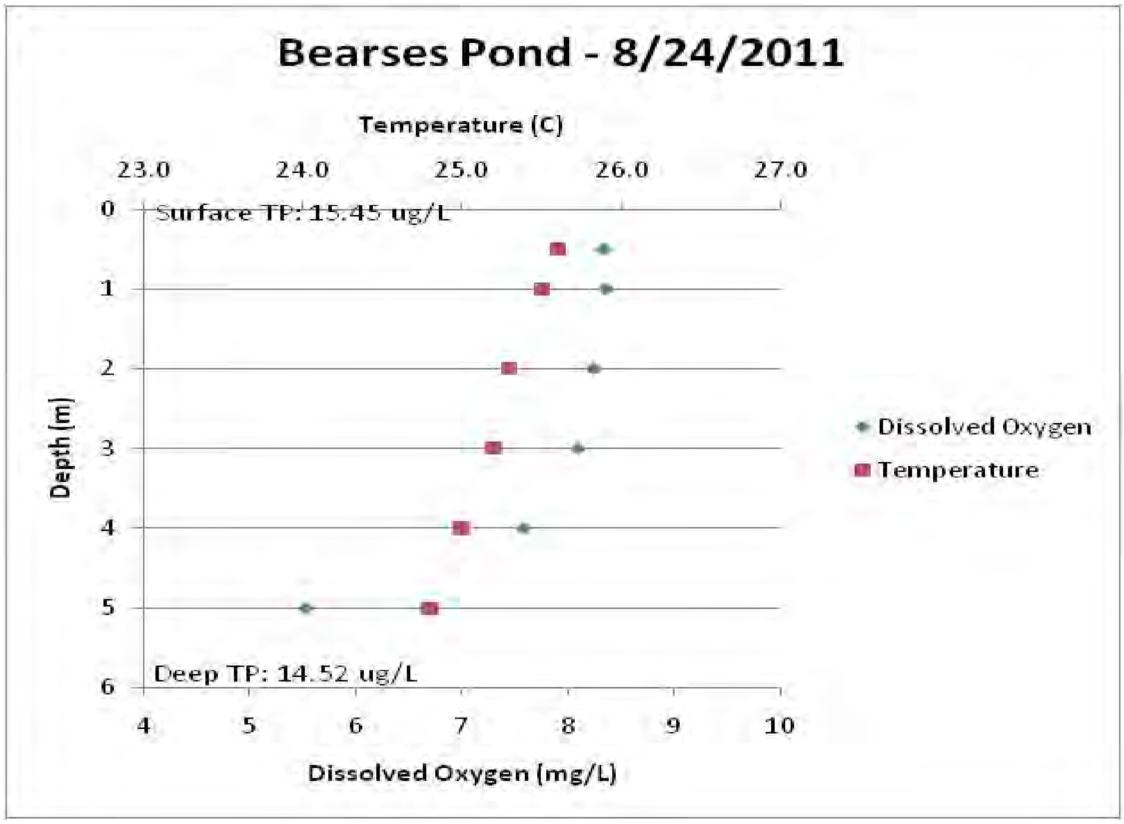

Main Basin - 9/19/2011
Temperature (C)
18.0
19.0
20.0
21.0
22.0
Surface TP: 10.51 ug/L
Deep TP: 12.36 ug/L
Depth (m)
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

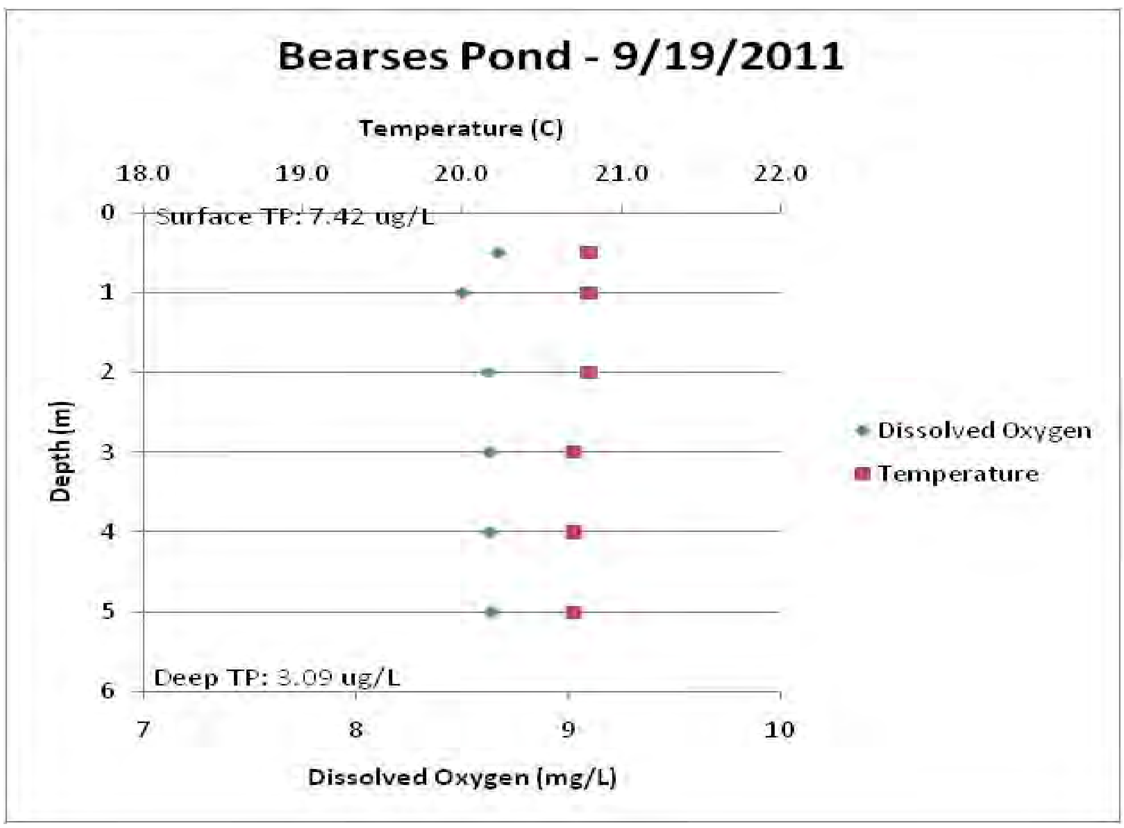
	Bearses Pond (STA 5)							
	DO				Temp			
Depth (m)	6/29/2011	7/27/2011	8/24/2011	9/19/2011	6/29/2011	7/27/2011	8/24/2011	9/19/2011
0.5	9.17	8.20	8.33	8.67	25.3	26.5	25.6	20.8
1	9.14	8.33	8.35	8.50	25.0	26.3	25.5	20.8
2	9.30	8.34	8.24	8.62	24.5	26.2	25.3	20.8
3	9.43	8.33	8.09	8.63	23.2	26.1	25.2	20.7
4	7.88	7.58	7.57	8.63	21.5	26.0	25.0	20.7
5	2.67	0.66	5.53	8.64	20.0	23.5	24.8	20.7

	TP Surface	**TP Bottom**
	ug/L	
6/29/2011	26.27	37.698
7/27/2011	11.12	17.613
8/24/2011	15.45	14.523
9/19/2011	7.42	3.09


Bearses Pond - 6/29/2011
Temperature (C)
19.0 20.0 21.0 22.0 23.0 24.0 25.0 26.0
Surface TP: 26.27 ug/L
Deep TP: 37.69 ug/L
Depth (m)
0 1 2 3 4 5 6
2 3 4 5 6 7 8 9 10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

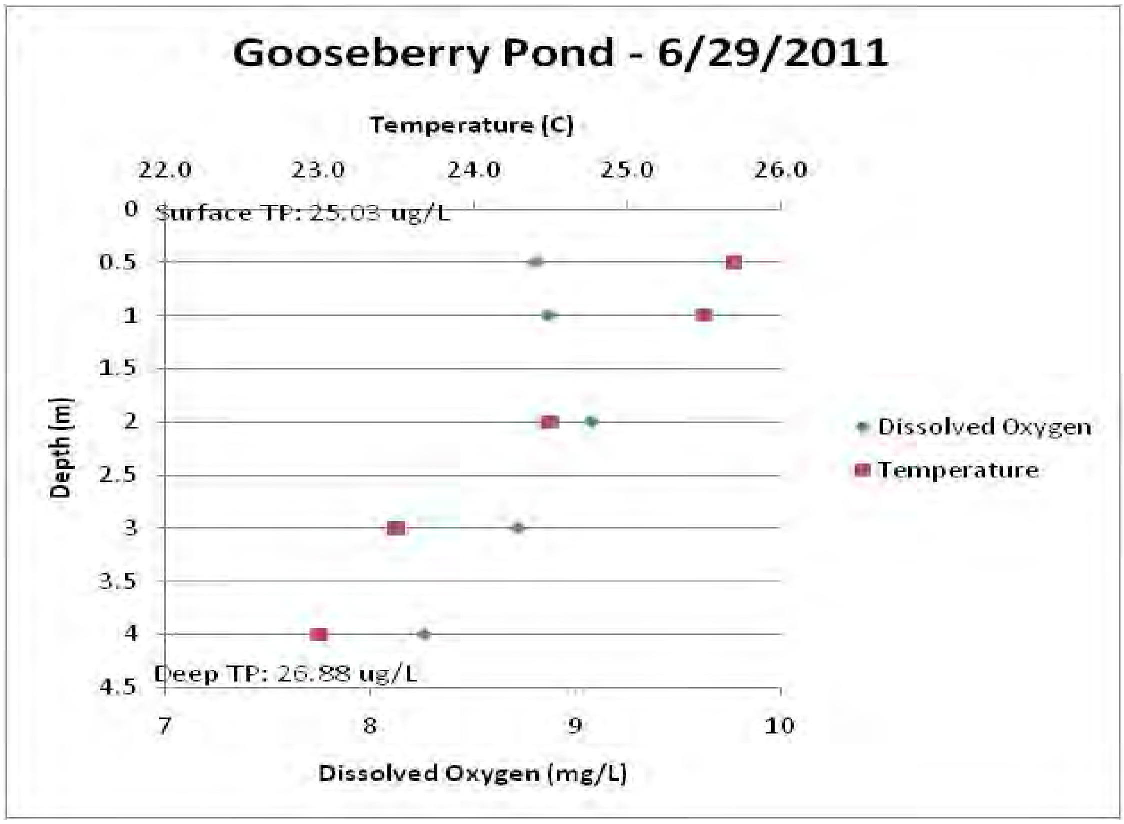

Bearses Pond - 7/27/2011
Temperature (C)
23.0 24.0 25.0 26.0 27.0
Surface TP: 11.12 ug/L
Deep TP: 17.61 ug/L
Depth (m)
0 1 2 3 4 5 6
0 1 2 3 4 5 6 7 8 9 10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

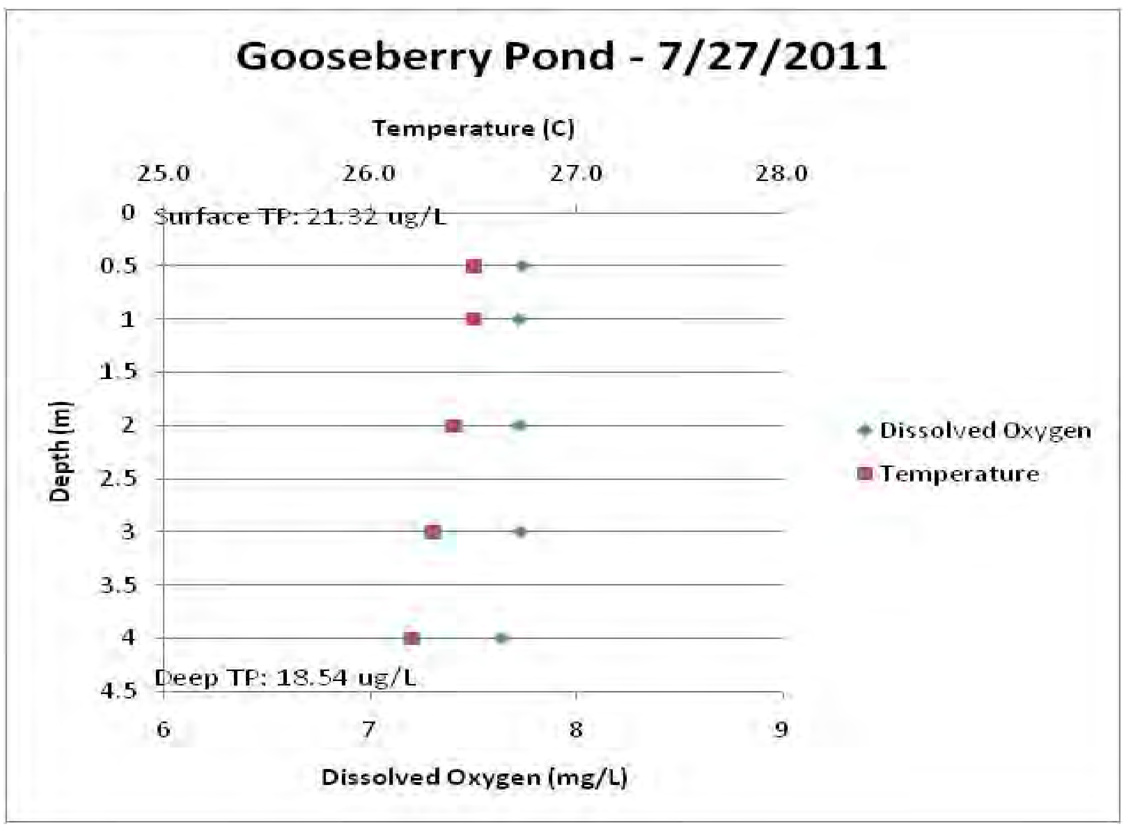

Bearses Pond - 8/24/2011
Temperature (C)
23.0
24.0
25.0
26.0
27.0
Surface TP: 15.45 ug/L
Deep TP: 14.52 ug/L
Depth (m)
0
1
2
3
4
5
6
4
5
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

