



Lake Auburn Watershed Protection Commission

REPORT

Diagnostic Study of Lake Auburn and its Watershed: Phase I

March 2013

**CDM
Smith**

In collaboration with:
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and
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Executive Summary

1. Project Background

Lake Auburn, the principal drinking water supply for the communities of Lewiston and Auburn, Maine, has been known for its excellent water quality as a result of a strong watershed protection program implemented by the two communities. In 2011 and 2012, however, water quality was degraded due to a combination of factors that raised turbidity in the lake to near the limit allowed under the filtration avoidance waiver granted to the Auburn Water District and Lewiston Water Division (AWD/LWD). In 2012, dissolved oxygen was severely reduced throughout the bottom waters of the lake, compromising the cold water fishery habitat and resulting in the death of some lake trout (Togue) in September 2012.

While relationships between drivers of decreased water quality are not completely known, it is clear that if the quality in the lake continues to degrade construction of more advanced water treatment facilities may be required. Also, if levels of algae in the fall were to increase further, there could be taste and odor issues in the distribution system and threats to the fishery in the lake.

This study summarizes the investigation into the causes of recent degradation in water quality and recommends short-term management actions to better understand and reduce the sources and adverse impacts of excess phosphorus on the water quality of Lake Auburn. The study team includes Comprehensive Environmental, Inc. (CEI) to address watershed changes and management actions, and Dr. Ken Wagner of Water Resources Services LLC to advise on lake water quality and in-lake management options.

2. What Was Measured

Water quality data from AWD/LWD and Bates College¹ underpins this study. The water quality changes observed in 2011 and 2012 included:

- **Surface Phosphorus Levels Increased; Figure 1** – While data are limited, increases in phosphorus concentration were seen both across years (from 2005 to 2012) and within each year (from June – “clear water period” to fall). Surface water phosphorus concentrations fuel algal blooms.
- **Area of Bottom with Very Low Oxygen Levels Increased; Figure 2** – An increase was seen in both the number of days and area of bottom layer of the lake with very low oxygen. Low oxygen can be harmful or fatal to fish and other life, and cause phosphorus to be released from sediment, which can fuel algal blooms.
- **Iron-bound Phosphorus Levels Measured in Sediment; Figure 3** – In November 2012, sediment samples were analyzed for iron-bound phosphorus, an indicator of phosphorus that could be released from sediment. Below 10 meters, samples indicate that the amount of iron-bound

¹ Dr. Holly Ewing and co-Principal Investigators (see Section 2.1) provided valuable water quality data used in this study. Their data was collected, analyzed and compiled under grants from the National Science Foundation (NSF): (1) NSF DEB-0749022, (2) NSF EF-0842112, (3) NSF EF-0842125, and (4) NSF EF-0842267.

phosphorus in the sediment that is available to move into the water column under low oxygen conditions is more than sufficient to support algal blooms.

- **Number of Days when Turbidity higher than 1 NTU; Figure 4** -- Turbidity is a measure of water transparency; high turbidity in Lake Auburn indicates increases in algae. Turbidity has historically been far below 1 NTU, with only rare excursions above 2 NTU. To maintain the filtration waiver turbidity must not exceed 5 NTU for more than two events per year and not more than 5 events in ten years. The reportable turbidity at the Lake Auburn intake has never exceeded 5 NTU, with the highest level occurring in 2011. Particle size distribution matters as much as the overall quantity of particles to turbidity, so there can be substantial variation in turbidity with changing algal communities.
- **Blue-Green Algae were Prevalent in the Summer and Fall; Figures 5 and 6** – While algal community data are sparse, Bates College data show progressive blooms of *Gloeotrichia*, *Microcystis* and *Anabaena* in 2011; only *Gloeotrichia* were measured in 2012 though the lake also had a visible and extensive *Anabaena* bloom. All of these forms are buoyant and can produce taste and odor compounds.
- **Record Shallow Secchi Depth in Late Summer/Fall; Figure 7** -- Secchi depth is another measure of transparency, which is a surrogate for algae in this lake. Late summer/fall of 2011-12 produced the shallowest Secchi depth readings recorded since 1978, with record low values from mid-September through October.
- **Rainfall was Normal; Temperature was Atypical; Figures 8 and 9** – Annual rainfall in 2011 and 2012 was average, but the distribution of monthly rainfall in 2012 differed significantly with a dry winter and fall and a very wet June. Water temperatures at the intake were above average, and were often at near record high values, starting in October 2011 and extending into the summer 2012; high water temperature can enhance algal growth.

3. What We Know or Determined

Analysis of the data tells us that:

- Land use in the watershed has changed very little in the last 5 years.
- The frequency of intense storms has increased. Using the Portland, Maine rain gauge, which has the longest record in the region, there have been six storms greater than 3.6 inches of rain in the last 7 years versus twelve storms in the previous 65 years, which is 1.3 storms per seven years.
- The intense storms can have two effects:
 - Runoff can deliver a large load of phosphorus and organic matter from the watershed to the lake; depending on the relative temperature of the runoff and the lake, the inflow can either be on the surface, in a middle layer or on the bottom of the lake.
 - Wind can disrupt stratification and enhance mixing across the lake's layers when it is stratified.
- Sediment deltas in the lake suggest recent deposits due to erosion from several intense storms since 2005; sediment adds phosphorus load to the lake and most likely oxygen demanding substances as well.

- The alga *Gloeotrichia* can bring extra phosphorus from the lake bottom into the top water layer, enriching phosphorus levels there.
- High turbidity is caused by a late summer/early fall algae bloom. *Anabaena* and *Microcystis* are the dominant algae during periods of high turbidity. *Gloeotrichia* is not directly the source of turbidity (Figure 5 and 6).
- Aside from the actual increase in algae observed, the apparent [there are no previous algal data to determine this] shift to blue-green algae is problematic, as many of the types involved have buoyancy mechanisms and float to the surface, concentrating algae in the upper waters and reducing Secchi depth. Furthermore, some blue-greens (e.g., *Anabaena*) can undertake a nighttime migration to deeper waters to collect phosphorus, returning to the surface water in the morning.
- The 2012 fish kill was caused by a warm year (high surface water temperatures) and a bottom layer completely devoid of oxygen. The fish did not have adequate habitat left that was sufficiently cool with enough oxygen to survive.

4. What We Hypothesize

Several factors could increase phosphorus in the surface water layer in late summer/fall: (1) inputs from the watershed, (2) migration of higher phosphorus concentrations that have built up in the bottom waters under low oxygen conditions to the surface water via gradual deepening of the surface layer or a disturbance (storm), (3) *Gloeotrichia* releasing excess phosphorus when it dies, (4) growth of other blue-green algae that migrate down into deep areas of higher phosphorus each day to ‘feed’ and rise in morning to photosynthesize. In evaluating these we hypothesize:

- Watershed loads alone do not explain the phosphorus increase.
- The increase in phosphorus in the top layer drives the late summer/early fall bloom of blue-green algae.
- Intense storms in 2011 and 2012 may have had the following effects:
 - Winds from Hurricane Irene in late August 2011 may have disrupted the water column and added substantial phosphorus to the surface layer by mixing with the deeper layers of the lake (Figure 5),
 - The large June 3-4, 2012 storm contributed phosphorus at a time when the reservoir typically has very low phosphorus levels (Figure 1), which could have helped fuel algal blooms, and
 - The June 2012 storm could have entered the lake and ‘dived’ into the bottom waters, bringing material to be degraded into the bottom waters, further depressing oxygen levels there.
- *Gloeotrichia* could transport sufficient phosphorus to the surface water to match the increase measured, but this increase follows the *Gloeotrichia* bloom (is not coincident with it).
- The late summer/fall *Anabaena* bloom, which starts with resting stages on the bottom that form filaments that float upward and occurs when the total phosphorus levels are high, does not by itself contain enough phosphorus to account for the increase in phosphorus concentration.

- Internal loads of phosphorus (generated from the sediment when bottom water has very low dissolved oxygen) could have contributed sufficient phosphorus to explain the increase
 - In 2011, the high phosphorus in the bottom water is unlikely to reach the surface water until the lake is fully mixed in November, except for possible severe disruptions of the stratification (timing of Hurricane Irene matches rise in phosphorus; data are insufficient to determine if disruption occurred).
 - In 2012, the high phosphorus in bottom water could have more easily reached the surface while lake was still stratified because the entire deep layer had no oxygen after September 13.

Insufficient data are available to determine definitively whether the degraded water quality observed in 2011 and 2012 was a response to long-term changes in the lake or a response to changes that occurred in the current year. Aspects of the available data support both findings, and perhaps both are valid.

5. What This Means

Both improved watershed management and lake management will be needed.

6. What Needs To Be Done Now

Actions that need to be started now are:

- Implement a revised monitoring program to track water quality in 2013 and better understand drivers behind the degraded water quality.
- Begin planning for algicide application for use as a contingency plan if turbidity levels rise in 2013 or beyond while implementing measures to reverse the degradation of the lake water quality.

7. Next Steps

Both holistic watershed and lake management options will be investigated in the next phase of work. These include:

- Identify structural and management controls for high-load areas of phosphorus to strengthen watershed management.
- Recommend changes to on-going watershed monitoring programs.
- Recommend regulations that will further strengthen watershed protection.
- Investigate and recommend an in-lake management measure to control phosphorus. This will include examining:
 - Aeration
 - Alum treatment
 - Dredging
 - Other alternatives to comply with the Safe Drinking Water Act.

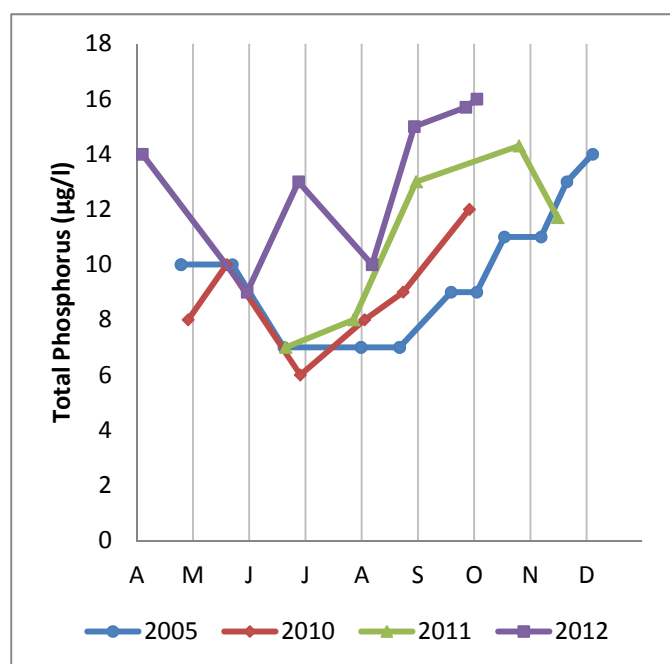


Figure 1: Concentration of Total Phosphorus in Surface Water at Deep Hole (0 to 5 meter depth)

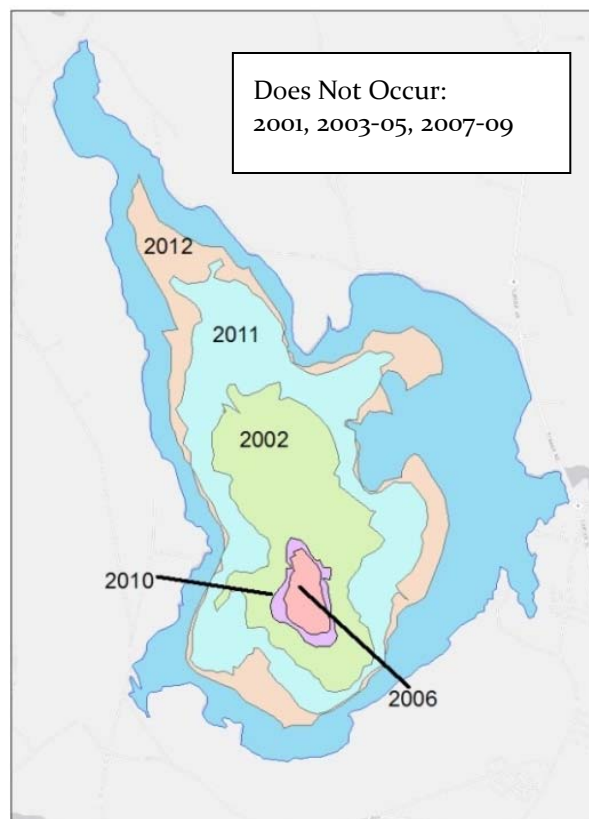


Figure 2: Bottom Area of Lake Auburn with Dissolved Oxygen < 2 mg/l

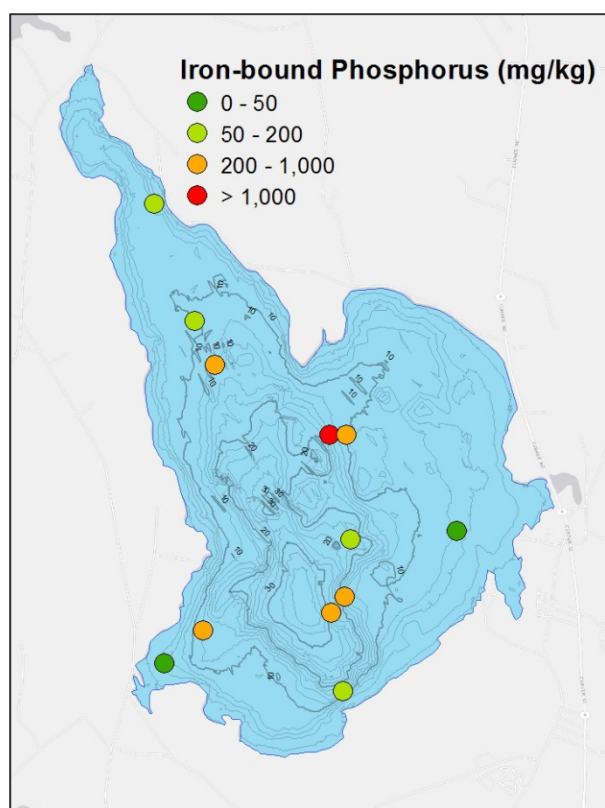


Figure 3: 2012 Iron-Bound Phosphorus in Sediment

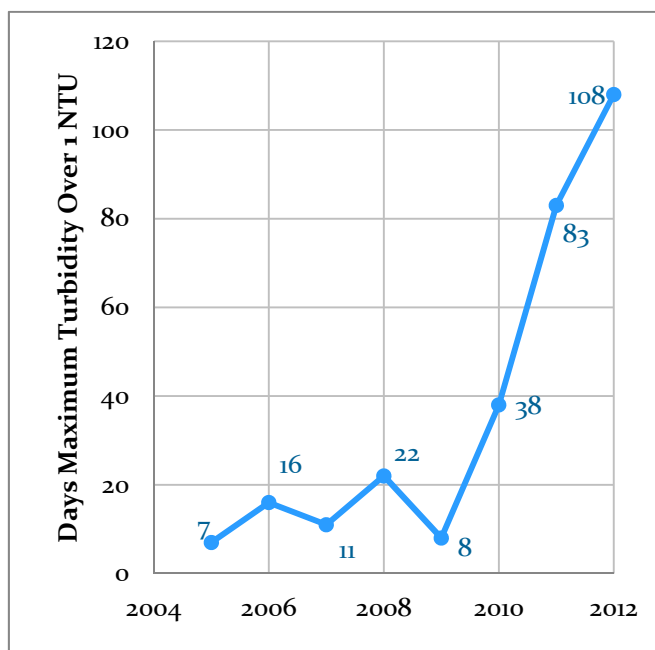


Figure 4: Days per Year When Maximum Turbidity in Raw Water Intake is Over 1 NTU

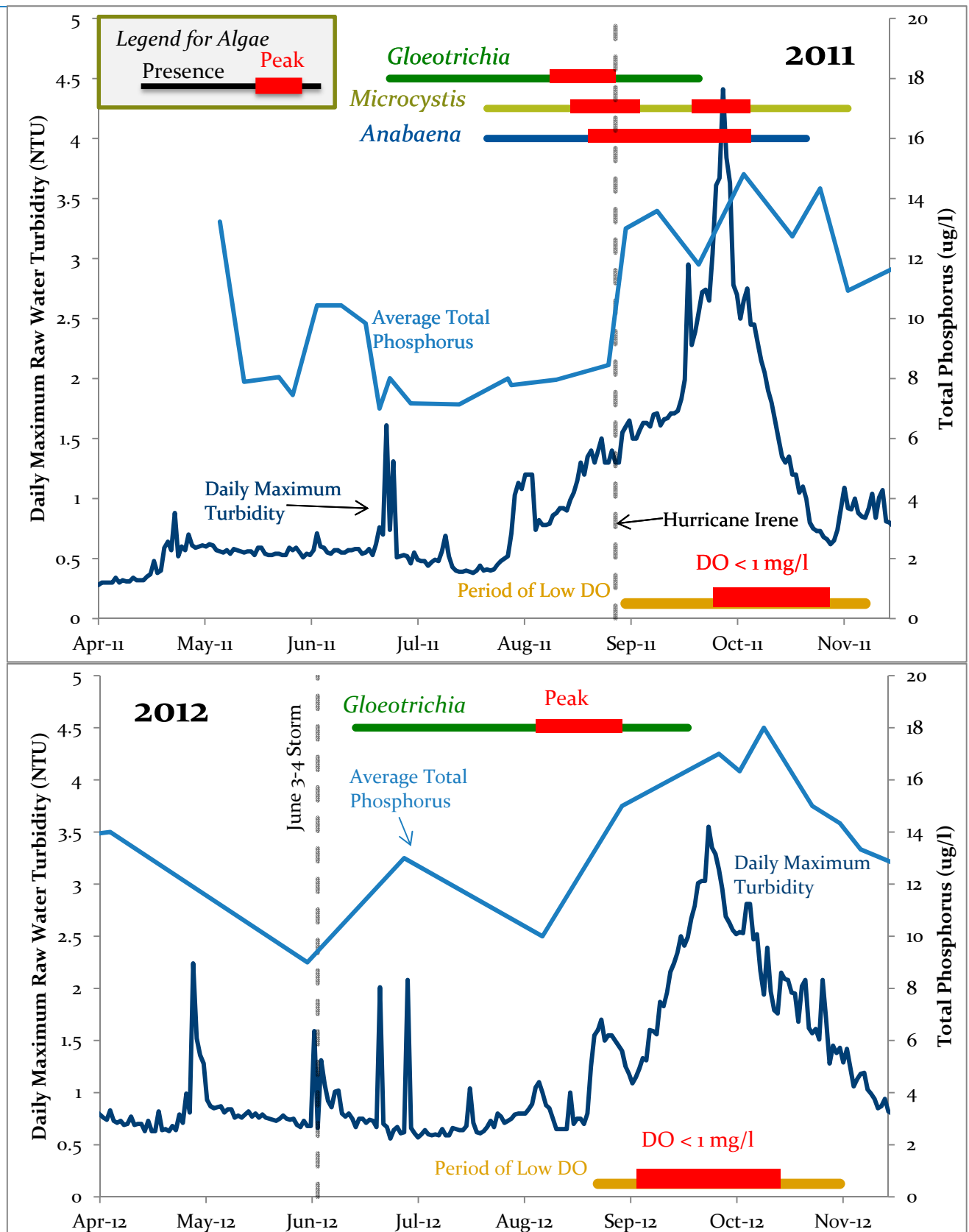


Figure 5: Average Surface Water Total Phosphorus, Algal Succession, Daily Maximum Turbidity, and Low Dissolved Oxygen Conditions, 2011 and 2012. Algal and 2011 TP data from Drs. Ewing, Weathers, and Cottingham under NSF grants NSF DEB-0749022 NSF EF-0842112m NSF EF-0842125, NSF EF-084226

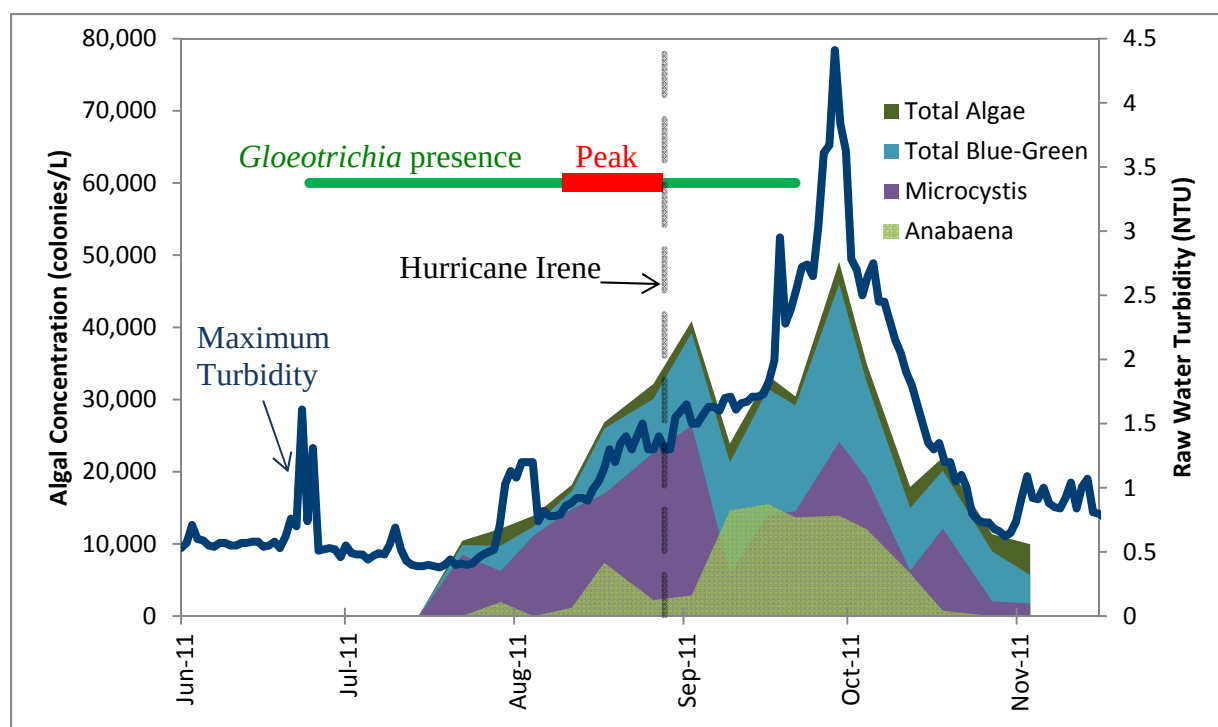


Figure 6: 2011 Maximum Daily Turbidity and Algal Succession. Algal data from Drs. Ewing, Weathers, and Cottingham under NSF grants NSF DEB-0749022 NSF EF-0842112m NSF EF-0842125, NSF EF-084226

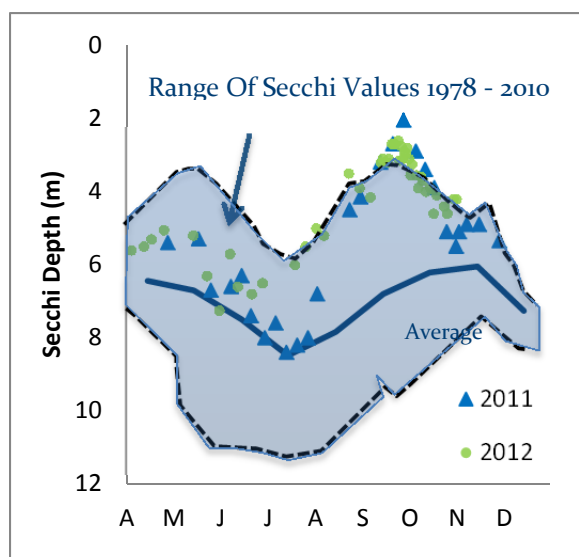


Figure 7: 2011-12 Secchi Depths Compared to Long-term Range and Average

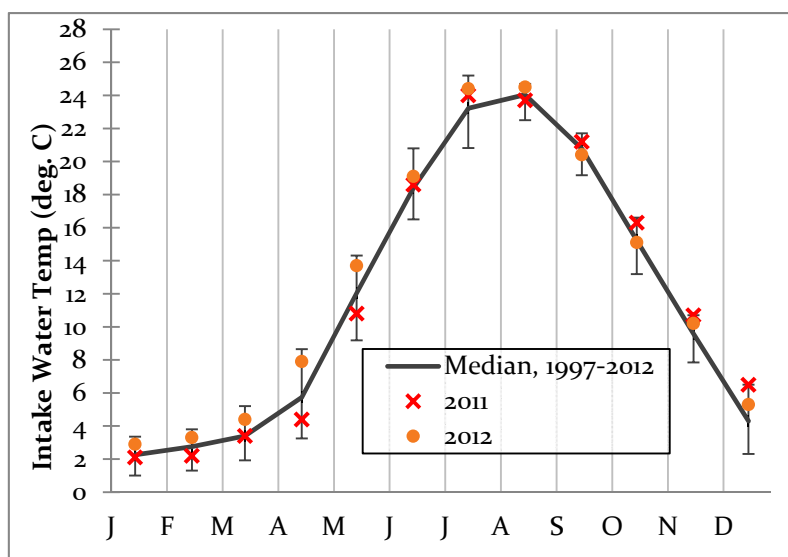


Figure 8: 2011-12 Water Temperature Compared to Long-Term Median

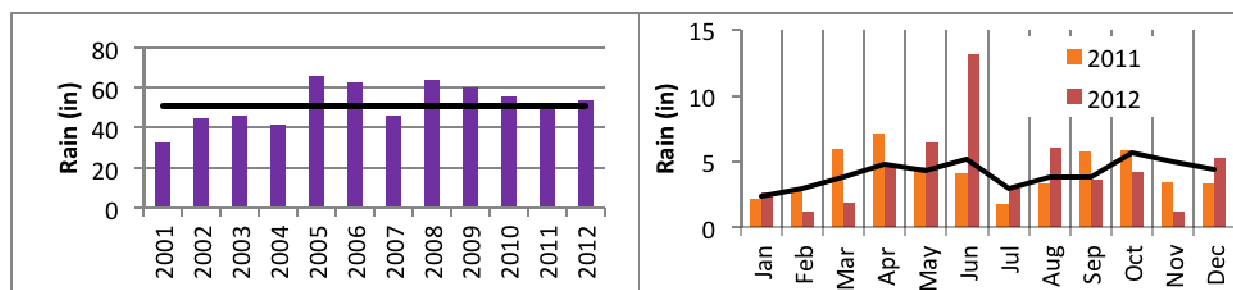


Figure 9: 2011-12 Annual and Monthly Rainfall Compared With 1998-2012 Average, Poland, ME

Section 1

Introduction

1.1 Project Background

Lake Auburn is the principal drinking water supply for the communities of Lewiston and Auburn, Maine. Historically, Lake Auburn has been known for its excellent water quality, and the Auburn Water District and Lewiston Water Division (AWD/LWD) were granted a filtration waiver for Lake Auburn from Maine Division of Environmental Health in 1991. Lake Auburn's excellent water quality results from its largely undeveloped watershed and the strong watershed protection program implemented by the utilities. The ongoing work to protect the watershed and the lake to maintain the filtration waiver has resulted in significant cost savings to AWD/LWD over the years.

In late summer/fall 2012, water quality in Lake Auburn was degraded due to a combination of factors that raised turbidity in the lake close to the limit allowed under the filtration avoidance waiver granted to AWD/LWD. Dissolved oxygen (DO) was severely reduced throughout the bottom waters of the lake (DO was <2 mg/l) creating anoxic conditions, compromising the cold water fishery habitat, and resulting in the death of some lake trout (Togue). Following the fish kill, Maine's Department of Inland Fisheries and Wildlife conducted a survey where they netted and identified the fish and found that some of the lake trout survived.

While the causal relationships in water quality are not completely known, it is clear that if the lake's water quality continues to degrade it would put AWD/LWD at risk for violation of the compliance parameters for filtration avoidance waiver, and thus, could require the need for more advanced water treatment facilities. The increase in late summer/early fall algal blooms caused the increase in turbidity, which is one of the compliance parameters for maintaining the filtration waiver. This compliance criterion requires that turbidity at the point of withdrawal at Lake Auburn must not exceed 5 NTU for more than two events per year and not more than 5 events in ten years. The primary agency may waive an exceedance (a 'turbidity event') if they determine that the event or the circumstances leading to the event exceeding 5 NTU are unusual and unpredictable. If the turbidity levels are exceeded and not waived, filtration would be required to be added to the existing water treatment plant.

An additional concern related to an increase in algal activity is the potential for increased taste and odor issues throughout the distribution system and threats to Lake Auburn's cold water fishery. The dominant algae in late summer/fall blooms in 2011 and 2012 have the potential to generate unpleasant taste and odor; although not a health issue or specifically a regulatory compliance issue, it is an aesthetic issue that impacts water customers. When these algae die, decomposition consumes dissolved oxygen in the lower waters of the lake, jeopardizing the health of the fishery there.

The Lake Auburn Watershed Protection Commission contracted with CDM Smith Inc. to investigate the causes of recent degradation in water quality and to recommend short-term and long-term management options to mitigate the adverse impacts of excess phosphorus on the water quality of Lake Auburn. The study team includes Comprehensive Environmental, Inc. (CEI) to address on

watershed changes and management actions, and Dr. Ken Wagner of Water Resources Services Inc. to advise on lake water quality and in-lake management options. This report covers Phase I activities of the study, which were:

- **Task 1: Data Review and Gap Analysis** – Collect and review existing data for the Lake Auburn watershed. Collect additional data to fill data gaps, which included:
 - An extensive survey of the watershed and lake shore to identify potential sources of phosphorus that could reach the lake and stimulate algal growth. This work was conducted by CEI and is summarized in their report on the watershed in Appendix A.
 - A visual and analytical survey of the bottom sediments in the lake. The visual survey was conducted with an underwater camera to determine areas of sediment that could contribute phosphorus to the overlying waters. Samples were collected and analyzed for grain size, phosphorus and solids. The data are reported in Section 2.

Section 2 also provides a summary of the existing data for Lake Auburn; existing data on the watershed is described in Appendix A.

- **Task 2: Update the Water Budget** – CEI’s April 2010 Watershed Management Plan included a water budget for Lake Auburn; as part of this study the water budget was updated through 2012. The results are described in CEI’s watershed report in Appendix A.
- **Task 3: Update the Nutrient Budget** – CEI’s April 2010 Watershed Management Plan also included a phosphorus budget for Lake Auburn; as part of this study the phosphorus budget was updated through 2012. In addition, a nitrogen budget for the watershed was created. The results are described in CEI’s watershed report in Appendix A.
- **Task 4: Diagnostic Assessment of Lake Auburn** – A diagnostic assessment of the lake and its watershed was prepared. CEI’s report on the watershed in Appendix A describes changes in watershed characteristics, trends in overall lake water quality and the potential effects of climate change on the lake. Section 3 of this report provides additional detail on trends in lake water quality, focusing specifically on factors that contributed to the observed degradation in water quality in 2011 and 2012.
- **Task 5(a): Evaluation of Short-term Management Options for Lake Auburn** – Section 4 describes short-term management options for the lake, while CEI’s report in Appendix A describes short-term management options for the watershed.

Phase II of this study, which will be conducted in the spring/summer of 2013, will incorporate the results of Phase I and recommend additional (long-term) management options to improve water quality in Lake Auburn. Phase II will include recommendations for both holistic watershed management and in-lake remediation activities.

Section 2

Data Summary

2.1 Data Sources

2.1.1 Existing Data

This section summarizes the data on Lake Auburn that were considered during this study. The summary of existing data fulfills the requirement of Task 1. The data include:

- Bathymetry from the Maine Department of Inland Fisheries and Wildlife and University of Maine Farmington
- Meteorological data from the National Climatic Data Center
- Lake water quality and algal data from AWD/LWD
- Intake water quality data from AWD/LWD
- Additional water quality and algal data from Bates College
- Hydrologic water budget performed by USGS (Dudley 2004).

The data from Bates College was kindly supplied by Dr. Holly A. Ewing to support the evaluation of water quality changes in Lake Auburn. CDM Smith gratefully acknowledges Dr. Ewing and her colleagues and co-Principal Investigators Dr. Kathleen C. Weathers (Cary Institute of Ecosystem Studies) and Dr. Kathryn L. Cottingham (Dartmouth College) for the use of the data for Lake Auburn and their intellectual contributions to this study. Their data was collected, analyzed and compiled under grants from the National Science Foundation (NSF): (1) NSF DEB-0749022 to KLC, HAE, and KCW, (2) NSF EF-0842112 to HAE, (3) NSF EF-0842125 to KCW, and (4) NSF EF-0842267 to KLC.

In addition the AWD/LWD lake data were restructured and placed in an excel spreadsheet in database format (one parameter per row with all pertinent data about the sample included in the row); it will be provided to AWD/LWD for future use. We recommend that AWD/LWD continue to store data in this format as it facilitates examination of the data and tracking trends in lake water quality.

Each of the existing data sources is summarized in Sections 2.2 through 2.5.

2.1.2 Sediment Data Collected for this Study

As part of this study, a visual and analytical survey of the phosphorus content of lake sediment was performed in November 2012 by Dr. Ken Wagner and AWD/LWD staff. The visual survey of the lake bottom was conducted to determine the presence of muck sediments with the aid of a Marcum underwater video system operated from a boat supplied by AWD/LWD. Sediment was sampled with an Ekman dredge, a stainless steel device that has jaws that snap shut and collect a sample of surficial sediment when the spring-loaded mechanism is triggered. Collected material was gently placed in a plastic pan and a sample of the upper 10 cm (4 inches) of sediment was placed in labeled glass jars

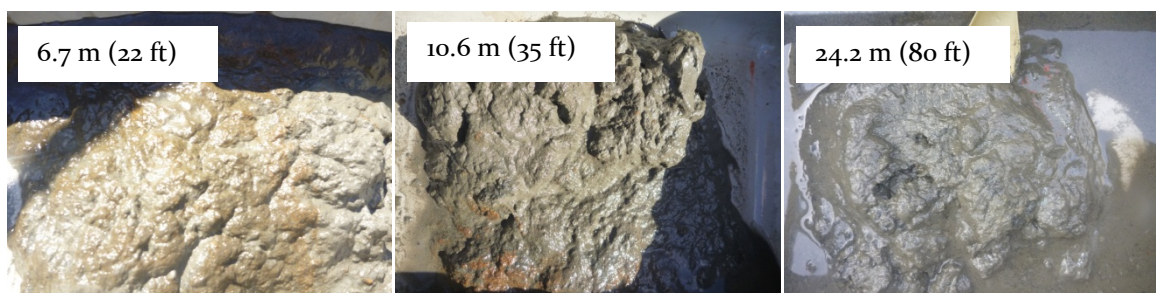
with a Lexan spoon. The invaluable aid of AWD/LWD staff including Water Quality Manager Mary Jane Dillingham in this field effort is acknowledged. Twelve sediment samples were placed on ice and transported to Spectrum Laboratories in Agawam, MA for analysis for sediment phosphorus, iron-bound sediment phosphorus, moisture content, solids content and total volatile solids. In addition to these 12 sample sites, an additional 13 sites were included in a visual survey. Figure 2-1 shows all sediment sampling and survey locations within Lake Auburn, with the sediment sampling sites color-coded according to iron-bound phosphorus concentration. The results of sediment analyses are provided in Table 2-1.

Table 2-1
Sediment Sample Survey Results for 2012

Sample ID	Lake Depth at Sample (ft)	Lake Depth at Sample (m)	Total Phosphorus (mg/kg)	Iron-bound Phosphorus (mg/kg)	Solids (%)	Moisture Content (%)	Total Volatile Solids (%)
AS-1	47	14.2	1,030	302	34	73	8
AS-2	90	27.3	1,210	309	26	81	11
AS-3	35	10.6	832	86	38	69	7
AS-4	15	4.5	423	31	67	47	3
AS-5	42	12.7	1,860	815	20	84	13
AS-6	48	14.5	1,930	841	24	84	13
AS-7	31	9.4	906	162	47	70	5
AS-8	27	8.2	789	74	33	77	12
AS-9	47	11.2	2,280	1,220	25	82	12
AS-10	37	14.2	1,090	249	31	78	9
AS-11	22	6.7	558	38	73	40	2
AS-12	80	24.2	964	110	27	80	11

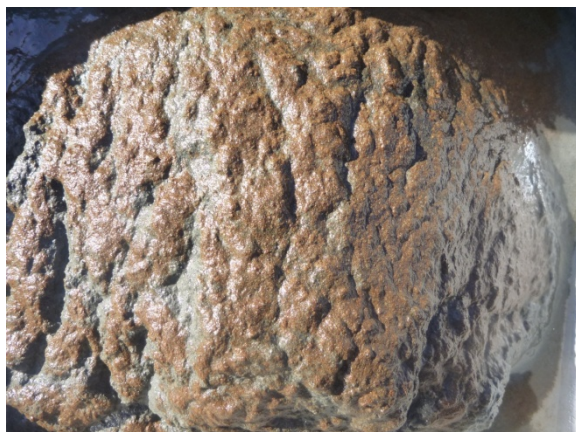
Phosphorus is of particular concern; it is typically found in organic compounds or bound to iron in the organic sediment. Only some of the organic matter decays, and that portion tends to release phosphorus slowly. Therefore it is less of a threat than iron-bound phosphorus, which can be released by chemical reactions under anoxia at a rate that will change the phosphorus concentration in overlying water. The total sediment phosphorus level is worth knowing, but it is not useful for calculation of seasonal internal recycling. Such internal recycling can be a major source of the phosphorus budget to a lake and thus a major contributor to algal blooms.

Visual observations at the 25 identified sites and at other locations around the shoreline indicate that while the immediate shoreline area is rocky to sandy, most areas under 2 m (7 ft) and above 10 m (33 ft) of water depth are largely inorganic silts (e.g., AS-4, AS-7 and AS-11 in Table 2-1), having high solids and low organic content. Where iron precipitates are abundant, silts can still be significant contributors of phosphorus, but usually the iron-bound phosphorus values are low (<50 mg/kg). Under deeper water, the sediment tends to transition to more organic, lower solids content material, although this transition is not smooth everywhere within the lake. The deep water sediment (>10 m, >33 ft) of Lake Auburn has a lower organic content than many New England lakes, with a higher clay content yielding more cohesive sediments (Photograph 2-1). These sediments tend to be gray in color, contrasting with black or brown sediments in most lakes where organic content is high and seasonal anoxia is encountered.



Photograph 2-1
Sediments from Various Depths in Lake Auburn

However, with an increase in organic content there is also a tendency for iron-bound phosphorus to increase, and even at the relatively low levels of organic matter found in Lake Auburn sediment, iron-



Photograph 2-2
Lake Auburn Sediment showing Brown Surface Layer (11.2 m (47 ft))

bound phosphorus can be high (Table 2-1). One observed feature of interest was a thin brown layer at the surface of the sediment found in some areas (Photograph 2-2). This layer was present in some areas with the highest iron-bound phosphorus levels, but was not always indicative of very high iron-bound phosphorus; iron precipitates have this appearance, but so might diatoms (algae) that have settled onto the sediment.

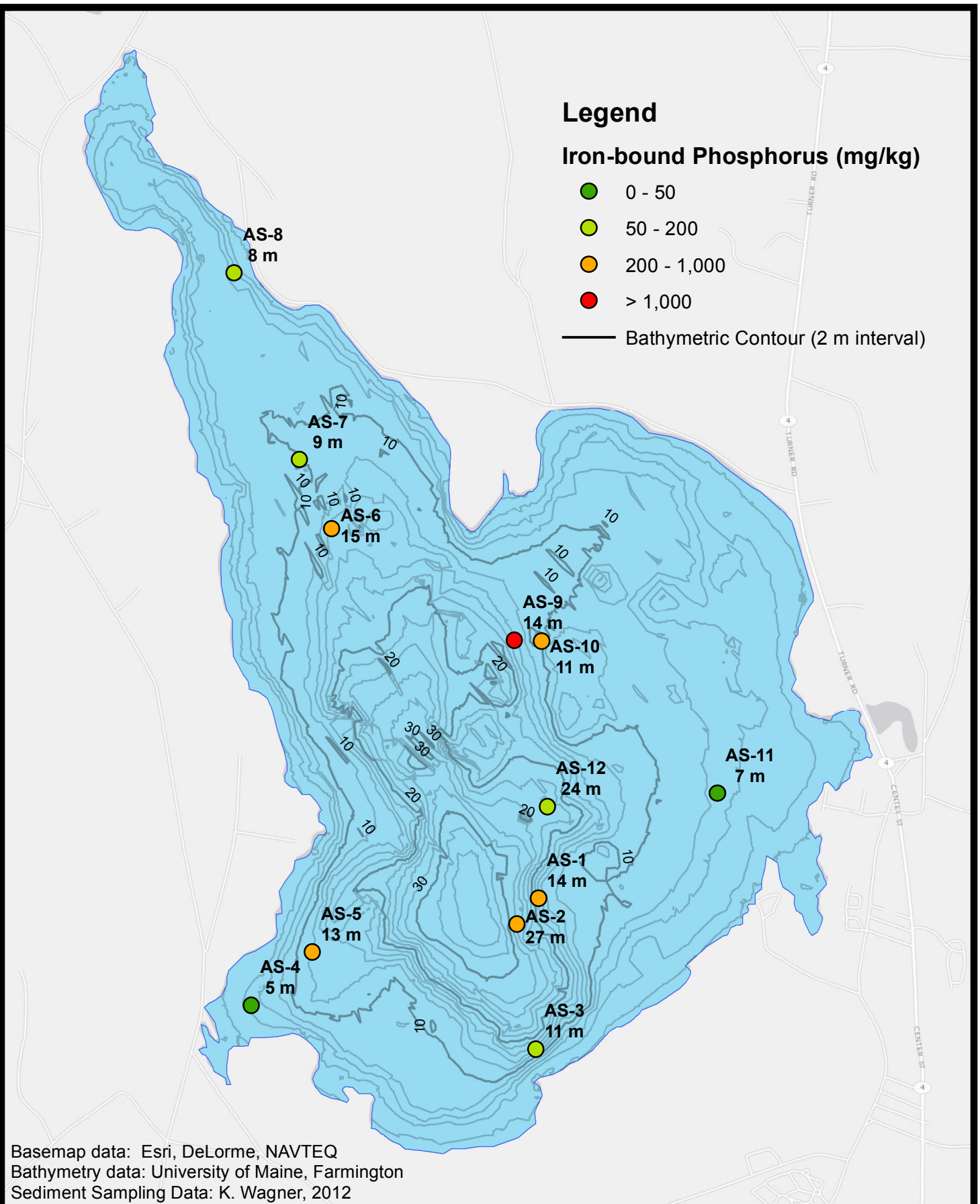
In Phase 1 of this study, the analytical data are used to estimate the internally generated load of phosphorus to the lake; in Phase 2, additional analyses will be completed and used to help identify long-term phosphorus control measures.

Legend

Iron-bound Phosphorus (mg/kg)

- 0 - 50
- 50 - 200
- 200 - 1,000
- > 1,000

— Bathymetric Contour (2 m interval)



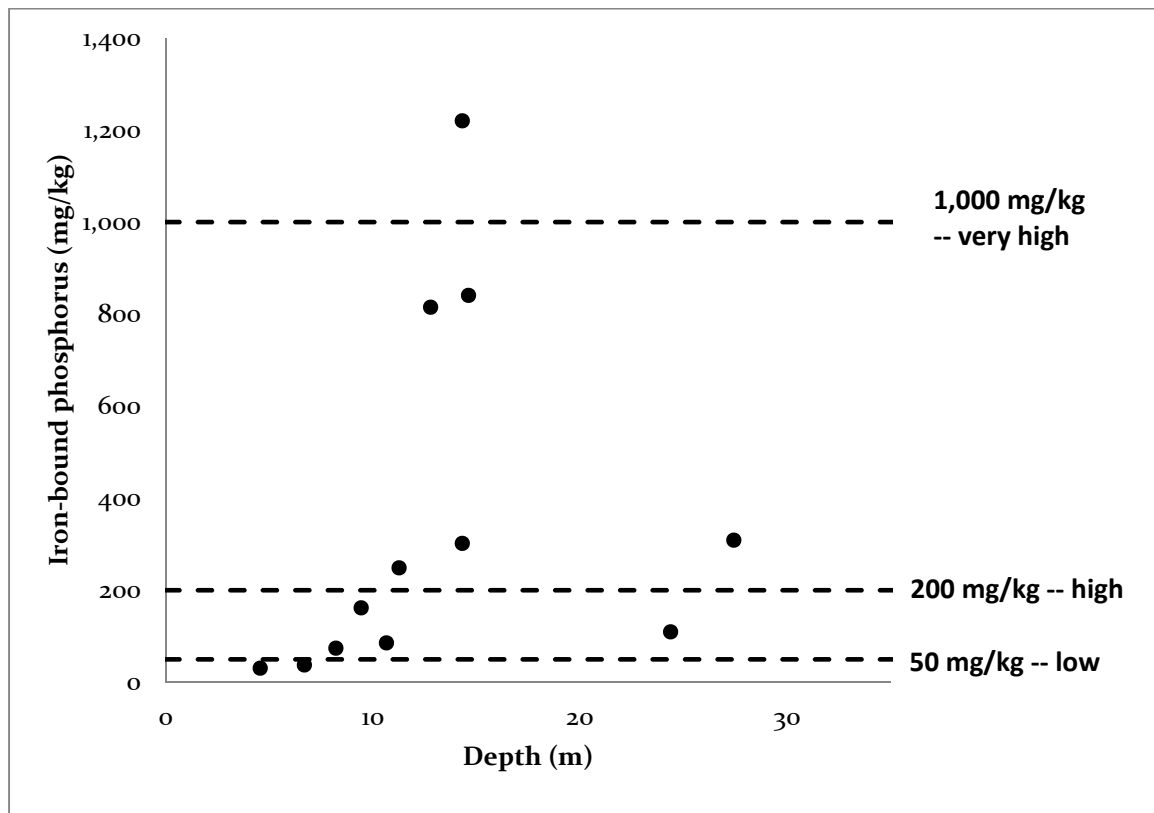


Figure 2-2
2012 Sediment Survey, Relationship between Iron-bound Phosphorus and Depth

The sediment samples were analyzed for iron-bound and total phosphorus. The iron-bound phosphorus concentration is of particular importance to this study because it represents the fraction of the sediment phosphorus that is available for release under low oxygen conditions. Figure 2-2 shows the relationship between measured iron-bound phosphorus concentration and depth in Lake Auburn. This figure correlates with the visual sediment observations discussed above and echoes the results in Table 2-1, where sediment collected from shallow water depths has relatively low iron-bound phosphorus concentrations, sediment collected from mid-depth water has very high iron-bound phosphorus concentrations, and sediment collected from deep water depths has much lower iron-bound phosphorus. This information can help us determine where release of phosphorus will occur during low oxygen conditions.

The sediment samples were also analyzed for percent solids and total volatile solids. Figures 2-3 and 2-4 show the relationships between iron-bound phosphorus and solids and organic material, respectively. In general, the highest iron-bound phosphorus concentrations were found in sediment with relatively low solids fractions, 20 to 30 percent. Higher solids fractions, indicating denser sediment, tend to have lower iron-bound phosphorus concentrations. Conversely, as organic material content increases—here measured by the total volatile solids—the iron-bound phosphorus concentrations increase.

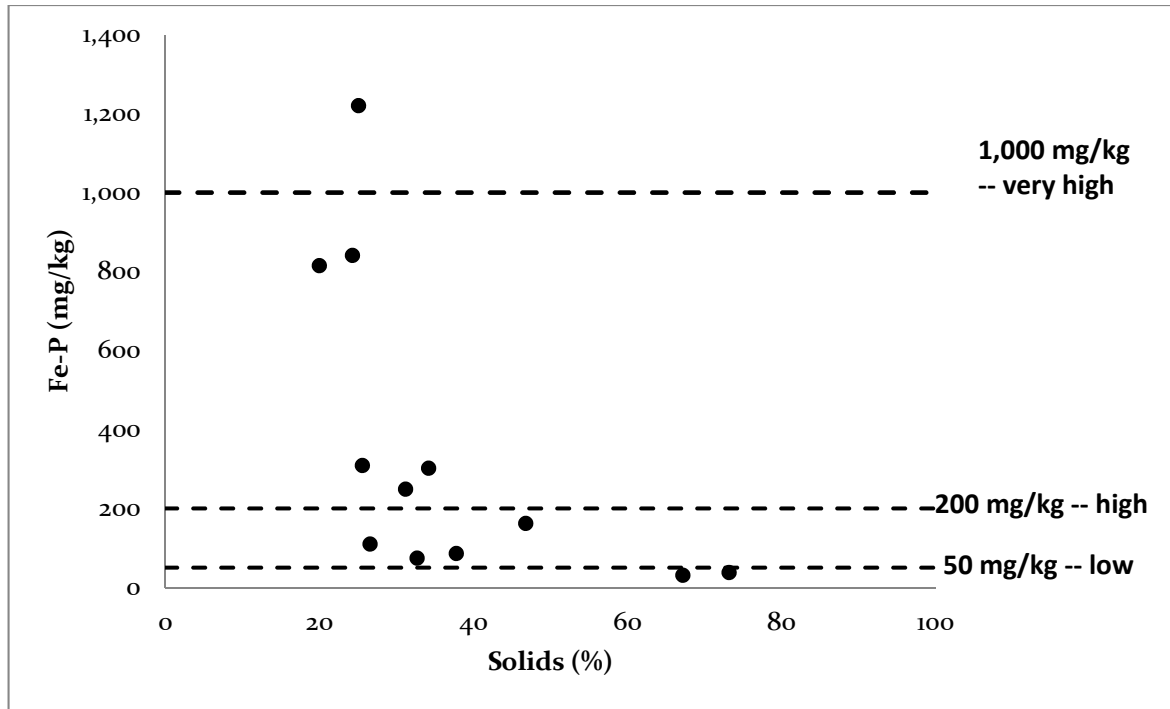


Figure 2-3
Iron-bound Phosphorus Relationship with Solids Fraction

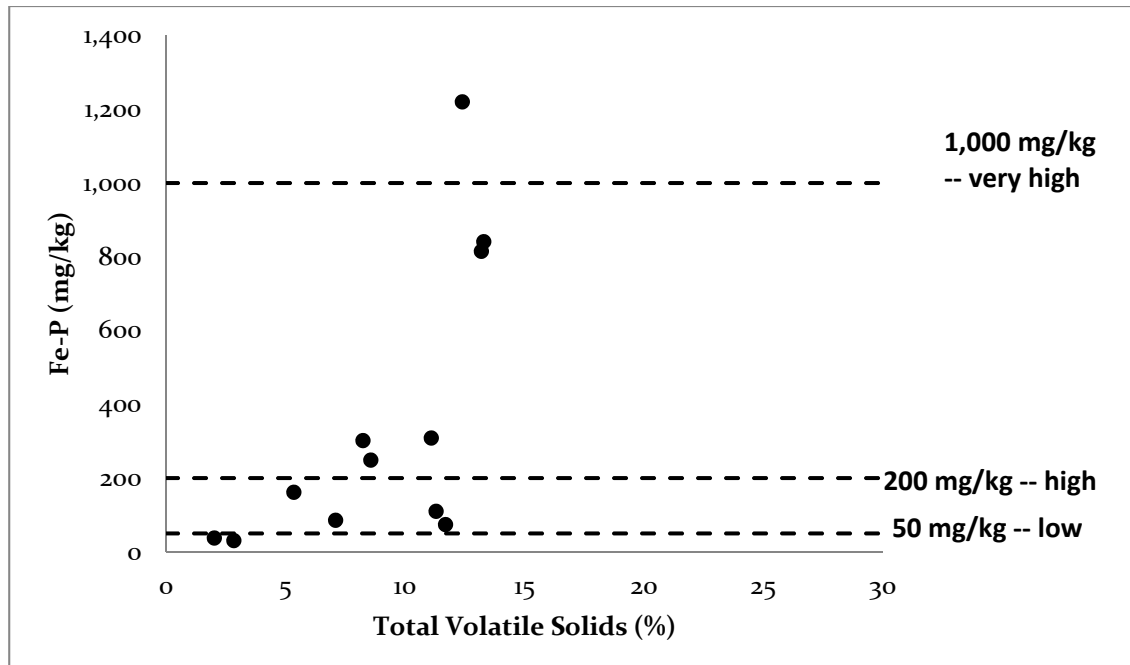


Figure 2-4
Iron-bound Phosphorus, Relationship with Organic Solid Material

2.2 Description of Existing Data

2.2.1 Bathymetry

Two known bathymetric surveys informed this study: the Maine Department of Inland Fisheries and Wildlife performed a depth survey in 1970, and the University of Maine at Farmington performed an updated depth survey in 2001 (MDIFW, 1970; UMF, 2001). The University of Maine dataset was performed using a finer spatial resolution, and was thus used to infer the bathymetry in Figure 2-5. The data indicate that most of Lake Auburn is no deeper than 27 meters (90 feet). The deepest part of the lake, appropriately named the deep hole, is located near the southern end. This area has a maximum depth of 36 meters (120 feet), creating a deep, isolated area that is separated from the dynamics of the rest of the lake.

The bathymetry data was used to create depth-area and depth-volume curves for the lake. These are shown in Figures 2-6 and 2-7.

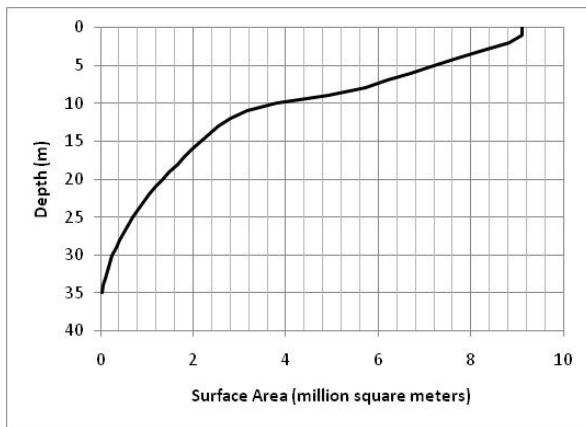


Figure 2-6
Depth-Area Curve for Lake Auburn

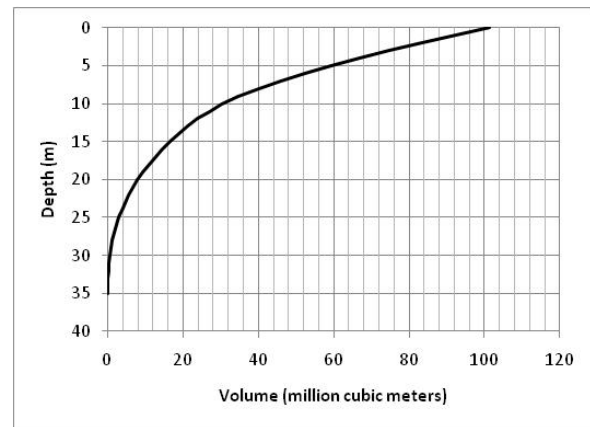


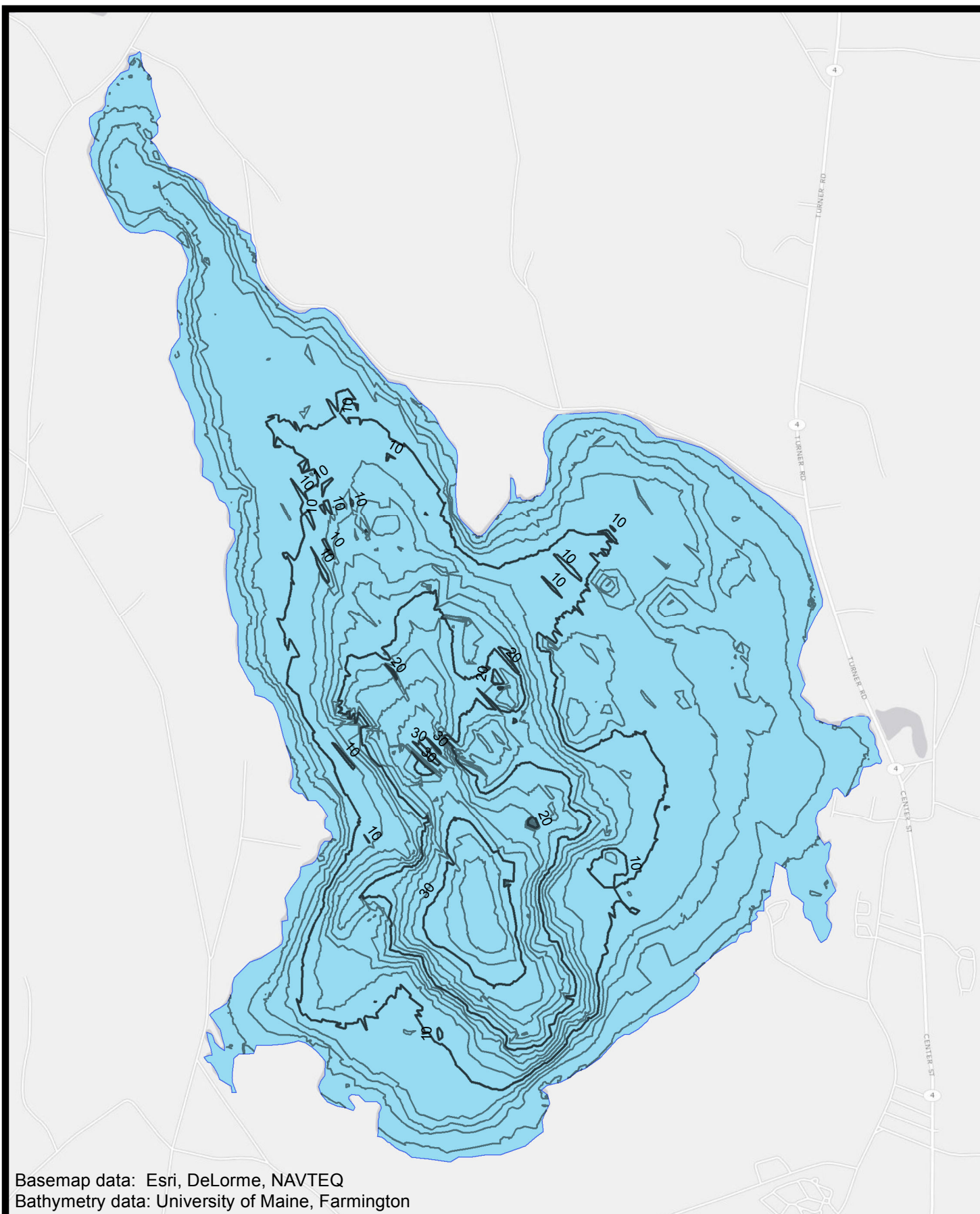
Figure 2-7
Depth-Volume Curve for Lake Auburn

2.2.2 Meteorological Data

Meteorological data are available from the National Climatic Data Center. Four National Weather Service Cooperative Observer Program (COOP) stations are active within a 15-mile radius of Auburn, Maine; they are located at Durham, Poland, Gray and Turner. Another COOP station was formerly located in Lewiston, but the completeness of its dataset dropped beginning in 2002, and recordkeeping ceased in 2010.

Average precipitation over the decade from 2003-2012 among these stations varied by less than two inches, from 53.8 inches at Turner, to 54.7 inches at Poland, and 55.4 inches at Durham and Gray, as described in Table 2-2.

Variation in annual rainfall among the gages was two inches or less some years (two to three percent), and never more than nine inches (12 percent). The area's annual precipitation is thus reasonably consistent for the purpose of estimating precipitation over a watershed. As Poland is the closest gage to Lake Auburn, it offers the best basis for estimating daily precipitation over its period of record.



Basemap data: Esri, DeLorme, NAVTEQ
Bathymetry data: University of Maine, Farmington



0 250 500 1,000 Meters

Figure 2-5: Lake Auburn Bathymetry

Contour Interval: 2 m

Table 2-2
Annual Precipitation Volume and Statistics for National Weather Service COOP
Gages near Auburn, Maine

COOP ID	176856	172048	178817	173295	COOP Mean		S.D.
	Poland (10 mi SW, 559 ft)	Durham (11 mi SE, 144 ft)	Turner (13 mi NW, 564 ft)	Gray (15 mi SW, 377 ft)			
1994		44.13			44.1	±	0
1995		42.43			42.4	±	0
1996		57.58		58.57	58.1	±	0.5
1997		45.04		41.6	43.3	±	1.7
1998	50.55	56.82		57.28	57.1	±	0.2
1999	52.31	48.74		49.61	49.2	±	0.4
2000	45.58	45.12		46.66	45.9	±	0.8
2001	32.46	35.8		34.8	35.3	±	0.5
2002	44.62	45.17	42.48	46.96	44.9	±	1.8
2003	46.14	45.8	44.68	44.81	45.1	±	0.5
2004	41.79	42.21	38.79	43.84	41.6	±	2.1
2005	65.75	69.78	63.49	71.9	68.4	±	3.6
2006	62.46	61.26	55.96	61.88	59.7	±	2.7
2007	45.98	48.6	48.38	47.12	48	±	0.7
2008	64.04	64.96	64.82	65.61	65.1	±	0.3
2009	59.98	60.69	59.64	61.27	60.5	±	0.7
2010	55.6	56.33	56.28	57.88	56.8	±	0.7
2011	50.51	53.41	56.98	52.48	54.3	±	1.9
2012	54.38	50.99	48.48	46.92	48.8	±	1.7
Mean 2003-2012	54.66	55.4	53.75	55.37	54.8	±	0.8

Lake Auburn: 261 ft

driest

wettest

2.2.3 AWD/LWD Lake Water Quality Data

AWD/LWD collects water quality data frequently to track water quality trends and evaluate compliance with its filtration waiver. Water quality data has been collected at the 13 different locations shown in Figure 2-8 in the lake since 1979, although not all sites are sampled every year or at consistent depths. In 2012, four additional locations in the lake were sampled; these are also shown on Figure 2-8.

Prior to 2005, limited sampling data are available outside of the deep hole sample location (#8). During routine sampling, *in situ* temperature and dissolved oxygen profiles were regularly collected at 1-m increments, along with Secchi depth. Discrete or core samples were analyzed for one or more of the following parameters: algae (mostly total count; occasionally enumerated by class), ammonia, chlorophyll *a*, nitrate, nitrite, nitrate + nitrite, orthophosphate, temperature, total phosphorous, color, conductivity, dissolved organic carbon, pH and turbidity.

Appendix B contains an inventory of the number of samples for each sample location, depth, and year. The data are organized in two tables. Table B-1 includes the number of samples for ammonia, chlorophyll *a*, nitrate, nitrite, nitrate + nitrite, orthophosphate and total phosphorous. Table B-2 covers parameters collected at more frequent depth intervals: temperature, turbidity, color, conductivity, dissolved oxygen and pH. Reported temperature and dissolved oxygen measurements in Table B-2 at the deep hole sample location are subsets of the larger temperature and dissolved oxygen profile dataset described previously, and represent locations with matched pair data for conductivity, pH and/or turbidity. Temperature and dissolved oxygen are collected with an *in situ* YSI probe; the remaining parameters are collected discretely.

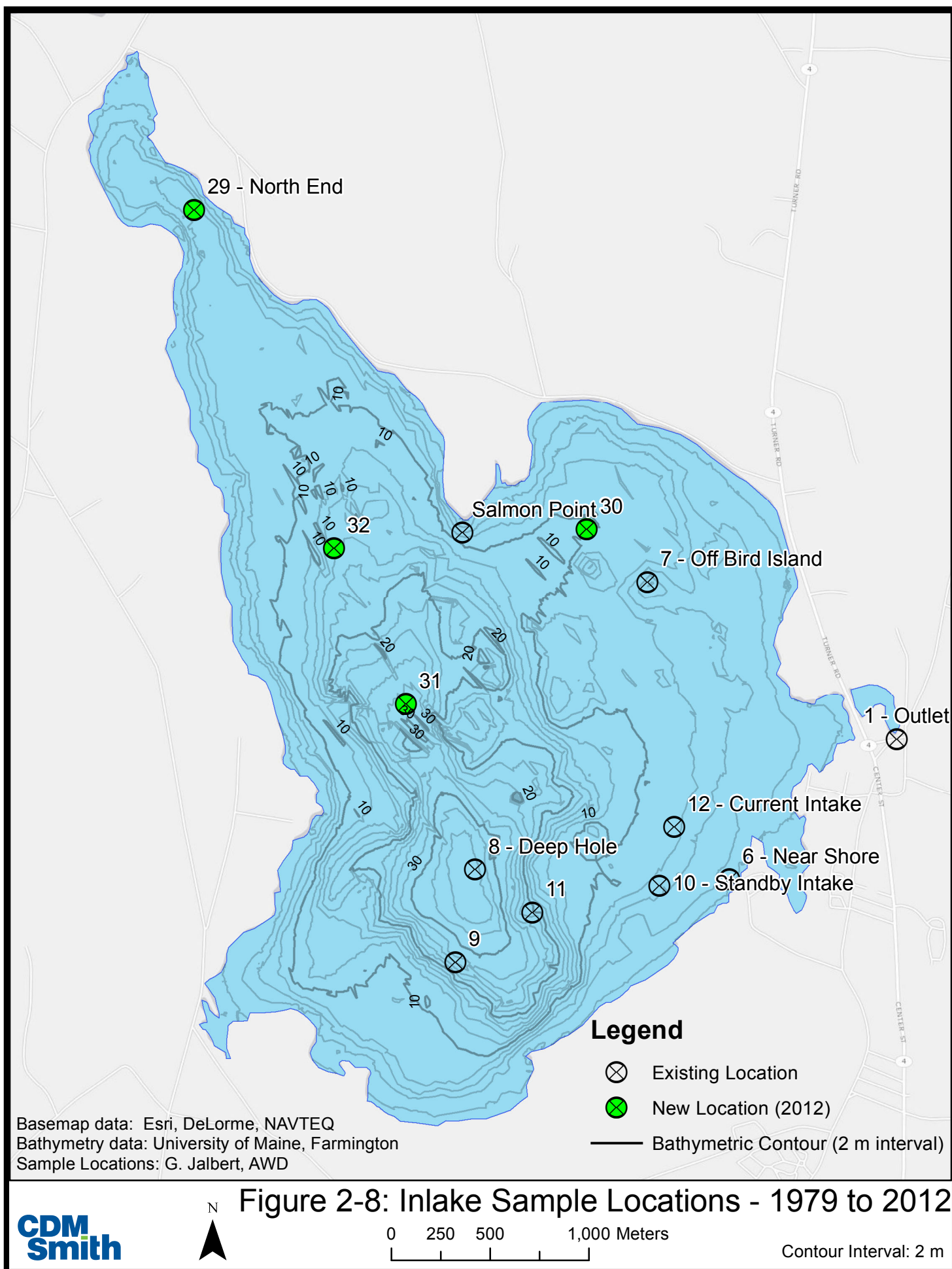
2.2.3.1 Secchi Depth

Secchi depth has been collected at the deep hole monitoring location from 1978 to present, and a continuous record of turbidity at the raw water intake is available from 1997 to present.

Secchi disk measurements (and turbidity) are used as an indicator of water clarity. In general, Secchi depth is correlated with turbidity such that a shallow Secchi disk measurement implies a high turbidity measurement. Low Secchi depth and high turbidity measurements are indicative of particles in the water column such as sediment, bacteria or algae.

Figure 2-9 displays Secchi depth data by month along with the monthly average. To simplify the figure, data from some years were plotted together using a single symbol. A high value for Secchi depth implies clearer, more transparent water.

In general, monthly average Secchi depths range from 6 to 8 meters, while individual measurements range of between 2 to 11 meters. The values and trend of the monthly average Secchi depths are typical for a high quality lake, where Secchi depths tend to be somewhat shallower in the spring and fall due to algal blooms and deeper in the summer when phosphorus, and thus, algal levels are lower.



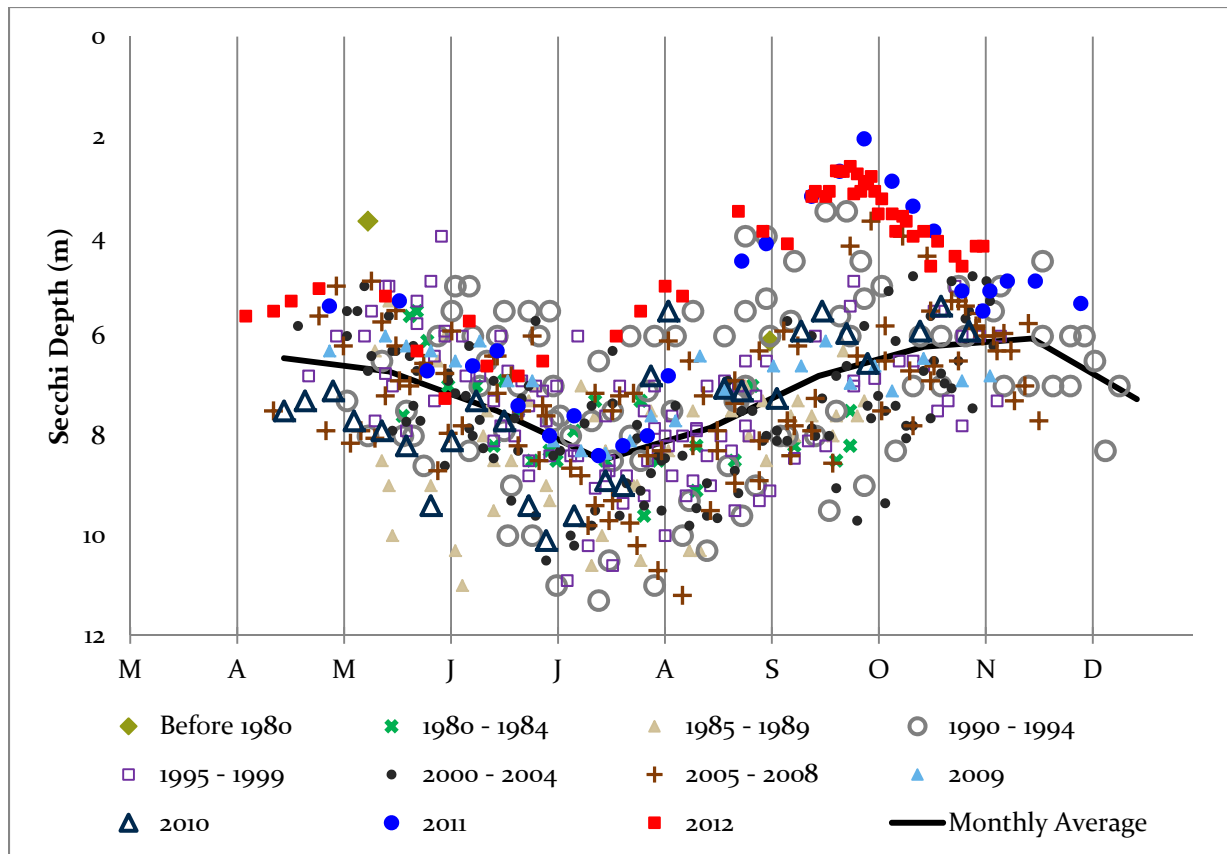


Figure 2-9
Secchi Depth Measurements at the Deep Hole Sample Location, 1978 to 2012

Figure 2-9 shows that Secchi depths in 2011 and 2012 were among the shallowest measured in Lake Auburn, particularly from late summer through the fall. Other years when shallow Secchi depths were also observed in the fall are 1993, 1994 and 2008.

2.2.3.2 Stratification - Temperature and Dissolved Oxygen

Data that describe the vertical structure of temperature and dissolved oxygen in Lake Auburn were collected at 1-m intervals at the deep hole site (#8) from 1978 through 2012. Temperature and dissolved oxygen profiles were collected 3 to 4 times per year in the late 1970s and 1980s, about 10 times per year in the 1990s, and approximately weekly during non-winter months after 2000. Isopleths of annual temperature and dissolved oxygen structure are presented in Appendix C.

The profile data show that Lake Auburn is a typical northern temperate lake with stratification forming in the spring, and strengthening into mid-summer. Peak stratification is typically observed in the July or August profile. Between mid-August to early September, the epilimnion (surface layer of the lake) cools and deepens. This process continues throughout the fall until the lake reaches uniform temperature in early winter. Lake Auburn does not undergo a rapid destratification (fall turnover) found in many northern temperate lakes.

The dissolved oxygen profile data can often be used as a surrogate for algal productivity in the upper waters of a lake. For instance, the isopleths in Appendix C often show an increase in dissolved oxygen around 7-9 meters depth in the early summer months, which typically indicates algae growing at the top of the thermocline. This pattern is clearly evident in oxygen isopleths for 2005, 2008 and 2010. The profile data of DO saturation in 2011 show saturation values greater than 105% in late June to a depth of about 10 meters, with small zones (to about 5 m) just above saturation in the July and August profiles. The 2012 DO saturation profiles indicate more widespread algal activity with DO saturation peaking above 120% at depth of 7 meters in late May (above 110% saturation from 2 to 9 meters). In late June, DO saturation also peaked above 120% at 4 meters, and ranged above 110% saturation from the surface to 7 meters. By early August, the extent of the profile greater than 100% saturation occurred from 3 to 6 meters and peaked at about 105%.

Dissolved oxygen profile data show that the deep waters of the lake (hypolimnion) experience depressed oxygen in most years. Typical hypolimnetic dissolved oxygen concentrations just prior to complete mixing in the autumn range from 3 and 4 mg/l, but anoxia (<2 mg/l) sometimes occurs in the deep waters of the lake (for example, from late September through October 2002 anoxic conditions were found below a depth as high as 21 meters).

2011 and 2012 were notably different from previous years as widespread anoxic conditions were found throughout the hypolimnion, with dissolved oxygen concentrations dropping below 1 mg/l prior to the complete mixing of the water column that occurs in late fall. However, the timing and vertical extent of depletion of dissolved oxygen in those years differed. In 2011, dissolved oxygen deficits first occur in the deepest water (indicative of sediment oxygen demand) and both the deficit of oxygen and the vertical extent of bottom water with a deficit of oxygen slowly increases through from July to September. In October, about 75% of the deepest waters in the hypolimnion are anoxic. In 2012, nearly the entire volume of the hypolimnion has low dissolved oxygen concentrations, with the decline in concentration starting in late June. The deficit of dissolved oxygen increases to the entire hypolimnion, and anoxic conditions are reached by early September. By late September, dissolved oxygen is less than 1 mg/l across the entire hypolimnion. Isopleths in Appendix C depict these differences.

The anoxic factor (Nürnberg 1995) provides a method for understanding the potential impact of varying anoxic conditions on water quality. It is used to quantify the longevity and extent of anoxia in a stratified lake, and is normalized by the lake surface area so that this factor can be compared between lakes of different sizes. The anoxic factor is described by the equation

$$AF = \left(\sum_{i=1}^n t_i a_i \right) / A_o$$

where t_i is the total number of days where anoxic conditions were observed, a_i is the surface area of sediment in contact with anoxic water in square meters and A_o is the lake surface area in square meters. Nürnberg defines anoxia as water with a dissolved oxygen concentration of less than 1 mg/l, although she recommends using a threshold of 2 mg/l if the data are of questionable quality or if there are large portions of the hypolimnion with dissolved oxygen between 1 and 2 mg/l.

In general, a healthy, oligotrophic lake will have an AF of less than 10 days per year. If the AF exceeds 20, lake health is in danger but can be recovered with appropriate management. AF over 100 indicates a hypereutrophic lake with widespread anoxia throughout the hypolimnion.

The AF was calculated for Lake Auburn for 2001 through 2012 using the more conservative threshold of 2 mg/l to define anoxia within the hypolimnion. Table 2-3 presents the AF for each year. Years where the AF is zero indicate that no anoxia was observed in the hypolimnion (hypolimnetic phosphorus concentrations discussed in the next section indicate some degree of anoxia likely occurs every year at the sediment-water interface, at least in the deep hole).

Table 2-3
Anoxic Factor (Nürnberg 1995) for Lake Auburn
2001 through 2012

Year	AF (d/y)
2001	0
2002	5.7
2003	0
2004	0
2005	0
2006	0.26
2007	0
2008	0
2009	0
2010	0.28
2011	18.1
2012	18.9

2.2.3.3 Nutrients

Limited samples were collected for in-lake nutrient levels prior to 2011. The tables in Appendix B summarize the number of individual analyses by year, location and depth. In total, the number of analyses is: ammonia (147), nitrate (28), nitrite (28), nitrate+nitrite (197), orthophosphate (110) and total phosphorus (412, over half of which were collected in 2011-12).

The expanded dataset in 2011-12 includes samples collected at multiple depths in the water column, which facilitates understanding the internally generated phosphorus load. The most comprehensive dataset of total phosphorus was taken at the deep hole sample location, but periodic phosphorus samples have been collected across all 13 sample locations since 1990.

Total phosphorus levels in the epilimnion (to 5 meters depth) range from 6 to 18 µg/l (discounting samples in the early 1990s where detection limits appear to be at issue and an anomalous 1999 value of 62 µg/l), while deep samples (30-35 meters) range from 7 to 58 µg/l.

Table 2-4 provides the average monthly total phosphorus concentration in the epilimnion (to 5 meters depth) for 2005, 2010, 2011 and 2012. In general, values around 10 µg/l are considered desirable as

they are indicative of lakes with low algal productivity, while values above 25 µg/l are considered undesirable with high levels of algal productivity.

Epilimnetic total phosphorus in Lake Auburn typically falls in the desirable range, but these data are quite sparse making it difficult to draw firm conclusions. The first observation about the data is that there appears to be an increase in late summer-fall total phosphorus concentrations in the epilimnion from 2005 to 2011 and to 2012. The spring data are more variable, and could have been influenced by the lack of ice cover in the winter 2011-12 (April 2012 value) or very high rains in June 2012. Second, there is an increase in total phosphorus concentration within each year starting about mid-summer. Examining this rise, 2011 and 2012 are notable for their large increases. In 2011, there was a 50% increase in epilimnetic phosphorus between the June and August samples. A similar rise occurs in 2012 with a 40% increase in epilimnetic phosphorus from May to August.

Table 2-4
Average Epilimnetic (0-5 meter) Total Phosphorus Concentrations

Month	Average Total Phosphorus (µg/l)			
	2005	2010	2011	2012
April	10	8	-	14
May	10	10	-	9
June	7	6	7	13
July	-	-	8	-
August	7	8.5	13	12.5
September	9	12	-	15.7
October	10	-	14.3	16
November	12	-	11.7	-
December	14	-	-	-

Figure 2-10 presents deep water total phosphorus measurements since 2000. Although sampling was relatively infrequent prior to 2010, the data indicate that hypolimnetic phosphorus concentrations increase throughout each year until the lake fully mixes in November. In all years when samples were collected in the fall (2001, 2002, 2010, 2011, and 2012), total phosphorus values were above 35 µg/l. Notably, 2000 had a single total phosphorus measurement of 57 µg/l in October, comparable to the highest 2012 value of 58 µg/l.

This increase suggests that the magnitude (concentration) of hypolimnetic phosphorus increase observed in 2011 and 2012 was not unusual. It is expected, however, that due to the greater extent of anoxia that the mass of phosphorus in the hypolimnion was greater in those years. Full profiles of total phosphorous were collected on two dates each in 2011 and 2012 (Figure 2-11). The profiles indicate that not only was there more mass of phosphorus in the hypolimnion in 2012 than 2011, but that the elevated concentration was observed at shallower depths in the water column (albeit the total phosphorus concentrations exhibit more variation with depth than the dissolved oxygen concentration profiles collected on the corresponding dates).

Limited nitrogen data collection has occurred historically, and the nitrogen samples available are generally below the detection limit. Samples have been analyzed for nitrate, nitrite and ammonia sporadically between 2005 and present day. The combined nitrogen parameters have generally always been measured at desirable levels in the lake.

Ammonia was only detected in 18 samples between 2005 and May 2012, and was typically found to be 0.01 mg/l and only once at 0.3 mg/l. In 2012, 44 samples were collected in October-November at various locations and depths in the lake that had typical ammonia concentrations ranging between 0.03 and 0.04 mg/l in October and 0.05 and 0.06 mg/l in November. Peak values were found at 0.18 and 0.31 mg/l at 30 and 33 meters at the deep hole, respectively, on November 7th. The increase in ammonia in the bottom is likely a function of ammonium build-up under anoxic conditions.

Nitrate was measured between 2000 and 2004, was often not detected, and never exceeded 0.2 mg/l. Nitrite was never detected in the same time period. Starting in 2005 a combined parameter nitrate+nitrite was measured. This was rarely detected in the lake (and then never exceeding 0.02 mg/l) until October 2012. Using only the discrete samples (and not the cores), the nitrate+nitrite was typically 0.03 or 0.04 mg/l, with the highest concentrations of 0.07 and 0.09 mg/l at 20 and 25 meters depth, respectively on November 1st.

2.2.3.4 Chlorophyll *a* and Algae

Chlorophyll *a* has been collected sporadically across all 13 sample locations since 1999, with most samples collected at the deep hole location. Furthermore, most chlorophyll *a* samples are epilimnetic core measurements, which capture a depth-integrated concentration throughout the epilimnion. The available chlorophyll data (excluding estimate values) for both discrete and core samples is plotted in Figure 2-12. While chlorophyll data are usually evaluated as summer average concentrations because the occurrence of a short-duration bloom is not usually a cause for concern; summer average chlorophyll levels below 3 µg/l would represent a high quality lake with low algal productivity. For Lake Auburn, the individual sample points are used instead because of the variability in the data collection program.