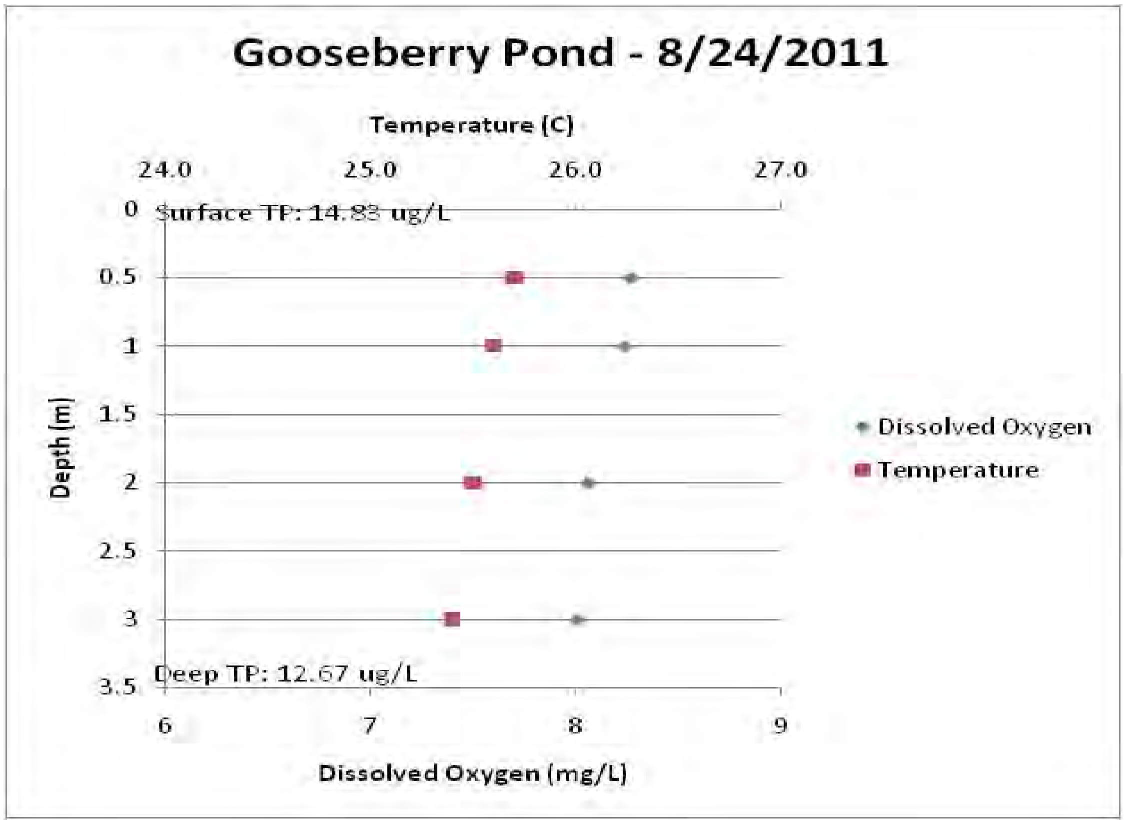

Bearses Pond - 9/19/2011
Temperature (C)
18.0
19.0
20.0
21.0
22.0
Surface TP: 7.42 ug/L
Deep TP: 3.09 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

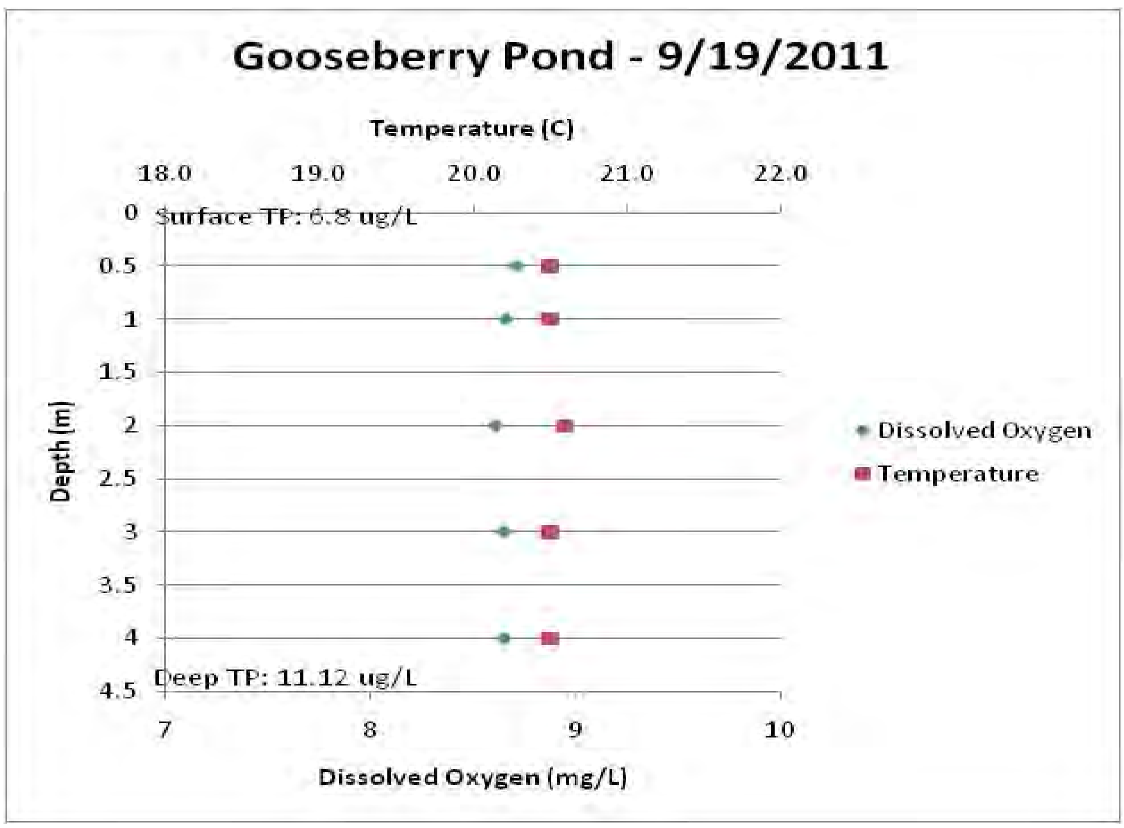
	Gooseberry Pond (STA 4)							
	DO				Temp			
Depth (m)	6/29/2011	7/27/2011	8/24/2011	9/19/2011	6/29/2011	7/27/2011	8/24/2011	9/19/2011
0.5	8.81	7.74	8.27	8.71	25.7	26.5	25.7	20.5
1	8.87	7.72	8.24	8.66	25.5	26.5	25.6	20.5
2	9.08	7.72	8.06	8.61	24.5	26.4	25.5	20.6
3	8.72	7.73	8.01	8.65	23.5	26.3	25.4	20.5
4	8.26	7.64		8.65	23.0	26.2		20.5

	TP Surface	**TP Bottom**
	ug/L	
6/29/2011	25.03	26.88
7/27/2011	21.32	18.54
8/24/2011	14.83	12.67
9/19/2011	6.80	11.12


Gooseberry Pond - 6/29/2011
Temperature (C)
22.0
23.0
24.0
25.0
26.0
Surface TP: 25.03 ug/L
Deep TP: 26.88 ug/L
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

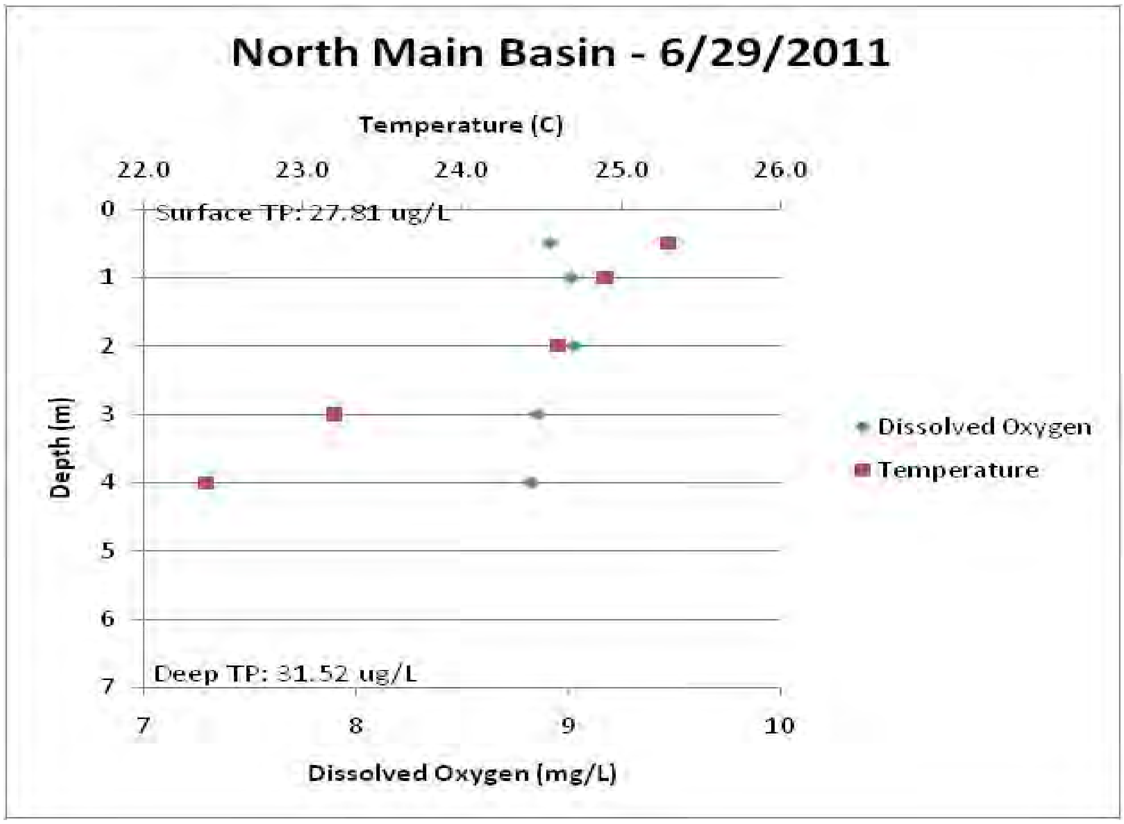

Gooseberry Pond - 7/27/2011
Temperature (C)
25.0
26.0
27.0
28.0
Surface TP: 21.32 ug/L
Deep TP: 18.54 ug/L
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
6
7
8
9
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature


Gooseberry Pond - 8/24/2011
Temperature (C)
24.0
25.0
26.0
27.0
Surface TP: 14.83 ug/L
Deep TP: 12.67 ug/L
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
6
7
8
9
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

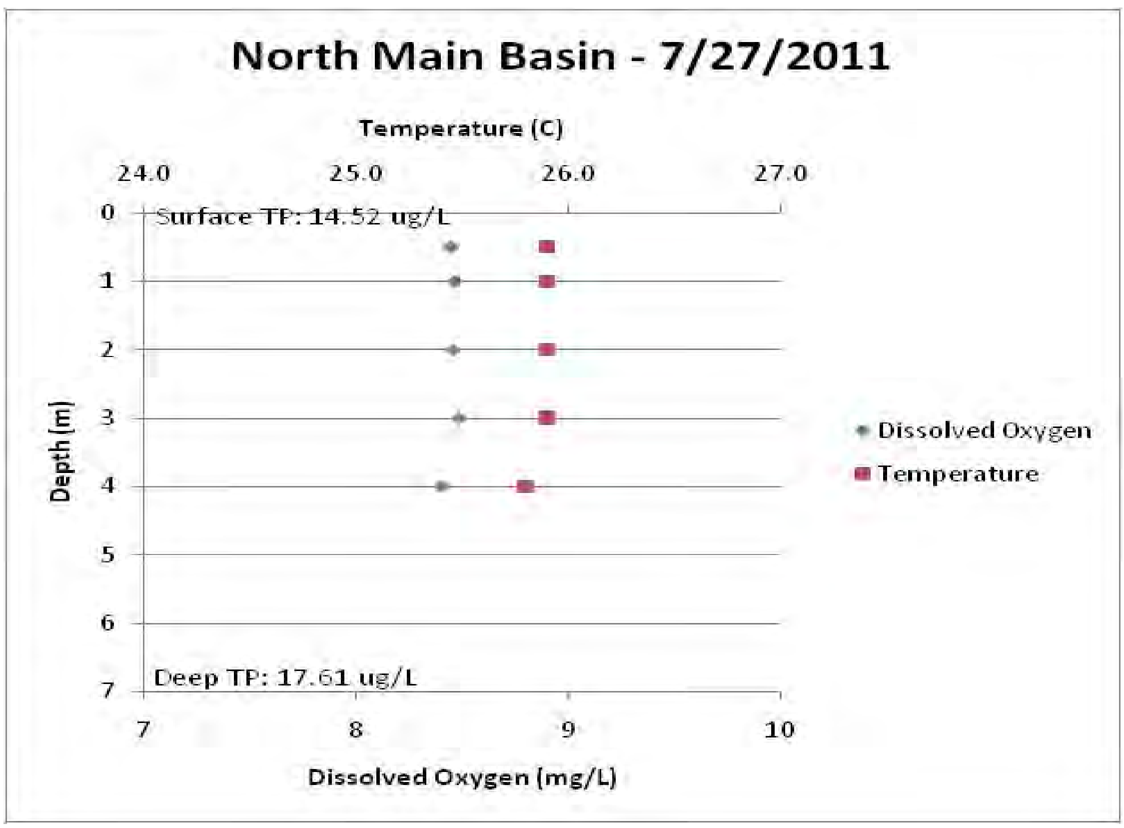

Gooseberry Pond - 9/19/2011
Temperature (C)
18.0
19.0
20.0
21.0
22.0
Surface TP: 6.8 ug/L
Deep TP: 11.12 ug/L
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

	North Main Basin (STA 2)							
	DO				Temp			
Depth (m)	6/29/2011	7/27/2011	8/24/2011	9/19/2011	6/29/2011	7/27/2011	8/24/2011	9/19/2011
0.5	8.92	8.45	8.44	9.09	25.3	25.9	25.0	20.5
1	9.02	8.47	8.43	9.06	24.9	25.9	25.0	20.6
2	9.03	8.46	8.36	9.04	24.6	25.9	25.0	20.6
3	8.86	8.49	8.36	9.04	23.2	25.9	24.9	20.6
4	8.83	8.41	8.31	9.03	22.4	25.8	24.9	20.6
5			8.27	9.02			24.8	20.6
6			8.29	9.00			24.8	20.6