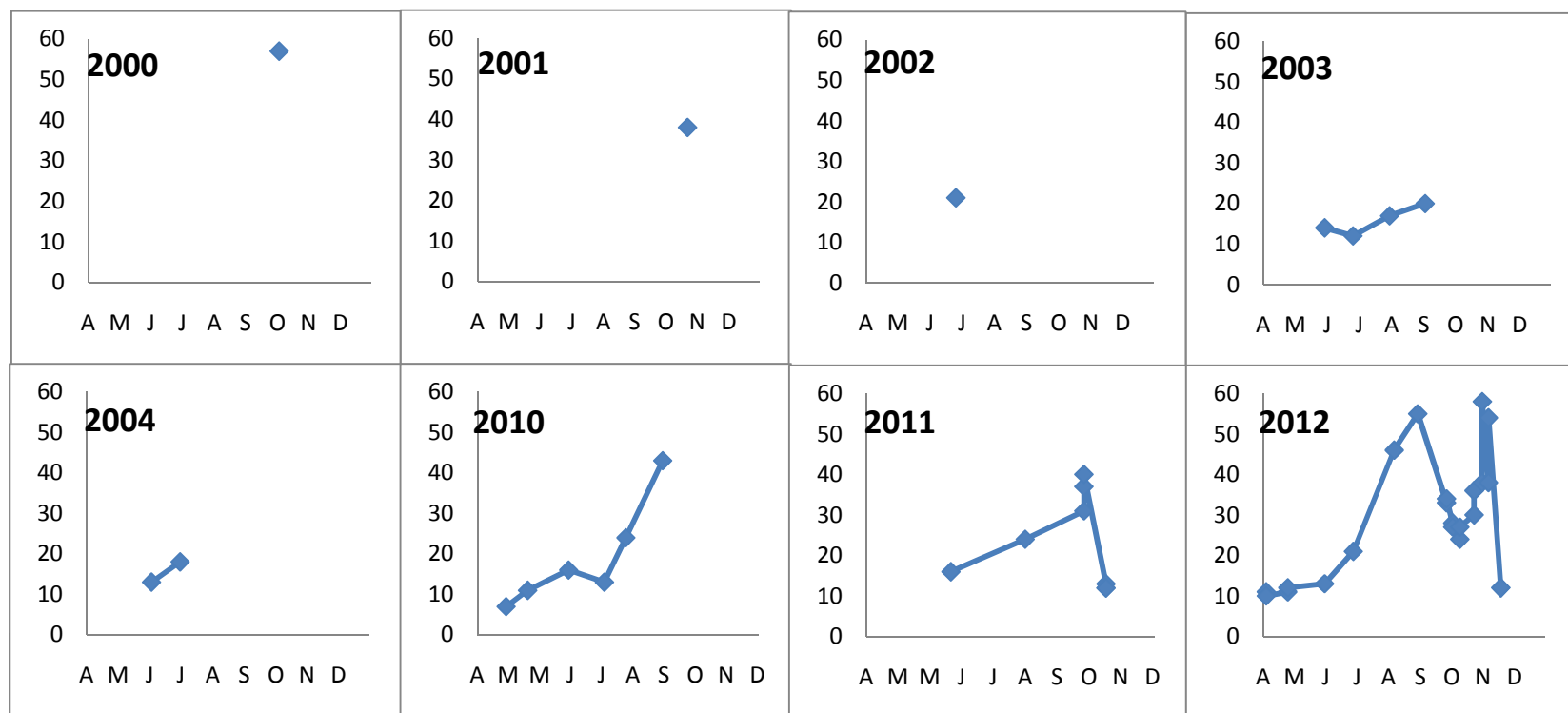


Figure 2-10
Hypolimnetic Total Phosphorus Concentration, 30 to 35 Meters

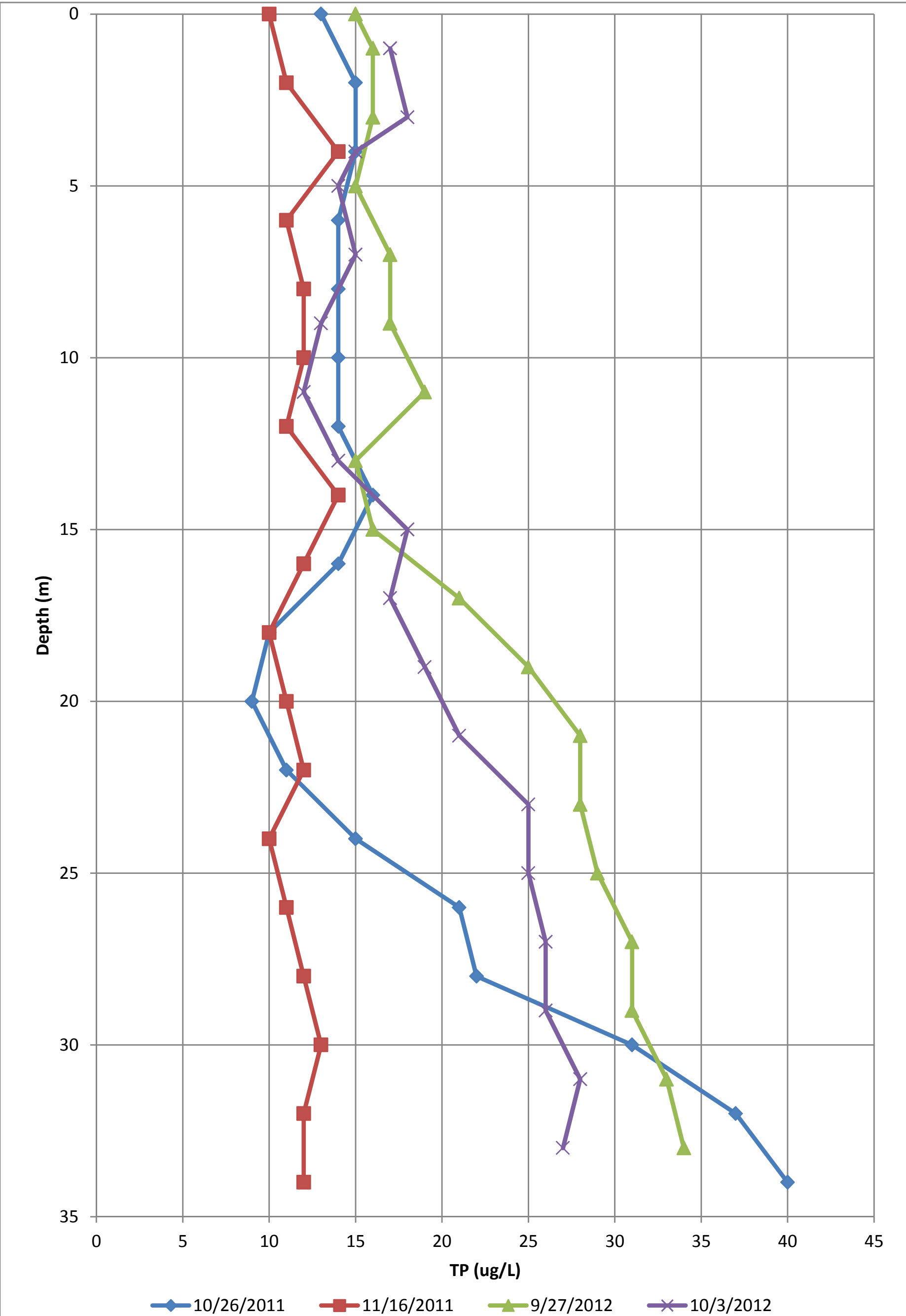


Figure 2-11. Total Phosphorus Profiles at the Deep Hole, 2011 and 2012

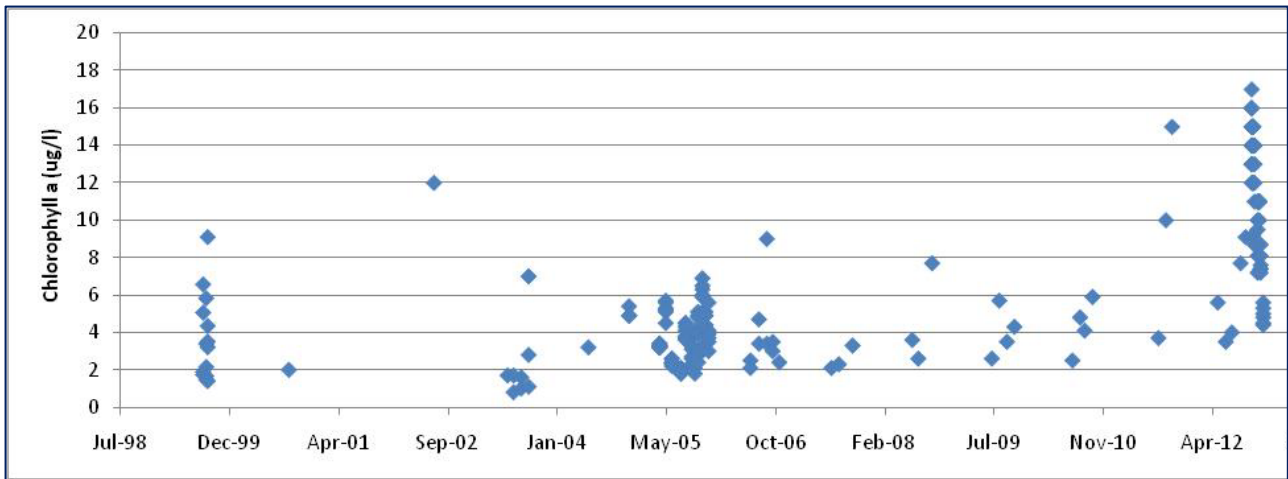


Figure 2-12
Chlorophyll *a* Data for Lake Auburn from 1999 through 2012 (excludes estimated values)

Figure 2-12 shows that algal blooms have occurred throughout the record: high ($>10 \mu\text{g/l}$) chlorophyll concentrations were measured in 2002 (June 26), 2011 (August 31 and September 28) and 2012 (nearly every sample from late September through October). While chlorophyll *a* samples are sparse in 2011, the low Secchi depths recorded in fall (Figure 2-9) suggest the presence of an algal bloom similar to that found in 2012.

Algal sampling was performed by AWD/LWD from 2005 to present day near the intake, and at seven additional sites in 2005. Most of the analyses provide total count of algae and are not used in this study. Some results were enumerated and these generally follow the expected pattern of algal dominance for a high quality Maine lake. Notable was the occurrence of *Gloeotrichia echinulata* in August 2006, where in e-mail communication between Ms. Mary Jane Dillingham, Water Quality Manager with the Auburn Water District and Jim Pescatore of CDM Smith, Ms. Dillingham noted that a sample on August 25th had a count of 16 per 500 ml and a sample on August 28th had a count of 5 in 300 ml but 3 of them appeared to be *Volvox*. She further noted that *Gloeotrichia* was occurring in other Maine lakes. While standard sampling and enumeration techniques reduce the chance of identifying *Gloeotrichia*, this correspondence documents its occurrence in Lake Auburn at least as far back as 2006. *Gloeotrichia* has been the subject of National Science Foundation grants in New England that include Lake Auburn (Section 2.2.5).

2.2.4 AWD/LWD Intake Water Quality Data

Water withdrawn from the lake plant passes through continuous analyzers prior to its entering the water treatment, and high frequency data are available. While a number of parameters are collected, the only parameters from this dataset analyzed for this study are temperature and turbidity.

Lake temperature has been continuously recorded at the raw water intake since 1952, with a supplemental dataset that has been collected since 1997. Unfortunately, the older dataset is of questionable quality, so the more recent dataset was used for analysis. Daily water temperature is collected from water withdrawn from the lake and is analyzed on a monthly average basis. Figure 2-13 shows the range and median lake temperature data from the raw water intake presented along with monthly average temperatures during 2011 and 2012. Error bars on this plot indicate the maximum

and minimum observed monthly temperatures between 1997 and 2011. Median monthly lake temperatures range from a low of 2.2°C to a high of 25.2°C. Most notable is the near-record-high water temperature starting in October 2011. The elevated temperatures continue to be well above average from January to May 2012. Further, almost all of 2012 was warmer than average with the exception of September, which was slightly cooler than average, and late fall, which was very close to the long-term average.

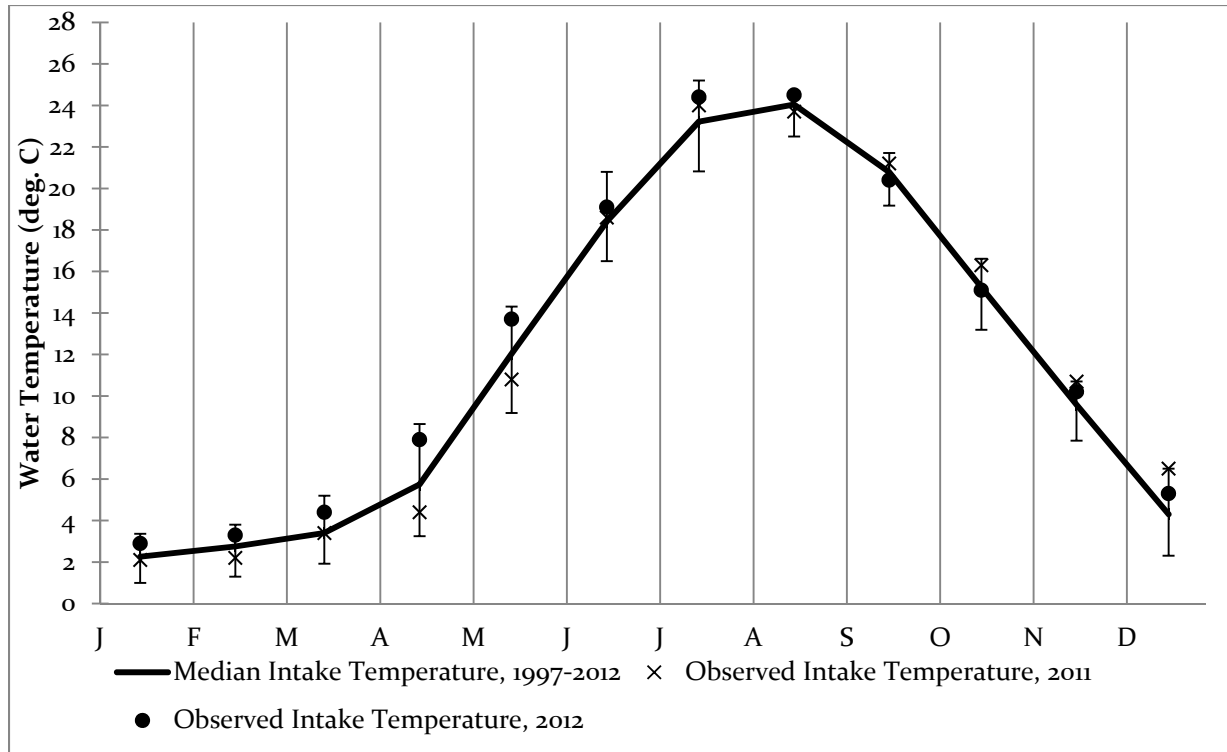


Figure 2-13
Monthly Average Raw Water Intake Temperature for 2011 and 2012
Presented with Median Intake Temperature from 1997 to 2012

(Error bars shown on the plot indicate the maximum and minimum reported monthly temperatures.)

Intake turbidity data are also available from 1997 to present. Data prior to 2005 are monthly average grab samples from the raw water intake; data after 2005 are a daily average taken directly from the SCADA system. Figure 2-14 shows the average turbidity and the maximum turbidity measurement over 1 NTU for 1997 through 2012.

This turbidity record indicates that the average turbidity is generally well below 1 NTU prior to 2011; only the peak value had rare excursions above 2 NTU. In 2011 and 2012, average daily turbidity values were about 2 NTU and peak values nearly reached 4.5 NTU in 2011 and 3.5 NTU in 2012.

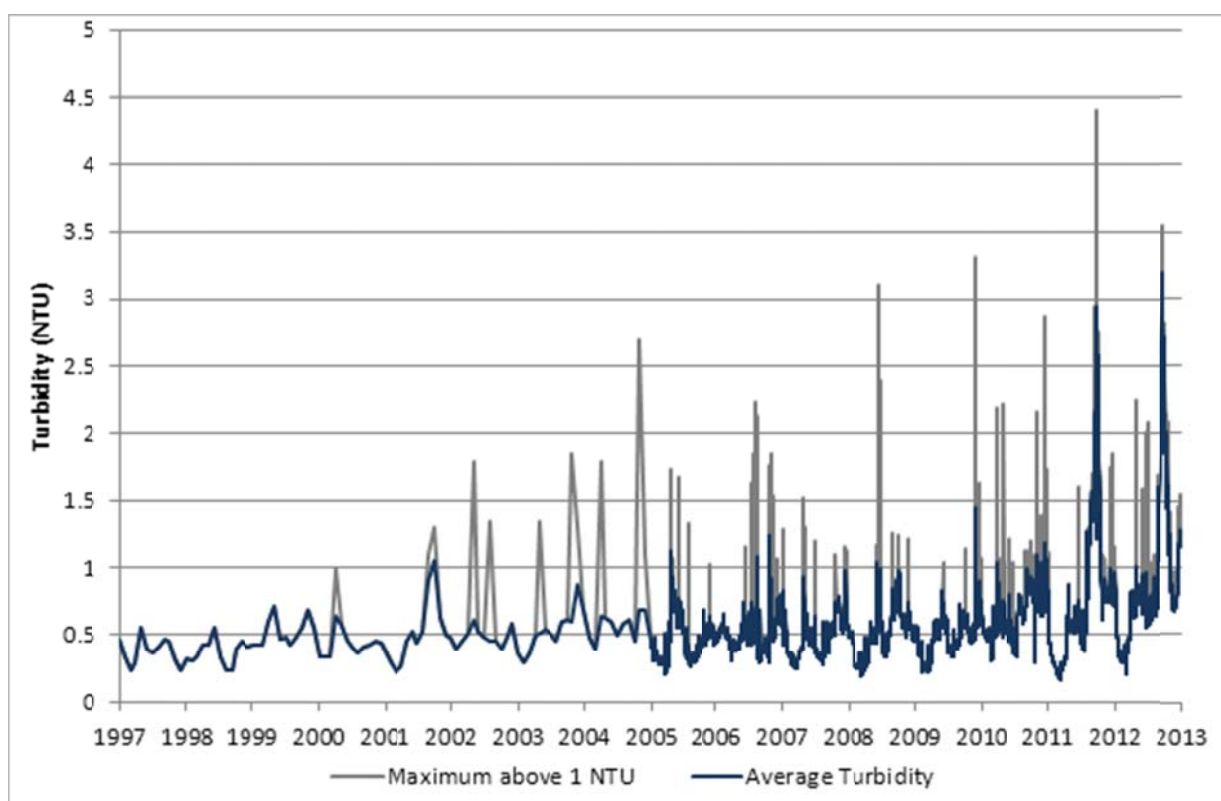


Figure 2-14
Average and Maximum when Above 1 NTU Raw Water Intake Turbidity for 1997 to Present
Average Turbidity is Monthly Average until 2005 and Daily Average from 2005

Table 2-5 shows the number of days per year where turbidity exceeds 1 NTU since 2005. This table indicates that the number of days of high turbidity prior to 2009 was relatively constant; from 2010 to 2012 the number of days of high turbidity has increased significantly.

Table 2-5
Days per Year where Maximum Turbidity exceeded 1 NTU, 2005 – 2012

Year	2005	2006	2007	2008	2009	2010	2011	2012
# of Days	7	16	11	22	8	38	83	108

To better understand the occurrence of the high turbidity, Table 2-6 provides the number of days per month in 2011 and 2012 where turbidity exceeds 1 NTU.

Table 2-6
Number of Days per Month where Turbidity exceeded 1 NTU
2011 and 2012

Month	Turbidity Above 1 NTU (days/month)	
	2011	2012
January	1	3
February	0	0
March	0	0
April	0	3
May	0	1
June	2	7
July	3	1
August	20	13
September	30	30
October	20	31
November	4	9
December	3	10

Turbidity, along with the bacteria concentration in the lake, is one of the compliance parameters for AWD/LWD's filtration avoidance waiver. Federal regulations (40 CFR 141.71) describe the criteria as:

(2) The turbidity level cannot exceed 5 NTU (measured as specified in § 141.74 (a)(1) and (b)(2)) in representative samples of the source water immediately prior to the first or only point of disinfectant application unless: (i) the State determines that any such event was caused by circumstances that were unusual and unpredictable; and (ii) as a result of any such event, there have not been more than two events in the past 12 months the system served water to the public, or more than five events in the past 120 months the system served water to the public, in which the turbidity level exceeded 5 NTU. An "event" is a series of consecutive days during which at least one turbidity measurement each day exceeds 5 NTU.

2.2.5 Bates College Water Quality and Algal Data

Through the NSF grants described in Section 2.1, Dr. Holly Ewing and her co-Principal Investigators collected data on temperature, dissolved oxygen, nutrients and algae from five locations around the periphery of Lake Auburn. For this study, the data of greatest interest are total phosphorus concentrations in 2011 only (Figure 2-15) and enumerations of *Gloeotrichia* in 2008, 2011 and 2012 (Figure 2-16), and a full algal enumeration collected from May 6 to October 29, 2011 (Figure 2-17).

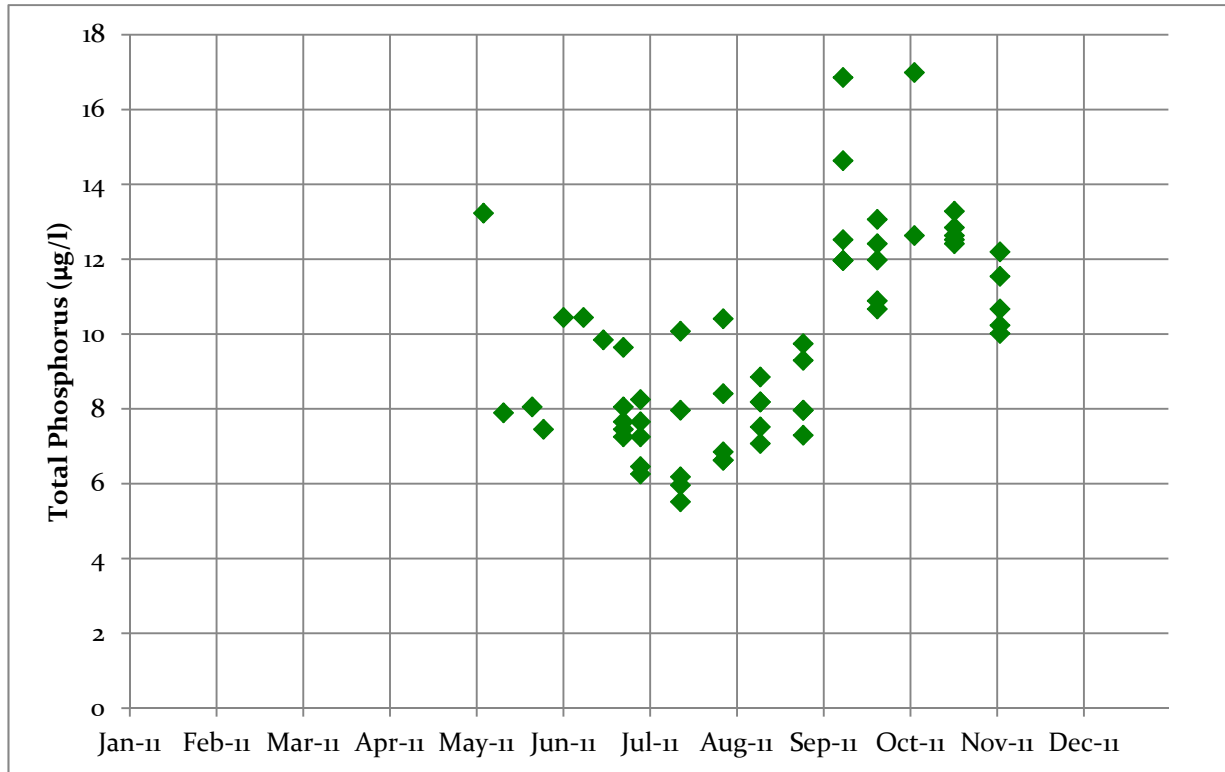


Figure 2-15

Total Phosphorus Concentrations measured around Lake Auburn Perimeter
Data collected by Drs. Ewing, Weathers, and Cottingham under NSF grants NSF DEB-0749022
NSF EF-0842112m NSF EF-0842125, NSF EF-084226

Figure 2-15 shows that prior to early September total phosphorus concentrations were between 5 and 11 µg/l, whereas after September they were between 10 and 17 µg/l.

Figure 2-16 and results in 2006 (Section 2.2.3.5) suggest that peak levels of *Gloeotrichia* are typically found in August. In 2012, the *Gloeotrichia* bloom appeared about a month earlier than in 2011, which may be due to elevated water temperatures of 2012.

The algal data in Figure 2-17 show that the algal community was a mix of diatoms, blue-green and golden-brown algae in July 22nd and August 3rd samples, with an intermediate sample on July 29th dominated by blue-green algae (*Anabaena*). The August 11th and 17th samples are also dominated by *Anabaena*. On August 26th the community was determined to be about 40% each diatoms and blue-greens. *Anabaena* again dominated the community during September. In October, a bloom of diatoms (*Tabellaria*) begins and becomes the dominate algae in the lake by mid-October.

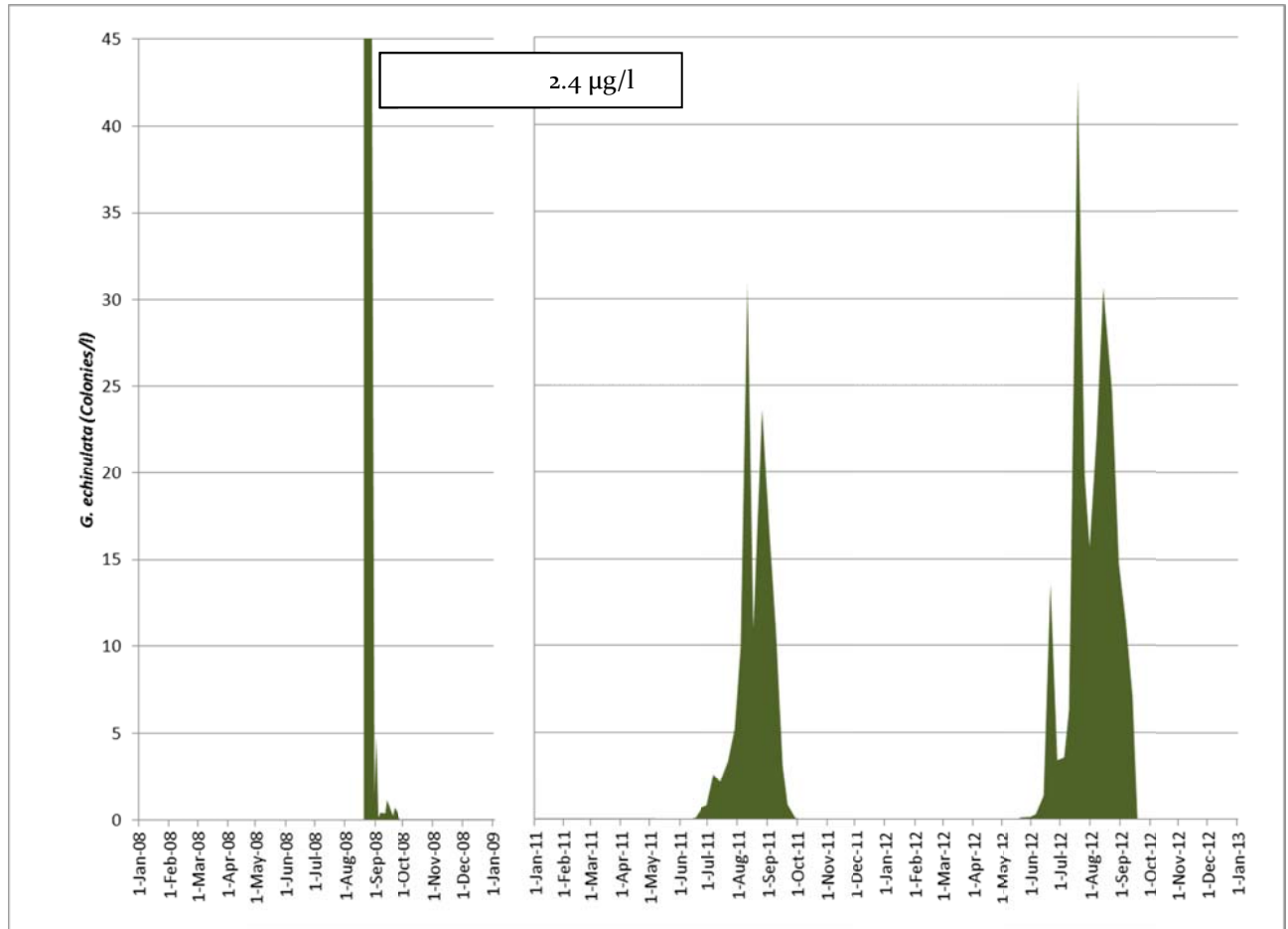
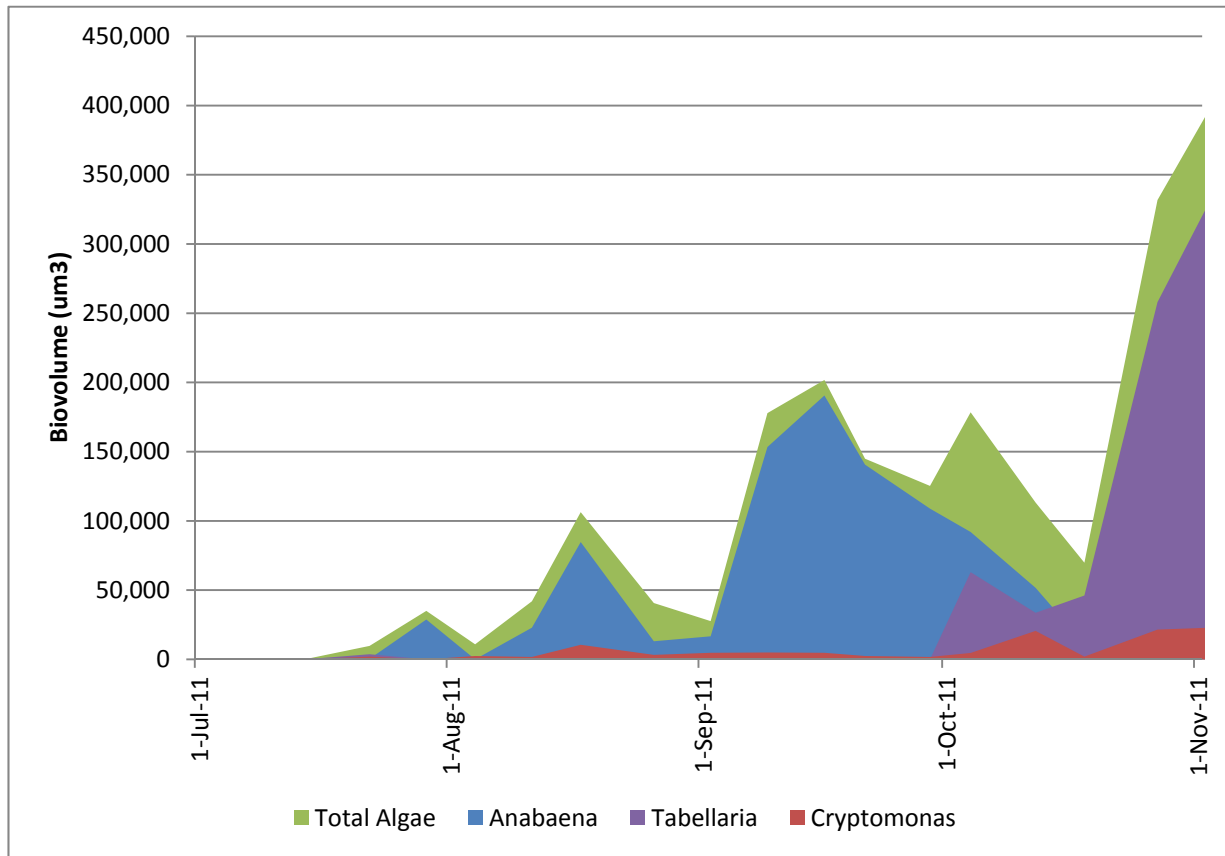


Figure 2-16
Average *Gloeotrichia* Concentrations, 2008, 2011, and 2012
Data collected by Drs. Ewing, Weathers, and Cottingham under NSF grants NSF DEB-0749022, NSF EF-0842112m NSF EF-0842125, NSF EF-0842267

**Figure 2-17****Full Algal Enumeration for 2011**

Data collected by Drs. Ewing, Weathers, and Cottingham under NSF grants NSF DEB-0749022, NSF EF-0842112m NSF EF-0842125, NSF EF-0842267

Section 3

Lake Auburn Water Quality Assessment

3.1 Problem Statement

Throughout most of the available water quality record, Lake Auburn is shown to be a typical high quality northern temperate lake. It is a large, deep lake that is strongly stratified throughout the summer months. Although the timing and strength of stratification vary from year to year, the onset of stratification is generally in May with the thermocline located at about 5 meters depth. The thermocline gradually deepens through the stratified period typically reaching into November with maximum depths between 10 and 14 meters depending on the year. By mid-November, the lake is usually fully mixed. When the lake is stratified, the density difference between the epilimnion (upper layer) and hypolimnion (lower layer) inhibits mixing between the layers.

Secchi depth readings (Figure 2-9) indicate that Lake Auburn has a long record of excellent quality water; spring and fall Secchi depths average over 6 meters, while the readings deepen in mid-summer to average 8 meters. The high transparency allows sunlight to foster algal growth into the middle layer of the lake. Following ice out, total phosphorus concentrations in the surface waters are sufficient to support what is assumed to be moderate growth of algae in the spring, hence the slightly shallower Secchi depth compared to summer. Dissolved oxygen readings often show a metalimnetic maximum indicating the growth of algae in this layer. The deeper Secchi readings in mid-summer correspond to lower total phosphorus levels in the surface layer, and suggest a reduced algal community. In the fall, the deepening of the thermocline allows phosphorus in the lower layer of the lake to reach the surface waters, likely fueling an algal bloom and causing shallow Secchi readings.

The excellent water quality conditions in the lake are further evidenced by a long history of low turbidity readings (Figure 2-14), which make Lake Auburn a high quality source of drinking water. Turbidity at the intake, located at 6 meters depth, rarely exceeded 1 NTU.

The bottom layer of Lake Auburn is large and poorly mixed (40% of the lake's volume is below 8 m depth). Dissolved oxygen levels in this layer decrease as summer progresses, as oxygen demand from organic detritus (*e.g.* dead algae) in the sediments is satisfied by the available oxygen in that layer (while the upper water column is re-aerated at the air-water interface, the thermocline severely inhibits the passage of oxygen from the upper to bottom layers of the lake). By the end of the stratified period, the oxygen levels are typically 3 to 4 mg/l. In some years, greater depletion is seen, and in a few years, anoxic (<2 mg/l) conditions are found originating in the deep hole and in some years extending across the lower layer of the lake.

While water quality has varied among years, perhaps due to increased development or changes of land use in the watershed or with changes in rainfall patterns, year over year comparisons show the lake seemed to absorb the interannual variations without changing its high quality. Over this long period (and prior to 2011-12), two changes in water quality in the past decade are noteworthy:

- In 2005, bacteria concentrations in the lake increased, and the filtration waiver for the water treatment plant was threatened. A study by CDM Smith (2006) found that increased waterfowl populations were a significant contributor to the elevated bacteria levels and a waterfowl harassment program was undertaken in cooperation with Maine regulatory agencies. The harassment program continues and along with the efforts of the strong watershed management program, bacteria levels are again low.
- By 2006, a new alga – *Gloeotrichia echinulata* – was identified at high levels in the lake. Monitoring and research at similar high quality lakes indicate its increasing presence in other lakes in central Maine and New Hampshire through the 2000s, including the Great and Long Ponds in Maine and Lake Sunapee in New Hampshire (Carey *et al.* 2008; King and Laliberte 2005). The first recorded occurrence in Lake Auburn was in 2006. *Gloeotrichia* is notable as an alga that overwinters as resting cells on the lake’s bottom. It initially grows on the sediment surface. When sufficiently large, it rises through the water column to the surface bringing with it additional phosphorus to fuel its growth. As colonies die, some of the phosphorus is released in the upper water column, adding phosphorus to surface waters that can fuel the growth of other algae. *Gloeotrichia* in Lake Auburn has been the subject of research by Dr. Holly Ewing and her co-Principal Investigators (Section 2.1).

The long record of high water quality changed In 2011 and 2012, when water quality in Lake Auburn declined dramatically, as indicated by:

- increased epilimnetic phosphorus concentrations from summer to fall across a limited data record (Table 2-4),
- an increase in the number of days and spatial extent of hypolimnetic anoxia (Table 2-3), which increased the areal extent of sediment overlain by anoxic water and likely increased the phosphorus load in the hypolimnion,
- an increase in the number of days where turbidity is higher than 1 NTU, which as a surrogate for algae indicate exceptionally large late summer-fall algal blooms in comparison with the historical record (Table 2-5),
- record shallow Secchi depths measured from August through October, which again indicate exceptionally large late summer-fall algal blooms on the scale of the historical record (Figure 2-9),
- near record temperatures at the intake (Figure 2-13; late 2011 and 2012 only), and
- a fish kill in September 2012, which affected some of the lake trout population.

This section uses the available data described in Section 2 to investigate what caused Lake Auburn – a lake with a long record of excellent water quality – to experience such a rapid change in water quality. Deciphering drivers for the changes in water quality is complicated because (1) the main drivers can experience wide interannual variations and (2) lakes are complex physical, chemical, biological systems. To facilitate our analysis of the changes in water quality in 2011 and 2012, we have posed the following questions:

1. What is the cause of the increased turbidity observed in 2011 and 2012? Was this observed in previous years?
2. What can explain the increase in extent of anoxia in 2011 and 2012?
3. If the fall algal blooms are fueled by increased epilimnetic phosphorus, what could have caused the increase in phosphorus concentrations? Consider watershed loads, internally generated loads from sediment and algal recruitment from sediments.
4. Is the degraded lake water quality in 2011 and 2012 part of a long-term trend or better explained by unique events within these years?
5. Are these degraded conditions likely to continue in the future?
6. How does Lake Auburn's water quality compare to the Maine DEP's current draft of numeric nutrient criteria?

The remainder of this section starts by providing more detailed information on water quality in the lake. First, drivers or measures are described among years from 2001 to present, and then a more detailed depiction of lake water quality is described on a monthly basis for 2011 and 2012. Figure 3-1 provides a conceptual diagram of the interrelationships of the main factors driving water quality in Lake Auburn in 2011 and 2012 to aid in understanding the discussions in the remainder of this section. Dashed connections indicate less certainty about the significance of the relationship; solid connections indicate more certainty.

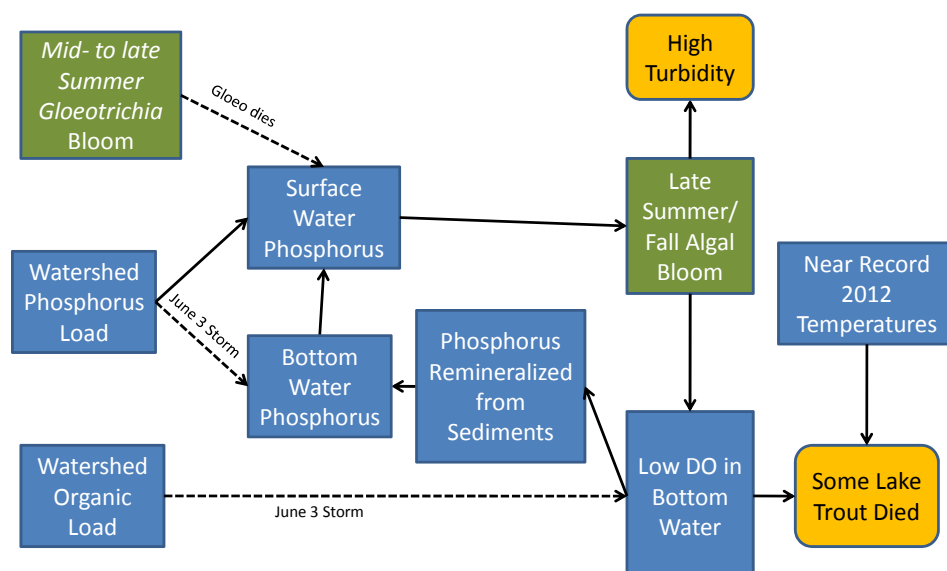


Figure 3-1
Conceptual Diagram of Key Factors influencing Water Quality in Lake Auburn

3.2 Timelines of Lake Auburn Water Quality

Understanding the timing of factors that contribute to poor water quality is critical to understanding why Lake Auburn has experienced higher than normal turbidity and shallower than normal Secchi depths (both assumed to be a surrogate for algae) and other indicators of poor water quality in the past two years. These are explored for Lake Auburn, first on an annual scale and then as a monthly examination of 2011 and 2012.

3.2.1 Water Quality Drivers on an Annual Scale

Drivers of water quality naturally undergo interannual variation. Table 3-1 summarizes from a macroscale some key factors that affect water quality in Lake Auburn for each year from 2001 through 2012. The following factors were examined:

- **Intake Water Temperature** – Warm temperatures in the spring lead to earlier onset of stratification; warm summers prolong and strengthen stratification.
- **Rainfall and Inflows from Intense Storms** – Rainfall generally correlates to the load of phosphorus delivered from watershed. Intense storms increase the load by creating high velocity in the tributaries that can cause bed scour; this sediment transported into the lake during intense storms is also a source of phosphorus.
- **Presence of Anoxia** – Anoxic conditions in the bottom waters lead to greater release of sediment phosphorus. For Lake Auburn this occurs by increasing the spatial extent of sediment covered by anoxia. Anoxic conditions can also stress or kill deep-dwelling life such as lake trout or salmon.
- **Turbidity** – Used as a surrogate for algal activity, as the available algae data are sparse. In Lake Auburn, turbidity readings above 1 NTU are likely due to algal particles in the water. The correlation is compared to algal count (as opposed to biovolume), where large algae such as *Gloeotrichia* often do not contribute significantly to increased turbidity.
- **Secchi Depth** – Also used as a surrogate for algal activity. The long-term Secchi depth for Lake Auburn is about 7 meters. Months with Secchi depths shallower than 6 meters are highlighted as months that likely have increased algal activity.

Another key water quality driver not included in Table 3-1 is phosphorus concentration. Lake phosphorus data are too sparse to be meaningfully included in the table of annual variations but salient points from the discussion in Section 2 are included here. Epilimnetic total phosphorus levels indicated a year-over-year increase in concentration for the 4 years with data: 2005, 2010, 2011 and 2012. Figure 3-2 shows this trend. We also examined available total phosphorus data from the tributaries to determine if they could explain the increase in the lake's epilimnetic concentration; the data are sparse, however, and they show no relationship between tributary phosphorus and the increase in the lake. Hypolimnetic phosphorus concentrations measured in the isolated portion of the deep hole (below 30 meters depth) were shown capable of reaching a similarly elevated value late in the stratified season across all the years with data at that time; thus, the bottom water concentration achieved is not considered as significant as the areal extent of anoxia across the bottom in defining potential for phosphorus load from the sediments.