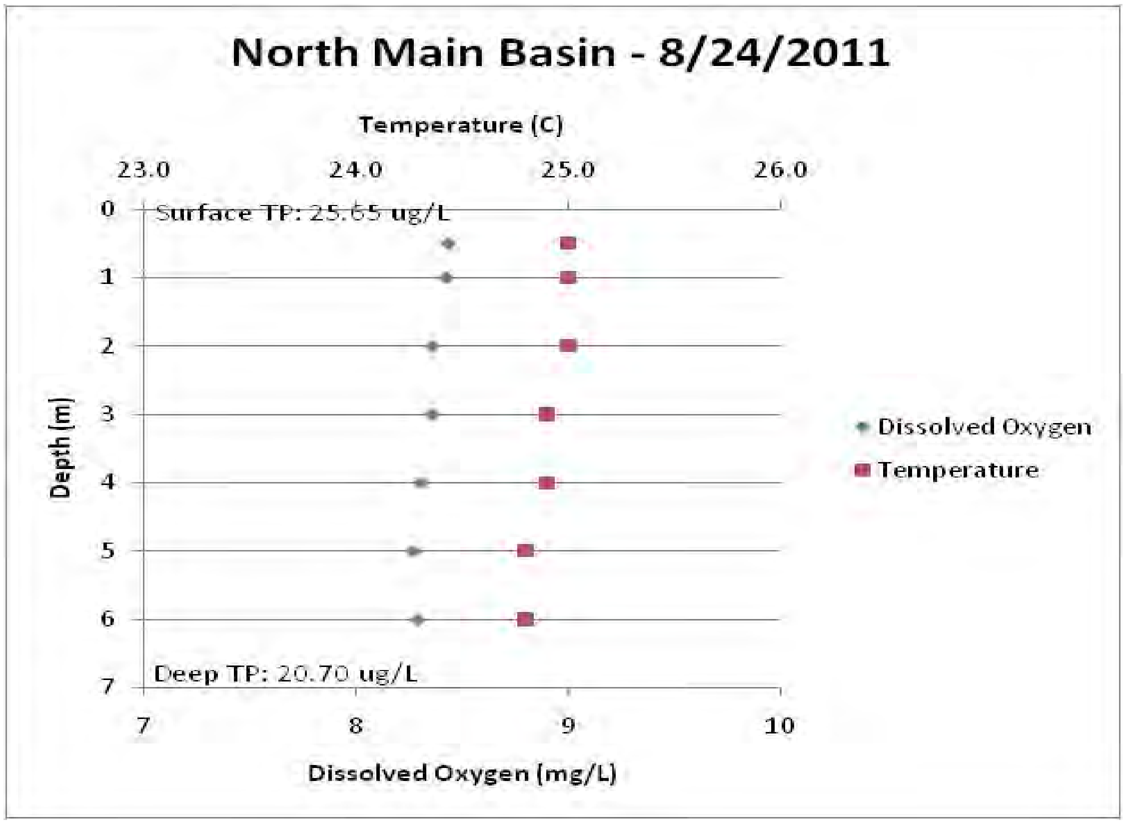
	TP Surface	TP Bottom
	ug/L	
6/29/2011	27.81	31.52
7/27/2011	14.52	17.61
8/24/2011	25.65	20.70
9/19/2011	12.67	18.85

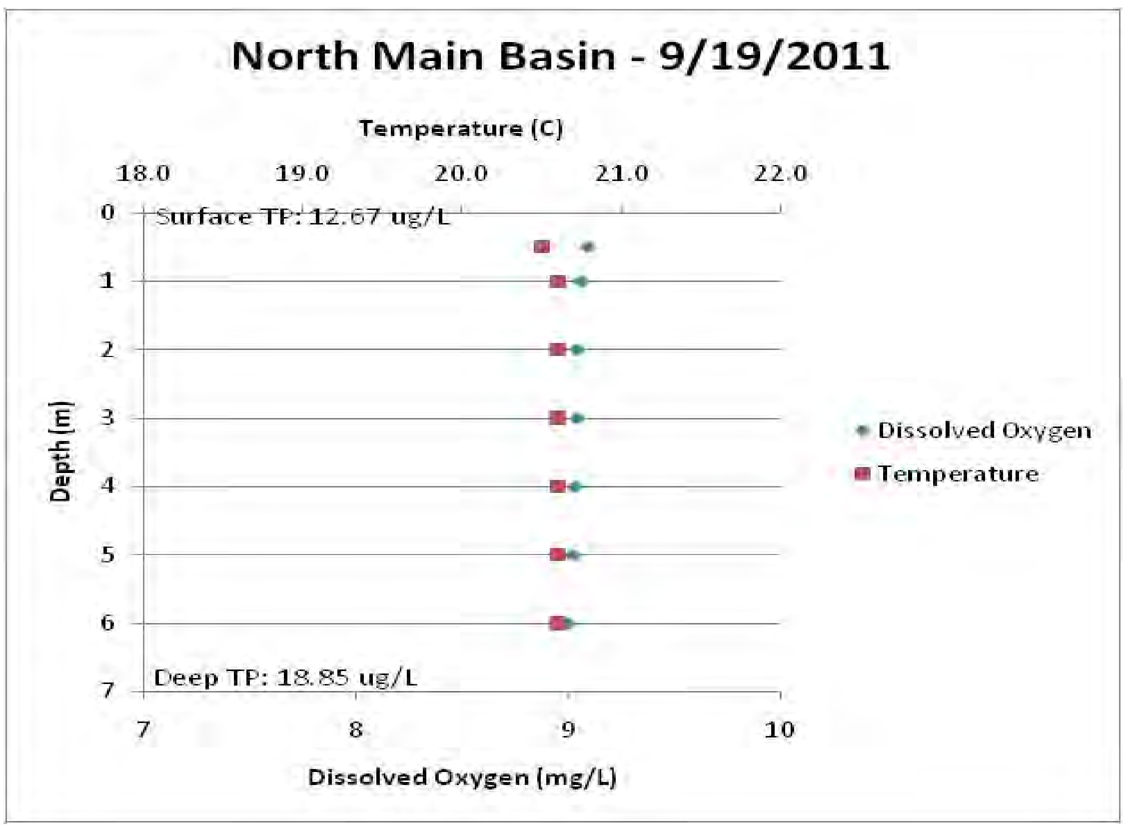


North Main Basin - 6/29/2011
Temperature (C)
22.0
23.0
24.0
25.0
26.0
Surface TP: 27.81 ug/L
Depth (m)
0
1
2
3
4
5
6
7
Deep TP: 31.52 ug/L
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature



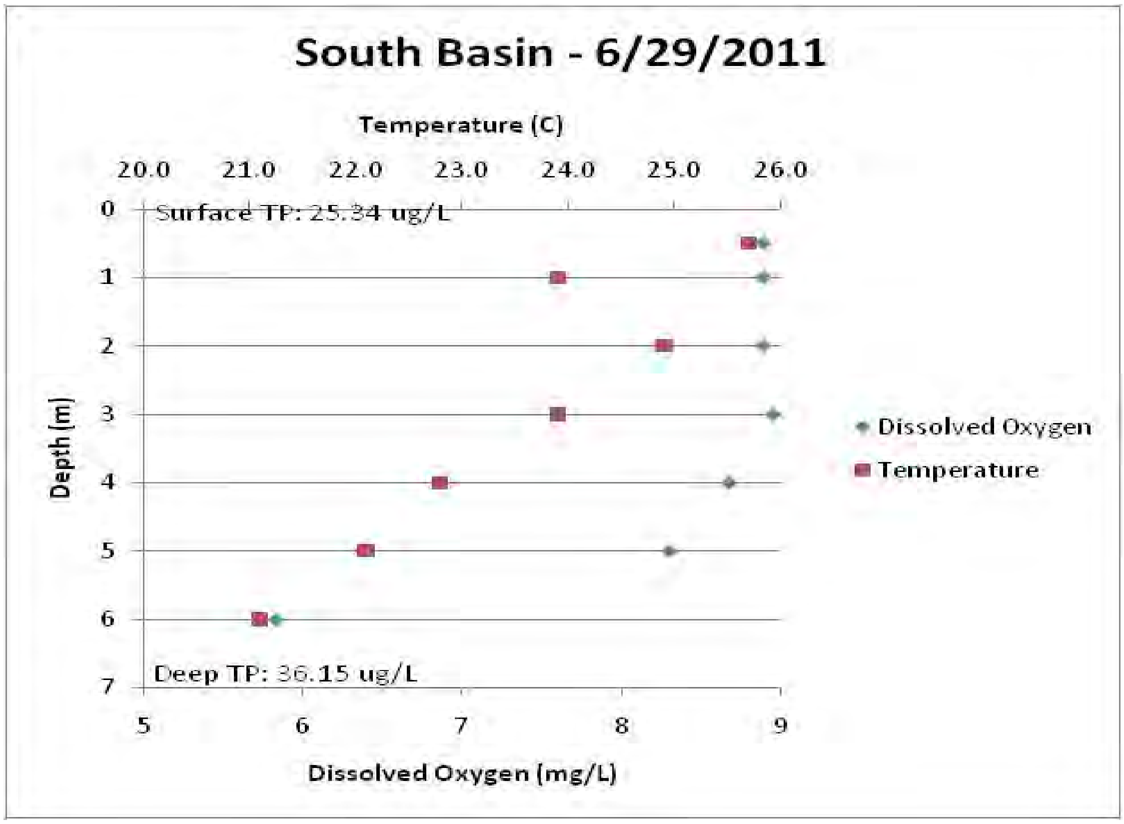
North Main Basin - 7/27/2011
Temperature (C)
24.0
25.0
26.0
27.0
Surface TP: 14.52 ug/L
Depth (m)
0
1
2
3
4
5
6
7
Deep TP: 17.61 ug/L
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

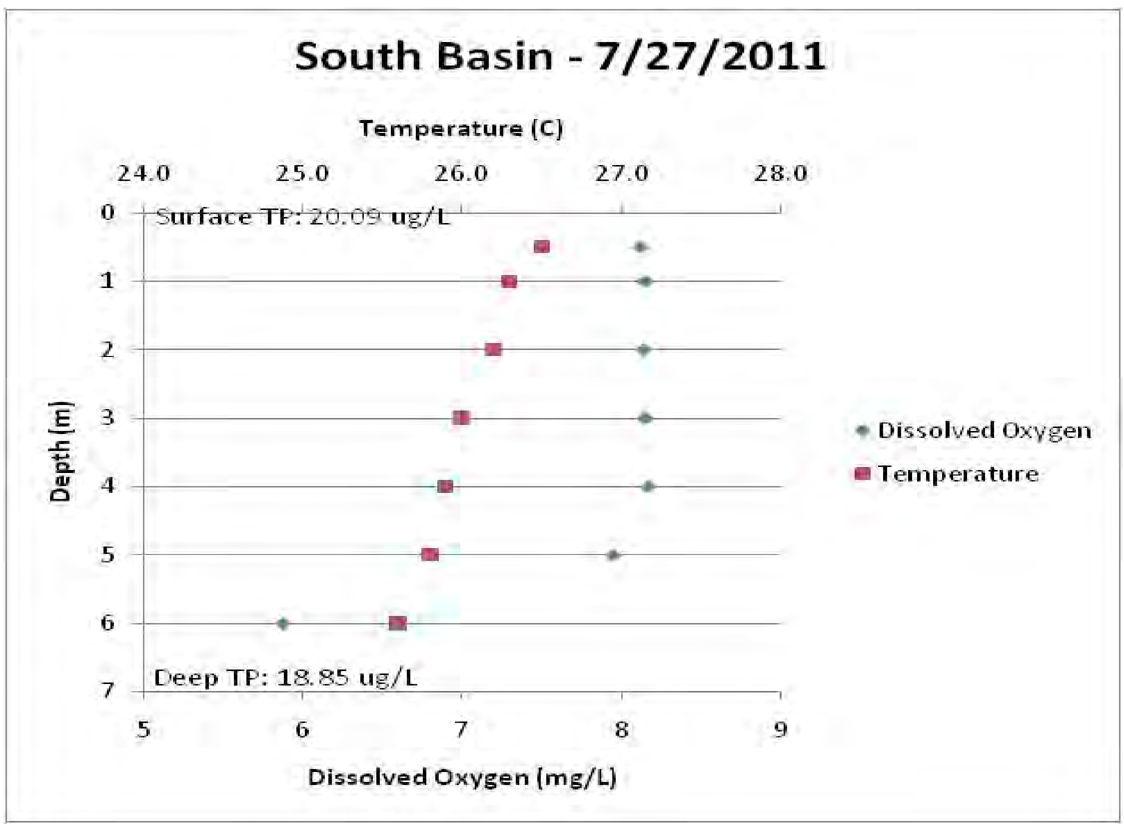

North Main Basin - 8/24/2011
Temperature (C)
23.0
24.0
25.0
26.0
Surface TP: 25.65 ug/L
Deep TP: 20.70 ug/L
0
1
2
3
4
5
6
7
Depth (m)
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

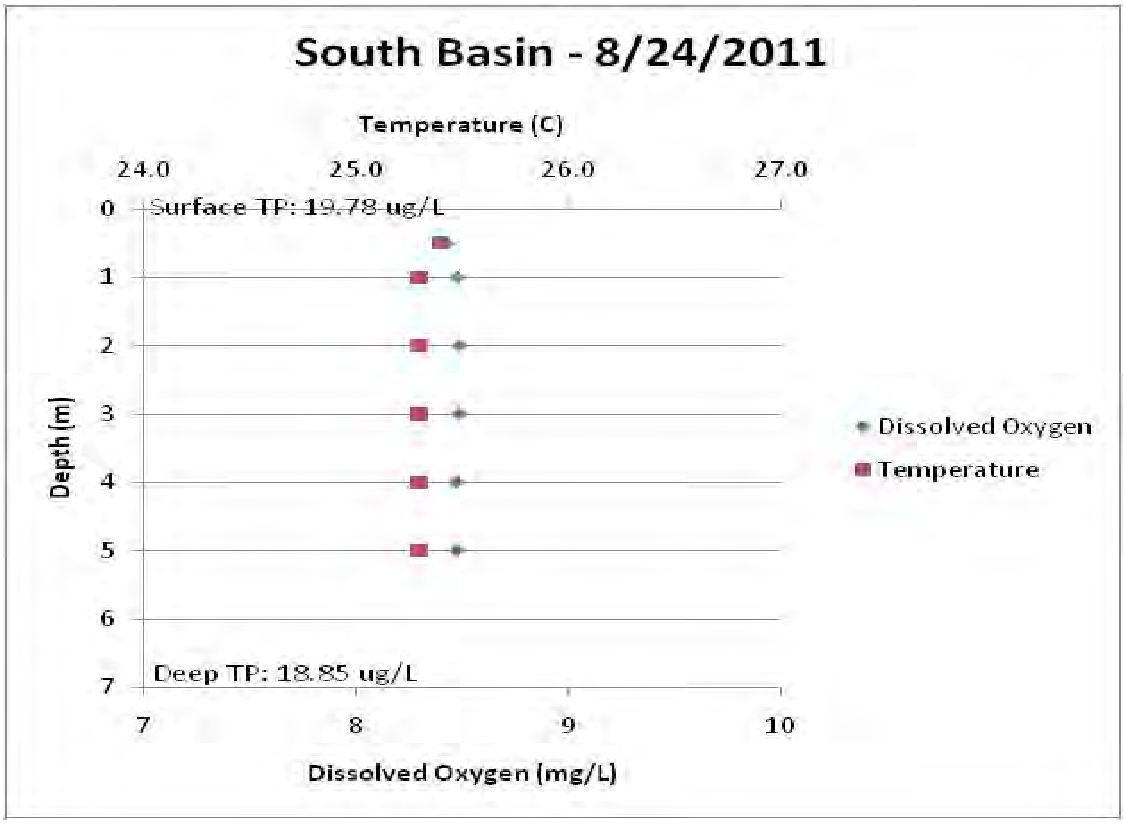

North Main Basin - 9/19/2011
Temperature (C)
18.0
19.0
20.0
21.0
22.0
Surface TP: 12.67 ug/L
Deep TP: 18.85 ug/L
0
1
2
3
4
5
6
7
Depth (m)
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