Table 3-1
Key Factors affecting Lake Auburn Water Quality, 2001-2012

Year	Intake Temperature	Rainfall/Extreme Precipitation Events	Anoxia Present?	Turbidity (days above 1 NTU from 2005)	Secchi Depth (months where 1 or more readings < 6 meters)
2001	Spring cooler than average; August through December warm	32.5 inches; severe drought with very low rainfall from August; lake level dropped 4 ft	No	Generally below 0.5 NTU; max turbidity of 1.3 in October	3 months: September through November
2002	Summer cooler than average. August through December warm	44.3 inches; well below average. April, May, and June above average	Onset 9/20; mild	Average close to 0.5. May and August higher	4 months: April, May, June, and October
2003	January, February, and July through November warmer than average	46.0 inches; below average, October wetter than average	No	Average close to 0.5; one reading above 1 in May and another in November	October below 6 meters
2004	Generally warmer than average, with cool June and July	41.6 inches; well below average	No	Highest in April and October	May below 6 meters
2005	Often warmer than average, but April through June, October, and December cooler than average	65.5 inches; far above average, very wet April/May (18 inches), October; 5+ inch storm in October	No	Average turbidity above 1 in April and early May	5 months: April, May, June, October, and November
2006	Warmer than average except for August and September	62.5 inches; well above average; large inflow associated with Mother's Day storm	Onset 10/4; mild, limited to deep hole	16 days; maximum > 2 NTU in August	2 months: October and November
2007	Generally average	45.9 inches; below average, large inflow associated with Patriots Day Storm	No	11 days; maximum is 1.5 NTU in April	3 months: April, May, and October
2008	Cooler than average. June, July, October, and November warm	63.9 inches; well above average, large inflow associated with Hurricane Kyle in late September	No	22 days; exceeds 3 NTU in June	4 months: June, September through November
2009	Mostly below average, but November and December warm	60.0 inches; above average, February, September, and November wet	No	8 days; Generally below 1, but exceeds 3 NTU in November	May below 6 meters
2010	Temperatures above average. Hot July. October and December cool	55.5 inches; Slightly above average	Onset 10/14; mild, limited to deep hole	38 days; Most spikes after November 1st	3 months; August through October. No data for November
2011	Above average T start in June. Warmest October, November, and December in period of record [1997-2012]	50.4 inches; slightly below average	Onset 8/31; severe but not anoxic at top of hypolimnion	83 days; record (4.4 NTU) in September. Average far above 1 for most of summer	6 months; April-May; Aug-Nov; Secchi depth is 2.1, lowest ever recorded
2012	Above average for most of year; average temperatures in September and October	53.5 inches; slightly above average, June 3 storm (6 inches) increased lake level by 1 foot; total June precipitation over 12 inches	Onset 8/23; complete bottom layer	108 days; average turbidity above 1 NTU for most of summer. Highest value 3.6 NTU in September	7 months: all growing season but June; near record low, but slightly deeper than 2011

Comparison of these key factors leads to several observations. At the beginning of the period, the watershed experienced a severe drought (2001) and the lake dropped 4 feet; a warm fall could have contributed to the inferred moderate algal blooms that correspond with Secchi depths of 5-6 meters.

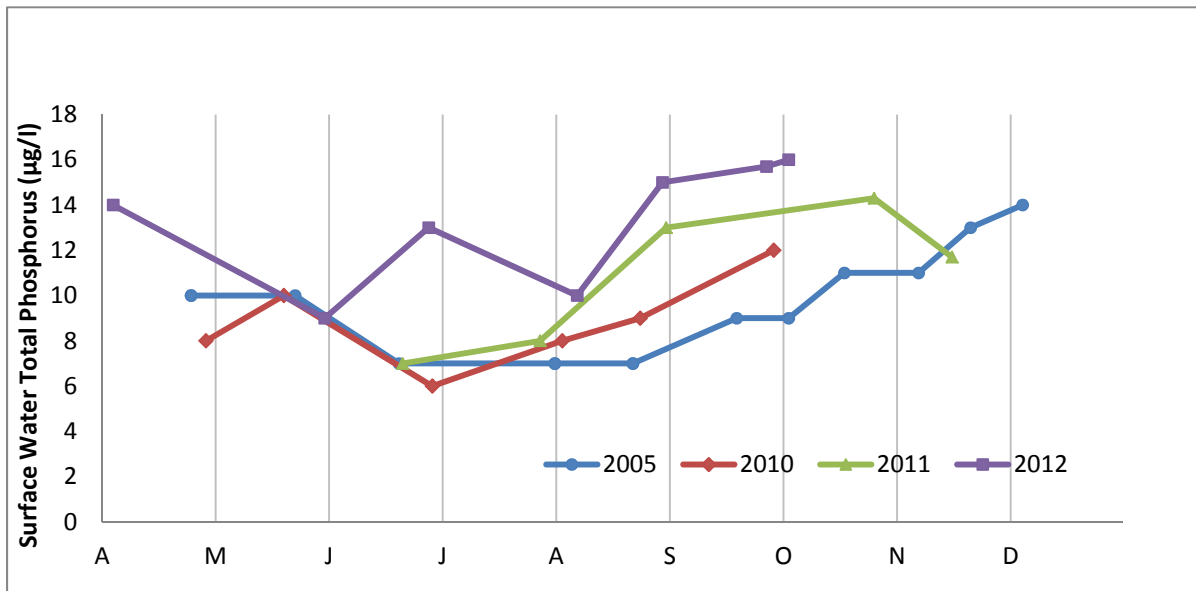


Figure 3-2
Trends in Epilimnetic Phosphorus Concentration, 2005 to 2012

A trend of below average rainfall continued from 2002 to 2004, and all three years had above average water temperature from August through November. Fall Secchi depths were deeper than average indicating below average algal growth.

2005 had the highest rainfall of the period examined with 18 inches of rain falling in April and May, and another 14 inches in October. While only one storm in April/May had greater than 3 inches of rain, the epilimnetic phosphorus data was constant at 10 µg/l in April and May sampling rounds suggesting no response in the water column from an increased load from the watershed. However, the Secchi depth data are slightly shallower than average suggesting increased algal activity or influx of inorganics from the long period of rain.

After the heavy rain in October, turbidity values were excellent with very few turbidity peaks above 1 NTU. Secchi depths, however, decline from 7.5 meters at the beginning of October to 5.8 meters by mid-November, indicating the likely presence of a fall algal bloom.

Above average rainfall continued as a trend for the next four years, except 2007 which had below average rainfall. There were even two large storms (Mother's Day in 2006 and Patriots Day in 2007) that likely contributed additional phosphorus load to the lake through tributary scour. With the exception of 2006, which had above average water temperatures except in August and September, water temperatures tended to be below average. The days with turbidity levels greater than 1 NTU were also small; the most excursions above 1 NTU occurred in 2008, which was also the year with the most months with Secchi depth shallower than 6 meters. *Gloeotrichia* was enumerated by Bates

College in 2008 and the counts were the highest in their record (Figure 2-16). As with 2005, this span of four years is notable primarily because the absence of shallower than normal Secchi depth readings, though 2008 had several Secchi depth readings shallower than 6 meters during the fall algal bloom period, which based on comparative Secchi depth trends was the third largest bloom of the last 12 years.

2010 begins a 3-year period with nearly average rainfall. Water temperatures were above average for the first 9 months of 2010 and again from mid-2011 through 2012. This 3-year period is notable for the steady decline in most factors that describe water quality. The winter of 2011-12 and most of 2012 was notable for its atypically warm weather; by nearly every measure, spring happened about a month earlier in 2012 than any year in memory. In the lake, this manifested itself as near record water temperatures and early onset of and strong summer stratification. The unusual climate in 2012 undoubtedly had a strong influence on the severity of water quality degradation compared with 2011.

While epilimnetic phosphorus values in each year (2010-12) start at 10 µg/l in late spring (the same as the long-term baseline for the lake), they diverge through the summer and fall, with each year building to higher epilimnetic values than the previous year (Figure 3-2). The number of occurrences of turbidity above 1 NTU also increases through the period (38 to 83 to 108 days), suggesting a larger algal community in the fall each year. This too is borne out in the Secchi depth data, where fall (September/October) values average 6 meters in 2010, 3.2 meters in 2011, and 3.4 meters in 2012.

Gloeotrichia data from Bates College also indicate a larger biomass of this alga in 2012 compared to 2011 (no counts are available for 2010); the bloom started earlier in 2012 and was notably larger in both peak and duration than in 2011. The same appears to be true for the *Anabaena* bloom that follows *Gloeotrichia* in 2011, where Ms. Mary Jane Dillingham, AWD's water quality director, noted that while not enumerated in 2012, the *Anabaena* was sufficiently prolific to form surface scums. A key difference in the drivers for water quality in 2011 and 2012 was a large quantity of rain in June 2012, where equivalent total annual rainfall on the lake did not occur until mid-August of 2011. Early June included an intense 48-hour storm, and the phosphorus inflowing from this storm combined with above average temperatures could have contributed to fueling additional algal growth in 2012. But watershed loads would not seem to explain similarly poor (and in some cases worse) water quality conditions in 2011 as rainfall patterns were decidedly average in magnitude and timing. 2011, however, had Hurricane Irene in late August, which may have caused extensive late summer mixing due to high winds; this may have been the source of increase in phosphorus concentrations observed in the surface waters.

While the data available to assess drivers are insufficient to draw firm conclusions, the inferences from this analysis and those that follow in this section is that watershed loads alone do not appear to explain the measured increase in year-over-year epilimnetic phosphorus concentrations from spring through fall. This is supported by the lack of apparent correlation between rainfall/intensity/timing of rainfall to deliver watershed loads during key growing periods and the available surrogates for algal community population (turbidity and Secchi depth). Other possible explanations for increasing epilimnetic phosphorus (internal loading from sediment and algal recruitment) are examined further in Section 3.5.

3.2.2 2011-12 Monthly Presentation of Water Quality Trends and Drivers

Table 3-2 describes the timing and significance of lake stratification, significant watershed inflows, Secchi depth and turbidity measurements, dissolved oxygen concentrations, algal community and phosphorus concentrations for 2011 and 2012.

3.3 Drivers of Increased Turbidity

What is the cause of the increased turbidity at the intake observed in 2011 and 2012? Was this observed in previous years?

Turbidity is a function of the amount of particles suspended in the water column, either suspended particulate matter or algae. Causes of high turbidity can include wave actions that stir near-shore sediments, runoff from intense storms that deliver a large load of fine organic or inorganic material and algal blooms. Before the intake in Lake Auburn was moved further offshore, turbidity values in the intake used to vary primarily due to wave-suspended sediment; with the new location, this is no longer the case. Similarly, water quality measured at the deep hole indicates that the lake has historically been clear with excellent Secchi depth suggesting watershed-delivered sediment is not a source of turbidity. Hence, it appears the recent high turbidity measurements are likely caused by an increase in algae. To test whether turbidity is an indicator of algae and to understand what algal species cause low turbidity, we compared the raw water intake turbidity record to the limited algal data observed by Bates College in 2008, 2011 and 2012.

The NSF studies of Lake Auburn completed by Bates College (Section 2.1) are the source of the available data, which was collected at five locations around the shore: *Gloeotrichia* was enumerated in 2008, 2011 and 2012, and a complete enumeration of the other algae was performed in 2011. The data indicate that *Gloeotrichia* blooms in summer, with peak values in August, and in 2011, this was followed by a fall bloom of cyanobacteria (*Anabaena*, *Microcystis* and *Gomphosphaeri*). Although detailed algal enumeration data do not exist for 2012, it is likely that it also had fall algal bloom evidenced by shallower Secchi depth readings. Observations by Ms. Mary Jane Dillingham, AWD's water quality director, confirmed a large *Anabaena* bloom in October 2012.

Figures 3-3 and 3-4 show the relationship between *Gloeotrichia* and turbidity and other algal species and turbidity, respectively, from the 2011 and 2012 Bates College algae survey.

Table 3-2
2011-12 Monthly Summary of Water Quality Trends and Drivers

	Lake Stratification, Thermocline Location, and lake temperatures	Inflows and significant precipitation events	Secchi Depth	Turbidity	Dissolved Oxygen	Phytoplankton	Phosphorus
May-11	Water column fully mixed in early May. Weak structure starts to develop in late May at around 6 m. Water temperatures below median.	Precipitation close to average, 4.63"; 1.53" event on May 16	5.7-6.3 m; Slightly below average.	Range from 0.51 to 0.62.	Supersaturated to 12 m depth; above 9 mg/l near bottom	Diatoms and Golden browns dominant.	No data available.
Jun-11	Well-defined structure develops. Thermocline at 7 meters. Intake water temperature close to median, around 19°C.	Close to average, 4.18"; almost 2" June 25 to 26.	6.3 – 8.0 m; below average in early June, close to average in late June.	Range from 0.46 to 1.61; average is 0.63.	Supersaturated to as deep as 12 m. By late June, the bottom 5 m of the lake has 2-3 mg/l DO.	Green algae dominant. <i>Gloeotrichia</i> starts to appear on June 24.	7 - 8 µg/l surface; 16 µg/l bottom.
Jul-11	Thermocline strengthens and deepens to between 8 and 9 m. Intake temperatures are slightly above normal.	Very dry, with only 1.80" rain.	7.6 – 8.4 m; close to normal.	Range from 0.38 to 1.13; average 0.52.	Surface concentrations around 8 mg/l. No metalimnetic oxygen maxima. DO continues to drop in hypolimnion, but no anoxia occurs.	Early July: <i>Tabellaria</i> and Golden browns. Late July, <i>Anabaena</i> and <i>Gloeotrichia</i> .	8 - 10 µg/l surface. No deep samples taken.
Aug-11	Thermocline begins to weaken slightly, and deepens to 10 m. Temperatures close to median.	Close to average, 3.37". 1.6" storm on August 16.	6.8 m on August 3. Drops to 4.2 m by August 31.	Range from 0.71 to 1.65; average 1.15.	Early August around 8 mg/l on surface, 2 mg/l at bottom. Late august anoxia develops in the deep hole below 30 m. Area of higher DO around 5 m.	<i>Gloeotrichia</i> blooms August 11. <i>Anabaena</i> bloom follows on August 17.	10-13 µg/l surface; 24 µg/l deep.

	Lake Stratification, Thermocline Location, and lake temperatures	Inflows and significant precipitation events	Secchi Depth	Turbidity	Dissolved Oxygen	Phytoplankton	Phosphorus
Sep-11	Thermocline weakens and drops to 11 m by end of month. Intake temperatures slightly elevated from normal.	Wet, with 5.74" rain.	Very low, dropping to 2.1 m on 9/28.	Range 1.5 to 4.4; average 2.33. Turbidity is always above 1.	8 - 9 mg/l in epilimnion. Hypolimnetic anoxia grows to be widespread by late September	Large <i>Anabaena</i> bloom on September 9. <i>Gloeotrichia</i> declines and is absent September 29.	No data available.
Oct-11	Thermocline weakens through October. Still weakly stratified structure in late October. Exceptionally warm lake temperature.	Wet, with 5.87" rain.	Low: 2.9 m on October 6, 5.1 m on 10/26.	Range 0.62 to 2.75; average 1.47.	Epilimnion saturated at ~9 mg/l. Steep gradient across metalimnion. Lower 70% of hypolimnion is nearly devoid of oxygen.	Early October: <i>Anabaena</i> dominant; <i>Tabellaria</i> present; by late October <i>Tabellaria</i> dominant.	13 - 15 µg/l surface; hypolimnion linearly increases to 40 µg/l at bottom.
Nov-11	Fully mixed by mid-November. Warmest November temperature since recordkeeping started in 1997.	Close to average precipitation, 3.44".	Below normal, 5.5 m on November 1 to 4.9 m on 11/16	Range 0.75 to 1.09; average 0.86.	Surface concentrations climb to above 10 mg/l. Hypolimnetic concentrations increase to 2 - 3 mg/l.	<i>Tabellaria</i> dominant.	Uniform 10 - 14 µg/l throughout water column.
Winter 2011-2012	Lake does not ice over; temperatures are warm throughout winter				n/a	Diatoms dominant.	No data available.
May-12	Water column begins to stratify in early May. Moderate structure develops around late May; weak thermocline around 5 m. Lake temperatures warm relative to median.	Very high, 6.5".	Low on May 14, 5.2 m. May 31 is 7.3 m.	Range 0.67 – 1.28; average 0.80.	Supersaturated to ~12 m, with maxima at 7 m. Depletion in hypolimnion starting DO approaching 7 mg/l at end of month.	Diatoms and Golden browns dominant.	10 - 13 µg/l throughout water column.

	Lake Stratification, Thermocline Location, and lake temperatures	Inflows and significant precipitation events	Secchi Depth	Turbidity	Dissolved Oxygen	Phytoplankton	Phosphorus
Jun-12	Temperature drop in early June (mixing event or watershed inflow) causes epilimnetic structure to briefly dissipate. Strong, steep temperature gradient develops by late June at around 6 m. Temperature slightly high relative to median.	Very high, 13.2". Over 6" fall in a single storm June 3 and 4.	5.7 to 6.8 m, slightly below normal.	Range 0.56 to 2.08; average 0.88.	9 mg/l at surface; 6 mg/l at bottom. Metalimnetic maxima dissipates early in June	<i>Gloeotrichia</i> present at low levels until a small bloom in mid June. Otherwise Diatoms and Golden browns dominant.	6/29 - Between 1-4-18 µg/l at the surface (maxima at 8 m) reaching 20 µg/l at the bottom.
Jul-12	Thermocline continues to strengthen. Depth around 8 m. Intake temperature high relative to median.	Dry, 2.95" rain.	Lower than normal in late July, 5.5 to 6.0 m. No data taken early July.	Range 0.57 to 1.04; average 0.68.	8-9 mg/l at surface; hypolimnetic DO depletion widespread with depth; 3-4 mg/l at bottom.	Second <i>Gloeotrichia</i> bloom occurs at mid-month. Green algae otherwise dominant.	No data available.
Aug-12	Thermocline deepens to 10 m. Brief mixing event in late August deepens thermocline slightly. Intake water temperature very high.	Wet, 6.05"; several moderate storms, but no large storms.	Reaches record low for August on the 23 rd , 3.5 m. Range from 3.5 to 5.2 m.	Range 0.65 to 1.7; average 1.05.	Early August around 8 mg/l on surface, 2 mg/l at bottom. Late August anoxia develops in the deep hole and extends to 25 m depth by month end.	<i>Gloeotrichia</i> high until end of month. <i>Anabaena</i> dominant.	15 µg/l throughout epilimnion. Bottom is 45 - 55 µg/l.
Sep-12	Thermocline weakens and deepens to 11 m. Intake water temperature cooler than long-term median.	Normal precipitation volume, 3.6".	Still low, 2.6 to 4.2 m.	Range 1.09 to 3.55; average 2.27. Turbidity is always above 1.	Surface 8 mg/l. Hypolimnion nearly completely devoid of oxygen. Concentrations below 1 mg/l.	<i>Gloeotrichia</i> absent by mid-month. <i>Anabaena</i> dominant. Some green.	15 - 20 µg/l in epilimnion; 35 µg/l deep.
Oct-12	Stratification weakened; thermocline ~11 m; by late October very weak structure. Temperature close to normal.	Normal precipitation volume, 4.25"	Begins to deepen, but still below normal.	Range 1.28 to 2.81. Average 2.03.	Surface 8 - 10 mg/l. Hypolimnion still completely anoxic. Concentrations < 0.5 mg/l below 17 m	Some <i>Anabaena</i> and green. Golden browns dominant.	15 - 20 µg/l in epilimnion; nearly 30 µg/l deep.

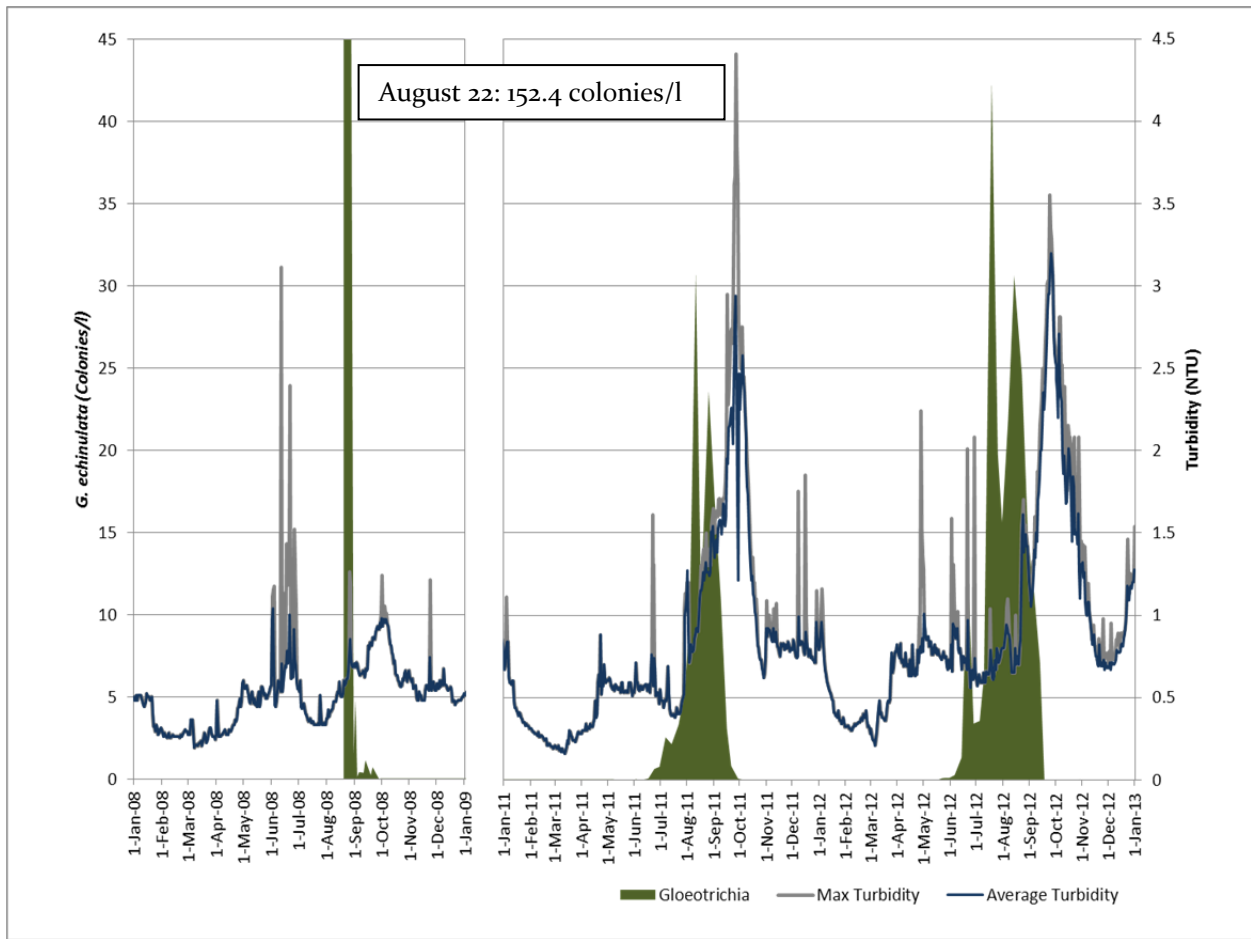


Figure 3-3
***Gloeotrichia* compared with Daily Average and Maximum Turbidity Measurements from the Raw Water Intake, 2008, 2011, and 2012**
Data collected by Drs. Ewing, Weathers, and Cottingham under NSF grants NSF DEB-0749022, NSF EF-0842112m NSF EF-0842125, NSF EF-0842267

Figure 3-3 shows that the *Gloeotrichia* bloom precedes the spike in turbidity in 2011 and 2012, indicating that *Gloeotrichia* itself is not driving the increased turbidity in the lake. It is not possible to make any conclusions about the 2008 dataset because algal sampling started too late, after the turbidity spike, and no other algal enumeration data are available. However, because 2008 Secchi depth is relatively normal in the spring, it is unlikely that a substantial spring algal bloom occurred. Secchi depth in fall 2008, however, is less than 6 meters, indicating that an algal bloom likely occurred in September. This observation matches the pattern observed in 2011 and 2012, though at a much reduced magnitude.

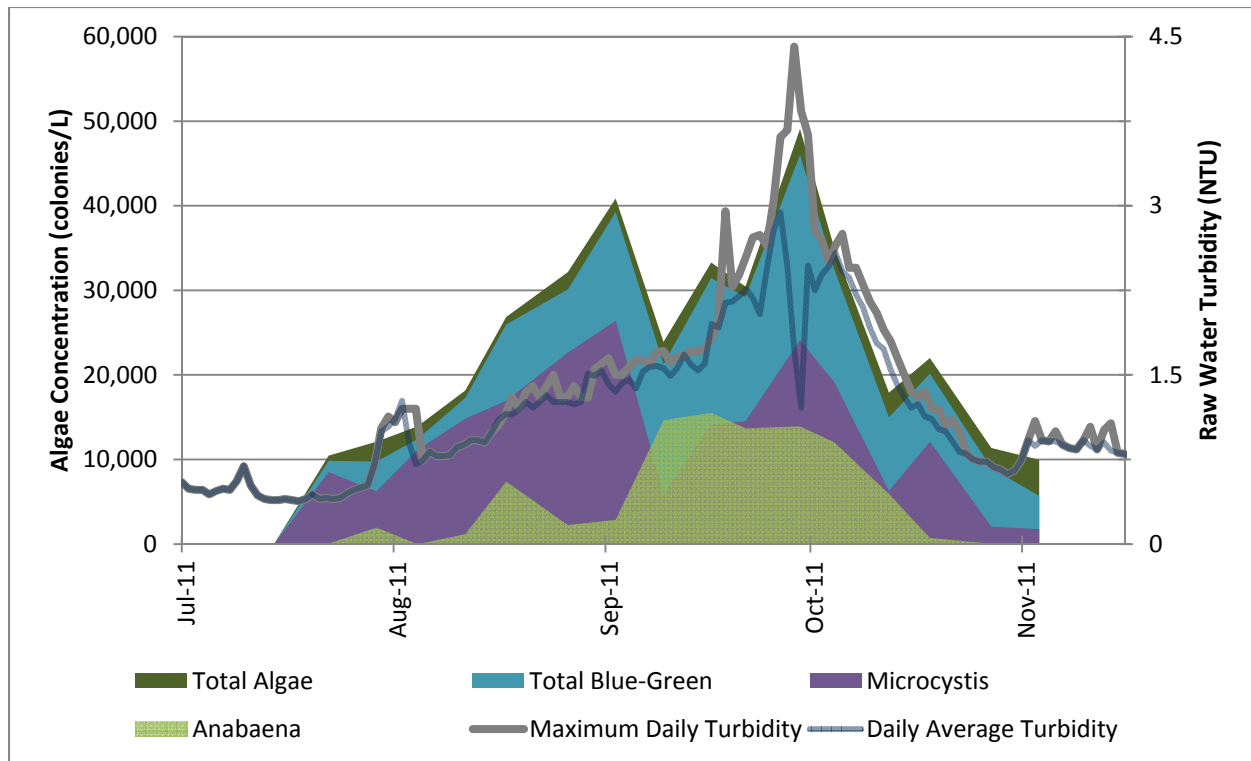


Figure 3-4
Dominant Algal Concentrations from the Bates College 2011 Algal Survey compared with Daily Average and Maximum Turbidity Measurements from the Raw Water Intake
Data collected by Drs. Ewing, Weathers, and Cottingham under NSF grants NSF DEB-0749022, NSF EF-0842112m NSF EF-0842125, NSF EF-0842267

The data in Figure 3-4 show that the spike in turbidity observed in 2011 occurs during a bloom of *Anabaena* and *Microcystis*. The *Anabaena* bloom and the second *Microcystis* bloom both occur in September after the *Gloeotrichia* have died off. Both *Anabaena* and *Microcystis* are much smaller than *Gloeotrichia*; smaller particles create increased turbidity.

This pattern leads to several conclusions about potential drivers of the recent water quality decline. First, the *Gloeotrichia* do not directly cause the turbidity problems observed in the lake. Instead the fall turbidity increase is attributable to blooms of *Anabaena* and *Microcystis*.

3.4 Drivers of Increased Anoxia

What can explain the increase in extent of anoxia in 2011 and 2012?

3.4.1 Anoxia in Lake Auburn

The dissolved oxygen profile dataset allows us to characterize the temporal and spatial extent of anoxic conditions for each year on record. If anoxic conditions are defined to be a dissolved oxygen concentration of less than 2 mg/l, then anoxia was measured at the deep hole station in 8 years since 1979. Data taken prior to 1986 are inconclusive because these profiles did not extend beyond 20 m,

and no dissolved oxygen or temperature data was collected in 1980. Table 3-3 presents the onset date of anoxia, the shallowest depth at which these conditions were recorded, the area of the bottom overlain by anoxic water and the anoxic factor (described in Section 2) which integrates the previous factors into a severity of anoxia index. The data highlight the severity of anoxia seen in 2011 and 2012 compared to previous years.

Table 3-3
Anoxic Conditions observed at the Deep Hole Sample Location

Sample Year	Onset Date for Anoxia	Shallowest Depth of Observed Anoxia (m)	Bottom Area Overlain by Anoxic Water (million m ²)	Anoxic Factor (see Section 2.2.3.2)
1993	October 12 th	34	0.06	0.1
1994	August 5 th	17	1.8	2.3
2000	October 2 nd	23	0.92	1.2
2002	September 20 th	19	1.5	5.7
2006	October 4 th	32	0.14	0.26
2010	October 14 th	30	0.25	0.28
2011	August 31 st	10	3.8	18.1
2012	August 23 rd	9	4.9	18.9

Assuming that the anoxia is entirely confined to the deep hole when the shallowest depth of observed anoxia is greater than 27 m, there are four years where anoxic conditions extended beyond deep hole. Of these factors, the bottom area overlain by anoxic water is key to determining the mass of sediment phosphorus released to the water column. This is important to understanding overall water quality because sediment exposed to anoxic conditions undergoes oxidation-reduction reactions that release phosphorus into the water column. Although periods of anoxia occur in previous years, the surface area of sediment exposed to water devoid of oxygen highlights the difference between 2011-12 and the rest of the historical record.

In general, anoxia occurs in the deep waters of a stratified lake when the mass of oxygen available at the start of stratification has been consumed by oxygen demanding substances. Primary sources of these substances are algae and other organisms that die in the lake and fecal pellets from organisms in the lake. These fall to the bottom of the lake and decompose, creating a sediment oxygen demand. Inputs of organic matter from the watershed can also contribute oxygen demanding substances.

While the data in Table 3-3 clearly indicate severe anoxia in 2011-12, it is not clear from available data whether the low DO and shallow anoxic depth observed in 2011-12 is indicative of a trend of increasing eutrophication or is part of natural variation in climate and watershed loading.

3.4.2 Impact of June 2012 Precipitation and Possible Influence on Anoxia

June 2012 is remarkable due to an abnormally high volume of precipitation, with over 12 inches of rain were recorded by the National Weather Service COOP gage in Poland, ME. Half of this volume fell during June 3rd and 4th. The intake temperature record indicates that the epilimnion temperature dropped by about 2°C after this storm. The lake elevation increased by about a foot, implying that

about one billion gallons of water was retained in the lake. The total inflow, however, was larger as a stop log was pulled and the sluice gate opened to increase outflow from the lake. Even with these actions, the lake's water levels approached the top of the earthen berm adjacent to the spillway nearly overtopping of the berm (Storer 2013).

The vertical placement of the inflow from the June 3-4 storm event likely influenced water quality in 2012. As an overflow, the storm would have added phosphorus load to the surface of the lake directly benefiting algal communities. If it was significantly colder than the lake, the inflow would have plunged into the hypolimnion, depositing a large mass of oxygen demanding substances into the deeper portions of the lake, helping to create the strong anoxia in 2012.

The placement of the inflow will depend on the relative temperature of the inflow and the lake, and the degree of mixing as it enters the lake. Because temperature is not recorded on the tributaries to Lake Auburn, nearby USGS stream gauges with daily temperature records were used: Wild River in Gilead, ME and Sheepscot River in North Whitefield, ME. Figure 3-5 shows a time series of daily average temperature for each of these rivers plotted alongside the daily average Lake Auburn intake temperature.

The temperature trend in both the Wild and Sheepscot Rivers is similar: both experienced an approximate 5°C temperature drop immediately following the storm. Figure 3-5 shows that Lake Auburn temperatures drop as well, but that this temperature drop at the intake occurs one to two days later and is smaller in magnitude, about 2°C. The isopleths of temperature profiles collected in 2012 (Appendix C) show a strong mixing event in the surface waters of the lake, with uniform and temporarily lower epilimnetic temperature and steep drop in the thermocline from about 4-5 meters before the storm to about 7 meters after the storm. This suggests that capture of the cooler, slightly deeper water could at least partly explain the drop of temperature at the intake.

May 31st sampling data indicate that Townsend Brook was 18.6°C. Assuming that the same change in temperature of 5°C as was seen at the USGS gages, the Townsend Brook inflow during the storm would be around 13.5°C. Fischer *et al.* (1979) suggest that inflows colder than the epilimnion flowing into a shallow portion of a deep stratified lake will almost instantaneously drop to the lake bottom. The inflow will then spread out laterally along the bottom until the inflow enters an area where its temperature is the same as the surrounding lake water. When this occurs, the inflow will be neutrally buoyant, and will enter the water column at this depth and continue as an interflow.

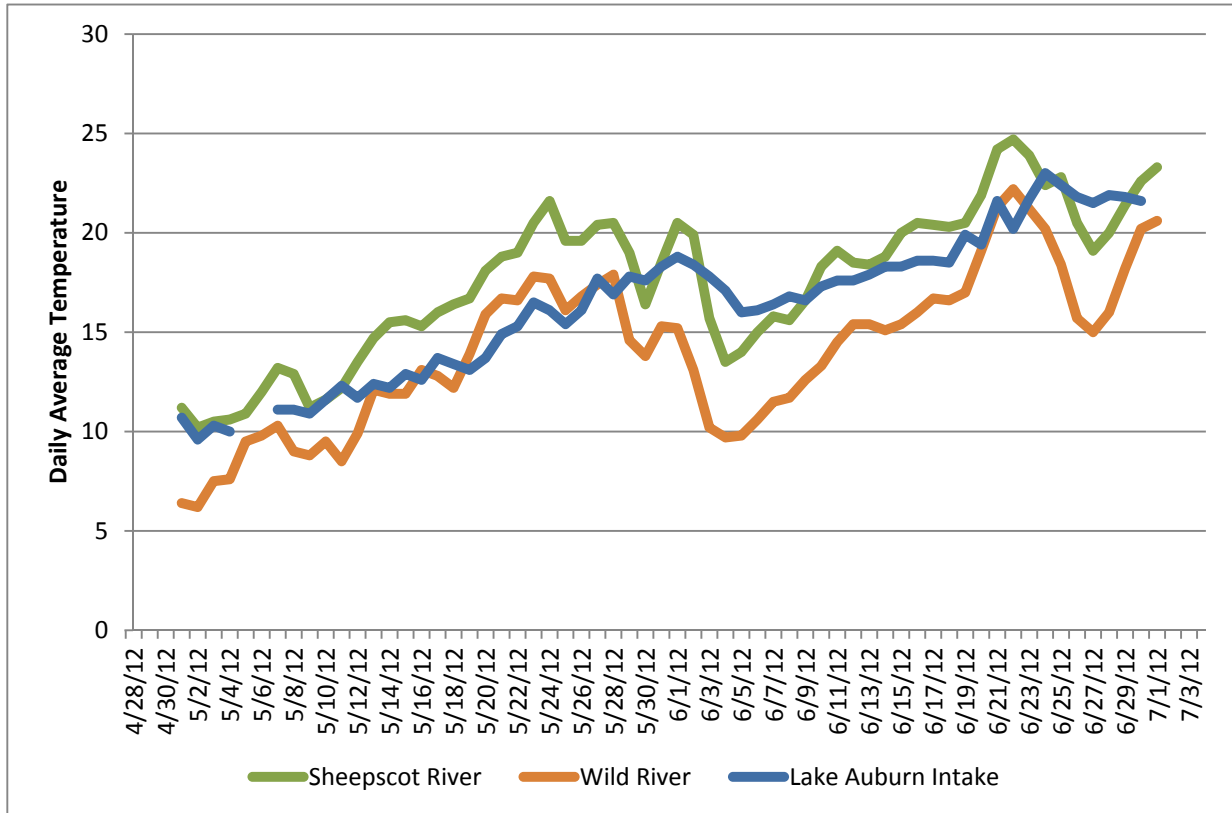


Figure 3-5
Daily Average Temperature for the Sheepscot and Wild Rivers and the Lake Auburn Intake

The closest temperature profile to the June 3 storm was taken on May 31; it indicates that surface temperature is around 18°C, and that the thermocline is around 5 meters. Based on the temperature structure on May 31, the inflows from the storm event would have likely entered the hypolimnion at around 6-7 meters depth, depositing a large inflow of nutrients and organic, oxygen demanding material into the top of the hypolimnion. This influx of organic material into the hypolimnion may have helped consume all of the oxygen in a very short amount of time, subsequently triggering anoxic release of phosphorus from sediments throughout large portions of the lake.

3.5 Drivers of Water Column Phosphorus Concentrations

If the fall algal blooms are fueled by increased epilimnetic phosphorus, what could have caused the increase in phosphorus concentrations? Consider watershed loads, internal generated loads from sediment and algal recruitment from sediments.

This section discusses factors that may have contributed to the observed trend of increasing epilimnetic phosphorus (Figure 3-2) and examines whether this increase can be causally related to interannual variation in watershed loads, internal recycling of phosphorus from sediment in contact with anoxic water or recruitment of sediment phosphorus by algae.

3.5.1 Interannual Variation in Watershed Load

To answer whether interannual variation in watershed loads could be a factor in the increased water column phosphorus, we first need to determine an annual baseline watershed load. Several empirical lake models have been developed to estimate lake phosphorus concentration from watershed loads (e.g., Reckhow 1977; Vollenweider 1975; Larsen-Mercier 1976; Jones-Bachmann 1976). This analysis uses these empirical models in reverse, finding an estimated watershed load given an observed epilimnetic phosphorus concentration.

Because each empirical model was developed to fit a different set of lake data, each model is best applied to lakes similar to those used to develop the empirical fit. Table 3-4 describes several empirical models used in this analysis and compares their data sources, constraints, and biases. In Table 3-4, P is total phosphorus concentration in mg/l, L is the watershed load in units of $\text{g}/\text{m}^2/\text{yr}$ distributed over the lake surface area, z is the mean lake depth in meters and T is the hydraulic retention time in years. The factor LT/z for Lake Auburn is on the order of 0.05 mg/l, and the average epilimnetic P concentration has historically been around 10 $\mu\text{g}/\text{l}$.

Table 3-4
Empirical Models used to Evaluate Potential Watershed Loads to Lakes

Model	Data Source	Constraints	Biases	Comments
Reckhow Quasi-General	47 north temperate lakes	$P < 0.135 \text{ mg/l}$	none significant	-
		$LT/z < 0.298 \text{ mg/l}$		
		$q_s < 187 \text{ m/yr}$		
Kirchner-Dillon 1975	12 Canadian Shield lakes	$P < 0.015 \text{ mg/l}$	not evaluated	will likely overestimate P in lakes with high z/T and underestimate P in highly enriched lakes
		$LT/z < 0.050 \text{ mg/l}$		
Vollenweider 1975	unspecified	unknown	not evaluated	
Larsen-Mercier 1976	20 north temperate lakes, primarily oligotrophic	$P < 0.012 \text{ mg/l}$	significant underestimation of P in lakes with $LT/z > 0.300 \text{ mg/l}$	-
		$LT/z < 0.025 \text{ mg/l}$		
Jones-Bachmann 1976	51 natural lakes, primarily north temperate	unknown	not evaluated	Will likely overestimate P in shallow lakes with high values of z/T

Each empirical model describes the underlying lake data well, but this does not guarantee that the model will describe Lake Auburn water quality well even if the lake is within the constraints specified for the model. Thus, it is important to examine a range of empirical equations so that any load estimates are not unreasonably biased towards the lakes used to develop any one empirical model.

Here, we estimate watershed load using each of these equations. The results of the Reckhow Quasi-General, Kirchner-Dillon, Vollenweider, Larsen-Mercier, and Jones-Bachmann equations are then averaged to estimate the watershed load necessary to achieve observed epilimnetic concentrations.

Assuming the long-term average epilimnetic phosphorus concentration in Lake Auburn is 10.3 $\mu\text{g}/\text{l}$, these models predict that an estimated baseline watershed total phosphorus load between 597 and

1,425 kg/year (Table 3-5); the average predicted load from all is 1,029 kg/yr. This average is indicative of the order of magnitude of phosphorus loading that can be expected in a typical year.

Table 3-5
Estimated Watershed Loads Assuming an Average 10.3 µg/l
Epilimnetic Total Phosphorus Concentration

Model	Estimated Watershed Load (kg/yr)
Kirchner-Dillon 1975	1,058
Vollenweider 1975	597
Reckhow 1977 (General)	1,425
Larsen-Mercier 1976	848
Jones-Bachmann 1976	1,219
<i>Model Average</i>	<i>1,029</i>

In 2012 the average epilimnetic phosphorus concentration approached 15 - 20 µg/l in late fall, representing an increase of approximately 6 µg/l from concentrations observed during late summer. The empirical models were used to estimate the watershed load required for a 16 µg/l epilimnetic concentration to compare the additional watershed load needed to elevate the epilimnetic phosphorus concentration above the average baseline concentration. The results of the empirical models are described in Table 3-6.

Table 3-6
Estimated Watershed Loads Assuming an average 16 µg/l
Epilimnetic Total Phosphorus Concentration

Model	Estimated Watershed Load (kg/yr)	Change From Load @ 10.3 µg/l (kg/yr)
Kirchner-Dillon 1975	1,643	585
Vollenweider 1975	927	330
Reckhow 1977 (General)	2,213	788
Larsen-Mercier 1976	1,318	470
Jones-Bachmann 1976	1,894	675
<i>Model Average</i>	<i>1,599</i>	<i>570</i>

The models predict that an additional 330 to 788 kg of phosphorus is required to match the observed increase in epilimnetic phosphorus concentration observed in late 2012; the average predicted increase in watershed phosphorus load is 570 kg.

Given that the typical phosphorus load from the watershed is on the order of 1,000 kg/yr, it is unlikely that the watershed around Lake Auburn delivered the entire 570 kg of phosphorus that was added to the epilimnion during the fall 2012. This indicates that there were likely other sources of phosphorus during 2011 and 2012 in addition to the watershed load.

Although this analysis indicates that the watershed is unlikely the sole contributor of the phosphorus load required to increase epilimnetic phosphorus concentrations, June 2012 is remarkable due to an abnormally high volume of precipitation. During this month, over twelve inches of rain were recorded by the National Weather Service COOP gage in Poland, ME; half of this volume fell during June 3rd and 4th. Since nonpoint source loading typically increases with increased precipitation volume, the June 3-4th storm would have added a substantial amount of phosphorus into the lake. Furthermore, this volume of rain typically causes high amounts of scour, transporting additional inorganic material into the lake.