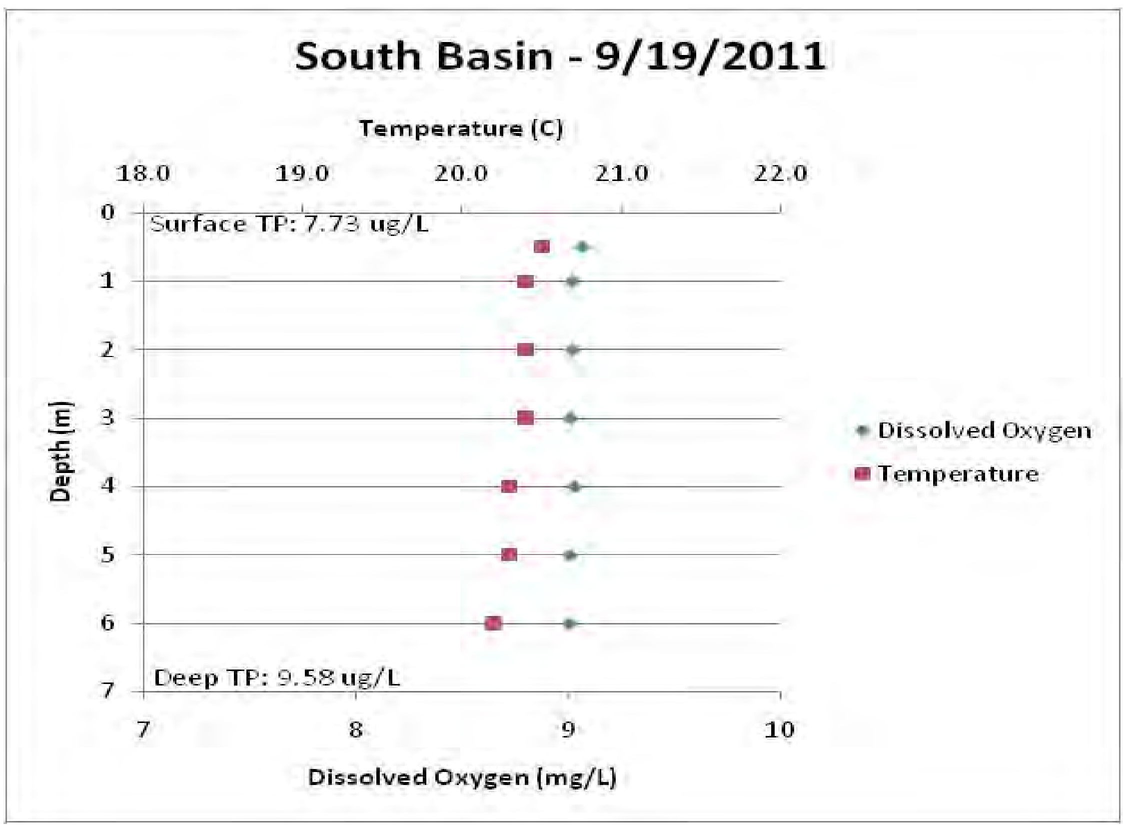
	South Basin (STA 3)							
	DO				Temp			
Depth (m)	6/29/2011	7/27/2011	8/24/2011	9/19/2011	6/29/2011	7/27/2011	8/24/2011	9/19/2011
0.5	8.89	8.12	8.43	9.07	25.7	26.5	25.4	20.5
1	8.89	8.15	8.48	9.02	23.9	26.3	25.3	20.4
2	8.89	8.14	8.49	9.02	24.9	26.2	25.3	20.4
3	8.95	8.15	8.49	9.01	23.9	26.0	25.3	20.4
4	8.67	8.17	8.48	9.03	22.8	25.9	25.3	20.3
5	8.30	7.95	8.48	9.01	22.1	25.8	25.3	20.3
6	5.83	5.88		9.01	21.1	25.6		20.2

	TP Surface	**TP Bottom**
	ug/L	
6/29/2011	25.34	36.15
7/27/2011	20.09	18.85
8/24/2011	19.78	18.85
9/19/2011	7.73	9.58


South Basin - 6/29/2011
Temperature (C)
20.0
21.0
22.0
23.0
24.0
25.0
26.0
Surface TP: 25.34 ug/L
Deep TP: 36.15 ug/L
Depth (m)
0
1
2
3
4
5
6
7
5
6
7
8
9
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature


South Basin - 7/27/2011
Temperature (C)
24.0
25.0
26.0
27.0
28.0
Surface TP: 20.09 ug/L
Deep TP: 18.85 ug/L
Depth (m)
0
1
2
3
4
5
6
7
5
6
7
8
9
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

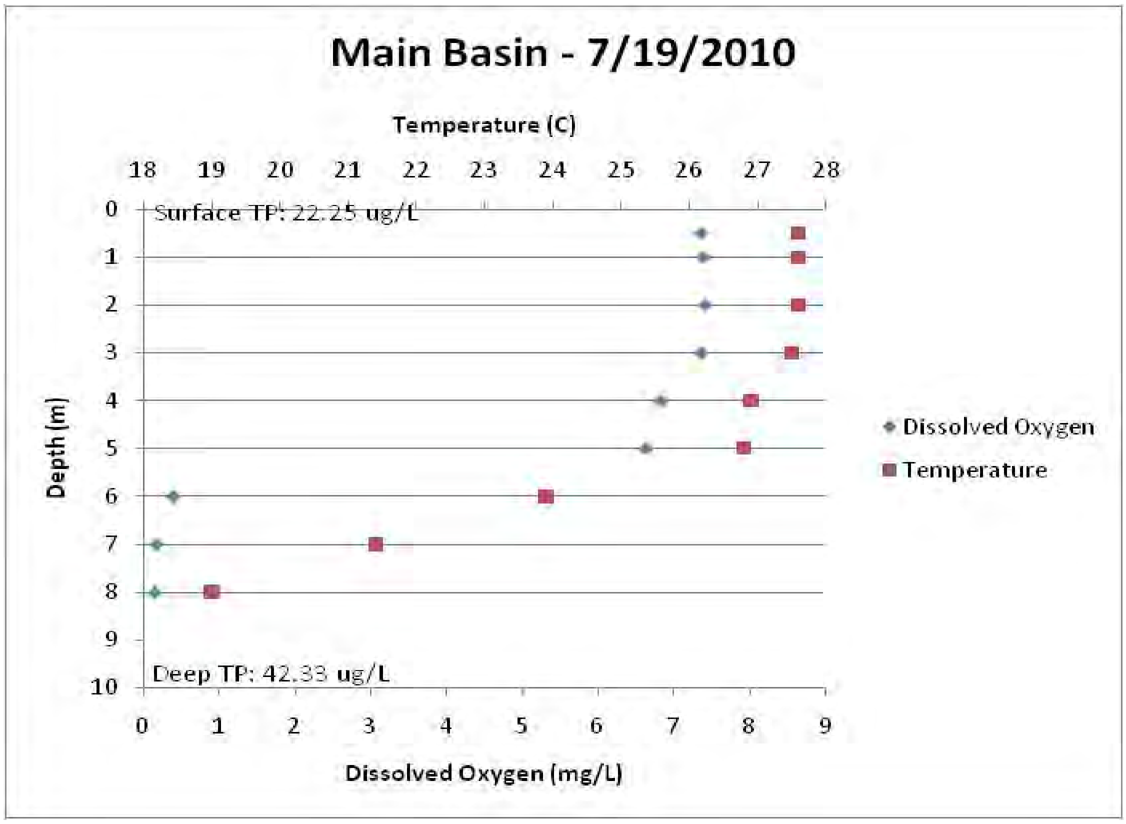

South Basin - 8/24/2011
Temperature (C)
24.0
25.0
26.0
27.0
Surface TP: 19.78 ug/L
Deep TP: 18.85 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

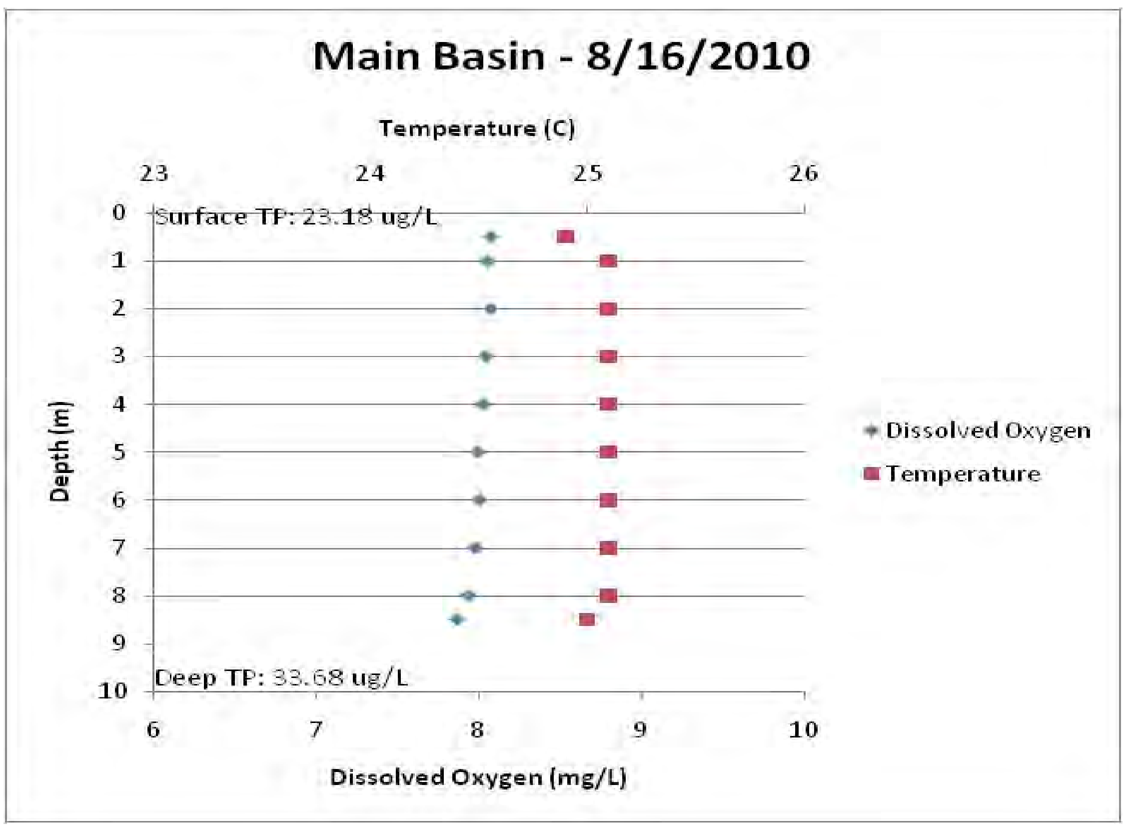

South Basin - 9/19/2011
Temperature (C)
18.0
19.0
20.0
21.0
22.0
Surface TP: 7.73 ug/L
Deep TP: 9.58 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

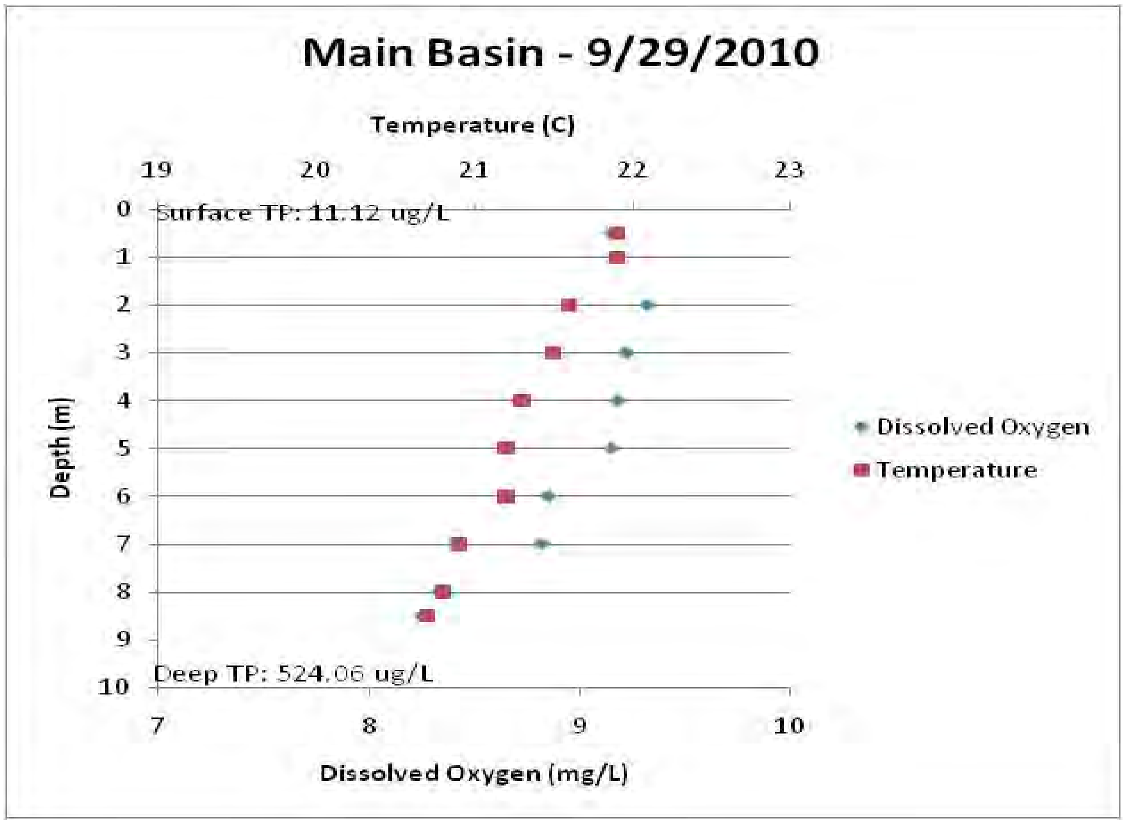
ATTACHMENT 2-5 2010 TEMP OXYGEN PROFILES

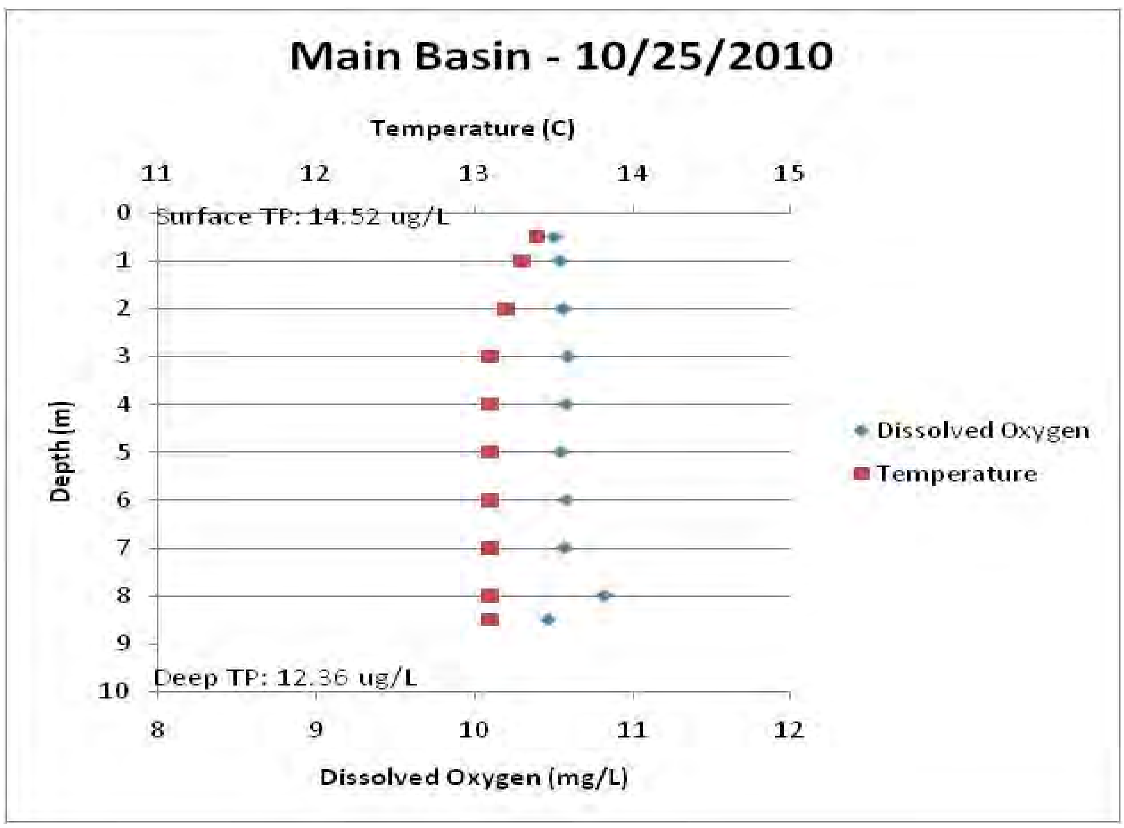
Main Basin (STA 1)							
DO				Temp			
7/19/2010	8/16/2010	9/29/2010	10/25/2010	7/19/2010	8/16/2010	9/29/2010	10/25/2010
7.35	8.08	9.15	10.51	27.6	24.9	21.9	13.4
7.38	8.06	9.18	10.54	27.6	25.1	21.9	13.3
7.4	8.08	9.32	10.56	27.6	25.1	21.6	13.2
7.35	8.05	9.22	10.59	27.5	25.1	21.5	13.1
6.82	8.03	9.18	10.58	26.9	25.1	21.3	13.1
6.62	8	9.15	10.55	26.8	25.1	21.2	13.1
0.4	8.01	8.85	10.58	23.9	25.1	21.2	13.1
0.18	7.98	8.82	10.57	21.4	25.1	20.9	13.1
0.16	7.94	8.33	10.82	19	25.1	20.8	13.1
	7.87	8.25	10.47		25	20.7	13.1

	TP Surface	**TP Bottom**
	ug/L	
7/19/2010	22.25	42.33
8/16/2010	23.18	33.68
9/29/2010	11.12	524.06
10/25/2010	14.52	12.36

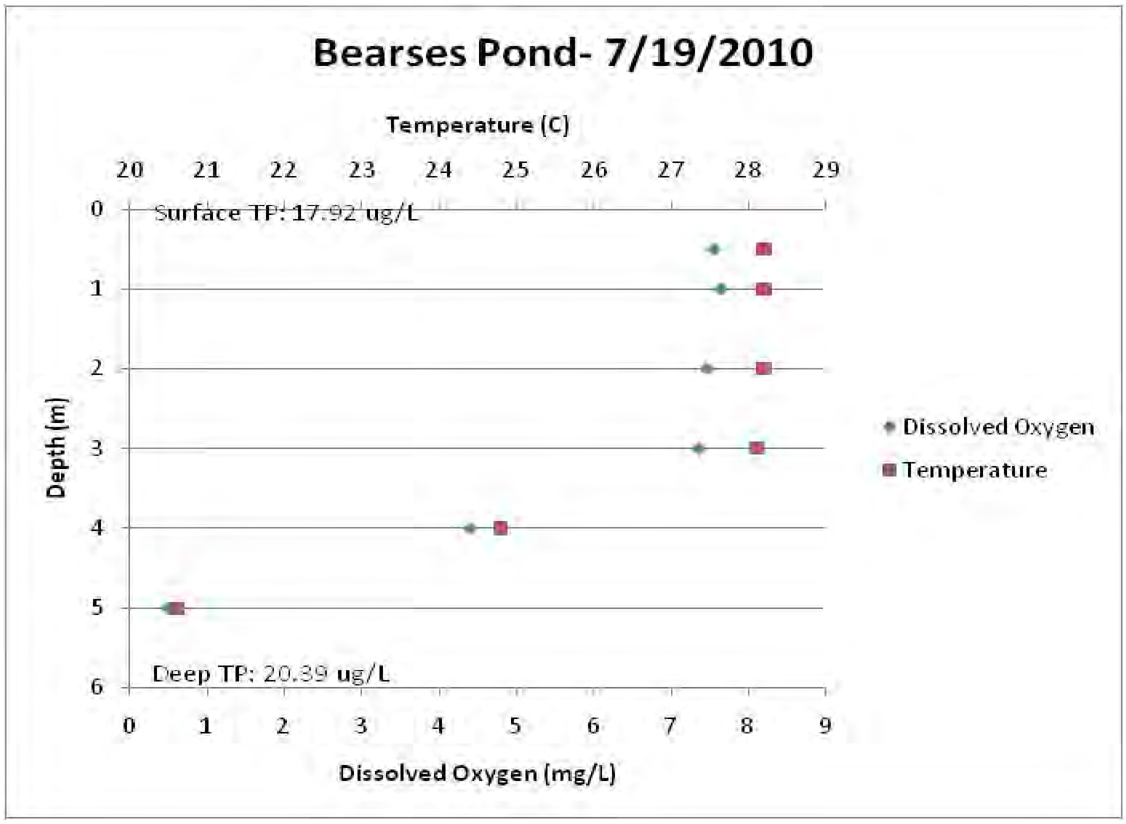

Main Basin - 7/19/2010
Temperature (C)
18 19 20 21 22 23 24 25 26 27 28
Surface TP: 22.25 ug/L
Deep TP: 42.33 ug/L
Depth (m)
0 1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

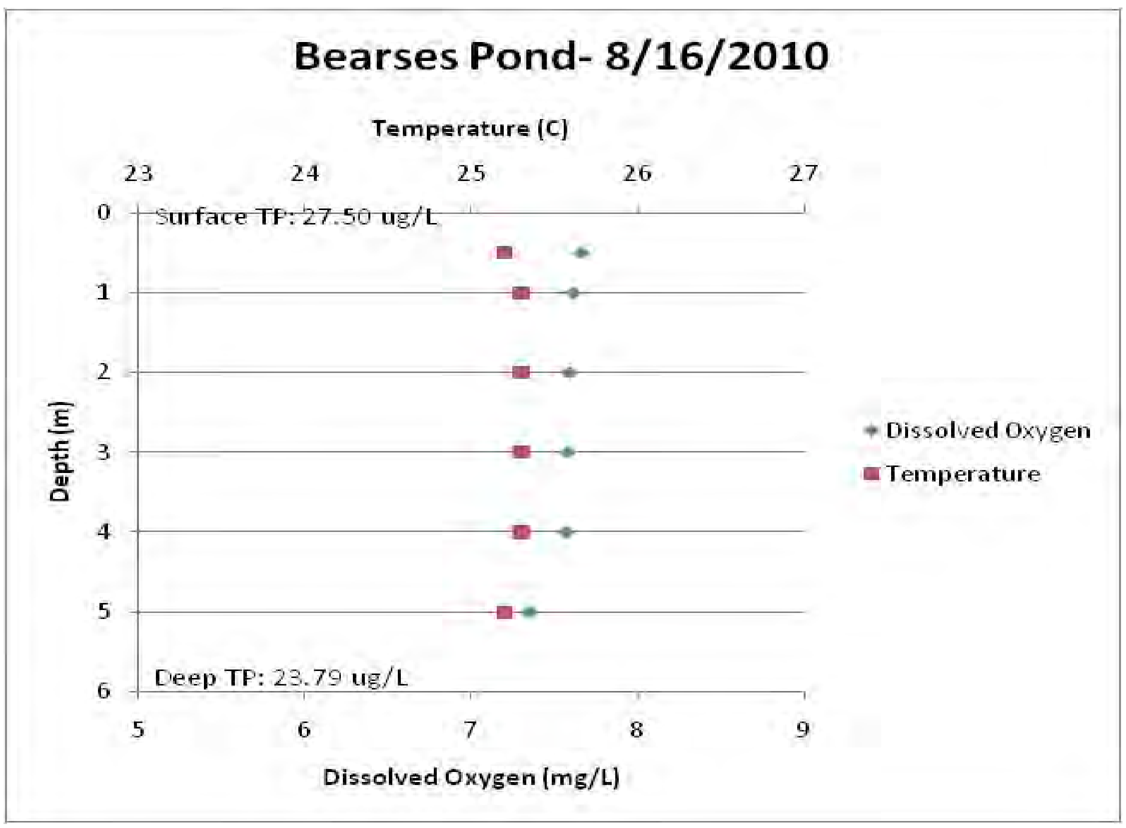

Main Basin - 8/16/2010
Temperature (C)
23 24 25 26
Surface TP: 23.18 ug/L
Deep TP: 33.68 ug/L
Depth (m)
0 1 2 3 4 5 6 7 8 9 10
6 7 8 9 10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

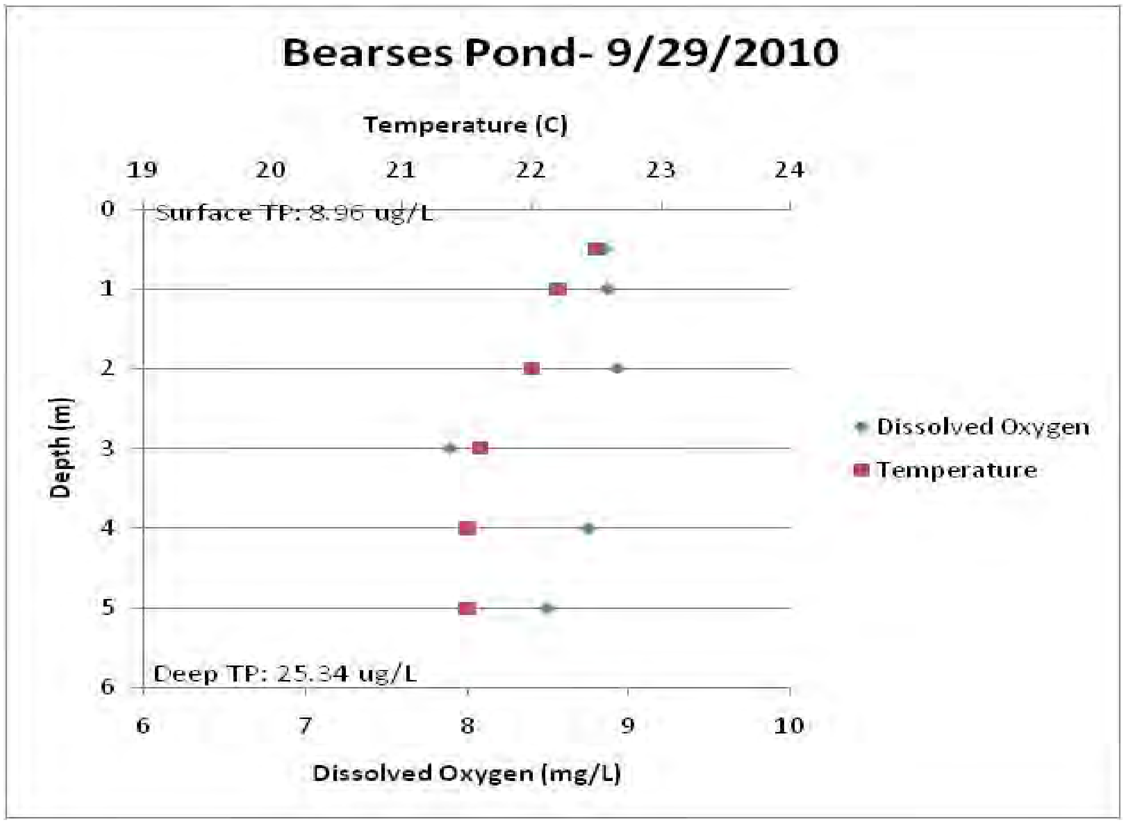

Main Basin - 9/29/2010
Temperature (C)
19
20
21
22
23
Surface TP: 11.12 ug/L
Deep TP: 524.06 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