This indicates that interannual precipitation variation may have supplied sufficient load to the lake to cause the severely degraded water quality observed in 2012. However, 2011 had similar degraded water quality, evidenced by high phosphorus concentrations, widespread hypolimnetic anoxia and high algae concentrations. There were no extreme precipitation events in 2011; therefore, even if interannual variations in watershed load helped explain why epilimnetic phosphorus has increased, the similarities in water quality and the differences in climate between 2011 and 2012 indicate that interannual variation is not the only factor that needs to be considered.

3.5.2 Estimates of Sediment Phosphorus Load

Under anoxic conditions sediment phosphorus undergoes a reduction-oxidation reaction and becomes dissolved in the water column. High phosphorus concentrations near the lake bottom are generally indicative of sediment phosphorus release; evidence of this mode of phosphorus release (higher concentrations of phosphorus in deep samples at the deep hole station) has been found during most years. This section estimates the amount of phosphorus that could be released from sediment under anoxic conditions. Two methods are used to estimate potential phosphorus release rates: the anoxic factor and measured iron-bound phosphorus concentrations.

3.5.2.1 Anoxic Factor

The AF provides a way to estimate the amount of phosphorus released into the water column under anoxia. Since the AF is defined as days per year of anoxia normalized by the lake surface area, we can calculate the potential phosphorus release from anoxic sediments by multiplying the AF by the lake surface area and by assuming a typical phosphorus release rate of $12 \text{ mg m}^{-2} \text{ d}^{-1}$ under anoxic conditions (Ken Wagner 2013).

Using the AF computed for 2012 (18.9; Table 2-3) yields a potential phosphorus release of 2,000 kg. In lakes, 10 to 40 percent of phosphorus released into the hypolimnion typically migrates into the epilimnion. This suggests that internal load due to anoxic release of phosphorus could have contributed somewhere between 200 and 800 kg of phosphorus into the epilimnion, which is consistent with the 330 to 778 kg of additional phosphorus load predicted by the empirical equations described in Section 3.5.1.

3.5.2.2 Sediment Iron Bound Phosphorus Estimate of Anoxic Load

Measurements of iron-bound phosphorus (Table 2-1) were also used to provide a second estimate of sediment phosphorus load that could be released into the hypolimnion. Observed solids fraction and moisture content found an average specific gravity of 1.43 and 30% solids content. Observed iron-bound phosphorus measurements were distributed throughout the lake sediment by depth; iron-bound phosphorus values for depths not sampled were computed using a linear interpolation.

The interpolated iron-bound sediment phosphorus concentrations were then applied to the average sediment characteristics to compute the available phosphorus mass per square meter of sediment area exposed to anoxic conditions; Table 3-7 provides this estimate for each lake depth (m), along with the sediment surface area below this depth and the total phosphorus available for anoxic release.

In 2012, anoxia was observed in water below 10 m during late fall. Using the computed available sediment mass per unit area and sediment surface area in Table 3-7, the available phosphorus mass is approximately 95,000 kg. However, the phosphorus release rate from anoxic sediments slows dramatically as water phosphorus concentrations increase. Most studies in the literature indicate that the sediment phosphorus release rate stops when the water concentration reaches 100 µg/l. If the volume of water below 10 meters depth is 3.03 million m³, then only 3,030 kg phosphorus is available for release under anoxic conditions. Again assuming that 10 to 40 percent of the hypolimnetic phosphorus released will migrate into the epilimnion, this implies an increased phosphorus load of 300 to 1,200 kg is possible from internal recycling.

3.5.2.3 Evaluation of Internal Recycling Estimates

Both methods of estimating internal phosphorus load contribution from internal recycling produce similar results. The estimate of additional phosphorus contribution using observed sediment phosphorus concentrations, 300 to 1,200 kg, is consistent with the 200 – 800 kg estimate from the AF calculation. Furthermore, these estimates are both consistent with the difference in load required to achieve an increased epilimnetic phosphorus concentration of 6 µg/l. While there is considerable uncertainty in the amount of sediment phosphorus that is able to make it into the epilimnion, these estimates show that internal recycling could have realistically caused the observed phosphorus concentration increase in 2012.

3.5.3 Internal Loading from Algal Recruitment from Sediments

Evidence from the Secchi depth and turbidity data strongly suggest that algal concentrations in Lake Auburn have increased in 2011 and 2012 when compared with previous years. Algal enumerations from 2011 suggest that *Gloeotrichia* in summer was succeeded by *Anabaena* in late summer and fall, which was followed by *Tabellaria*.

Gloeotrichia rises from the benthos in the spring, bringing excess phosphorus from the sediment into the water column to feed growth later in the season (Karlsson Elfgren 2003; Carey *et al.* 2008). When the *Gloeotrichia* die some phosphorus will return to the deep layer of the lake with algae, while some phosphorus will remain in the epilimnion. Thus, algal recruitment could have contributed some of the increased epilimnetic phosphorus load as a supplement to the anoxic phosphorus release.

This section estimates the potential phosphorus contribution of *Gloeotrichia* to see if it is a potential source of phosphorus. It also evaluates whether *Anabaena* could be the source of phosphorus to the epilimnion.

To estimate the phosphorus concentration of a *Gloeotrichia* colony, we need to estimate the biovolume, or the amount of organic material contained within each colony. *Gloeotrichia* biovolume was estimated by assuming that each colony is between 500 to 1,000 µm in diameter, with its biovolume ranging from one-third to one-half of the equivalent spherical volume. By assuming that 1

million μm^3 is equal to 1 $\mu\text{g/l}$ of algae, this amounts to 49 to 393 $\mu\text{g/l}$ algae mass. Then, assuming that 0.2 to 1 percent of the *Gloeotrichia* biomass is phosphorus, that 25 to 50 percent of the colonies remain in the epilimnion and that there are about 30 colonies/l, the estimated average concentration increase is 8 $\mu\text{g/l}$, with a range of 1 to 15 $\mu\text{g/l}$. This implies that the rise and decline of the *Gloeotrichia* population could be the vector for increased phosphorus in the epilimnion.

In 2011, the Bates College sampling program for *Gloeotrichia* included collecting concurrent samples to be analyzed for total phosphorus. Figure 3-6 displays the phosphorus values from the five stations in each sampling round, along with the average *Gloeotrichia* concentrations from the same five stations. Phosphorus concentrations before and during the *Gloeotrichia* bloom were generally 10 $\mu\text{g/l}$ or less. As the *Gloeotrichia* started to die off in mid-September, the phosphorus concentration increases significantly to ranges from 10 to 17 $\mu\text{g/l}$.

While Figure 3-6 suggests a relationship between the waning *Gloeotrichia* bloom and the increase in total phosphorus levels, the total phosphorus measurements should already include the phosphorus in *Gloeotrichia*'s cellular material. Thus, in this dataset, the timing of the increase in phosphorus would appear to be coincidental, rather than causal, with the decline in *Gloeotrichia*. Therefore, it is not entirely clear if the increased phosphorus concentrations are from the *Gloeotrichia* even though the relationship appears to be quite strong; unfortunately, there is not a 2012 total phosphorus dataset that we can use to see if this same trend happens in 2012.

Table 3-7
Phosphorus Mass Available for Release under Anoxic Conditions Calculated
Using the 2012 Sediment Iron-bound Phosphorus Data

Depth (m)	Sediment Fe-P (mg/kg)	Available P (g/m ²)	Surface Area	Total P Available (kg)
0	31	1.6	0	0
1	31	1.6	295,475	485
2	31	1.6	556,441	913
3	31	1.6	545,680	895
4	31	1.6	540,194	886
5	31	1.6	481,344	790
6	38	2.0	495,110	995
7	56	3.0	474,266	1,405
8	74	3.9	820,577	3,213
9	162	8.6	1,106,537	9,485
10	206	10.9	643,258	7,011
11	250	13.2	360,184	4,764
12	533	28.2	251,136	7,076
13	815	43.1	192,731	8,311
14	923	48.8	176,696	8,624
15	1,030	54.5	187,836	10,237
16	939	49.7	165,277	8,210
17	848	44.9	158,444	7,107
18	757	40.0	186,774	7,478
19	666	35.2	146,335	5,153
20	574	30.4	146,586	4,455
21	483	25.6	141,780	3,626
22	392	20.8	118,569	2,461
23	301	15.9	108,241	1,724
24	210	11.1	105,651	1,174
25	210	11.1	100,418	1,116
26	210	11.1	91,315	1,015
27	210	11.1	92,612	1,029
28	210	11.1	87,675	974
29	210	11.1	82,810	920
30	210	11.1	61,437	683
31	210	11.1	51,313	570
32	210	11.1	41,295	459
33	210	11.1	35,592	395
34	210	11.1	41,621	462
35	210	11.1	23,248	258

Notes: 1. Fe-P concentrations were assigned based on depth. Concentrations for depths not sampled were computed using a linear interpolation. 2. Assuming the average measured specific gravity of 1.43 and solids content of 37%

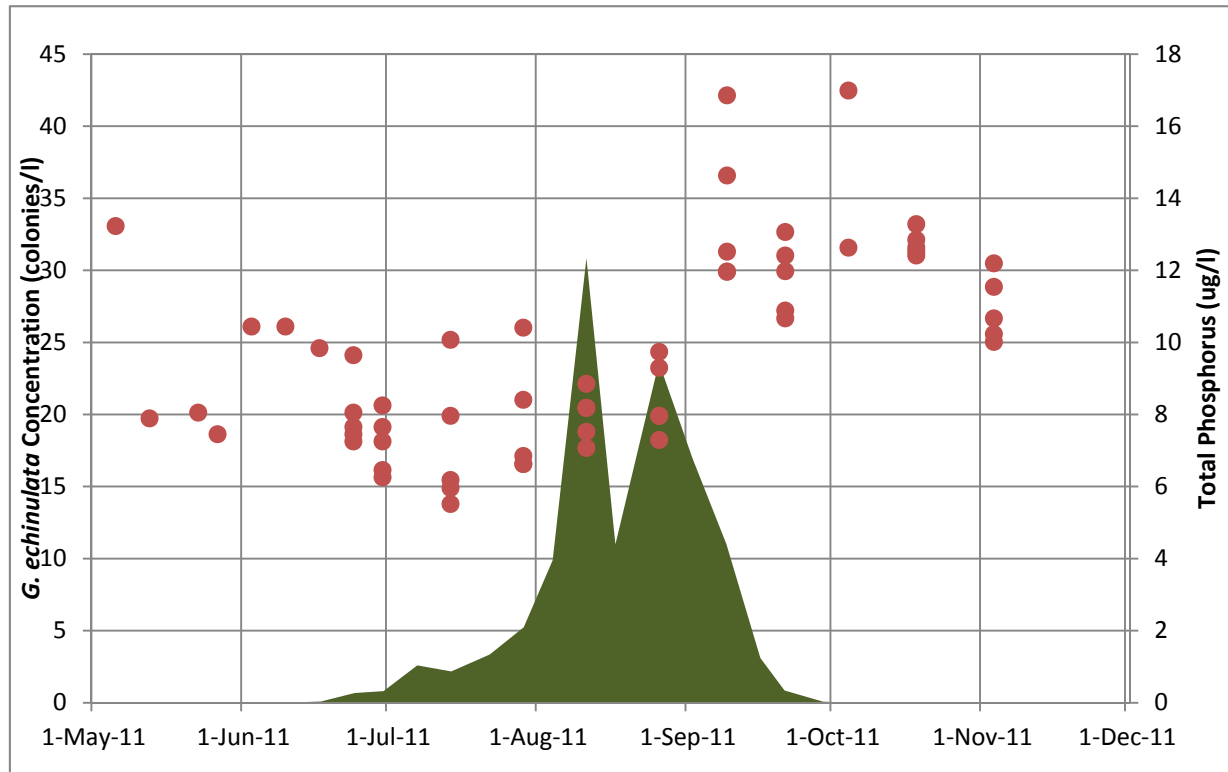


Figure 3-6

2011 *Gloeotrichia* compared with Concurrently Sampled Total Phosphorus Samples from around the Lake Perimeter

Data collected by Drs. Ewing, Weathers, and Cottingham under NSF grants NSF DEB-0749022, NSF EF-0842112m NSF EF-0842125, NSF EF-0842267

It is interesting to note that *Anabaena*, which was also very abundant in both 2011 and 2012, also rises from a resting stage in the sediment to bloom in the epilimnion. In 2011, the *Anabaena* bloom lasted for about 6 weeks, with the bloom rising as the *Gloeotrichia* bloom declined (compare Figures 3-3 and 3-4). Although the *Anabaena* bloom occurred in the fall after the phosphorus increase, we estimated the mass of phosphorus associated *Anabaena* rising from sediment to check if it is a potential vector of phosphorus into the epilimnion.

We can estimate the potential contribution of phosphorus to the epilimnion using observed algal concentrations and assuming that 1 million μm^3 is equal to 1 $\mu\text{g/l}$ biomass and that 0.1% of the biomass will be phosphorus. The observed concentrations during September and October 2011 suggest 22 to 88 million μm^3 of *Anabaena*. Assuming a 10-meter thick epilimnion in the fall results in an increased phosphorus concentration of much less than 1 $\mu\text{g/l}$, which is not enough to account for the 5-7 $\mu\text{g/l}$ increase in phosphorus observed from August to October. It does not appear that *Anabaena* could have carried sufficient phosphorus to the epilimnion to explain the increase in phosphorus there. It is reasonable to conclude that *Anabaena* was reacting to available phosphorus, not the source of it.

3.5.4 Findings

Epilimnetic phosphorus concentrations increased rapidly in the fall of 2011 and 2012. Data from 2012 were used to determine if those increases could be explained by watershed loads, internal loads derived from sediment or algal recruitment.

Empirical equations of watershed load and epilimnetic phosphorus concentration were used to determine that the observed increase in phosphorus concentration would have required delivery of 330 to 778 kg of phosphorus in watershed load over a few months (August to October). As this is a substantial portion of the estimate average annual watershed load of 1,000 kg/yr, it seems unlikely that the watershed alone could have contributed an additional load of this magnitude to the lake.

Further, CEI's analysis of changes in the watershed in the past few years (Appendix A) indicates only small changes in land use, discounting development as a likely source of increasing watershed loads. This combined with average annual rainfall conditions experienced since 2010 suggest that annual variations in runoff do not contribute to the increasing load.

Order of magnitude estimates of internally generated sediment load and recruitment of sediment phosphorus by *Gloeotrichia* both indicated that these mechanisms could have released sufficient mass to cause the observed increase in epilimnetic phosphorus.

Thus, while it is plausible that all three mechanisms contributed to the observed increase in epilimnetic phosphorus, the watershed load alone is not sufficient on its own to create the increase. Further, this analysis has shown that internal recycling, recruitment of phosphorus by *Gloeotrichia*, or a combination of both could have contributed to the observed increase in epilimnetic phosphorus.

The limited nature of the available data means that more study is necessary to better define and partition the load among these source vectors. There are many unknowns surrounding the phycology of *Gloeotrichia*, such as the depths it tends to settle on the benthos and the amount of phosphorus it will recruit. Similarly, the spatial variation in iron-bound phosphorus observed in the sediments and the uncertainty surrounding how much phosphorus is able to migrate into the epilimnion also limit this estimate. Section 4 includes recommendations on changes to the current monitoring program that would allow better measurement of watershed load and the mass of phosphorus in the hypolimnion. It also recommends continuing and expanding the enumeration of *Gloeotrichia*.

3.6 Long-term or Short-term Trend?

Is the degraded lake water quality in 2011 and 2012 part of a long-term trend or better explained by within year changes?

The available data do not support a firm conclusion to this question. Section 3.2.1 provided an analysis of the interannual changes in factors key to determining water quality in Lake Auburn. The most direct causal indicator of poor water quality is the increase in phosphorus levels in the epilimnion both in year-over-year comparisons from 2005 to 2010 to 2011 to 2012 and for each year from June through fall. It would appear that the levels of phosphorus that increased each year fueled ever larger algal blooms in the late summer and fall, resulting in the peaks in turbidity.

Evidence supporting a long-term trend hypothesis includes the year-over-year increases from 2001 to 2012 in incidents of turbidity over 1 NTU, shallow Secchi depth readings in the fall as a surrogate for algal blooms, the extent of anoxia and the epilimnetic phosphorus concentration. That these increases happened despite the apparent steady watershed load (*i.e.*, no significant change in rainfall or land use over the period) point to changes in the lake itself as a vector of change. The phosphorus --> algae --> anoxia --> phosphorus cycle can be a tightly coupled system, where given the multi-year residence time of Lake Auburn could drive declining water quality.

In this point of view, there needs to be a trigger to initiate this change. Two explanations are candidates.

- One explanation starts in the watershed: five preceding years (2005-2009) of well-above-average rainfall delivering increased phosphorus loads to the lake, slowly building phosphorus concentrations, and stimulating algal growth, which both ‘fertilizes’ the bottom increasing oxygen demand, expanding the areal extent of anoxia and increasing the mass of phosphorus to be regenerated. This increase in phosphorus mass released from the sediments then is the vector of change as contemporary watershed loads return to typical levels.

Using CEI’s estimated watershed phosphorus loads (Table 3-7; Appendix A), the change in watershed load has been relatively small, likely because 78% of the watershed is forested. For example, there was a 9% increase in loads comparing three-year periods in 2007-09 compared to 2010-12, and reaching back to 2005 (the highest rainfall year since 2000) the average load for 5 years was 15% higher than in 2010-12. Because the starting phosphorus concentration is small, even a 15% increase would only be a small change in the concentration in the lake. It is unclear if this sequence of events to dramatically change water quality as was observed in 2011-12.

- The alternative explanation is that recruitment of phosphorus by *Gloeotrichia* was the agent of change. Estimates made in Section 3.5.3 suggest, based on the size of the bloom measured in Lake Auburn, *Gloeotrichia* has the potential to add a large load of phosphorus from the sediments to the epilimnion. This load fuels the tightly coupled cycle of phosphorus --> algae --> anoxia --> phosphorus that lead to degraded water quality.

Evidence can also be presented to support a contrasting perspective – one where the lake is responding to near-term changes in drivers. Starting with epilimnetic phosphorus concentrations, Figure 3-2 shows that despite some variability in early spring phosphorus levels, the concentration in the epilimnion in each of the four years of record starts at the same point in late May/early June (10 µg/l), which is the same as the long-term epilimnetic phosphorus concentration. This suggests that regardless of the lake dynamics in the previous year, the post-spring bloom period has the same starting point to fuel algal growth (excepting *Gloeotrichia*, which brings its own phosphorus to the surface).

CEI’s estimates of seasonal phosphorus input to the lake indicate a large increase in watershed load in the spring from 2010 (about 250 lbs) to 2011 (about 550 lbs) to 2012 (about 950 lbs, fueled by a very wet June). Delivery of this much additional load prior during the early algal growth period could contribute a seasonal organic load to the lake bottom. Add to this the atypical climate from late 2011

through 2012 (early ice out, near record water temperatures, abundant spring and summer sunlight) and ideal conditions exist for stimulating algal growth to raise oxygen demand in the bottom exacerbating that year's anoxia. Slightly warmer water holds less oxygen so the starting mass may have been lower in 2012. Because anoxia reached to the top of the hypolimnion and there was a larger mass of phosphorus regenerated from the sediments there was a greater probability that hypolimnetic phosphorus would reach the upper water column fueling the late summer/fall blue-green algal bloom(s).

Regardless of which explanation (or both) can be shown to best clarify the drivers for the poor water quality in Lake Auburn in the last two years, it seems clear that in-lake management options will be needed in addition to continuing to strengthen watershed management. This is the topic of the next phase of this study.

3.7 Predicting Future Water Quality

Are these degraded conditions likely to continue in the future?

The limited data and the large amount of uncertainty involved in estimating the drivers of the poor water quality in 2011 and 2012 mean that we cannot conclude with any certainty whether these conditions are likely to continue into the future. More data collection and analysis is required to fully characterize conditions that may have led to the degraded water quality; suggestions for short-term changes to the monitoring program are discussed in Section 4. Nonetheless, the trends discovered in the available data do indicate several factors that would be indicators of continued or worsened water quality impairments:

- Unusually high spring total phosphorus concentrations. High phosphorus concentrations can fuel excessive algal growth, which in turn may cause high turbidity, shallow Secchi depth and anoxic conditions.
- Unusually warm temperatures. High temperatures increase algal growth rates and decrease dissolved oxygen saturation concentration.
- Large, intense storm timed during algal growth periods. This analysis has shown that a large, intense storm in June 2012 may have contributed a large amount of organic matter and phosphorus into the water column at the perfect time to fuel algal growth. Storms similar to this large event may cause degraded water quality in the future.

Section 4 of this report examines short term management options to prevent the water quality problems experienced in 2012 from occurring in 2013. Phase II of this study will investigate long-term management options that will prevent similar water quality problems from occurring in the future.

3.8 Numeric Nutrient Criteria

How does Lake Auburn's water quality compared to Maine DEP's current draft of proposed numeric nutrient criteria?

3.8.1 History of ME DEP Nutrient Criteria

The U.S. Environmental Protection Agency and Maine DEP recognize that nutrient enrichment is a threat to surface water quality. Excess nutrients can cause algal blooms, low dissolved oxygen, fish kills, and generation of cyanotoxins. As a result, EPA has required that each state develop a plan to implement numeric criteria for nitrogen and phosphorus to incorporate into their existing water quality standards. Maine DEP has been developing numeric nutrient criteria since 2001.

Maine DEP has written draft nutrient criteria for surface waters and has solicited public comments. The current draft was issued June 12, 2012, and describes "methods [...] used to make decisions about attainment or impairment of designated and existing uses of surface waters established in the State's water quality classification system." (MEDEP 2012).

3.8.2 Statutory Classification

Maine state standards for classification of lakes and ponds are described in 38 M.R.S.A. §§ 465-A and 480-B. Lake Auburn is classified as a "great pond," defined as "inland bodies of water which in a natural state have a surface area in excess of 10 acres and any inland bodies of water artificially formed or increased which have a surface area in excess of 30 acres." (38 M.R.S.A. § 480-B). The sole classification for great ponds is Class GPA, described as follows:

1. Class GPA waters. Class GPA shall be the sole classification of great ponds and natural ponds and lakes less than 10 acres in size.
 - A. Class GPA waters must be of such quality that they are suitable for the designated uses of drinking water after disinfection, recreation in and on the water, fishing, agriculture, industrial process and cooling water supply, hydroelectric power generation, navigation and as habitat for fish and other aquatic life. The habitat must be characterized as natural. [2003, c. 227, §5 (AMD); 2003, c. 227, §9 (AFF); 2005, c. 561, §10 (AFF).]
 - B. Class GPA waters must be described by their trophic state based on measures of the chlorophyll "a" content, Secchi disk transparency, total phosphorus content and other appropriate criteria. Class GPA waters must have a stable or decreasing trophic state, subject only to natural fluctuations and must be free of culturally induced algal blooms that impair their use and enjoyment. The number of *Escherichia coli* bacteria of human and domestic animal origin in these waters may not exceed a geometric mean of 29 per 100 milliliters or an instantaneous level of 194 per 100 milliliters. [2007, c. 292, §23 (AMD).]

(38 M.R.S.A. § 465-A)

The full text of 38 M.R.S.A. §§ 465-A and 480-B is in Appendix D.

3.8.3 Draft Nutrient Criteria for Surface Waters

The draft nutrient criteria consist of a series of nutrient and response indicators that are used to determine whether or not a body of water is impaired. Nutrient and response indicators applicable to Lake Auburn are described in Table 3-8.

Table 3-8
Maine DEP Draft Numeric Nutrient Criteria

Indicator	Notes	Criteria
Total Phosphorus	Seasonal mean or determined using the Diatom Total Phosphorus Index.	$\leq 15.0 \mu\text{g/l}$.
Percent algal cover	Not applicable to class GPA waters	-
Water column chlorophyll <i>a</i>	Samples should not be adjusted for phaeophytin. For class GPA waters samples should be collected using depth-integrated, epilimnetic cores.	$\leq 8.0 \mu\text{g/l}$
Secchi disk depth	-	≥ 2 meters
Patches of fungi and filamentous bacteria	Includes macroscopically observable patches of fungi and filamentous bacteria on the substrate. Excludes iron and manganese bacteria.	-
pH	-	6.0 – 8.5
Dissolved oxygen concentrations	Established in 38 M.R.S.A §§ 465 and 465-A	None for class GPA waters
Aquatic life use attainment	Established in 38 M.R.S.A § 465-A	

3.8.3.1 Implementation of Nutrient Criteria

Maine DEP proposes to use the following decision framework to determine whether a body of water is impaired.

- A. Not Impaired. All measured response indicators and total phosphorus concentration meet the values stated in Table 3-8.
- B. Not Impaired. All measured response indicators meet the values stated in Table 3-8. Total phosphorus exceeds $15 \mu\text{g/l}$.
- C. Impaired. One or more of the measured response indicators do not meet the values stated in Table 3-8, but the mean total phosphorus concentration is less than $15 \mu\text{g/l}$.
- D. Impaired. One or more of the measured response indicators do not meet the values stated in Table 3-8 and the mean total phosphorous exceeds $15 \mu\text{g/l}$.

If the lake is determined to be not impaired but the phosphorus concentration exceeds 15 µg/l, Maine DEP has the option of setting a site-specific total phosphorus value. If the mean total phosphorus concentration is not more than 20 µg/l, then a site-specific total phosphorus guideline may be set using two different methods: (1) using the mean total phosphorus value as the new site-specific total phosphorus value without conducting further study,” or (2) conducting a study to establish a site-specific total phosphorus value. If the mean total phosphorus concentration is greater than 20 µg/l, then Maine DEP may conduct a study to determine whether a site-specific total phosphorus guideline greater than 15 µg/l is appropriate. In some circumstances the site-specific total phosphorus value may be less than 15 µg/l if Maine DEP deems it necessary for water quality.

3.8.3.2 Lake Auburn and the Draft Nutrient Criteria for Surface Waters

Lake Auburn water quality was compared with the requirements for Class GPA surface waters described in the draft Maine DEP Nutrient Criteria for Surface Waters.

Response Indicators

- Chlorophyll a concentrations have historically been less than the 8 µg/l standard proposed in the draft nutrient criteria. However, the 2012 average chlorophyll a concentration was 14 µg/l, in violation of the 8 µg/l standard.
- Secchi disk measurements have always been greater or equal to 2.0 meters; the minimum recorded Secchi depth was 2.1 m in September 2011. Lake Auburn currently passes the proposed standard.
- To our knowledge, patches of fungi and filamentous bacteria have not been observed on the lake surface.
- The average pH in 2012 was 7.4; Lake Auburn currently meets the pH standard.
- There are no dissolved oxygen criteria for class GPA waters. However, 38 M.R.S.A § 465-A indicates the following criteria must be met:

Class GPA waters must be of such quality that they are suitable for the designated uses of drinking water after disinfection, recreation in and on the water, fishing, agriculture, industrial process and cooling water supply, hydroelectric power generation, navigation and as habitat for fish and other aquatic life. The habitat must be characterized as natural.

Thus, dissolved oxygen is implicitly considered in the aquatic life use attainment indicator.

Nutrient Criteria

Historically, average epilimnetic phosphorus has been around 10 µg/l, below the 15 µg/l standard set by the draft nutrient criteria. However, average 2012 epilimnetic phosphorus concentrations from May through October were 16 µg/l, exceeding of the proposed 15 µg/l standard. Since this is less than 20 µg/l, Maine DEP would have the option of setting a higher site-specific total phosphorus standard.

3.8.3.3 Implications for Lake Auburn

Historically, Lake Auburn would have been classified as “Not Impaired – Nutrient Criteria Attained” according to the requirements stipulated in the Draft Nutrient Water Quality Criteria. In 2012 water quality degraded substantially, and two exceedances of the proposed nutrient criteria were recorded: chlorophyll *a* concentrations were above the 8 µg/l standard, and average phosphorus was above the 15 µg/l standard. This indicates that the lake would be classified as “Impaired – Nutrient Criteria not Attained.” Thus, in order to maintain the lake’s “Not Impaired” status, total phosphorus concentrations and algae concentrations must be reduced in the future through the short- and long-term lake management guidelines.

Section 4

Short-term Actions for Lake Auburn

This section discusses short-term actions recommended for immediate implementation that will allow for improved data collection and start the planning process to reduce turbidity in the lake.

Since the algal bloom-fish kill in fall 2012, AWD/LWD both through this project and by themselves have implemented steps to allow the utilities to be better prepared to address the changing conditions in the lake. To date, AWD/LWD have:

- Collected additional water quality data at additional locations and depths to better understand the conditions in the lake during the algal bloom.
- Acquired equipment and initiated a training program to allow laboratory staff to be able to identify and enumerate algal samples.
- Began releasing water from the sluice gate at the East Auburn Dam to reduce phosphorus mass in the lake, but had to stop shortly thereafter as salmon were following the flow out of the lake. They worked with Maine Inland Fisheries and Wildlife to establish guidelines in the East Auburn Dam Level Control standard operating procedure (SOP) to include considerations to reduce outmigration of salmon and smallmouth bass with outflowing water.
- Organized available water quality data for Lake Auburn in a single format, and established this as a standard to allow for uniform data entry and facilitate 'real-time' analysis of trends in lake conditions.
- Installed pressure transducers at Townsend Brook and North Auburn (Basin) Dam to allow better monitoring of inflows of the major tributaries to the lake.

In addition to these completed or on-going actions, we recommend the following additional actions begin immediately:

1. Implement a revised monitoring program for lake water quality. This is described in Section 4.1.
2. Begin the process on consulting with Maine Department of Environmental Protection (DEP) and Board of Pesticides Control (BPC) to develop an application for the use of an algicide (copper sulfate or hydrogen peroxide) on the lake as a contingency plan if turbidity values rise again in 2013 or beyond. This is described in Section 4.2.

4.1 Comprehensive Monitoring Program for Lake Auburn

4.1.1 Monitoring Objectives

CDM Smith recommends a monitoring program designed to collect a comprehensive array of water quality data sufficient to evaluate recent changes to water quality in Lake Auburn. This sampling plan is designed with the following objectives in mind:

1. Collect data sufficient to improve the understanding of key drivers of water quality in the lake;
2. Have recommendations build on existing sampling programs to maximize the usefulness of existing data;
3. Design the sample collection to obtain sufficiently frequent data with both time and in vertical depth; and
4. Describe a data management and assessment approach that would facilitate review of the data on a timely basis.

The monitoring program suggested in this section does not address the on-going monitoring program for bacteria and pathogens.

4.1.2 Overview of Monitoring Programs

AWD/LWD has an on-going monitoring program. This section makes recommendations to amend the program to align with the objectives in Section 4.1.1.

1. **Vertical Structure Data** – Currently AWD/LWD collect profiles for temperature and dissolved oxygen on a weekly basis with a data sonde during the non-winter months. This should continue. The profiles are supplemented with discrete samples for conductivity, pH, and turbidity taken at 4-m increments. We recommend exploring whether the existing data sonde can be expanded to include additional probes to ease the collection of the parameters collected discretely. If the data sonde can be modified, then the additional parameters should also be collected at the same depth increments as temperature and dissolved oxygen. In addition, we recommend installing at least one thermistor chain at the deep hole sample location (#8) to record continuous temperature data. These data can be used to accurately assess timing and strength of stratification and observe mixing events.
2. **Reservoir Water Chemistry Data** – The sampling plan describes a complete suite of water quality parameters that will provide a thorough evaluation of reservoir water quality.
3. **Reservoir Algal and Chlorophyll Data** – Two programs are recommended: (1) core samples for chlorophyll analysis and identification and enumeration of the algal community, and (2) continuing the sampling program started by Bates College for *Gloeotrichia* and, if possible, adding two sampling locations in the open water of the lake (#12 and #32).
4. **Tributary/Outlet Sampling** – Two programs are recommended: (1) baseline tributary/outlet sampling for water chemistry parameters on a nominal weekly basis and (2) storm event sampling to better characterize pollutant loading to the reservoir.

5. **Reservoir Operations** – A log book should be started to note the changes in operations at the East Auburn Dam. This would include adding or removing stop logs, opening the sluice gate and any other operations that would impact the elevation of the reservoir.
6. **Baseline Sampling in Watershed Ponds** – The water quality in Little Wilson Pond and Mud Pond is not currently understood; a monthly sampling program would better characterize conditions in these upstream ponds.

An important component of a monitoring plan is to have a plan for storing, backing up, and using the data to manage the reservoir. This requires having the resources to input and review the collected data on a timely basis, and, if possible, a dedicated part-time resource (e.g., an intern) should be assigned to this work.

Sampling Locations

The recommended sampling locations are shown in Figure 4-1, and described below. To meet the sampling objectives, at least five open water lake locations should be routinely sampled:

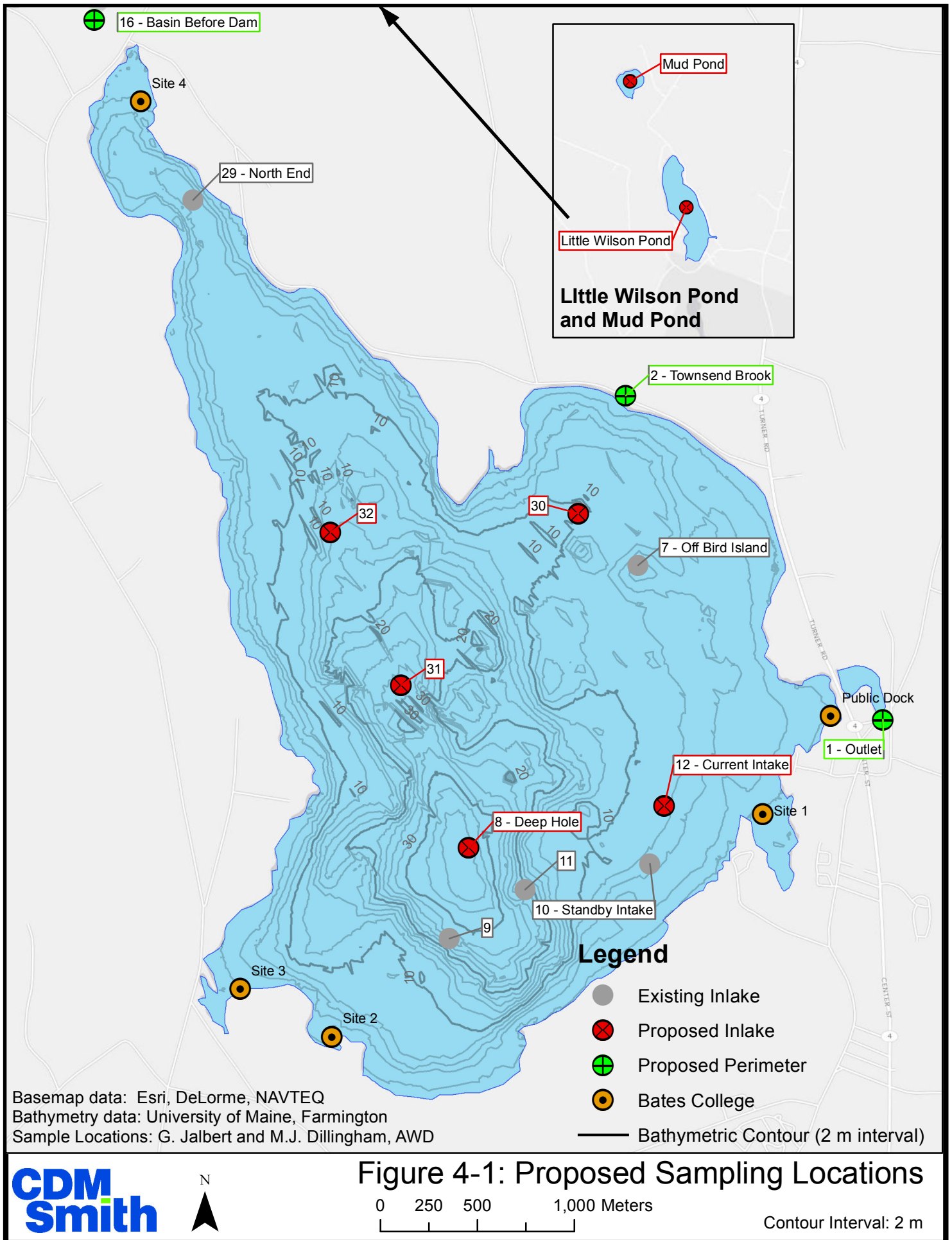
1. The current intake (#12)
2. The deep hole (#8)
3. In the north toward the Basin inlet (#32)
4. In the northeastern lobe of the reservoir (#30)
5. In between the deep hole and the Basin where the water depth reaches 30 m (#31)

These stations are fewer than covered by the current lake sampling program. The reduction in stations will allow for more detailed data collection at the recommended stations.

Sampling for *Gloeotrichia* should continue at the five shoreline sites used in the Bates College program.

Two open water sites, Mud Pond and Little Wilson Pond, in the contributing watershed should also be sampled. These sites are shown on the inset map in Figure 4-1.

In addition, we recommend increasing the sampling frequency of the outlet (#1) and two main tributaries to the lake: Townsend Brook (#2) and Basin before the Dam (#16). These two inlet locations represent over 60% of the inflow to the lake; no other single location represents more than 7% (Dudley 2004). With the recent addition of pressure transducers to monitor water level (and hence flow) to the lake, more frequent samples at the tributary locations will allow for better estimates of loads entering the lake. Outlet samples should only be taken when water is being released from the lake.



Sampling Frequency

Profiles for *in situ* parameters (temperature, dissolved oxygen, pH and conductivity) and Secchi depth readings should continue on a weekly basis. Because vertical profiles using a data sonde and Secchi depth are easily measured, these should also be collected whenever a sampling team is on the reservoir and sampling for another reason.

All open water sampling within Lake Auburn (water chemistry, chlorophyll and algae) should be conducted every two weeks during growing season (mid-April or ice out, whichever is earlier, and until the reservoir is fully mixed in the fall). As safety permits, samples should be collected monthly throughout the winter. This frequency may need to be increased to weekly during periods of change in water quality (e.g., the start of an algal bloom or if high turbidity returns). The exception is sampling for *Gloeotrichia*, which should occur weekly during its growth period; historical data indicate this can be as early as June and extend to mid-September.

Baseline tributary sampling at stations #2 and #16 should ideally occur weekly with additional targeted wet weather sampling during rain events. Sampling at the Outlet (#1) should occur only when water is released from the lake.

Monthly sampling in Little Wilson Pond and Mud Pond will provide data to develop a baseline understanding of their water quality.

Sampling Parameters

Recommended sampling parameters are divided into four categories: *in situ* parameters, thermistor chain, discrete samples, depth integrated core samples and *Gloeotrichia* samples. A summary of sampling parameters, suggested sampling frequency and depth intervals and sampling locations for each parameter is presented in Table 4-1 for Lake Auburn and its tributaries and in Table 4-2 for the watershed pond locations, Little Wilson Pond and Mud Pond.

In situ measurements should be collected at each sampling site as appropriate. Total depth and Secchi depth should be measured at open water lake sites before taking any samples. To characterize the water column, vertical profiles of temperature, dissolved oxygen, pH, conductivity and turbidity should be measured in 1-m increments, if possible. Currently AWD/LWD only has the instrumentation to collect temperature and dissolved oxygen with a data sonde to facilitate this high frequency sampling. If additional probes for the sonde cannot be obtained then the current practice of collecting samples at 4-m intervals is adequate.

The *thermistor string* should be configured so that temperature is measured every meter from 0 – 4 meters, every half meter from 4 to 12 meters, every meter from 12 to 20 meters and then every 5 meters for depths deeper than 20 meters.

Discrete samples for water chemistry should be collected at open water locations in Lake Auburn, the two main watershed ponds, two main tributary and the outlet locations. When the lake is not stratified, surface samples should be taken 1 m below the water surface, and the bottom sample should be taken 1 m above the sediment. If the lake is stratified, then additional samples should be taken in 4-m increments, with the surface sample taken at 1 m depth.

Table 4-1
Recommended Sampling Parameters: Lake Auburn

	Parameter	Sample Instructions	Frequency	Locations
In situ Parameters	Water depth	Measure for open water stations only	Weekly profiles in lake and whenever other samples are collected	Open water lake stations: #8, #12, #30, #31, and #32
	Secchi depth			
	Temperature	Open Water: Collect at 1.0 meter increments for all parameters collected by data sonde; 4 m increments for those collected discretely		
	Dissolved oxygen			
	Percent DO saturation			
	pH			
	Conductivity			
	Turbidity	Tributary/Outlet: Surface		
	Thermistor Chain	Temperature		
Discrete Samples	Total phosphorus	Collect at surface and 1 m off bottom of the water column when no stratfication observed. When stratification is observed, collect at 4.0 meter increments but include a bottom sample	Open Water: Every 2 weeks during growing season; monthly during winter if safe	Open water lake stations: #8, #12, #30, #31, and #32
	Dissolved phosphorus			
	Total Kjeldhal nitrogen			
	Nitrate+Nitrite			
	Ammonia	Tributary/Outlet: Surface	Tributary/outlet: Target every week	Tributary/outlet stations: #1, #2, #16
	TSS (Tributary Only)			
Composite Samples	Chlorophyll <i>a</i>	Two core samples: 0-6 m composite to represent surface waters and 3 m sample centered on the thermocline	Every 2 weeks during growing season, monthly during winter if safe	Open water lake stations: #8, #12, #30, #31, #32.
	Phaeophytin			
	Algal Enumeration			
Gloeotrichia Stations	Gloeotrichia	Plankton tow following Bates technique	Every week from May through September	Bates College Site 1, Site 2, Site 3, Site 4 and public dock; open water stations #12 and #32
	T, conductivity, DO, pH	Surface		
	Total phosphorus	Surface		

Mud Pond has a maximum depth of 6.5 meters and is unlikely to stratify. Little Wilson Pond has a maximum depth of 17 meters, indicating that thermal stratification is possible. The sampling procedures outlined for Lake Auburn open water samples should be used depending on whether the pond is stratified.

In addition, surface samples should be taken at the outlet and two main tributaries.