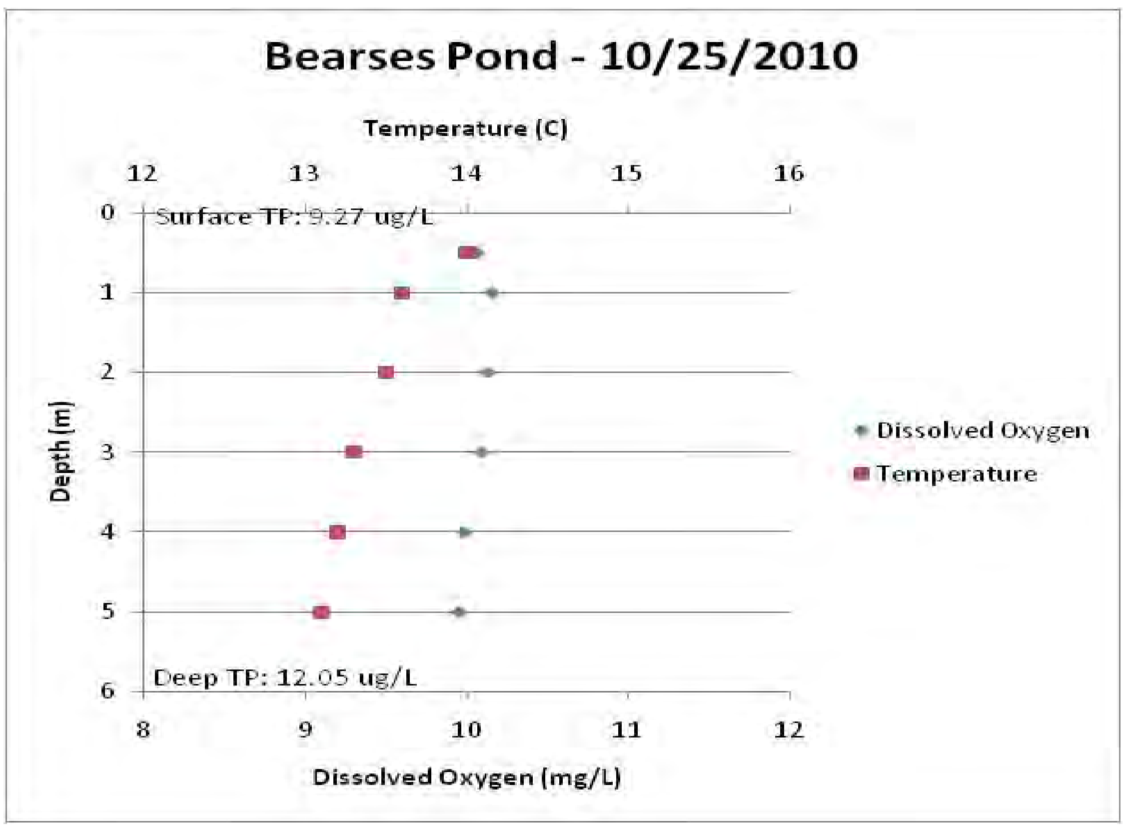

Main Basin - 10/25/2010
Temperature (C)
11
12
13
14
15
Surface TP: 14.52 ug/L
Deep TP: 12.36 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
8
9
10
11
12
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

	Bearses Pond (STA 5)												
	DO				Temp								
Depth (m)	7/19/2010	8/16/2010	9/29/2010	10/25/2010	7/19/2010	8/16/2010	9/29/2010	10/25/2010				**TP Surface**	**TP Bottom**
0.5	7.55	7.66	8.85	10.06	28.2	25.2	22.5	14				**ug/L**	
1	7.64	7.61	8.87	10.16	28.2	25.3	22.2	13.6			7/19/2010	17.92	20.394
2	7.45	7.59	8.93	10.13	28.2	25.3	22	13.5			8/16/2010	27.50	23.793
3	7.35	7.58	7.9	10.09	28.1	25.3	21.6	13.3			9/29/2010	8.96	25.338
4	4.4	7.57	8.75	9.98	24.8	25.3	21.5	13.2			10/25/2010	9.27	12.051
5	0.5	7.35	8.5	9.95	20.6	25.2	21.5	13.1					


Bearses Pond- 7/19/2010
Temperature (C)
20 21 22 23 24 25 26 27 28 29
Surface TP: 17.92 ug/L
Deep TP: 20.39 ug/L
Depth (m)
0 1 2 3 4 5 6
0 1 2 3 4 5 6 7 8 9
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

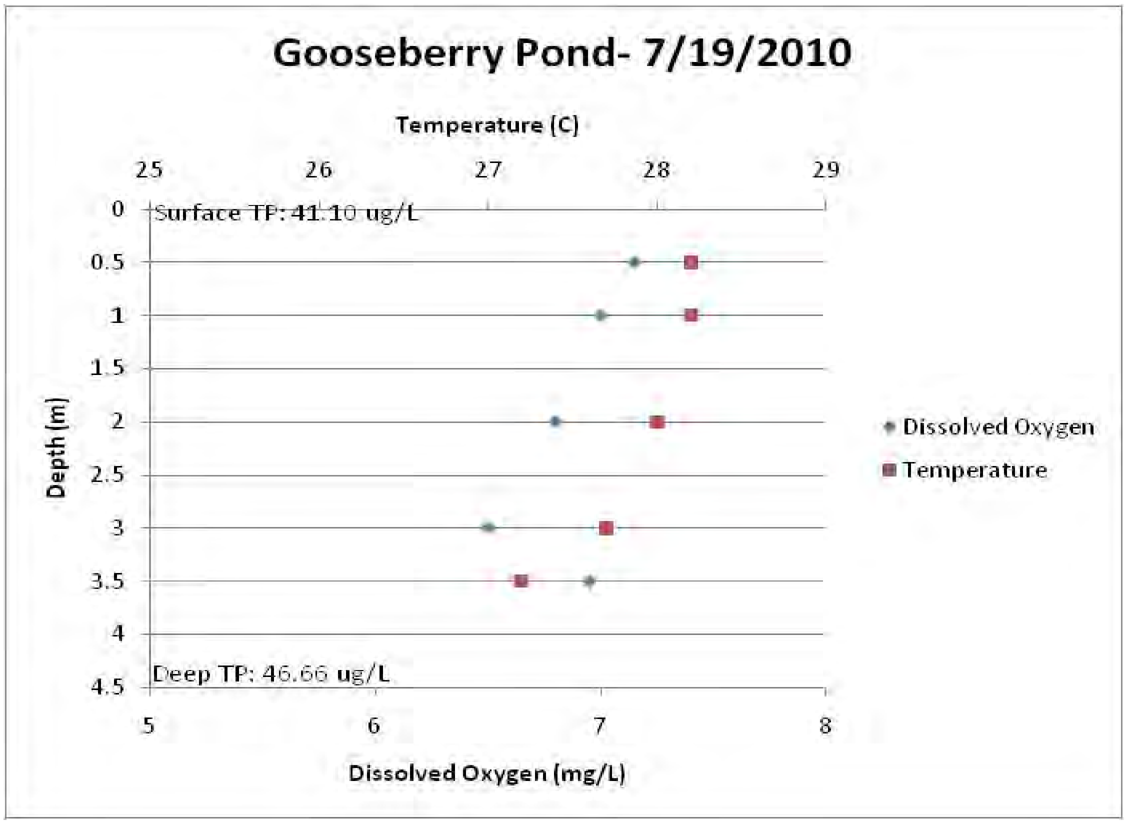

Bearses Pond- 8/16/2010
Temperature (C)
23 24 25 26 27
Surface TP: 27.50 ug/L
Deep TP: 23.79 ug/L
Depth (m)
0 1 2 3 4 5 6
5 6 7 8 9
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

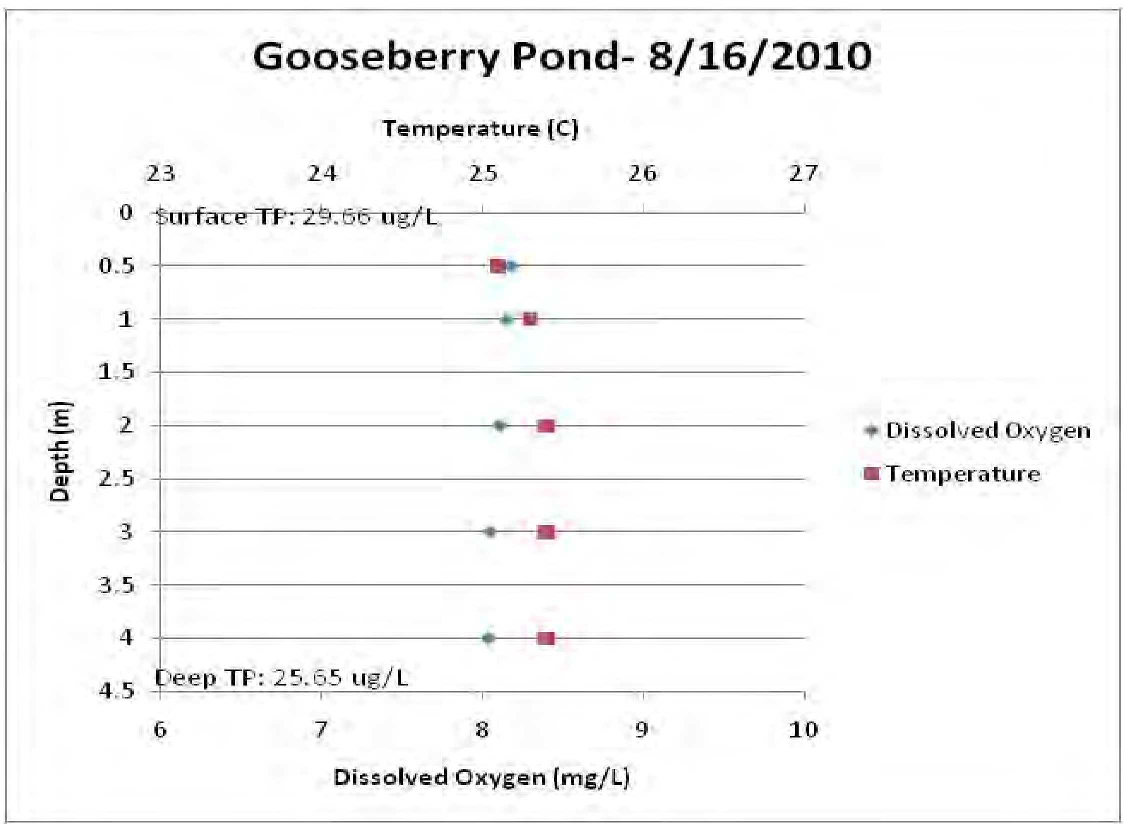

Bearses Pond- 9/29/2010
Temperature (C)
19
20
21
22
23
24
Surface TP: 8.96 ug/L
Deep TP: 25.34 ug/L
Depth (m)
0
1
2
3
4
5
6
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature


Bearses Pond - 10/25/2010
Temperature (C)
12
13
14
15
16
Surface TP: 9.27 ug/L
Deep TP: 12.05 ug/L
Depth (m)
0
1
2
3
4
5
6
8
9
10
11
12
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

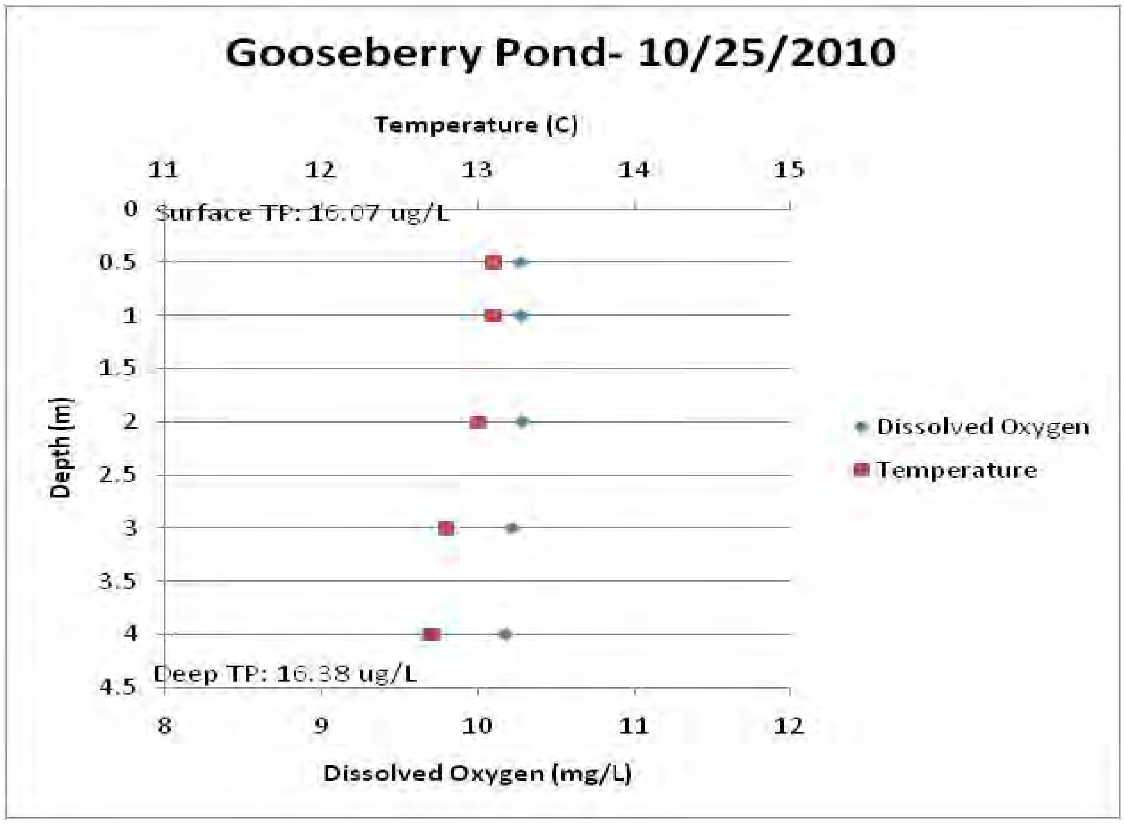
	Gooseberry Pond (STA 4)							
	DO				Temp			
Depth (m)	7/19/2010	8/16/2010	9/29/2010	10/25/2010	7/19/2010	8/16/2010	9/29/2010	10/25/2010
0.5	7.15	8.18		10.27	28.2	25.1		13.1
1	7	8.15		10.27	28.2	25.3		13.1
2	6.8	8.11		10.28	28	25.4		13
3	6.5	8.05		10.22	27.7	25.4		12.8
3.5	6.95				27.2			
4		8.04		10.18		25.4		12.7

	TP Surface	**TP Bottom**
	ug/L	
7/19/2010	41.10	46.66
8/16/2010	29.66	25.65
9/29/2010	NA	NA
10/25/2010	16.07	16.38


Gooseberry Pond- 7/19/2010
Temperature (C)
25
26
27
28
29
Surface TP: 41.10 ug/L
Deep TP: 46.66 ug/L
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
6
7
8
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

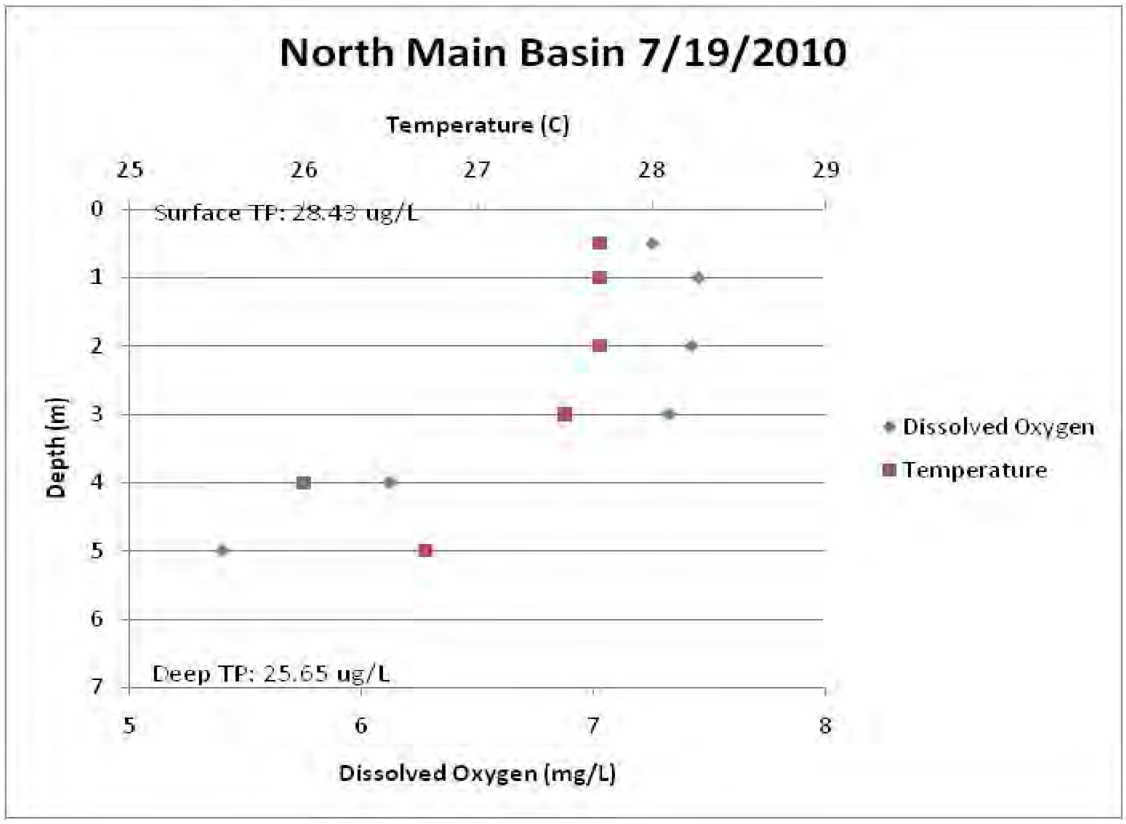

Gooseberry Pond- 8/16/2010
Temperature (C)
23
24
25
26
27
Surface TP: 29.66 ug/L
Deep TP: 25.65 ug/L
Depth (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

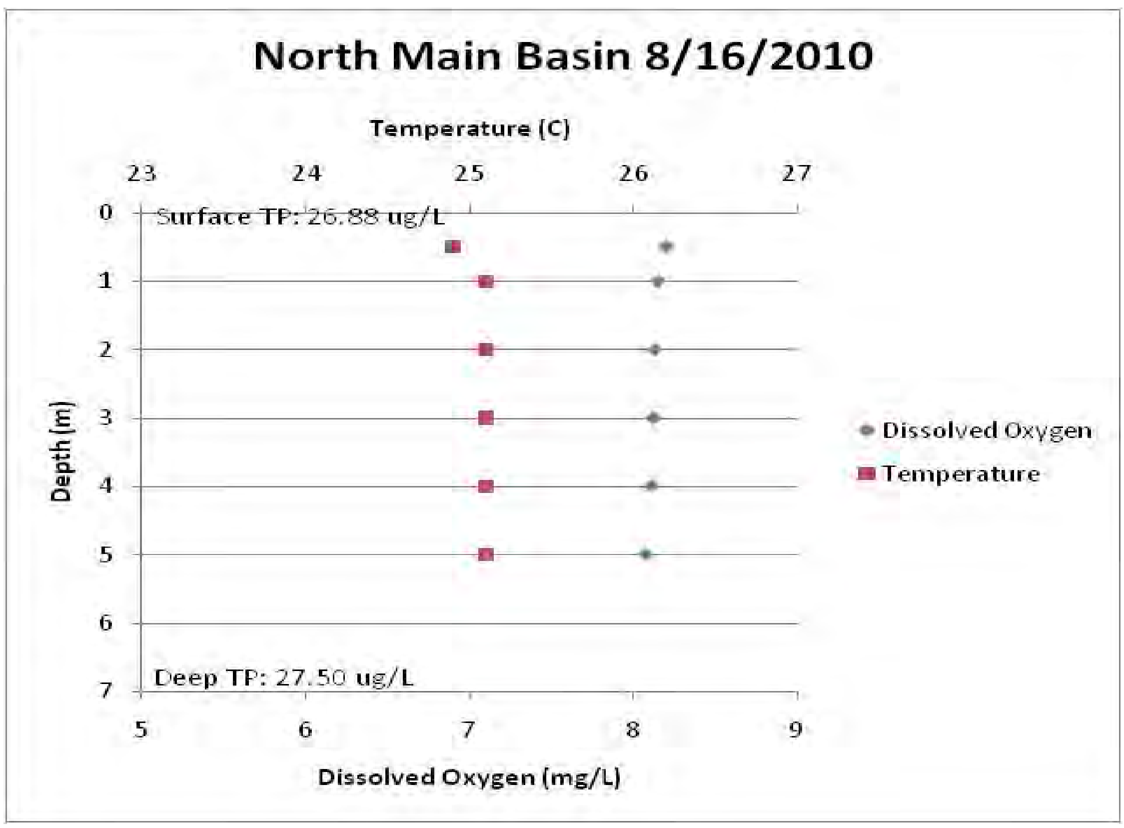
Gooseberry Pond was not sampled	
on September 29, 2010	

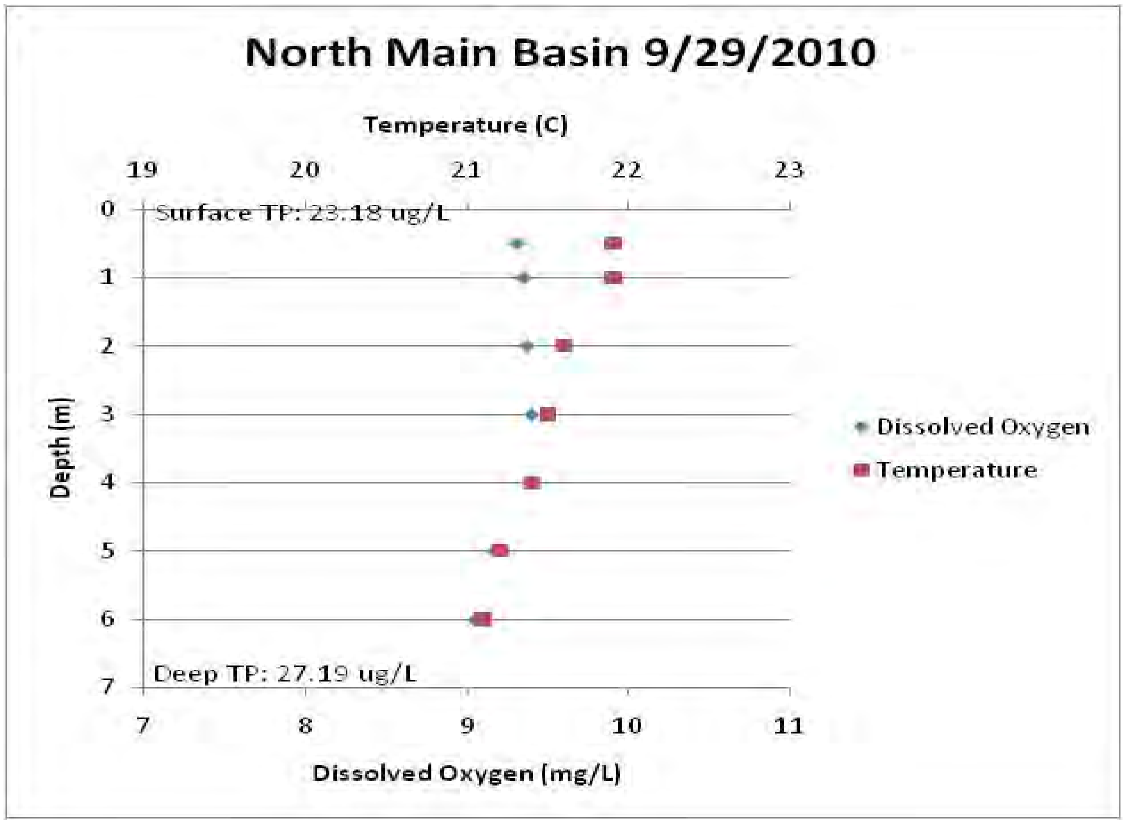


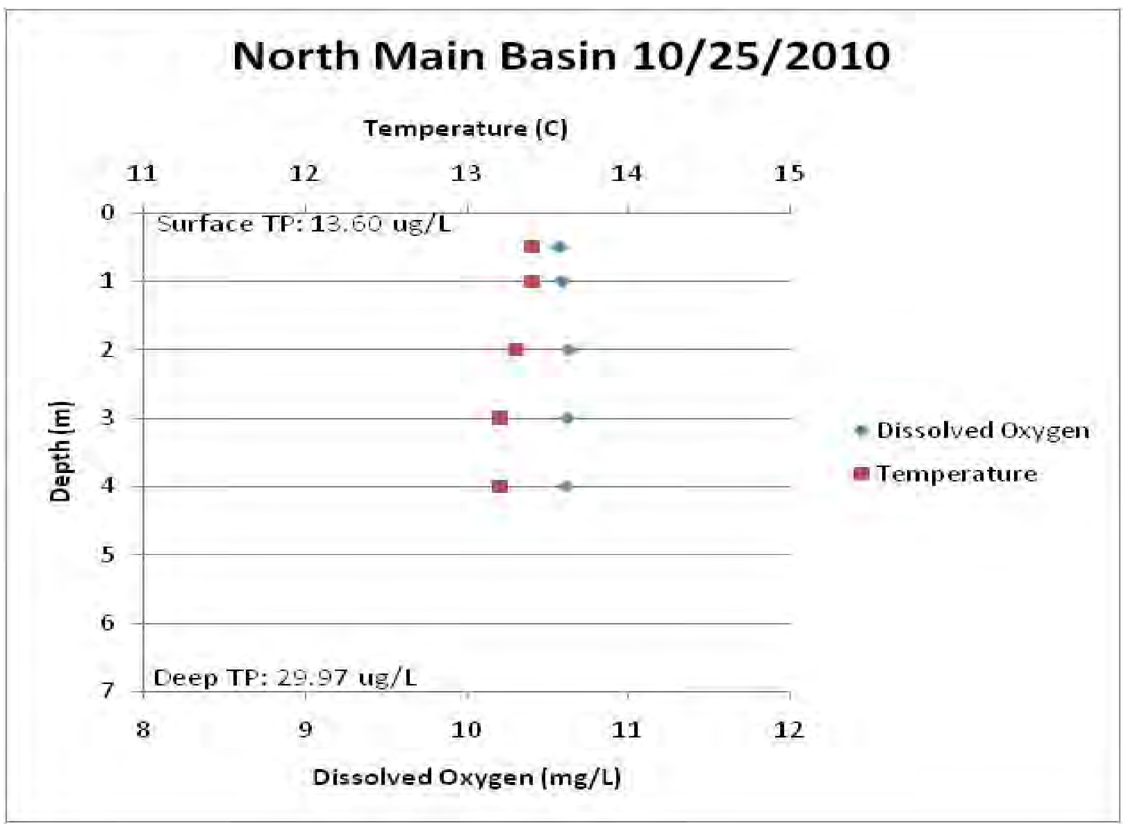
	North Main Basin (STA 2)							
	DO				Temp			
Depth (m)	7/19/2010	8/16/2010	9/29/2010	10/25/2010	7/19/2010	8/16/2010	9/29/2010	10/25/2010
0.5	7.25	8.2	9.31	10.57	27.7	24.9	21.9	13.4
1	7.45	8.15	9.35	10.59	27.7	25.1	21.9	13.4
2	7.42	8.13	9.37	10.63	27.7	25.1	21.6	13.3
3	7.32	8.12	9.4	10.62	27.5	25.1	21.5	13.2
4	6.12	8.11	9.38	10.61	26	25.1	21.4	13.2
5	5.4	8.07	9.17		26.7	25.1	21.2	
6			9.05				21.1	

	TP Surface	**TP Bottom**
	ug/L	
7/19/2010	28.43	25.65
8/16/2010	26.88	27.50
9/29/2010	23.18	27.19
10/25/2010	13.60	29.97


North Main Basin 7/19/2010
Temperature (C)
25
26
27
28
29
Surface TP: 28.43 ug/L
Deep TP: 25.65 ug/L
0
1
2
3
4
5
6
7
Depth (m)
Dissolved Oxygen
Temperature
5
6
7
8
Dissolved Oxygen (mg/L)