Table 4-2
Recommended Sampling Parameters: Mud Pond and Little Wilson Pond

	Parameter	Sample Instructions	Frequency
<i>In situ</i> Parameters	Water depth	Collect at 1.0 meter increments for all parameters collected by data sonde; 4 m increments for those collected discretely.	Monthly during the growing season.
	Secchi depth		
	Temperature		
	Dissolved oxygen		
	Percent DO saturation		
	pH		
	Conductivity		
	Turbidity		
Discrete Samples	Total phosphorus Dissolved phosphorus	Collect at surface and 1 m off bottom of the water column when no stratification observed. When stratification is observed, collect at 4.0 meter increments but include a bottom sample.	Monthly during the growing season.
Composite Samples	Chlorophyll <i>a</i>	One core sample: shallower of twice the Secchi depth or just short of the pond bottom.	Monthly during the growing season.
	Phaeophytin		
	Algal Enumeration		

Composite samples should be collected at each site to measure chlorophyll *a* and phaeophytin concentrations and to identify and count algae. Total chlorophyll *a* is a measure of water column productivity, and phaeophytin is a measure of recently deceased algae. The algal community data enumeration survey indicates the species and quantities of algae in the reservoir. This information is helpful because management strategies may differ depending on the species of algae found.

Two composite samples should be taken within Lake Auburn: the first from at the surface, from 0 to 6 meters depth, and the second sample from within 3 meters of the thermocline. The first, surface composite sample captures the conditions in the fully mixed epilimnion, while the sample around the thermocline is to capture any algal growth at this depth. One composite sample should be taken from Little Wilson Pond and Mud Pond from the surface to twice the measured Secchi depth or just short of the pond bottom, whichever is shallower.

Samples at the *Gloeotrichia* stations should be sampling using a similar methodology to that is currently used by Bates College to maintain the ability to conduct trend analyses.

Wet Weather Sampling

Wet weather sampling should ideally be performed after 72 hours of antecedent dry conditions (total precipitation totaling less than 0.1 inches); a 72-hour antecedent dry period is difficult to achieve in New England, so a 48-hour period of antecedent dry conditions is acceptable for wet weather sampling if the longer 72-hour period has not been reached. If possible, both stations (#2 and #16) should be sampled during the same storm. During each storm, five grab samples should be collected:

1. before the rainfall event,
2. the first flush of runoff, if possible
3. during the rising limb of the storm hydrograph,
4. near the peak of the hydrograph, and
5. during the receding limb of the storm hydrograph.

These five samples will help characterize and understand the distribution of pollutant loadings throughout the course of a storm event. In addition to wet weather sampling, depth should be measured using a stake with an attached ruler as a backup to the pressure transducer and to facilitate the field team's selection of sampling times.

To help locate the peak of the hydrograph during wet weather sampling, we recommend installing crest stage gauges at sites #2 and #16. The gauges consist of a clear plastic tube 2 inches in diameter and 3-5 feet in length attached vertically to the stake used for measuring depth. The lower portion of the tube is submerged during low flow conditions, leaving plenty of room for water and sediment to flow beneath the opening. Crumbled cork pieces are floated in the water inside the tube, and the top of the tube is covered so that rain will not enter and vented so that the water level within the tube may rise and fall simultaneously with the water in the stream. When the water rises and recedes, the crumbled cork remains stuck to the inner walls of the tube. Prior each sampling event, the team should pour water down the tube to ensure the cork is floating on the water surface and is not adhered to the tube wall. Figure 4-2 illustrates an example of a crest stage gauge as built, at low flow, and after a storm event.

These crest stage gauges should be used to determine the height of peak flow at each location to assist the sampling teams in timing for sample collection. The gauges are not designed to be used to calculate the peak flow; this information should instead be calculated from the pressure transducer data output.

Thermistor String

We recommend deploying at least one thermistor string at the deep hole sample location. A thermistor string allows for a continuous record of temperature measurements to be taken at a variety of depths throughout the water column. This fine-resolution temperature data will help characterize when and how strongly the lake stratifies and will provide a record of any mixing events that could transport bottom water phosphorus into the surface waters.

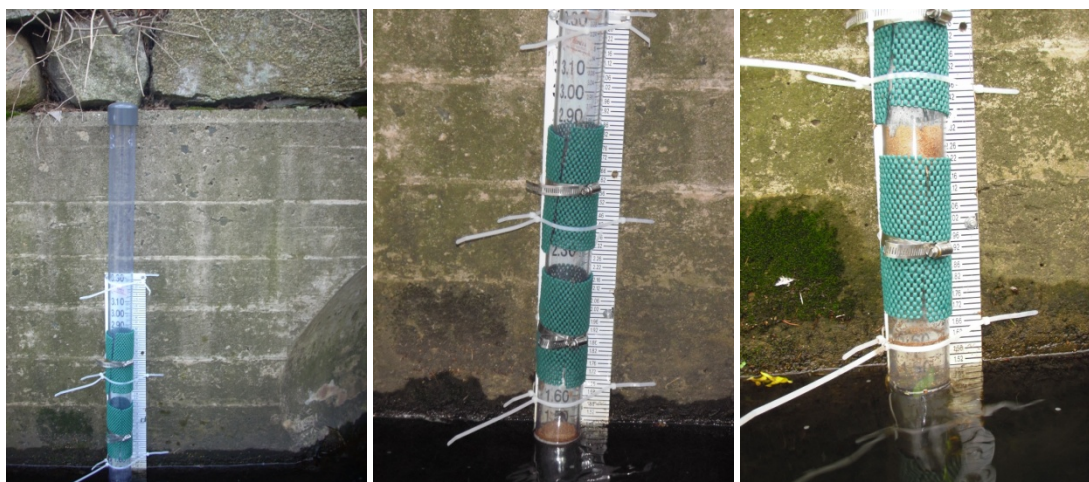


Figure 4-1

Example Crest Stage Gauge (Left); Gauge at Low Flow (Center); Gauge After Storm Event With Cork Line Showing Estimated Peak Water Level (Right)

Quality Assurance and Quality Control

Additional samples should be collected for quality assurance and quality control to ensure that data from the monitoring program are reliable and error-free. For the Lake Auburn program we recommend focusing on reproducibility of laboratory results by collecting *duplicate samples*. These samples are collected from the same water volume as the actual sample. Each parameter should have duplicates for 5% of the total samples collected during an entire monitoring season. The location of the duplicates samples should vary.

Data Management and Assessment

Water quality data collected during this sampling program should be maintained in a database format spreadsheet. This database should contain all data collected during sampling, including comments made by the sampling team, so that it serves as the complete record of all sampling activities and data. This information must include the date and time, sample location, sample depth, parameter, units, sample number or identifier, comments, value, and any relevant data flags (*i.e.*, non-detect, etc.). An example of a water quality database is presented in Table 4-3.

The fields contained water quality database can be customized to fit the needs of AWD/LWD's sampling program assuming that the minimum information described above is included. Even if a cross-tabulated format is desired for presentation purposes, it is important to maintain a copy of these data in this format. The database format makes it easy to sort, plot, and compare data across different years and different sites. A cross-tabulated table is easily created from this database using a pivot table in Microsoft Access or Excel.

Data entry can be a time consuming task. It can be made more efficient with customization of data entry screens designed for specific sampling programs or by using automated routines to upload data from analytical laboratories into the selected database format.

Table 4-3
Example Water Quality Database

Date	Time	Location	Depth (m)	Parameter	Units	PQL	MDL	Value	Flag	Comments
6/7/13	12:00	8-Deep Hole	1	Nitrate+Nitrite	mg/l			.023		
6/7/13	12:00	8-Deep Hole	1	Total Phosphorus	µg/l			10	EST	Sample Estimated
6/7/13	12:00	8-Deep Hole	1	Ammonia	mg/l			0.01	ND	
6/7/13	12:00	8-Deep Hole	1	TKN	mg/l			0.31		
6/7/13	12:00	8-Deep Hole	32	Nitrate+Nitrite	mg/l			0.01	<	
6/7/13	12:00	8-Deep Hole	32	Total Phosphorus	µg/l			22		
6/7/13	12:00	8-Deep Hole	0-6	Chlorophyll a	µg/l			3.56		

4.2 Contingency Planning for Algicide Use

4.2.1 Overview

The analyses in Section 3 has shown that the relative high levels of turbidity experienced in Lake Auburn in 2011 and 2012 were most likely attributed to blooms of blue-green algae. The 2011 data from Bates College show that *Anabaena* was the dominant (>95% biovolume; Figure 2-17) algae found in the lake during the period of high turbidity, though relatively high cell counts of *Microcystis* and *Gomphosphaeria* were also identified. All three of these blue-green algae can produce nuisance taste and odors. While there are no long-term records of algal levels in the lake, historical Secchi depth and turbidity data indicate that blooms of the magnitude and duration of the 2011 and 2012 blooms seem to be unprecedented.

In response to this change in water quality conditions of the lake, AWD/LWD are investigating immediate, short- and long-term actions that can be implemented to improve lake water quality. The application of algicide to the lake is a short-term measure that would allow AWD/LWD to respond quickly to an emerging bloom on the lake (should one emerge in 2013 or beyond) while implementing long-term measures to reverse the degradation of the lake water quality.

In order for AWD/LWD to be prepared to apply algicide to Lake Auburn the following actions need to be completed:

1. Obtain a Maine Waste Discharge License for application of aquatic herbicides to a “water of the state.” This is discussed further in Section 4.2.3.
2. Identify the specific species of possible target algae that occur in Lake Auburn, as various genera and species of algae are not all alike in their response to a particular algicide. Review literature on effectiveness of algicides. Palmer (1977), for example, has grouped several algal genera by their relative toxicity to copper sulfate into categories of “very susceptible” (e.g., *Anabaena* and *Asterionella*), “susceptible” (e.g., *Tabellaria*), “resistant,” and “very resistant.”
3. Consider performing bench-scale testing of effectiveness of algicides as the lowest concentration that is effective (toxic) for a particular alga varies with its abundance and lake water characteristics (e.g., temperature, alkalinity, organic matter etc.).
4. Determine if AWD/LWD staff will purchase and apply the algicide. If yes,
 - a. Staff will need to obtain a pesticide applicator’s license from the Board of Pesticide Control.
 - b. Identify vendors of algicides and establish a purchasing relationship(s).
 - c. Determine if/where algicide will be stored and make any necessary arrangements for its safe storage.
5. Develop a treatment strategy for applying the algicide (including factors such as trigger levels for application, type of boat needed, depth of application, whether solutions need to be prepared, target application area, effect of wind, etc.) and purchase any needed equipment.

6. Collect baseline levels of copper in sediments in the target treatment area to address questions about possible copper accumulation in sediments.
7. Develop monitoring plan to measure effectiveness of algicide treatment and whether treatment results in increased copper levels in water withdrawn or discharged from the lake.

The next step to pursue this short-term action is to attend a pre-application meeting with all Maine regulatory authorities who will contribute to the decision on the license. They are likely to include the Department of Environmental Protection, the Drinking Water Program, and the Department of Inland Fisheries and Wildlife. The purpose of the meeting will be to determine the requirements for license application including all supporting documentation.

4.2.2 Algal Blooms and Algicides

Algal blooms occur when conditions present in the reservoir favor rapid growth. Figure 4-2 presents a general schematic of an algal bloom with and without application of algicide. At the beginning of a bloom, there is an initial lag phase when the algae grow slowly without a rapid increase in population size. As the algae physiologically adapt to an applied stimulus (*e.g.*, increased light, nutrient levels or decline of a competing alga), the exponential growth phase begins and the population increases rapidly. When conditions are no longer favorable for rapid growth (*e.g.*, decreased light due to formation of mats or decreased nutrient levels due to uptake), the growth rate declines, although the population size can remain high (stationary phase). Finally, the death phase occurs when the stimulus is exhausted, and the algal population experiences a crash.

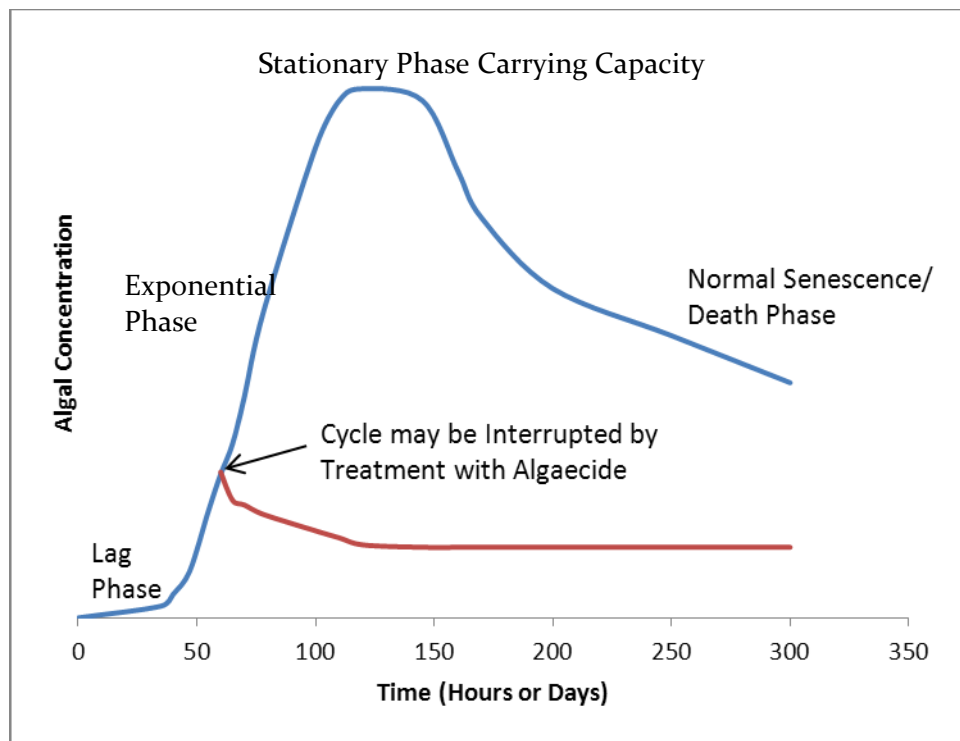


Figure 4-2
Phases of Algal Growth

One key to the control of algal blooms is the timing of the application of algicide. To be most effective, the algicide should be applied during the beginning of the exponential growth phase. This requires a water supplier understand the drivers for algal blooms in the lake and to frequently monitor the occurrence and count of algae in the lake during periods when blooms typically occur.

Optimizing the mass of algicide application consists of (1) determining how much algicide complexes or reacts with other matter present in the water column, rendering it less or non-toxic to algae; (2) determining the concentration required to kill a given nuisance species/genera; (3) compiling figures of application mass necessary to control a bloom vs. problem species for periods in the year which problem algae typically appear; (4) establishing the best spatial and depth coverage for algicide application.

4.2.3 Maine Requirements for Application of Algicide

The discharge of a pollutant (which includes algicides) to a surface water of the state requires Maine DEP approval pursuant to Maine law, 38 MRSA, §413, Waste Discharge Licenses, and Department Rule, Chapter 514, Aquatic Pesticides. This statute is included in Appendix D.

The statute has several provisions applicable to the application of an algicide to Lake Auburn, which is designated as a GPA water (Maine has a sole classification for all great ponds, natural lakes, and lakes under 10 acres). These include: 38 MRSA 414-1-A-1-A and 38 MRSA 414-1-A-1-C.

38 MRSA 414-1-A-1-A covers the license for copper sulfate applications to public water supplies. This regulation allows:

The commissioner may issue licenses to treat public water supplies with copper sulfate or related compounds. The commissioner may not issue more than 2 consecutive licenses for the same body of water.

A. A license may only be issued if the Department of Human Services, Division of Health Engineering has determined that:

(1) An abundant growth of algae producing taste or odor exists to such a degree that the water supply is in danger of becoming unhealthful or unpalatable;

(2) The abundance of algae is a sporadic event. For purposes of this section, "sporadic" means occurring not more than 2 years in a row; and

(3) The algae cannot effectively be controlled by other methods. [1997, c. 794, Pt. A, §22 (AMD).]

B. Any license issued under this subsection is for one application or series of applications not to exceed 6 months, as provided in the terms of the license. [1997, c. 794, Pt. A, §22 (AMD).]

C. The commissioner shall impose all conditions necessary to meet the requirements of this section and all other relevant provisions of law. [1989, c. 890, Pt. A, §40 (AFF); 1989, c. 890, Pt. B, §30 (AMD).]

38 MRSA 414-1-A-1-C covers the license for use of algicides in Class GPA waters. This regulation allows:

The commissioner may issue a license to a municipality for discharge of copper compounds or other materials registered by the Department of Agriculture, Food and Rural Resources to control excessive algal growth in Class GPA waters when the commissioner has determined that:

A. A lake restoration plan to reduce algae growth has been designed and implemented in cooperation with the department;

B. The plan has been found by the department to have failed to achieve the desired level of restoration in a reasonable period of time;

C. Because of technical or financial limitations, there is no further plan for restoration;

D. The affected water has a recent history of severe algae blooms of less than one meter Secchi depth transparency;

Maine DEP Considerations for Discharge License for Algicides

Is the use of the algicide a discharge to “waters of the State”?

Per Maine rule, if the resource is contained entirely on one person’s property and the product used will not be mobile into groundwater or flow through an outlet to another property or to a water of the state during the active period of the material, there is no discharge to a water of the State.

Even if a water supplier were able to prevent outflow from the lake by drawing down the lake, Robert Stratton of Maine DEP has interpreted this action as insufficient to control copper because some of the applied copper will settle to the lake bottom, and when the bottom is anoxic the copper will be re-introduced into the water column and thus be able to then be discharged to a waters of the State.

The Department recommends other materials that will be non-persistent with no discharges to surface or subsurface waters of the state.

E. A watershed plan to further reduce phosphorus loading to the affected water is being implemented by responsible parties including the department and all affected municipalities,

F. The Department of Inland Fisheries and Wildlife has found that the discharge will not have an adverse impact on the fishery management plan of the water body.

This license allows for no more than one application of copper compounds or other registered algicides per year for a period not to exceed 5 years. Algicides must be applied in an amount and in a manner that minimizes risk to nontarget organisms. The individual conducting the treatment must be certified by the Board of Pesticides Control for the use of aquatic pesticides. Application of an algicide may only occur after the Secchi disk transparency of the water is less than 2 meters. Relicensing is contingent upon an assessment of the water quality and the effectiveness of the phosphorus reduction plan for the watershed.

These conditions are very restrictive and, in practice, Maine regulators are reluctant to approve the application of an algicide to a public water supply. For instance, Mr. Ryan Lynch of the York Water District relayed the extensive work his district undertook to attempt to obtain a license to treat a winter algal bloom in Chases Pond with hydrogen peroxide. Ultimately he decided to buy water from another supplier than pursue the license. Some of the e-mail correspondence between Mr. Lynch and Mr. Robert Stratton of Maine DEP is included in the sidebar to illustrate Mr. Stratton’s viewpoint of license conditions.

Phase II of this study will consider long-term measures to mitigate the water quality problems observed in recent years. Long-term measures that will be considered include alum treatment of sediment, aeration, and dredging of the Basin.

Section 5

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Appendix A
Comprehensive Environmental, Inc.
Lake Auburn Diagnostic Watershed Study

Lake Auburn Diagnostic Watershed Study

Final Report
March 13, 2013

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Lake Auburn Watershed
Protection Commission

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Section 1 Introduction and Overview

1.1 Overview of This Report

Lake Auburn, located in Auburn, Maine is the drinking water supply for the cities of Auburn and Lewiston, Maine. Due to its excellent water quality and the communities' outstanding efforts to protect it, the utilities have maintained a filtration waiver for 22 years, saving water users millions of dollars in treatment and operation costs.

Many recreational and water supplies have been recently plagued with increasing water quality problems. The purpose of this initial report is to identify possible sources of pollution to the lake that may be contributing to the degradation of water quality and to evaluate recent changes that may be influencing these contributions. A second phase to be completed following this phase will identify what steps can be taken to protect Lake Auburn from these new threats.

CEI has partnered with CDM Smith to complete this study, with CDM Smith completing the in-lake diagnostic work and CEI completing the watershed diagnostic work. This report completes the Diagnostic Watershed Assessment and focuses on the watershed contributions to the lake.

1.2 Introduction

The Cities and the Lake Auburn Watershed Protection Commission (LAWPC), a commission formed to protect the watershed and water quality of Lake Auburn, use a Multiple Barrier Approach to deliver safe water to its customers. The first of this approach is source water protection to maintain a clean drinking water source that does not require filtration.

Using this approach, in 2010 the LAWPC completed an update to its 1987 Watershed Management Program, which developed and calibrated a watershed model for evaluating the watershed. The implementation of the recommendations from the 2010 study are ongoing, but focused on making septic system regulations more stringent (or at least not allowing them to be relaxed) and preparing for the potential impacts of buildout of the watershed. Other recommendations proposed long term stormwater controls that will take years to implement.

Recent events, including increased algae outbreaks in 2011 and 2012 and a fish kill in September, 2012, have led the Cities of Auburn and Lewiston and the LAWPC to perform a Lake Auburn Watershed-Lake Diagnostic Study that considers new data collected between 2009 and 2012. The assessment includes a detailed evaluation of the watershed and nutrient contributions from the watershed, and a detailed review of water quality trends within the lake to help identify potential causes for the recent algal blooms and fish kills. One focus is on phosphorus, considered the limiting nutrient, or food source, for algal blooms in most fresh water bodies and increasing levels can be correlated with increasing algal blooms. Algal growth can contribute to other water



quality problems such as increased turbidity, taste, and odor problems. Maintaining low turbidity levels is a prerequisite for maintaining a filtration waiver.

1.3 Purpose of the Diagnostic Watershed Assessment

This Diagnostic Watershed Assessment of Lake Auburn provides an update and re-evaluation of existing sources of pollution to the lake, considering recent water quality data collected between 2009 and 2012 and changes to the watershed within this same timeframe. The purpose of this study is to identify possible drivers of the recent degradation in water quality. This information will then be used in a future phase of the project to make recommendations to minimize and control future algal blooms and associated water quality problems.

1.4 Background

Lake Auburn has long been the primary source of water supply for residents and businesses in the Lewiston-Auburn area, currently serving over 59,000 people. The use of Lake Auburn as a water supply began in 1877 and the first water quality protection measures were enacted shortly afterwards with a “No Bathing in the Lake” ordinance.

The Auburn Water District formed in the early 1900s and immediately became involved in the protection of the lake and its watershed to ensure the distribution of clean, healthy water. The Lewiston Water Division later joined these efforts and the two communities formed the Lake Auburn Watershed Protection Commission (LAWPC) in 1993. Protection efforts to date include:

- Purchasing land in the watershed, including purchasing key or strategic land parcels in the watershed;
- Patrolling the lake shore;
- Conducting reforestation of acquired land;
- Maintenance of high lake water levels;
- Restricting boating and fishing around the intakes;
- Adopting the Lake Auburn Watershed Ordinance to seek the placement of controls on the types of development;
- Establishing a comprehensive sampling program in and around the lake to monitor water quality trends;
- Implementing sanitary inspections for each lot in the watershed;
- Maintaining records including sanitary inspections in a database;
- Developing and implementing a Lake Auburn Watershed Study¹ in 1987, which identified the most significant threats to the water supply; and
- Developing the Lake Auburn Watershed Management Plan in 2010, which served as an update to the 1987 study.

¹ Camp Dresser & McKee Inc., Final Report Lake Auburn Watershed Study, December, 1987.



Following is a description of each of the watershed studies and how this Diagnostic Watershed Study differs from past studies.

1.4.1 1987 Lake Auburn Watershed Study

The 1987 Lake Auburn Watershed Study included an evaluation of potential pollution sources to the lake and recommendations to address these sources. Recommendations for improvement included:

- Amending the ordinance to include additional sediment and erosion control and stormwater control provisions, prohibit certain land uses within the watershed, and prohibit certain uses of the lake;
- Establishing a committee for implementation of agricultural best management practices (BMPs);
- Continuing a public education program;
- Implementing a sanitary inspection program and incorporating into ordinance;
- Implementing a long-term water quality monitoring program;
- Closing the Gracelawn Landfill;
- Conducting a study of The Basin; and
- Establishing a Lake Auburn Watershed Commission.

In 1991, the Cities of Auburn and Lewiston received a waiver from filtration from the State of Maine and U.S. EPA at a time when these agencies originally required filtration of most surface water systems. The Cities obtained this waiver due to Lake Auburn's uniquely pristine water with high clarity and very low levels of phosphorus, pathogen and other pollutants, and the Cities' programs to control detrimental activities occurring in the watershed. These programs included the ordinances in place specific to the Lake Auburn Watershed and implementation of the 1987 Lake Auburn Watershed Study.

1.4.2 2010 Lake Auburn Watershed Management Plan

The Cities implemented the recommendations of the 1987 study and the LAWPC commissioned an update to the 1987 plan to ensure continued protection of the watershed. That study was completed in 2010 and included:

- Review of existing lake and tributary water quality data, focusing on phosphorus – existing in-lake data included phosphorus data at the deep hole between November 1986 and September 2008. There were a total of 51 sampling dates at the deep hole that included analysis for total phosphorus during this period, with collection of 24 samples from the epilimnion, 9 samples from the metalimnion (all before 1993), 23 samples from the hypolimnion, 4 core samples representing water quality between 0 and 9 meters and 9 full core samples representing the full depth of the lake at the deep hole.
- Modeling pollutant loads from the watershed using GWLF-E with AVGWLFGIS interface – modeling was performed using existing available data between 2001



and 2008. Modeling flows were calibrated to a USGS water budget² prepared for Lake Auburn. Model pollutant loads were calibrated to average observed in-lake phosphorus concentrations in the epilimnion layer (top-most layer of water in the lake, ranging from 0-23 feet under stratified conditions) in the spring.

- Review of existing regulations.
- Evaluation of three buildout scenarios with the model and their potential impact on in-lake concentrations.
- Identification of water quality goals to maintain/improve in-lake water quality.
- Recommendations to meet water quality goals, including structural and non-structural measures to reduce phosphorus inputs to the lake. Recommendations identified cost per pound of phosphorus removal.

The end result was a 10-year capital improvement plan that quantified pollutant removals to achieve water quality goals.

1.5 Scope of This Project

The purpose of this project is to identify changes since the 2010 watershed report, which was based on a modeling study using data up to 2008, including a detailed field review of the watershed. In addition to intensive field review of potential watershed sources of pollutants, this project also brought the model up-to-date to include the last four years of data (from 2009-2012) and provides a more detailed water budget to assess inflows and outflows to the lake and seasonal variation over the last several years. It was initiated based on unusual algal blooms and a fish kill in the lake, likely due to some extreme weather events, including about 13 inches of rain in June of 2012.

The scope of this Watershed Diagnostic Assessment is broken into two phases. The first phase, which is the focus of this report, focuses on evaluating the watershed to identify factors that influence the water quality and recent fish kill, reduction in dissolved oxygen and increases in turbidity. The scope of this phase included:

1. Project Initiation: Data Review and Gap Analysis – Collect data pertaining to Water Budget and Agriculture, Logging and Basin History.
2. Update Water Budget – Update the water budget included in the April 2010 Watershed Management Plan, create specific budgets for the 2011 and 2012 growing seasons and compare typical year water budget.
3. Update Nutrient Budgets – Update the phosphorus budget included in the April, 2010 Watershed Management Plan and prepare a conceptual level nitrogen budget.
4. Field review high load areas with AWD/LWD staff and consider how these may influence the nutrient budgets. Consider logging operations, septic system inputs, erosion, gravel pits, farming, waterfowl and other wildlife,

² Dudley, Robert. Water Budget for Lake Auburn, Maine, May 1, 2000 through April 30, 2003, Scientific Investigations Report 2004-5106.



permitted lake usage and other potential ‘high-load’ areas identified through discussions with AWD/LWD, and internal recycling loads.

5. Diagnostic Assessment of Lake Auburn – Perform a diagnostic assessment of Lake Auburn to include:
 - a. A description of any significant changes in the watershed characteristics, serving as an update to the description in the 2010 Watershed Management Plan.
 - b. Assessment of limnological data for the lake.
 - c. Findings of the water budget.
 - d. Estimate of nutrient loads to the lake.
 - e. Trends and the current health of the lake, including a discussion of factors driving the reduced water quality in the fall.
 - f. Discussion on the role that changes in future climate may have on future water quality.

The second phase will focus on the evaluation of long-term watershed management actions to improve water quality in Lake Auburn.



Section 2 Watershed Assessment

A detailed watershed assessment was performed to identify potential ‘high-load’ sources of pollution within the watershed. As noted in Section 1, the field review was focused on identifying areas that may be affected by intense storms and might need additional improvements over the extensive watershed measures that have already been taken over the years. This involved a mapping exercise to identify significant changes to the watershed from the 2010 study, field review of the lake shoreline and watershed to identify potential areas of concern, and collection of sediment samples from sediment deltas where tributaries entered the lake. The following describes the watershed, field investigations, sediment sample results and preliminary findings. More analysis will occur in Phase 2 of this project.

2.1 Watershed Description

2.1.1 General Description

Lake Auburn is located in the City of Auburn in central Maine as shown in Figure 2-1. Several perennial tributaries feed the lake, including:

- The Basin outlet, which drains a chain of ponds in the northwestern half of the Lake Auburn watershed including The Basin, Little Wilson Pond and Mud Pond;
- Townsend Brook;
- East Unnamed Brook at Lakeshore Drive;
- Unnamed Brook at Johnson Road; and
- West Unnamed Brook at Lakeshore Drive.

Bobbin Mill Brook is the sole outlet from the lake (excluding water supply withdrawals). The ponds in the northwestern half of the watershed comprise approximately 240 acres of water surface area, while Lake Auburn has a mean surface area of 2,260 acres or 3.53 mi² (square miles).¹

Lake Auburn has a mean depth of 40 ft (feet), a maximum depth of 120 ft and an approximate volume of 3,920 million ft³ (cubic feet).¹ The lake is generally stratified May through October with an average thermocline between 20 and 30 feet in spring (May), between 23 and 36 feet in summer (June through August), and between 43 and 49 feet in fall (September through October). Little to no stratification is generally observed November through April, however stratification can still occur during these periods with the right conditions. The estimated lake flushing rate is about three to four years based on average inflows from streams and precipitation. Table 2-1 provides a summary of the lake and watershed morphological data.

¹ USGS (2004), *Water Budget for Lake Auburn, Maine, May 1, 2000 through April 30, 2003*, (Scientific Investigations Report 2004-5106), Augusta, Maine: USGS.



Table 2-1. Lake Auburn Morphometric Data

Surface Area	2,260 acres	USGS, 2004
Maximum Depth	120 ft	USGS, 2004
Mean Depth	40 ft	USGS, 2004
Volume	3,920 million ft ³	USGS, 2004 (3,570 million ft ³ calculated by CEI using bathymetric data provided by the Auburn Water District)
Watershed Area	9,651 acres	Measured from GIS, excluding Lake Auburn Area
Shoreline Length	67,531 feet	Measured from GIS

The Lake Auburn watershed occupies about 9,650 acres of land and water (excluding Lake Auburn) in five central Maine cities and towns including Auburn, Turner, Minot, Hebron, and Buckfield. The land area alone, excluding all ponds and lakes, comprises about 9,413 acres. Figure 2-2 shows the watershed, tributaries and city/town boundaries. The watershed is lightly developed with a mix of forested area, hay/pasture, wetlands, low-intensity development, high-intensity development and cropland. Over the years, the Auburn Water District, Lewiston Water Division and LAWPC have acquired shoreline property within the watershed as it has become available. As a result, the District or LAWPC owns about 81% of the Lake Auburn shoreline and about 1,320 acres (14%) of the Lake Auburn watershed. Total protected lands in the watershed, including conservation easements, comprise about 1,975 acres or 21% of the watershed. Figure 2-3 shows these protected lands.

The lake tributaries were used to divide the watershed into 13 major subwatersheds, as shown in Figure 2-4, listed roughly from north to south:

- Mud Pond;
- Little Wilson Pond;
- The Basin;
- North Auburn;
- Spring Road;
- Lake Shore Drive, West;
- Lake Shore Drive, East;
- Townsend Brook;
- West Auburn Road;
- Route 4;
- Youngs Corner;
- Summer Street; and
- Gracelawn.



2.1.2 Field Review of Watershed

CEI crews performed a detailed field investigation of the lake's shoreline and watershed between October 15th and November 28, 2012. The purpose was to identify potential 'high-load' sources of pollution within the watershed through visual observation and where the crew found potential problem areas to collect sediment samples for laboratory analysis of contaminants.

Field observations were made by boat, by foot and by vehicle with assistance from the Auburn Water District. Lake Auburn, The Basin, Little Wilson Pond and Mud Pond were observed from many different angles allowing observations of the shoreline and tributary inlets for signs of erosion and sediment deltas. This work led to the identification of problem areas within the lake's shallow shoreline zones to help target follow-up ground investigations in the watershed. For example, the crews found significant sediment deltas at some of the tributary inlets. Since these could be a sign of erosion further up in the watershed, they were sampled and further assessment was done upstream. Some samples were subjected to additional analysis based on the percent solids and initial phosphorus concentrations. The sediment sampling results are discussed in Section 2.2.

The watershed was broken into five key areas for the purposes of presenting field investigations. The key findings of the field investigations are described further by area below. Refer to Figure 2-5 for the boundaries of each area and Figures 2-6 through 2-10 for potential source areas identified in each area. Section 4 summarizes the results, while Appendix A contains further details, photos and overview maps of the roadway crossings and additional potential nutrient sources.

<u>Area</u>	<u>Subwatersheds</u>
Route 4/Turner Road	• Townsend Brook • Route 4
Spring Road	• Spring Road • West Auburn Road
Lake Shore Drive	• Lake Shore Dr. East • Lake Shore Dr. West • North Auburn
Lower Watershed	• Youngs Corner • Summer Street • Gracelawn
Upper Watershed	• The Basin • Lake Shore Dr. East • Little Wilson Pond • Mud Pond



2.1.3 Route 4/Turner Road Area

The Route 4/Turner Road Area includes the areas within the Route 4 and Townsend Brook subwatersheds as shown on Figure 2-6. The Route 4 area is the most heavily developed area directly abutting Lake Auburn, with several direct stormwater discharges into the lake and should be targeted for future watershed management projects.

At several points, Route 4 forms the eastern border of Lake Auburn with little to no buffer between the pavement and lake. Runoff generated from Route 4 is collected through a series of catch basins along the roadway or enters the lake as sheet flow, as there is no curbing on the road. Additionally, the road is 10 to 20 feet higher than the lake elevation creating steep slopes between the lake and roadway. Numerous sediment deltas were observed along the shoreline, likely associated with sanding of the roadway and erosion of the steep embankment between the road and lake. Stormwater runoff from the road enters the lake untreated, carrying road salts, sediments, grease, oil and nutrients into the lake. Stormwater originating on the eastern (opposite) side of Route 4, furthest from the lake, is also untreated and is piped under the road and directly into Lake Auburn. The drainage area to the east of Route 4 is relatively flat and undeveloped. There was no evidence of significant erosion on the east side of Route 4. Additional areas of concern that should be addressed include:

- The northern section of the road contains several potential nutrient sources including an animal pasture to the east of the road, the drainage from which is routed under Route 4 (Site 48) and past a golf course before entering Townsend Brook and eventually Lake Auburn.
- Site T7, located farther north, is a greenhouse nursery with a manmade holding pond located right beside Townsend Brook. It contains highly turbid water and a failed outlet structure.
- Following Townsend Brook farther upstream, several active sand pits with gravel driveway crossings over the Brook exist along this section. Site 61 is one example of this land use type and brook crossing.

2.1.4 Spring Road Area

The Spring Road Area includes the areas within the Spring Road and West Auburn Road subwatersheds as shown on Figure 2-7. Spring Road is a gated gravel road following the lake's western border and hosts only a few houses along its stretch. Only members of the Auburn Water District (AWD) and local property owners have access to this road by vehicle. It has high pedestrian traffic and is used mainly for recreation with a few direct access points to the lake. To the west of the road is a very steep, wooded hill which runs parallel to Spring Road, along nearly its entire length.

At the top of this slope, around 100 feet above the lake, a large amount of residential development exists along the eastern side of Auburn Rd./N. Auburn Rd. While not heavily developed, the Spring Road area is a high priority area due to the large number of gravel roadway crossings, natural groundwater springs and the steep slope leading down to the gravel road. High velocity runoff from the long steep slope to the west of the road has generally created deep channels where the soil has been eroded away. This appears to



have been worsened by changes in drainage patterns as development has occurred on Auburn Road. This was evident during field investigations, where historical tributaries were observed to have dried up, with others receiving more runoff at higher velocities.

The severity of erosion in the area varies depending on the site with a substantial volume of soils finding their way into the lake, as evident by the large sediment deltas common along the shoreline. Several Best Management Practices (BMPs) have been completed or are currently being built on Spring Road, most notably along the section of slope to the north covering the area where sites LAT (1-7) and site 11 are located, but there are additional areas that will need erosion control, including:

- Upgrades similar to what is currently being built at site 11 should be examined for sites 8G, 9, 9D, 10, 10C and 11A. These 6 crossings are considered higher priority but nearly all of the sites along Spring Road could use maintenance or upgrades of one kind or another.
- Across most of the hillside located near sites LAT (1-7), there is evidence of historical logging operations which were under different stages of completion. Most of these are well stabilized, but there are some locations where erosion of unknown origin is proximal to the logging areas, and the logging roads were used to access these to try to stabilize them. Options for further mitigating erosion in these steep areas will be evaluated in Phase 2 of this project.

2.1.5 Lake Shore Drive Area

The Lake Shore Drive Area includes the areas within the Lake Shore Drive East, Lake Shore Drive West and North Auburn subwatersheds as shown on Figure 2-8. Lake Shore Drive follows the North/Northeast shoreline of the lake and bisects a small portion of Lake Auburn near the intersection with Route 4. Similar to Route 4, the proximity of the road to the lake poses considerable challenges in preventing stormwater runoff from entering the lake untreated. With zero buffering capacity between the road and lake in multiple locations; road salt, oil/grease and other contaminants associated with stormwater runoff from roadways directly enter the lake. A hazardous chemical spill of any kind in this area would be difficult to clean up before it adversely affects the lake. Examples of areas of concern in these subwatersheds include:

- Lakeshore Drive - due to the lack of buffer and its direct contribution of untreated stormwater runoff to the lake.
- A driving range and miniature golf course near the intersection of Lake Shore Drive and Maple Hill Road, which partially extends to the Lake Auburn shoreline and draws its irrigation water from the lake itself. Depending on the amounts of fertilizer used to maintain the range, there is the potential for nutrient laden runoff and groundwater inputs to the lake at this location. However, two tributaries run along the eastern and western borders of the course with small deltas at their outlets. Both deltas were sampled and showed phosphorus levels of 270 mg/kg and 180 mg/kg respectively. In comparison to all sediment samples collected from the watershed, these were on the lower range of phosphorus levels detected.
- Development along Lake Shore Drive is limited with only a handful of houses,



and only three of these are adjacent to the lake itself. Additional development should be avoided, however as septic systems, failing or not, can become significant nutrient sources.

2.1.6 Lower Watershed Area

The Lower Watershed Area includes the areas within the Youngs Corner, Summer Street and Gracelawn subwatersheds as shown on Figure 2-9. The lower watershed area is largely undeveloped in the direct vicinity of the lake and to the west of Route 4. The water treatment plant and Great Falls TV station are close to the lake but do not appear to be significant nutrient sources. Other areas of potentially more concern include:

- A large sandpit off Gracelawn Road with a forested buffer between the sandpit and the lake. This buffer should be maintained.
- A portion of West Auburn Road drains to a wetland known as the Ice House Wetland, which is located near the southwestern portion of the Lake Auburn Shoreline. A tributary in this area runs along Auburn Road prior to crossing the road and discharging into the Ice House Wetland. The crews observed erosion sources along the banks of this tributary and along roadway shoulders of Auburn Road and Shore Road.
- Significant portions of the lower watershed contain farmland or open fields that may have been historical farmland. The Dingley and Gravel Pit wetlands seem to absorb most of the runoff from these areas but only the Gravel Pit wetland returned comparatively higher Total Phosphorus (TP) and Total Kjeldahl Nitrogen (TKN) (990 mg/kg and 15,000 mg/kg, respectively).

2.1.7 Upper Watershed Area

The Upper Watershed Area includes the areas within The Basin, Lake Shore Drive East, Little Wilson Pond and Mud Pond subwatersheds as shown on Figure 2-10. The upper watershed is defined as all points upstream of The Basin outlet dam. This area of the watershed must go through at least one standing water body before discharging to Lake Auburn. This helps to treat and buffer stormwater runoff before it enters Lake Auburn, however, as the buffering capacity is used up, it can still present a significant source of sediment and nutrients to the lake as evidenced in the past when the Basin Dam was breached under large storm events, spilling its sediment contents into Lake Auburn. Areas of most concern include:

- The Basin and its upstream watershed area are mostly undeveloped land with only a single house near its shoreline. Holbrook Road runs next to its downstream shoreline and power lines run across its inlet from Little Wilson Pond, but otherwise The Basin is surrounded completely by forest. While this is positive, there is a mid-sized tributary into The Basin coming from the west which crosses Holbrook road at site 35A, upstream of which is a large wetland. At some point a beaver dam blocked off this wetland but has since been breached. There is evidence of some of the sediments from the wash out at site 35A. The outlet for this tributary was recently sampled for TP and TKN and registered significant concentrations: 1500 mg/kg and 7400 mg per kg, respectively. This indicates the



washout carried significant nutrient loads with it downstream and likely deposited them into The Basin. This may be an area that would be suitable for additional controls to contain upstream sediments.

- Comparatively high TP and TKN loads were also identified at the Basin Outlet with levels of 1300 mg/kg TP and 16,000 mg/kg TKN. Several samples taken after the outlet and in the lake were also elevated. Breaching and/or overtopping of The Basin dam is a concern and past breaches/overtopping events may have caused sedimentation of Lake Auburn.
- Little Wilson Pond is the next water body in the supply chain and feeds The Basin from a crossing at site 28. Little Wilson has a more developed watershed as compared to The Basin mostly associated with Gaunthier Hill Road running along its eastern shoreline. Following this road is a moderate slope leading down to the residential houses along the shoreline and small streams at sites 43 and 43A. A major tributary and the main inlet from Mud Pond which comes in at site 45.
- Mud Pond has a largely undeveloped watershed and is partially surrounded by a large wetland. It is fed by a tributary from the west which originates at another large wetland area. Most of the Mud Pond area is only accessible by all-terrain vehicles, which can contribute to the erosion of gravel trails and loads that lead to and drain to trail crossings. Future land use and increases in activity may be a concern here.