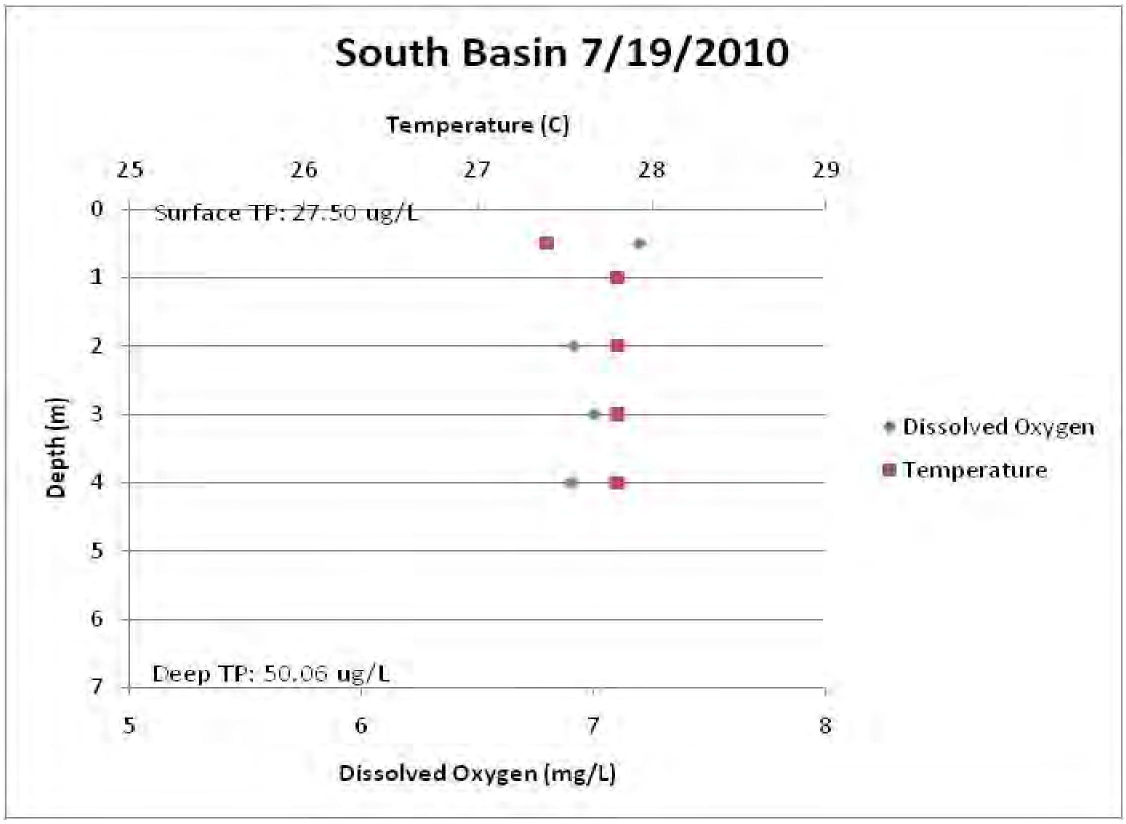

North Main Basin 8/16/2010
Temperature (C)
23
24
25
26
27
Surface TP: 26.88 ug/L
Deep TP: 27.50 ug/L
0
1
2
3
4
5
6
7
Depth (m)
Dissolved Oxygen
Temperature
5
6
7
8
9
Dissolved Oxygen (mg/L)

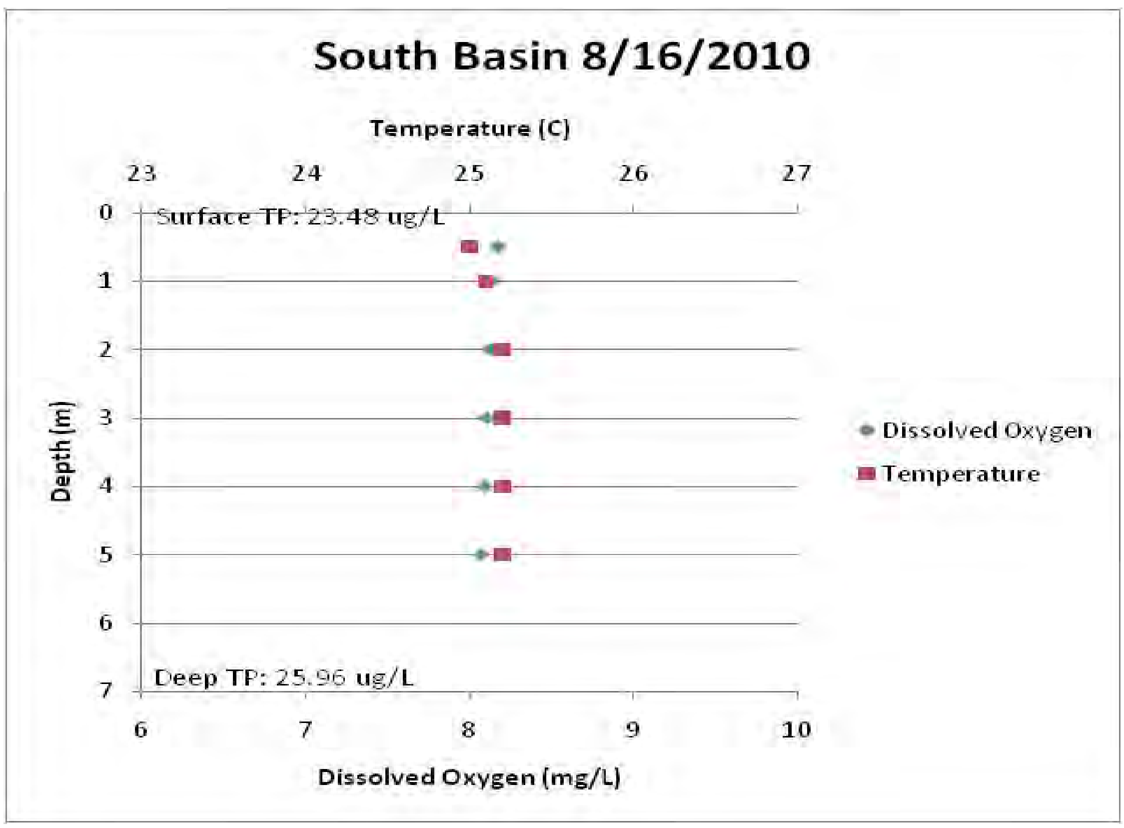

North Main Basin 9/29/2010
Temperature (C)
19
20
21
22
23
Surface TP: 23.18 ug/L
Deep TP: 27.19 ug/L
Depth (m)
0
1
2
3
4
5
6
7
7
8
9
10
11
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

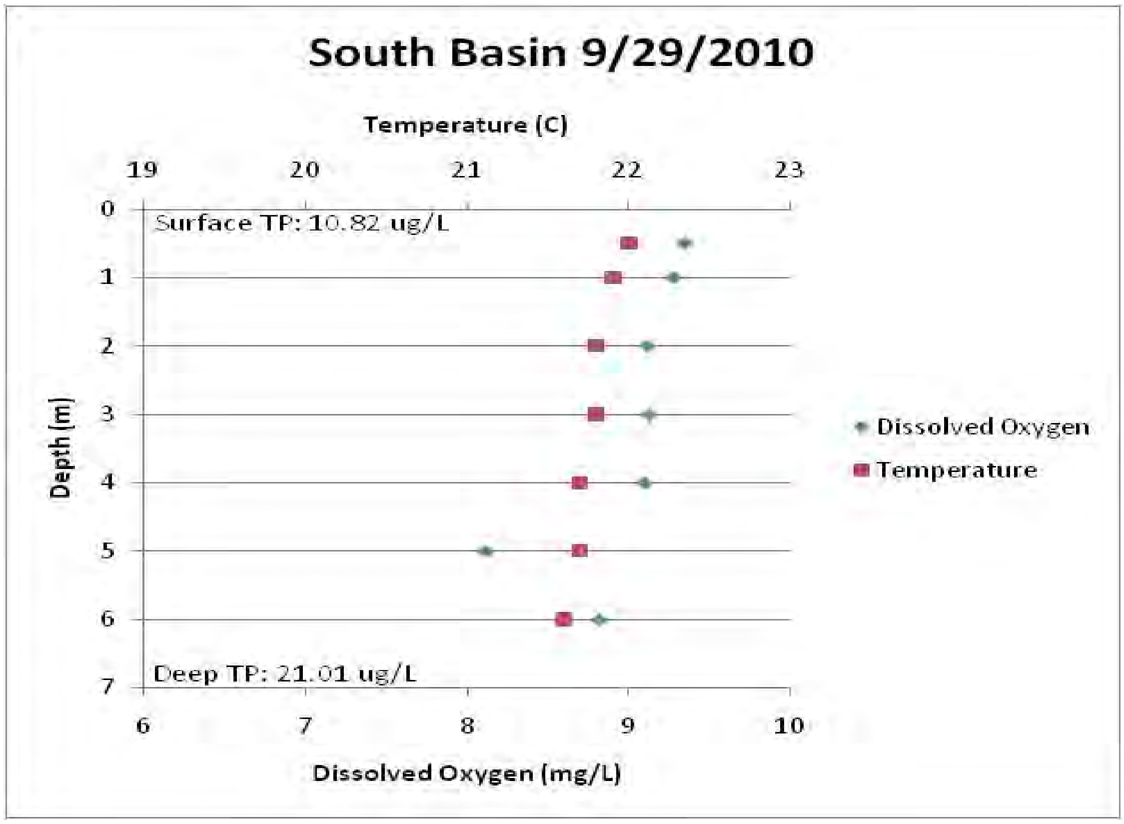

North Main Basin 10/25/2010
Temperature (C)
11
12
13
14
15
Surface TP: 13.60 ug/L
Deep TP: 29.97 ug/L
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature

	South Basin (STA 3)							
	DO				Temp			
Depth (m)	7/19/2010	8/16/2010	9/29/2010	10/25/2010	7/19/2010	8/16/2010	9/29/2010	10/25/2010
0.5	7.2	8.17	9.35	10.48	27.4	25	22	13
1	7.1	8.13	9.28	10.49	27.8	25.1	21.9	13.1
2	6.91	8.12	9.12	10.5	27.8	25.2	21.8	13
3	7	8.1	9.13	10.54	27.8	25.2	21.8	12.9
4	6.9	8.09	9.1	10.53	27.8	25.2	21.7	12.9
5		8.07	8.12	10.51		25.2	21.7	12.9
6			8.82	10.51			21.6	12.8

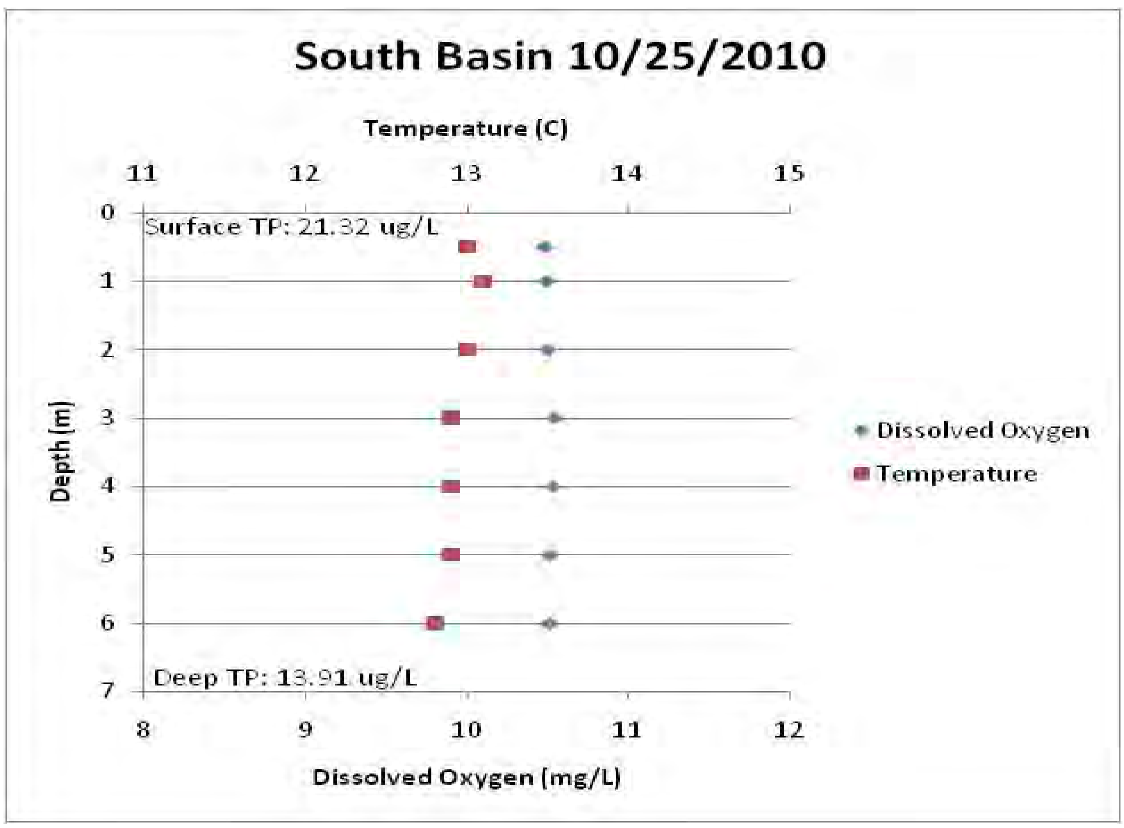
	TP Surface	**TP Bottom**
	ug/L	
7/19/2010	27.50	50.06
8/16/2010	23.48	25.96
9/29/2010	10.82	21.01
10/25/2010	21.32	13.91


South Basin 7/19/2010
Temperature (C)
25
26
27
28
29
Surface TP: 27.50 ug/L
Deep TP: 50.06 ug/L
Depth (m)
0
1
2
3
4
5
6
7
5
6
7
8
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature


South Basin 8/16/2010
Temperature (C)
23
24
25
26
27
Surface TP: 23.48 ug/L
Deep TP: 25.96 ug/L
Depth (m)
0
1
2
3
4
5
6
7
6
7
8
9
10
Dissolved Oxygen (mg/L)
Dissolved Oxygen
Temperature



South Basin 9/29/2010
Temperature (C)
19
20
21
22
23
Surface TP: 10.82 ug/L
Depth (m)
0
1
2
3
4
5
6
7
Dissolved Oxygen
Temperature
Deep TP: 21.01 ug/L
6
7
8
9
10
Dissolved Oxygen (mg/L)



South Basin 10/25/2010
Temperature (C)
11
12
13
14
15
Surface TP: 21.32 ug/L
Depth (m)
0
1
2
3
4
5
6
7
Dissolved Oxygen
Temperature
Deep TP: 13.91 ug/L
8
9
10
11
12
Dissolved Oxygen (mg/L)