2.2 Sediment Sampling

Sediment samples were collected from the Lake Auburn watershed from the locations shown in Figure 2-11. These samples were collected starting as far north as Mud Pond and extending down and around the shoreline of Lake Auburn itself. All samples were analyzed for total phosphorus (TP), with select samples also analyzed for Total Kjeldahl Nitrogen (TKN) and ammonia. These sediment samples were collected primarily from the water's edge to identify potential areas of nutrient loadings to the lake from the watershed. Table 2-2 summarizes the sampling results.

Further evaluation showed that as the percent solids content of the sediments sampled decreased, the overall nutrient content of the sample increased as shown in Figure 2-12. For example, samples that were <20% total solids exhibited the highest levels of both TP and TKN, and in some cases, the highest levels of ammonia. Data analysis shows that these low solid content samples had a high organic content that represent a relatively light fraction and mobile sediment/nutrient source that may indicate depositional areas of decomposing algae and other plant matter.



Table 2-2. Summary of Sediment Sampling Results

Sample ID	Total P (mg/kg dry wt)	Total Solids (%) / Dry Weight (%)	Ammonia (mg/kg)	TKN (mg/kg)
sample 1	1,010	14.8	90	13,000
sample 2	230	67.7		<50
sample 3	370	69.5		320
sample 4	260	73.7		200
sample 5	210	62.6		400
sample 6	400	77.8		370
sample 7	520	90		90
sample 8	320	49.3	20	2,200
sample 9	310	73.9		480
sample 10	250	76.6		300
ice house wetland	84	92		
auburn lake outlet beach	290	68	20	2,200
basin dam outlet	1,300	7.9	140	16,000
basin inlet 1	940	35		4,600
basin main inlet 2	170	75		
basin main inlet 2 sample 2	480	43		6,800
basin inlet 3 sample 1	1,500	21		7,400
little wilson outlet	290	79.3		
little wilson spring 1	280	62.8		
little wilson inlet sample 1	150	60		
little wilson inlet sample 2	170	77.5		
skillings corner brook	160	90		
mud pond inlet 1	1,000	11		13,000
mud pond trail entrance	300	28		
mud pond inlet 2 sample 1	73	80		
mud pond inlet 2 sample 2	160	62		
mud pond outlet	580	40		4,600
pumping sta wetland	480	39.6		1,900
dingley wetland	100	75.4		
gravel pit wetland	990	13.6		15,000
site 5 delta (surface)	320	94.1		
inlet from basin	640	21.5	30	6,000
site 3 delta	270	79.3		
horsepond	180	75		
townsend brook	120	80.4		
townsend Pond 11	460	74	<5	800



In-lake sediment sampling² (Figure 2-11) showed areas with significantly higher levels of TP (excess of 1000 mg/kg) as compared to other sample locations. These samples did not include other nutrient results like TKN but their results did include a component of iron-bound phosphorous (Fe-P). This represents one of the reactive fractions of phosphorus in sediments, namely the fraction of phosphorous bound to iron in the sediments that can be released into the water column under anoxic conditions. This is in contrast to the refractory fraction that will remain fixed to the sediment particles and are therefore, unavailable to be released into the water column.

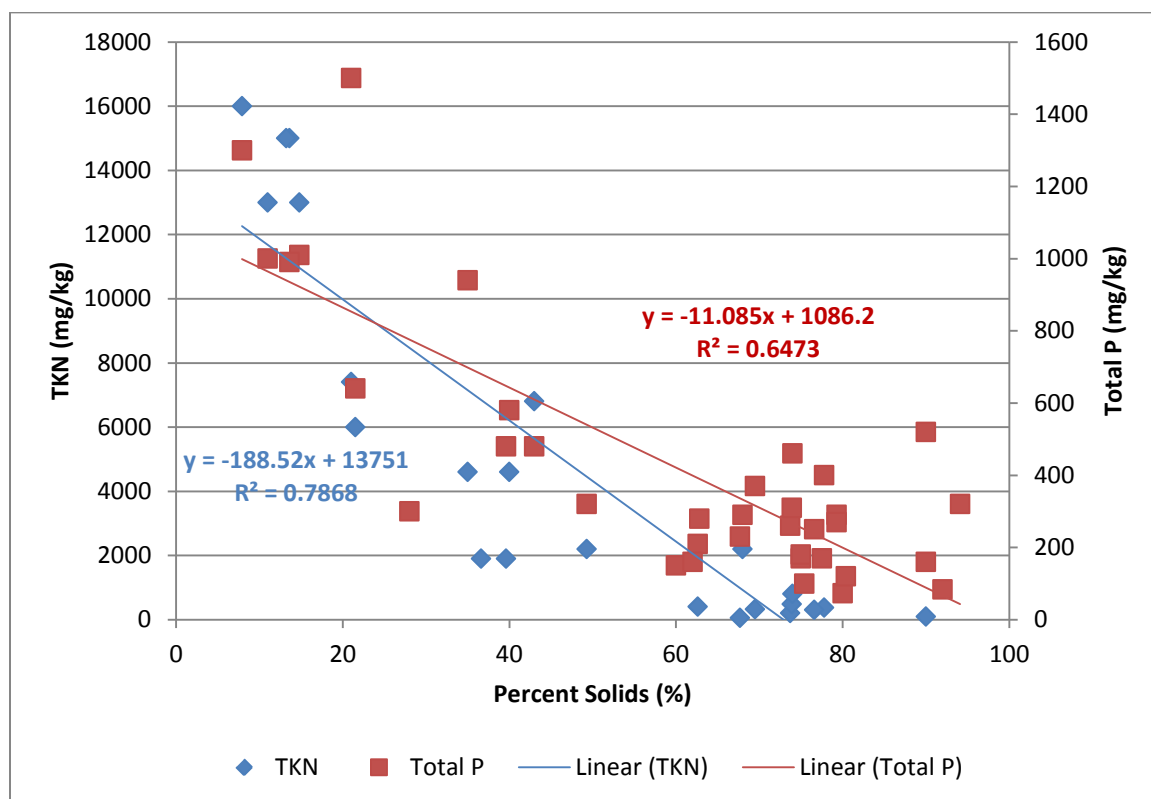


Figure 2-12. Watershed Sediment Sample Analysis TKN and Total Phosphorus

Sediment data was graphed in relation to the percent solids exhibiting the same trend of higher concentrations in the lower percent solids range, illustrated on Figure 2-13. The graph also indicates that in general, the iron-bound phosphorous represents approximately 40% of the Total Phosphorus value. In both cases, the concentration of phosphorus (TP and Fe-P) is higher in the lower percent solid sediments. Lower percent solid concentrations generally indicate more recent depositions rather than older, more compact and dense sediments. They also indicate a higher concentration of organics and a smaller, long-term storage capacity compared to sediments with heavy silt or clay concentrations. In other words, the storage capacity of these sediments is lower but the phosphorus concentrations are higher. Again, the available in-lake data is far too limited

² CDM Smith in-lake samples



to draw any concrete conclusions but seems to support the sampling trends showing a shift in phosphorus flux towards the water column.

In general, the overall data shows increasing phosphorus concentrations in the hypolimnetic layer. However, there is a large gap in deep water TP data between September, 2004 and May, 2010.

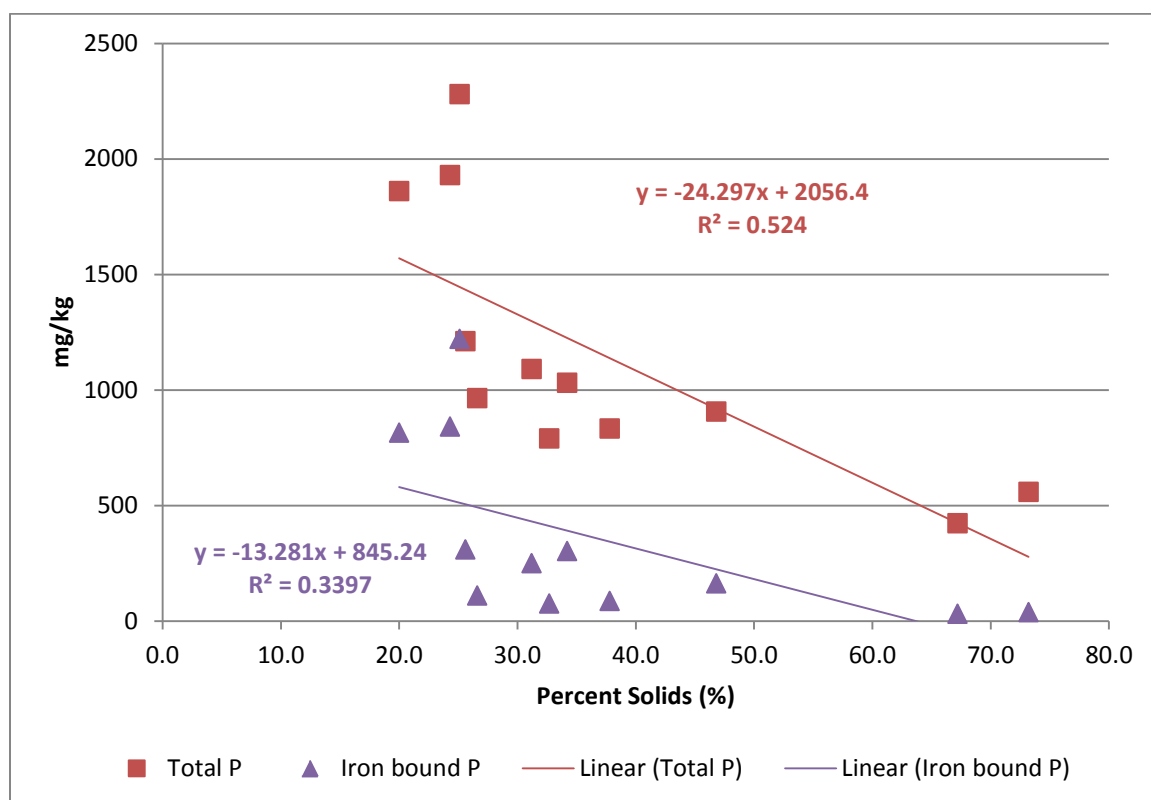
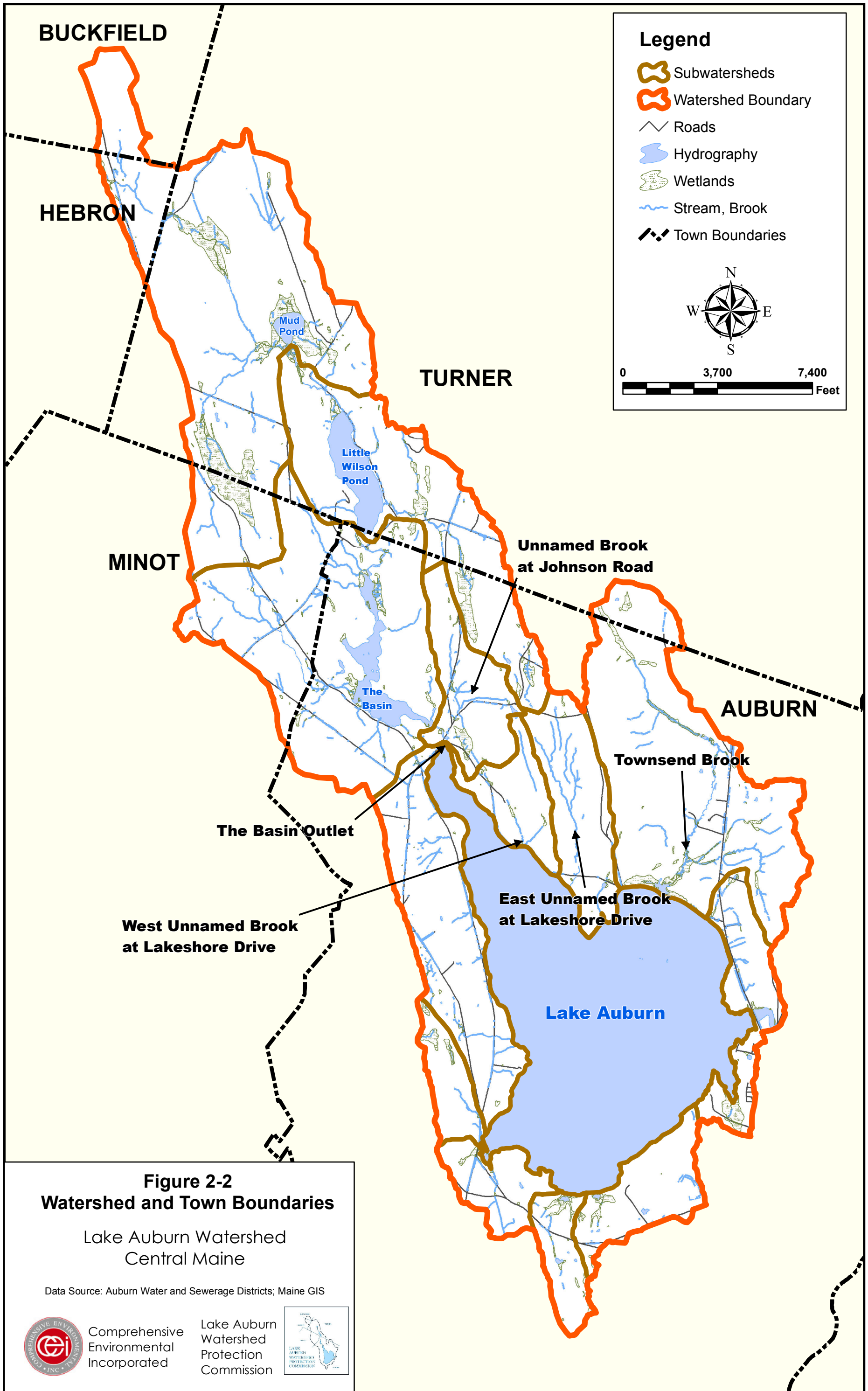


Figure 2-13. In-Lake Sediment Sample Analysis Total and Iron-bound Phosphorus

Based on the composition of sediments sampled, the more recent sediment deposits contain the largest portions of organic matter that also have the highest concentrations of phosphorus. Preventing nuisance algal blooms from returning to the lake may require both external and internal loads to the lake be addressed.







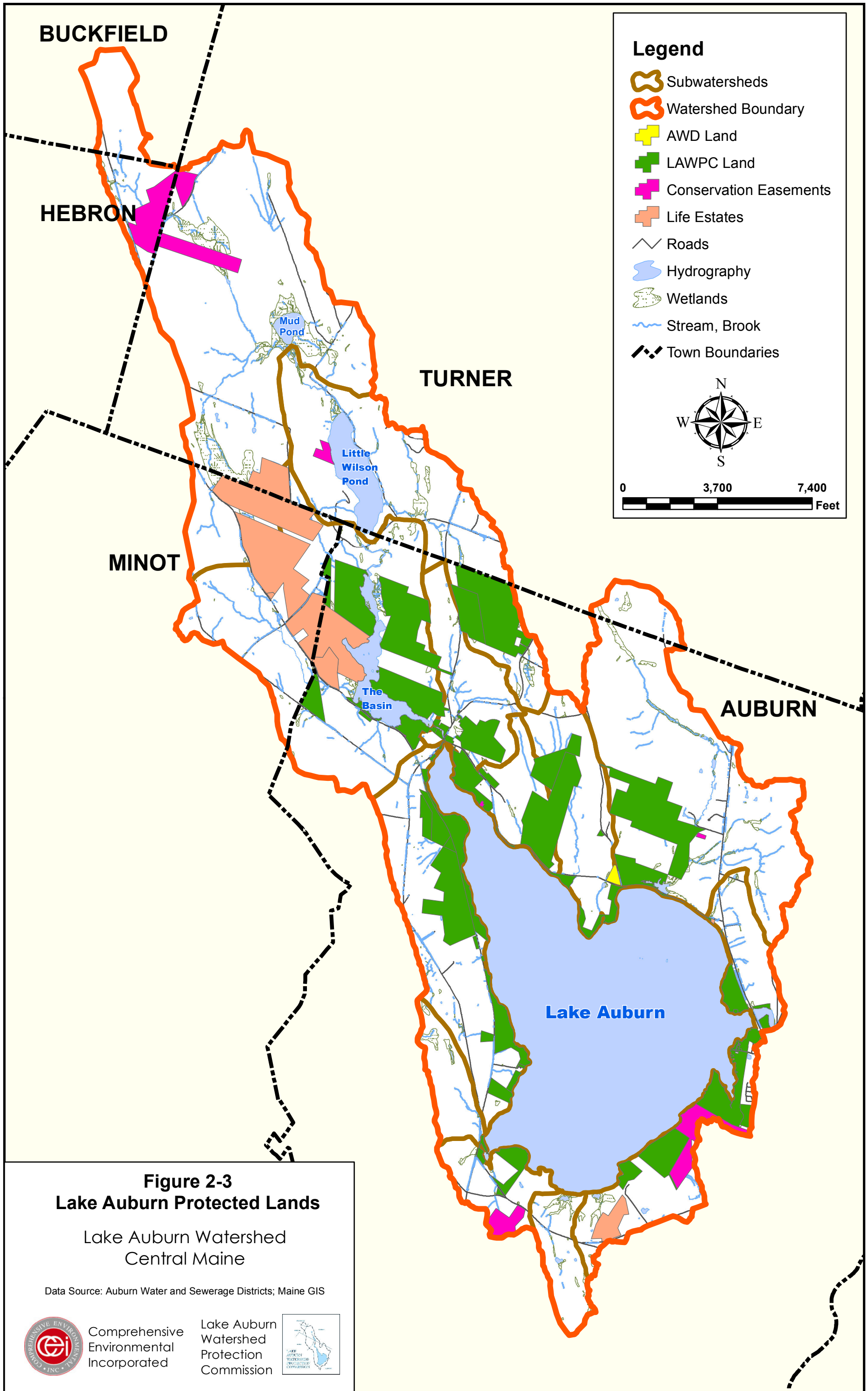


Figure 2-3
Lake Auburn Protected Lands

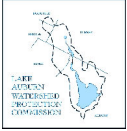
Lake Auburn Watershed
Central Maine

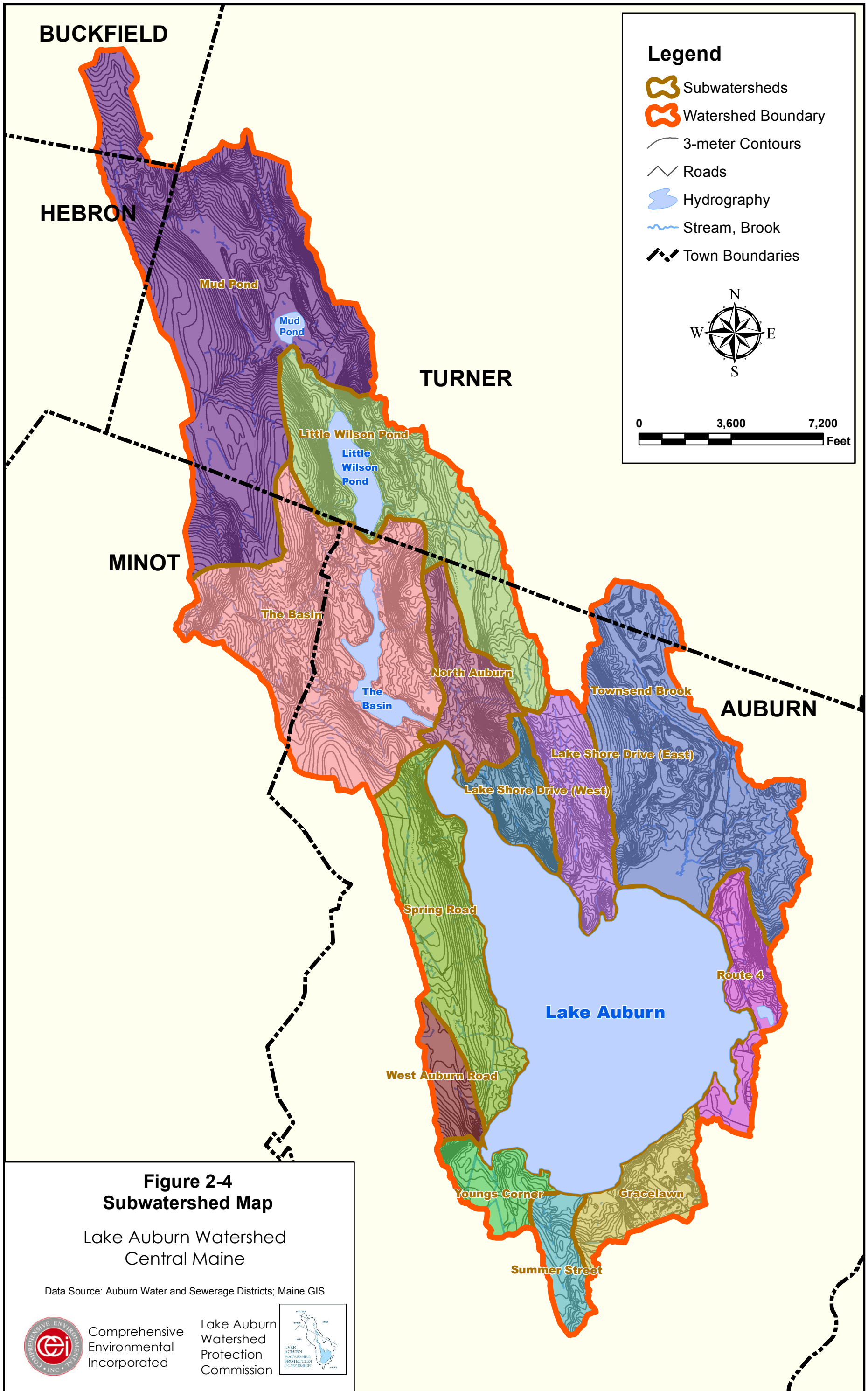
Data Source: Auburn Water and Sewerage Districts; Maine GIS

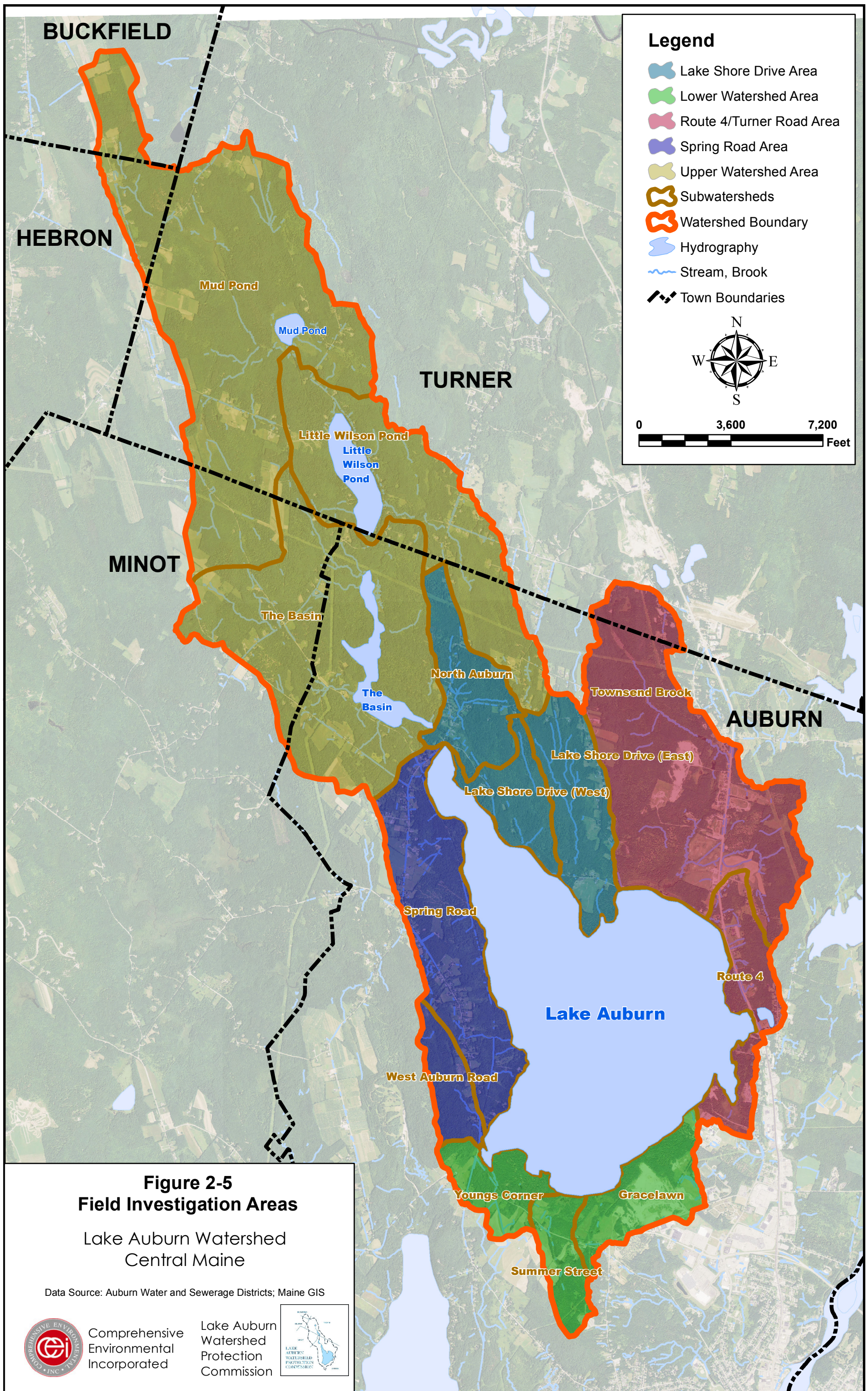


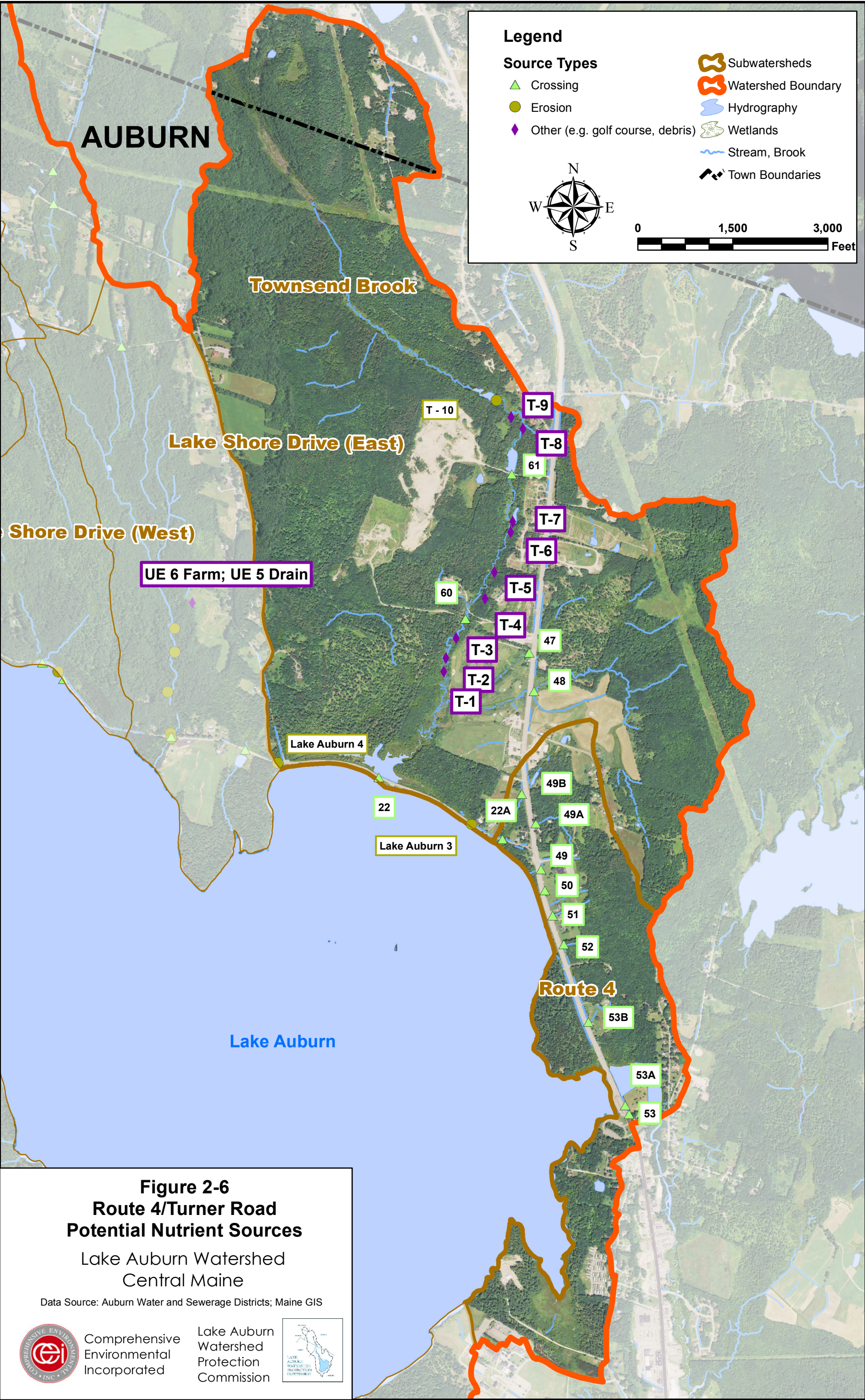
Comprehensive
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Lake Auburn
Watershed
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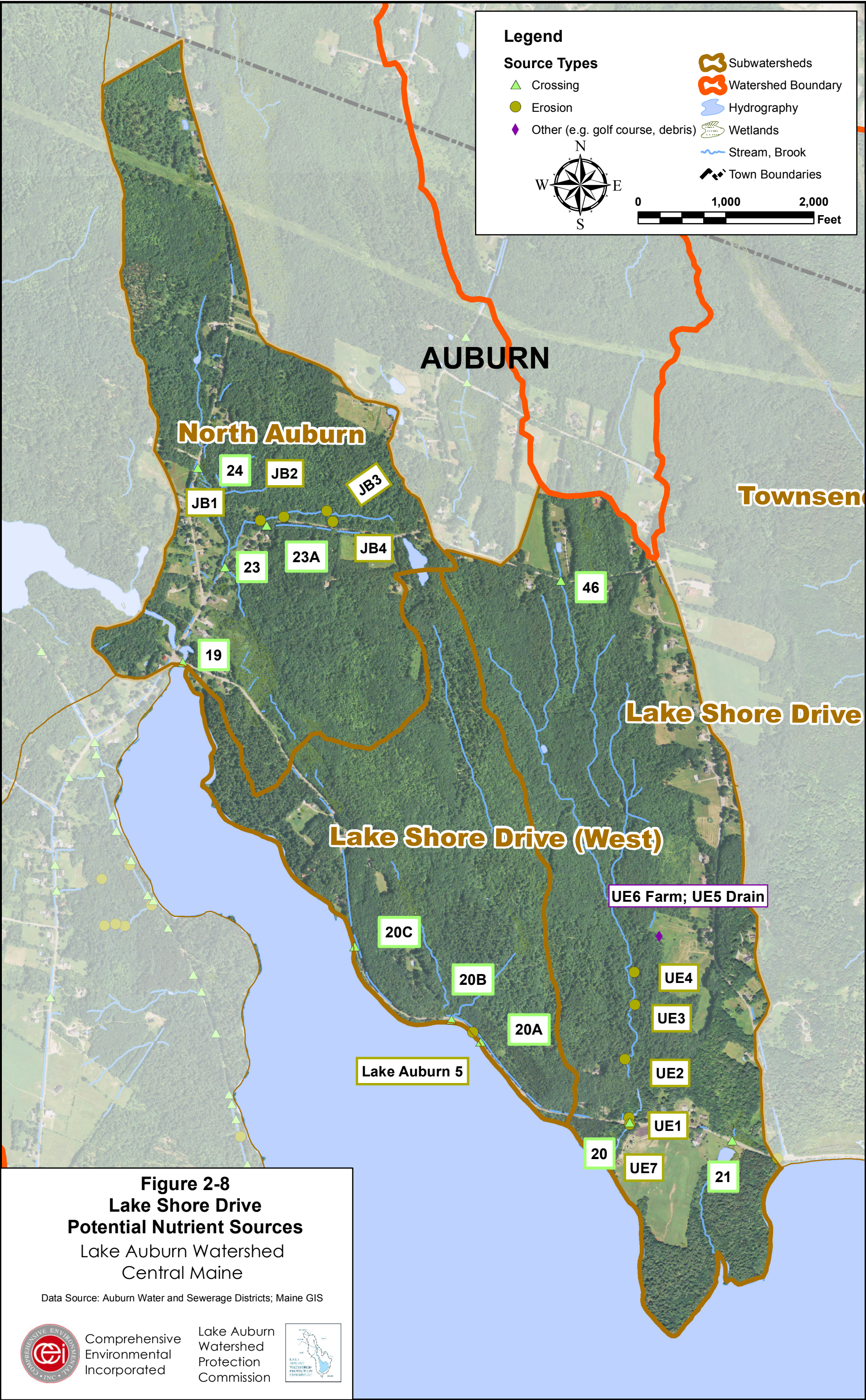


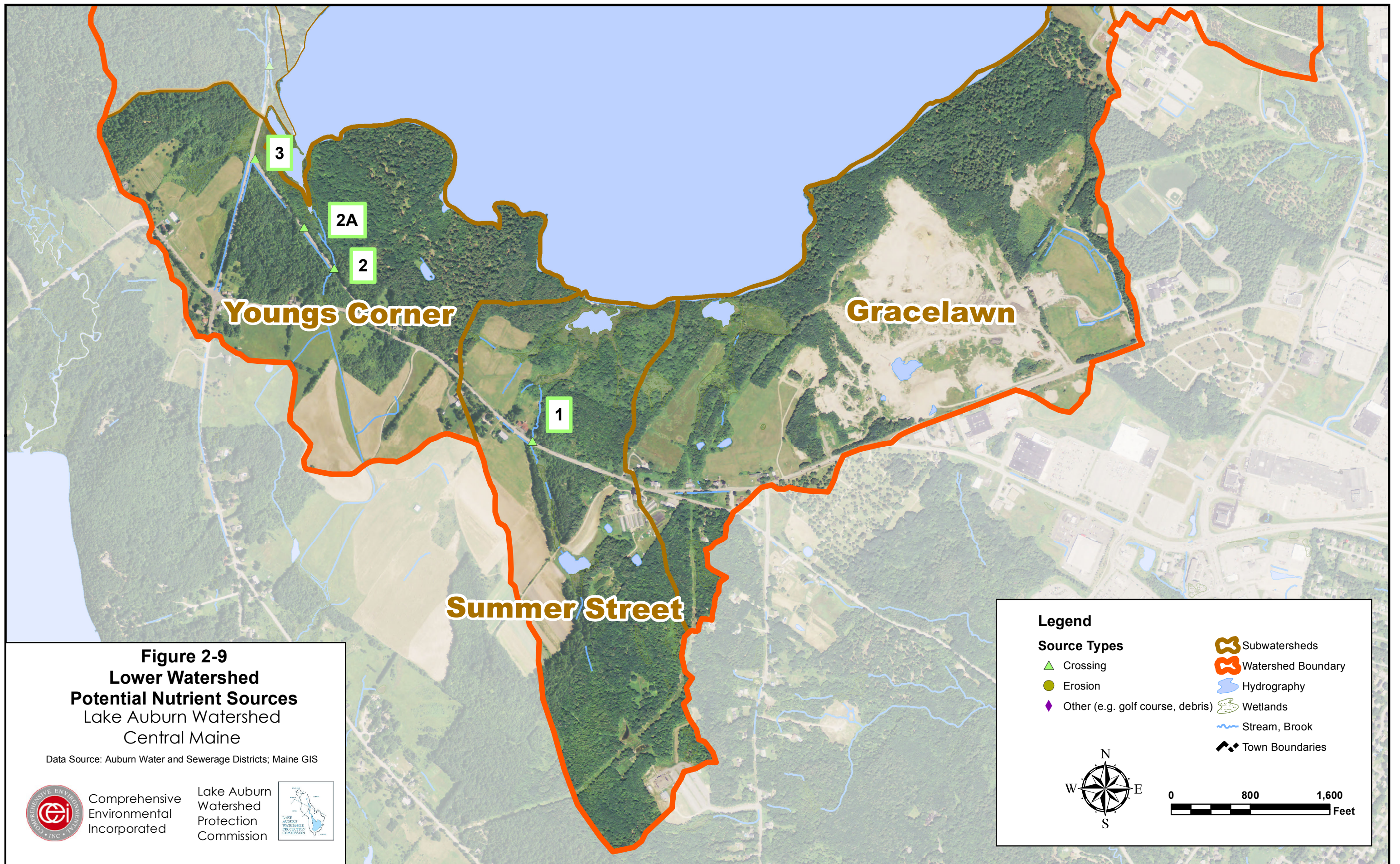


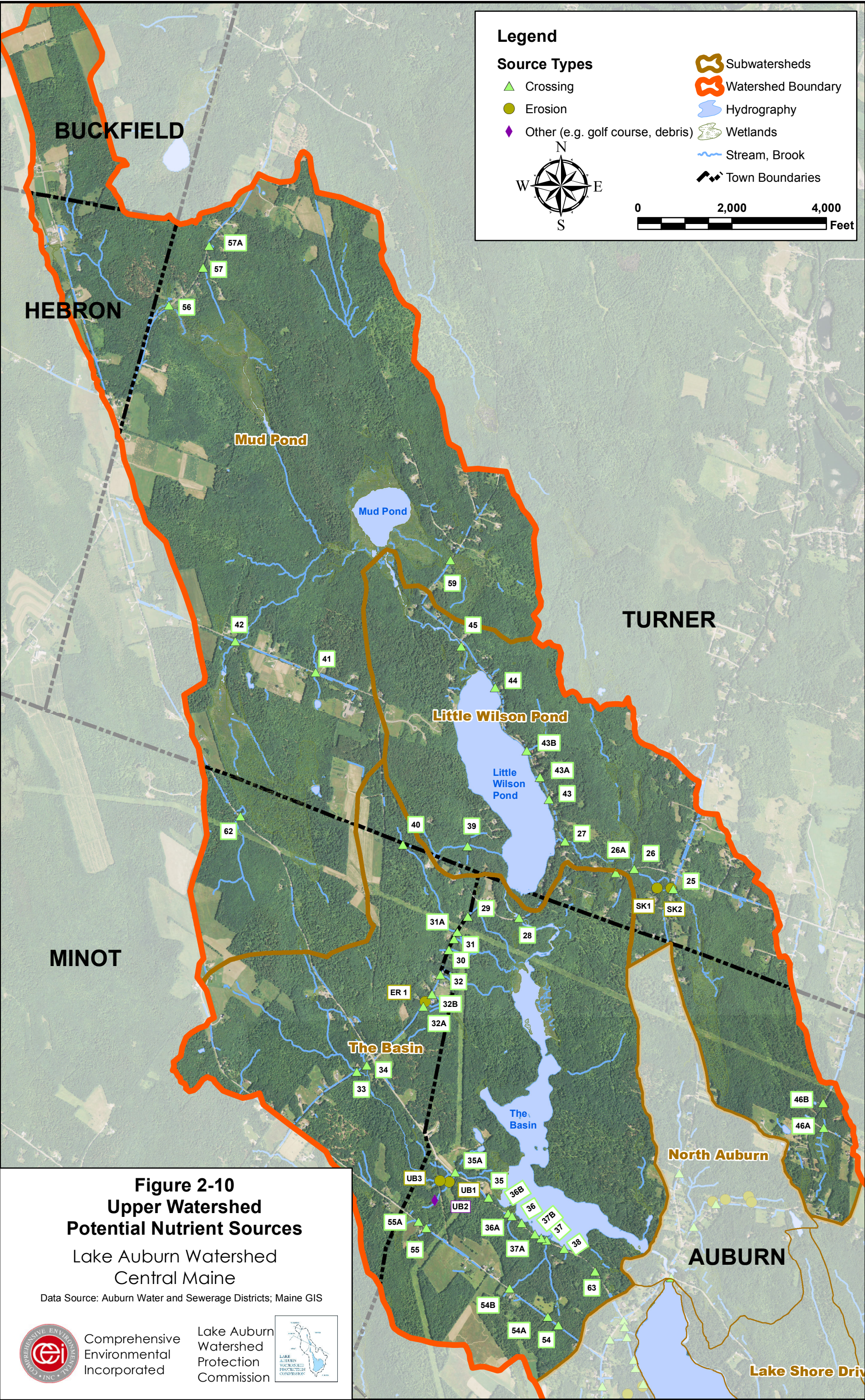


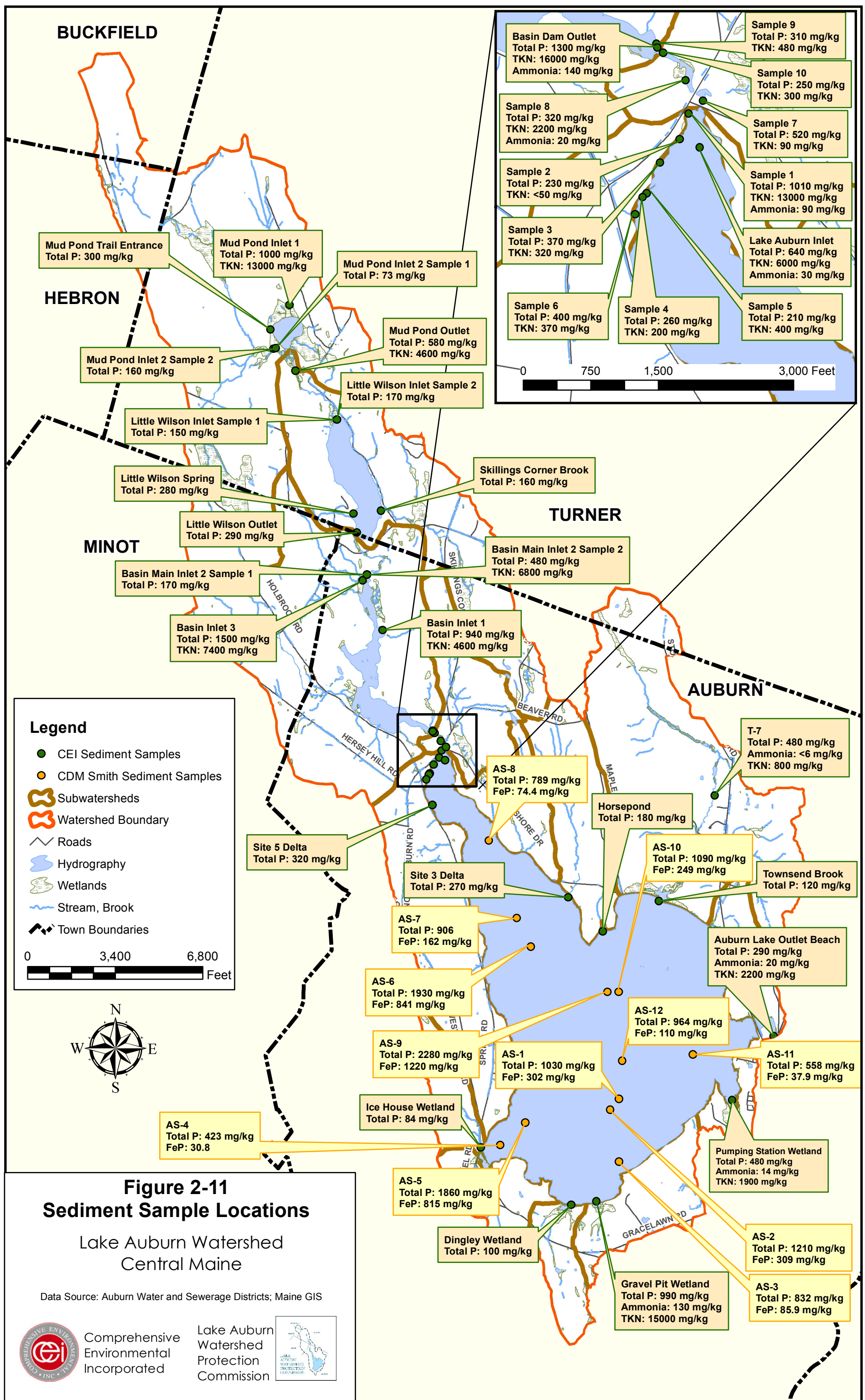












Section 3 Water and Nutrient Budget Update

The water and nutrient budgets from the 2010 Lake Auburn Watershed Management Plan were updated to include more recent data from 2009 through 2012, and to refine the budgets to evaluate monthly, seasonal and annual differences that may have influenced the recent algal blooms and 2012 fish kill.

Nutrient and hydrologic loads were simulated using the Generalized Watershed Loading Function – Enhanced (GWLF-E) Version 7.2.3 model with ArcView Generalized Watershed Loading Functions (AVGWLF) Version 7.1 geographical information systems (GIS) interface to assist with the 2001 to 2012 water and nutrient budget update. In combination with this software, CEI used the Reckhow Phosphorus Lake Model to help estimate annual in-lake phosphorus concentrations based on projected loadings from the model. The Dillon-Rigler and Vollenweider models were also used to predict trophic status based on the modeled loads. Refer to Appendix B for a full description of the model and parameters (as taken from the 2010 Watershed Management Plan). Any changes or updates to the model are indicated below.

3.1 Model Input Updates

3.1.1 Subwatersheds

No changes were made to the subwatershed boundaries included in the 2010 Lake Auburn Watershed Management Plan. The thirteen subwatersheds are summarized in Table 3-1 and shown in Figure 2-4.

3.1.2 Land Use and Land Cover

Land use data within the Lake Auburn Watershed was updated in the model to reflect any recent development changes since 2006. Existing land use totals as obtained from the New England Interstate Water Pollution Control Commission dataset, developed by Penn State Institutes of the Environment specifically for AVGWLF application¹, were modified to reflect current land uses based on comparisons between 2006 and 2011 NAIP (National Agricultural Imagery Program) orthophoto imagery (<http://mapserver.maine.gov/basemap/index.html>). The most recent orthophoto imagery indicated a 6-acre agricultural area within the Gracelawn watershed that was previously labeled as forested. Additionally, a total of four acres of forested area from the Mud Pond and three acres from the Little Wilson subwatersheds were converted to low intensity development. Table 3-2 shows the type and total area of each land use by subwatershed as modified to reflect actual conditions. Figure 3-1 shows the existing land uses throughout the watershed before the model modifications mentioned above.

¹Penn State Institutes of the Environment. February 2007. Summary of Work Undertaken Related to Adaptation of AVGWLF for Use in New England and New York.



Table 3-1. Land Area by Subwatershed	
Subwatershed	Land Area (acres)
Gracelawn	334
Lake Shore Drive (East)	450
Lake Shore Drive (West)	240
Little Wilson Pond	838
Mud Pond	2214
North Auburn	537
Route 4	346
Spring Road	803
Summer Street	189
The Basin	1587
Townsend Brook	1470
West Auburn Road	176
Youngs Corner	229
Total	9413

Table 3-2. Land Use Area by Subwatershed							
Subwatershed	Land Use Area (acres)						Total
	Hay/ Pasture	Cropland	Forested	Wetland	Low- Intensity	High Intensity	
Gracelawn	2	29	243	0	56	4	334
Lake shore Drive, East	70	14	348	5	4	9	450
Lake Shore Drive, West	2	0	224	1	3	10	240
Little Wilson Pond	11	11	734	12	30	39	838
Mud Pond	231	47	1704	148	27	56	2214
North Auburn	57	0	434	14	11	20	537
Route 4	42	6	200	16	38	44	346
Spring Road	141	12	580	5	19	46	803
Summer Street	21	38	122	4	0	4	189
The Basin	100	22	1361	25	27	52	1587
Townsend Brook	180	0	1096	54	82	58	1470
West Auburn Road	8	0	159	8	1	1	176
Youngs Corner	94	0	119	3	1	12	229
Total	960	179	7324	296	299	356	9413



3.1.3 Soils

No changes were made to the soils dataset since the 2010 Watershed Management Plan (Appendix B).

3.1.4 Precipitation and Temperature

The model was updated to include additional precipitation data from 2009 through September, 2012. Weather data, including precipitation and temperature data, were updated for the entire 2001 through 2012 period to reflect data collected at the rain gage in Poland, Maine, rather than the Lewiston gage that was used in the 2010 study. Data collected between 2009 and 2012 at the Lewiston gage was deficient and did not correspond well with other local gages. For consistency purposes, the entire weather dataset for the period of record was replaced to use the Poland, Maine gage. Any gaps within these datasets were supplemented with data from the National Weather Station in Durham, Maine and Portland, Maine. Average precipitation over the 2001 to 2008 period was approximately 50 inches per year. The average precipitation over the 2001 to 2012 period was about 52 inches per year, with a range between 32 and 66 inches per year.

3.1.5 Evapotranspiration

Average evapotranspiration over the 2001 to 2012 period was approximately 15 inches per year, with a range between 12 and 18 inches per year.

3.1.6 Flow Data

The calibrated flow modeling parameters from the 2010 Lake Auburn Watershed Management Plan were used in the model (Appendix B) with the new precipitation data from the Poland, Maine weather station. Flows generated by the GWLF-E model were used to update the 2001-2012 water and nutrient budget below.

3.1.7 Septic Systems

Phosphorus contributions from septic systems were estimated from about 281 systems within 300 feet of the lake as described in the 2010 Lake Auburn Watershed Management Plan. Septic system nitrogen loads were also calculated with the model. Nitrogen loads are calculated based on a count of all septic systems within the watershed, regardless of location. The 2010 study estimated a total of 318 septic systems in the watershed.

Based on information obtained from the Auburn Water District, only three additional septic systems were installed within the Town of Auburn since 2008. All three are farther than 300 feet from a water body, therefore, do not contribute an additional phosphorus load to the lake and do not significantly change the nitrogen loads to the lake.



3.1.8 Land Use Phosphorus Loadings

The GWLF-E modeling performed for the 2010 Lake Auburn Watershed Management Plan was calibrated to average observed in-lake phosphorus concentrations in the epilimnion layer (top-most layer of water in the lake, ranging from 0-23 feet under stratified conditions) in the spring. Calibration was performed by adjusting land use loadings to result in a phosphorus load that predicted an in-lake concentration that matched observed in-lake concentrations. The spring epilimnion was used since it reflected higher concentrations than the summer season, due to increases associated with fall turnover and distribution of the higher concentrated phosphorus loadings in the hypolimnion layer throughout the lake. Table 3-3 shows the adjusted pollutant loading coefficients by land use used in the model for total phosphorus. Note that the model was updated to include precipitation data from the Poland, Maine rain gage, but was not recalibrated for the 2001 through 2012 period or for the higher observed phosphorus concentrations in 2012. Calibration is best performed on a long-term average basis to represent average loads and lake response and to avoid the variability that can occur from year to year, keeping in mind that the average retention time of the lake is four years. The data can be used to highlight and evaluate trends and variations during these periods. Additional calibration may be performed at a later date depending on the internal recycling loads and severity of water quality changes noted after 2008.

Table 3-3. Phosphorus Loading Coefficients by Land Use

Source	Phosphorus Loading Coefficient	Units
Hay/Pasture	0.234	mg/L
Cropland	0.234	mg/L
Forest	0.007	mg/L
Wetland	0.007	mg/L
High Intensity Development	0.00526	kg/acre/d
Low Intensity Development	0.00081	kg/acre/d

3.1.9 Land Use Nitrogen Loadings

GWLF-E contains default nitrogen loadings determined by specific land use type². Existing dry weather streamflow data was used to approximate a groundwater total nitrogen loading coefficient. Based on the existing sampling data, which was available for various locations from April, 2000 to November, 2012, an average dry weather tributary total nitrogen concentration of about 0.05 mg/l (micrograms per liter) was estimated. Table 3-4 shows the nitrogen loading coefficients by land use used in the model for total nitrogen.

² Haith, Douglas A., Ross Mandel and Ray Shyan Wu. Generalized Watershed Loading Functions, Version 2.0, User's Manual. December 15, 1992.



Table 3-4. Total Nitrogen Loading Coefficients by Land Use		
Source	Nitrogen Loading Coefficient	Units
Hay/Pasture	0.29	mg/L
Cropland	0.29	mg/L
Forest	0.19	mg/L
Wetland	0.19	mg/L
High Intensity Development	0.04089	kg/acre/d
Low Intensity Development	0.00486	kg/acre/d

3.2 Water Budget

The GWLF-E model was used to estimate daily inflow to Lake Auburn based on updated AVGWLF files for the 2001-2012 time period mentioned above. The use of the Poland, Maine precipitation records brought the observed³ and modeled flow volumes for the 2001 through 2003 period closer together, within five percent (refer to Appendix C for the calibration curve using Poland, ME precipitation data) without recalibrating the model. Therefore, the Poland, Maine precipitation data was used in the model without further adjustment (e.g., recalibration) to other modeling parameters.

Note that like the pollutant loads, calibration is based on a longer-term average period; in the case of flow data January, 2001 to July, 2003 using gaging data from Townsend Brook (refer to Appendix B). This was then applied to the entire watershed to obtain an average annual water budget for calculating loads. This water budget represents annual water flow into the lake, but may not accurately represent daily or monthly fluctuations in flows associated with significant rain events. There are many surface waters and wetland areas in the watershed that can buffer and delay the daily and monthly flow volumes to the lake, making the water budget at this level less accurate than on an annual basis. However, the data can still be used to assess overall trends and variability from one period to the next as it relates to precipitation.

The model can be used to estimate inflows from direct precipitation and streamflow (e.g., baseflow and runoff) on a daily basis, with a breakout of baseflow and runoff on a monthly basis. Outflows can be estimated using available data as described in Section 3.2.2. Both, combined with the lake elevation, can be used to develop a water budget for the lake.

³ The observed flow volumes were obtained from: Dudley, Robert. United States Geological Services. Water Budget for Lake Auburn, Maine, May 1, 2000 through April 30, 2003. Scientific Investigations Report 2004-5106.



3.2.1 Inflows

Direct precipitation – Direct precipitation for each year was calculated by multiplying average annual precipitation by the lake surface area of about 2,259 acres. Direct precipitation fluctuated from year to year throughout the time period. The largest contribution to lake inflows occurred in 2005 with approximately 538 million cubic feet entering the lake. Figure 3-2 shows the distribution of precipitation by month and year over the period of record. Figure 3-3 shows the distribution of precipitation by season over the period of record.

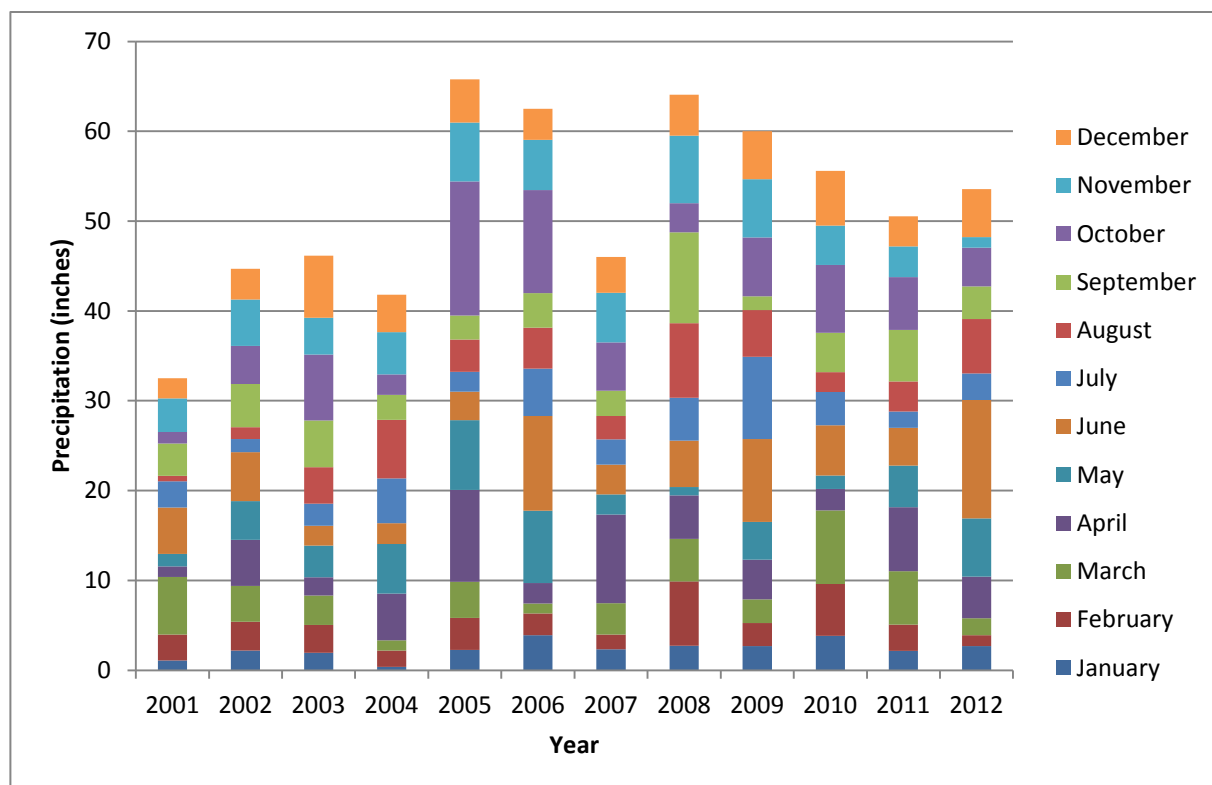


Figure 3-2. Annual and Monthly Precipitation Distribution in Lake Auburn Watershed



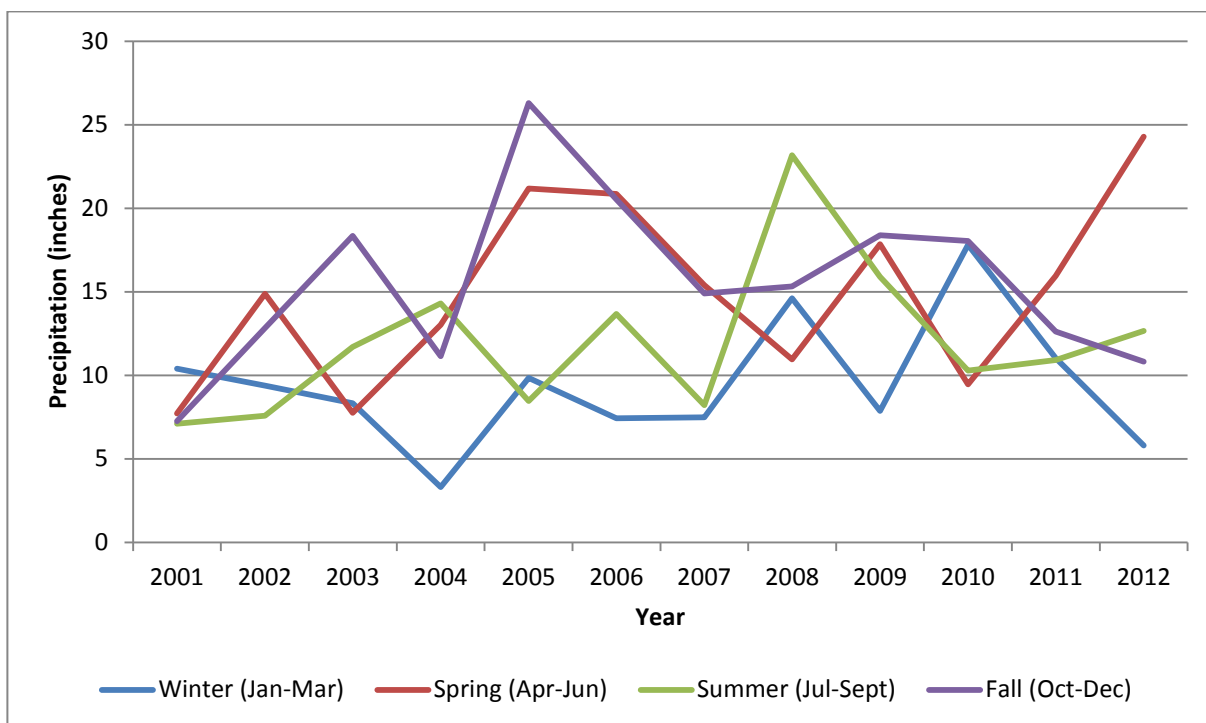


Figure 3-3. Seasonal Precipitation Distribution in Lake Auburn Watershed

Note that 2005, 2006, 2008 and 2009 were the wettest years, with 60 inches or more of precipitation each year. The fall season (October – December) typically received the greatest amount of precipitation each year, followed by the spring (April – June). 2008 had a notably wetter summer than other years and a considerably wetter June was noted in 2012. The June 2012 precipitation included the large precipitation event that caused extreme overtopping of the Basin, introducing higher pollutant loads into the lake.

Further review of the precipitation data reveals six storm events with greater than four inches of rain between October, 2005 and June, 2012, with two of these events larger than six inches. Most of these occurred over a two to three day period. As a point of reference, the 10-year frequency storm for the area is 4.60 inches and the 100-year frequency storm for the area is 6.5 inches. Although these design frequency storms represent rainfall over a 24-hour period, they serve as a good point of reference to illustrate the size and magnitude of the storm events over this period of time.

Streamflow – GWLF-E generated streamflow data on a daily basis. Streamflow data is comprised of baseflow and runoff, which are generated by the model on a monthly basis.

Baseflow – GWLF-E generated baseflow, also known as groundwater flow, on an average monthly basis that was summed to calculate average yearly totals. Baseflow fluctuated consistently throughout the time period, with the largest contribution existing in 2008 with approximately 745 million cubic feet entering the lake.



Runoff – Average monthly runoff generated in GWLF-E was also summed to calculate average annual totals. Throughout the time period, runoff fluctuated consistently with the largest contribution to lake inflows in 2005 with approximately 322 million cubic feet entering the lake.

3.2.2 Outflows

Evaporation – Evaporation from Lake Auburn was estimated using the Hamon equation. The Hamon equation uses saturation vapor density, which is a function of daily mean temperatures, and hours of daylight to compute evaporation in inches per day as follows:

$$ET = 0.55D^2Pt$$

Where:

ET = potential evapotranspiration (inches/day)

D = hours of daylight for a given day (12 hr)

Pt = $4.95e^{(0.062T_a)}/100$

T_a = daily mean temperature (°C)

Daily precipitation values were calculated and summed to get totals for each year.

Withdrawals – Withdrawals were adjusted to reflect actual withdrawals each year.

Outlet flows – Outlet flows represent the water leaving the lake through the Bobbin Mill Brook outlet or groundwater seepage and are estimated based on the modeled inflows and net change in lake volume as calculated based on lake elevations. Lake elevations were used to estimate the net change to lake volume and this net change was subtracted from inflows to determine total outflows from the lake, including evaporation and withdrawals. The outlet flows were calculated as the difference between the total outflows and known/estimated outputs (e.g., evaporation and withdrawals).

There is not enough data available to calculate actual outflows from the lake for comparison to these estimates. Outflows from the lake are controlled by the Auburn Water District through the outlet dam. Water is typically released in response to large rain events or to flush stagnant water at the beach at the outlet. Water is released by removing boards to lower the spillway and/or by opening the sluice gate. The Auburn Water District targets a stable lake elevation of 260 feet because it is achievable and provides buffer for either drought or rain. This corresponds with the elevation of the top of the dam. The goal is to prevent flooding of property by high lake level and problems caused by ice jams and shoreline damage under high level frozen conditions.

The Auburn Water district began targeting the stable lake elevation in 2003 after the dam was repaired to limit leakage. There are no records available on the removal of boards or opening of the sluice gate to calculate an accurate outlet flow. Future recording of this data will allow for calculation of outlet flows that can be used to refine the water budget and model inflows.



3.2.3 Water Budget Results

Lake elevations were used to calculate the net change in lake volume on a daily basis, which were then combined with estimations of streamflow, direct precipitation, evaporation and withdrawals to estimate outlet flows and a water budget for the lake. Table 3-5 summarizes the water budget. Figure 3-4 shows the total inflows and outflows to the lake and Figure 3-5 shows the seasonal inflows to the lake. Figure 3-6 shows the net change in lake volumes as a gain or loss. Figure 3-7 shows the seasonal net changes in lake volumes as a gain or loss for each year.

Table 3-5. Water Budget												
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Precipitation (inches)	32.5	44.3	46.0	41.6	65.5	62.5	45.9	63.9	60.0	55.5	50.4	53.5
Inflows (million ft³)												
Direct Precipitation	264	363	378	342	538	511	374	525	491	455	415	441
Streamflow (Baseflow + Runoff)	403	594	645	474	1,046	862	623	1,006	850	835	709	720
Total	667	956	1,023	816	1,584	1,373	997	1,531	1,341	1,291	1,124	1,161
Outflows (million ft³)												
Outlet	240	126	341	302	1,012	848	545	951	741	714	630	686
Evaporation	219	196	190	187	199	206	195	195	186	208	199	207
Withdrawals	375	392	378	360	353	337	337	337	332	338	347	337
Total	834	714	909	850	1,564	1,392	1,077	1,483	1,258	1,261	1,176	1,230



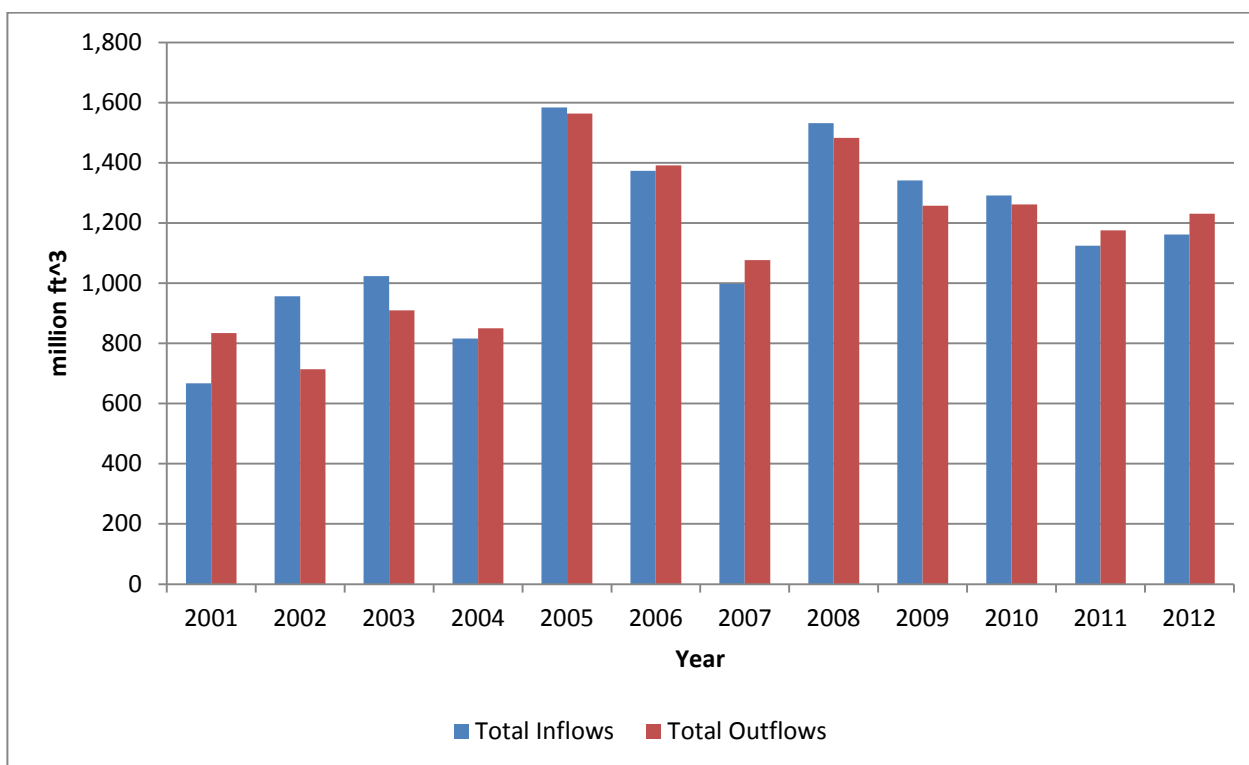


Figure 3-4. Annual Inflow and Outflow in Lake Auburn

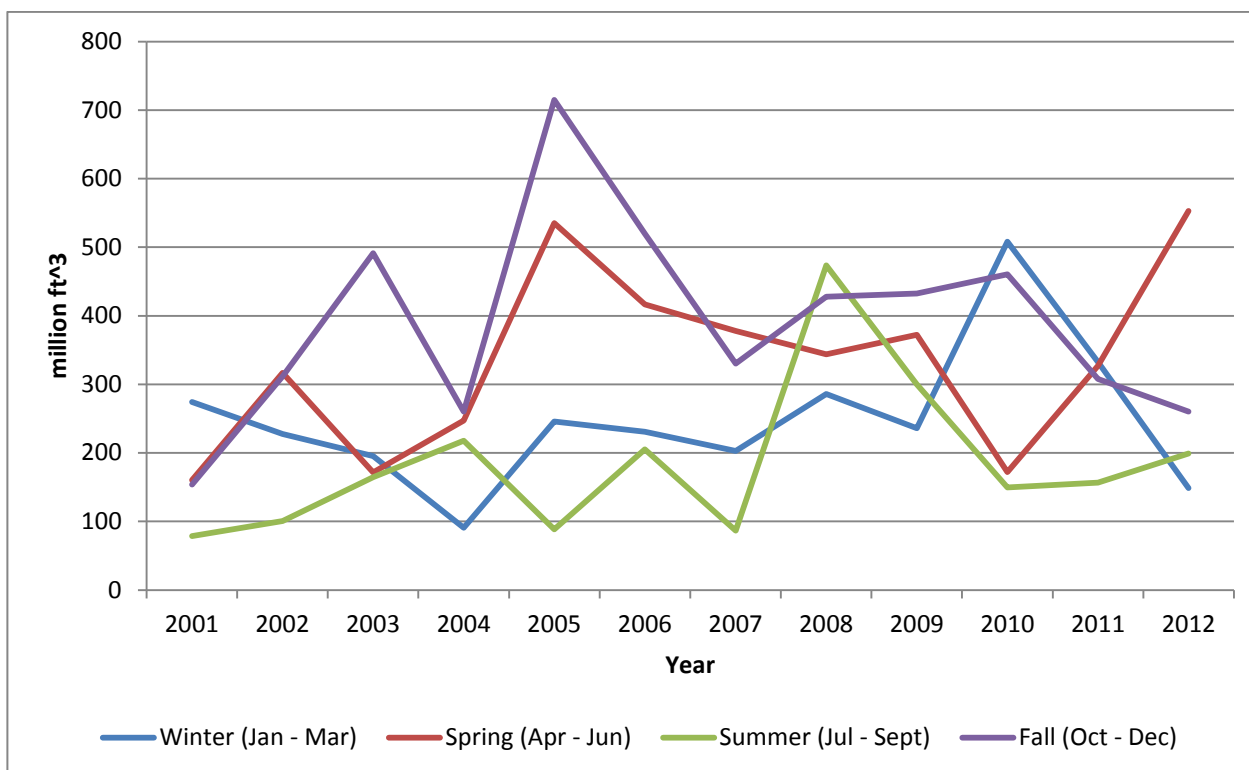


Figure 3-5. Seasonal Inflows in Lake Auburn



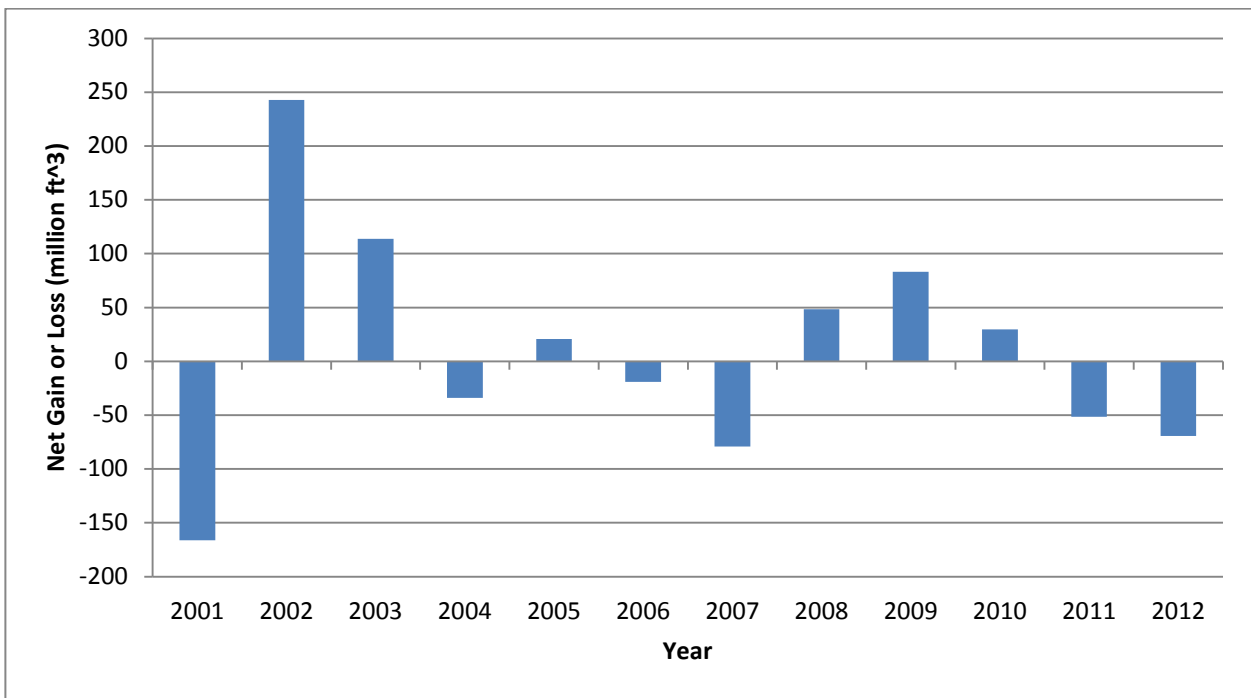


Figure 3-6. Annual Net Gain or Loss in Lake Volume

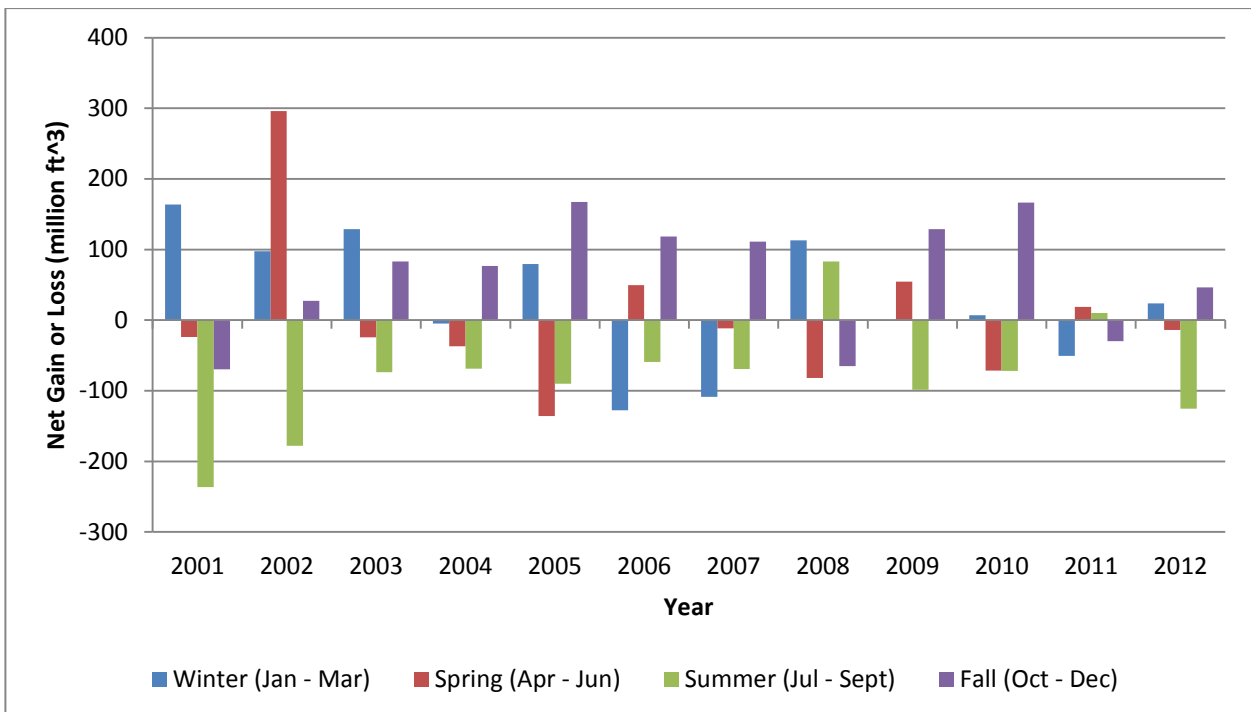


Figure 3-7. Seasonal Net Gain or Loss in Lake Volume



The budget matches closely with the USGS water budget that was performed between 2000 and 2003, which showed surface-water inflow to contribute 62.2% of the inflow to the lake and precipitation to contribute 37.8% of the inflow to the lake. USGS showed the outflow was comprised of 47% from municipal withdrawals, 22.6% from evaporation and 30.4% from surface-water outflow. Similar values were observed from the modeled outputs for this study over this same period.

The hydrologic water budget follows the precipitation distribution with much greater flows entering the lake between 2005 and 2012, with the exception of 2007, which was in line with previous years. Highest inflows were observed in 2005 and 2008, followed closely by 2006 and 2009. Very high inflows were observed in spring 2012. The year 2010 experienced the highest inflows over the winter and fall. As described further below, pollutant loadings will generally follow the same trends as precipitation and inflow, with greater runoff bringing in higher pollutant loads.

Figure 3-6 shows that the greatest net loss of water in the lake occurs during the driest years, with the greatest net loss in drought year 2001 and then in 2007. Seasonally, summer nearly always shows a net loss to the lake, associated with less precipitation, greater withdrawal and more evaporation, while fall typically shows a net gain to the lake. However, the trend over the 2001-2012 period shows an overall decrease in summer net losses and an overall decrease in the net gain to the lake during the spring and winter seasons.

Lake elevation data in relation to the outlet dam elevation were also plotted against precipitation to identify trends and changes in lake elevations across the 2001 to 2012 period. Figure 3-8 shows this comparison, along with total phosphorus concentrations in the surface and deep waters. As can be seen in the Figure, the lake elevations were higher beginning in 2008. Prior to 2008, there were several periods where lake elevations were lower than the dam elevation. Between 2000 and 2004, including the drought year of 2001, these lower lake elevations typically occurred in the fall into or through the winter. Between 2005 and 2006, lower lake elevations occurred more often over the summer and into the fall, with one incident of lower lake levels in the winter/spring of 2006. There was a long stretch of lower lake elevations between May, 2007 and January, 2008, followed by higher than average precipitation in January and February of 2008.

Fluctuations in lake elevations could have some influence on the water quality of the lake. For example, release of water over the winter, may release some of the phosphorus load from internal recycling of sediments that mixes with the epilimnion layer after fall turnover. Alternatively, lower lake elevations in the spring, before stratification occurs, may allow for higher retention of phosphorus loads that enter at that time.

Existing water quality data was overlaid with the lake elevations and precipitation graph. It appears the in-lake concentrations have increased with the higher maintained lake elevations; however, the data is too limited to conclusively make this relationship.



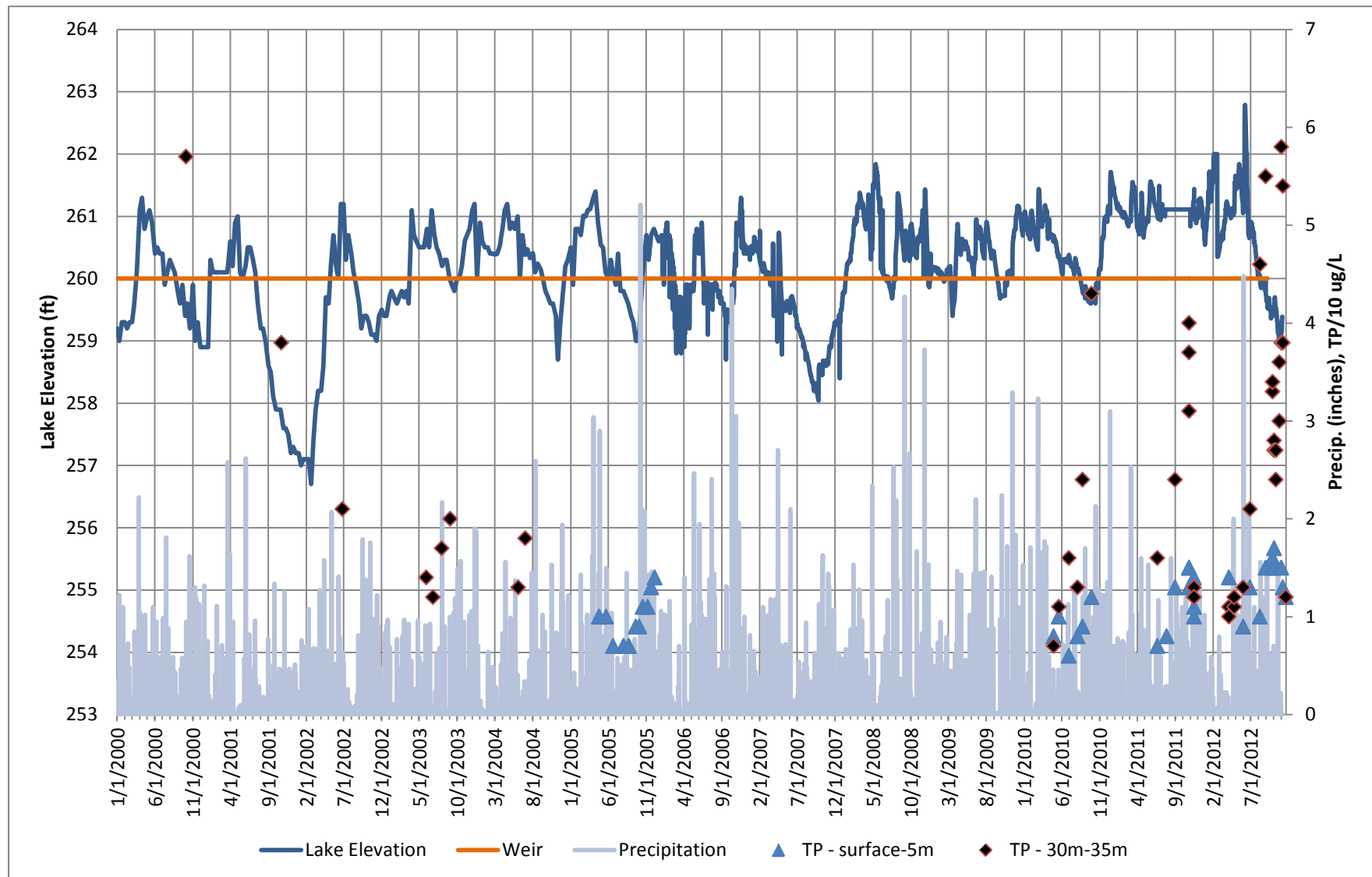


Figure 3-8. Lake Elevation in Relation to Dam Elevation and Precipitation

3.2.4 Lake Residence Time

The water budget will also influence the lake residence time. It is calculated by dividing the lake volume by the average annual flow in or out of the lake. The residence time can impact the trophic state of the lake, which is based on the pollutant load and inflow to the lake. The average residence time of the lake is about three to four years. When calculated on an individual year basis, it will range based on the amount of precipitation and inflow as shown in Figure 3-9. Considering the long residence time of the lake, the average calculations are more representative, however, the yearly data can be used to illustrate the influence that water flow through the lake has on lake response.

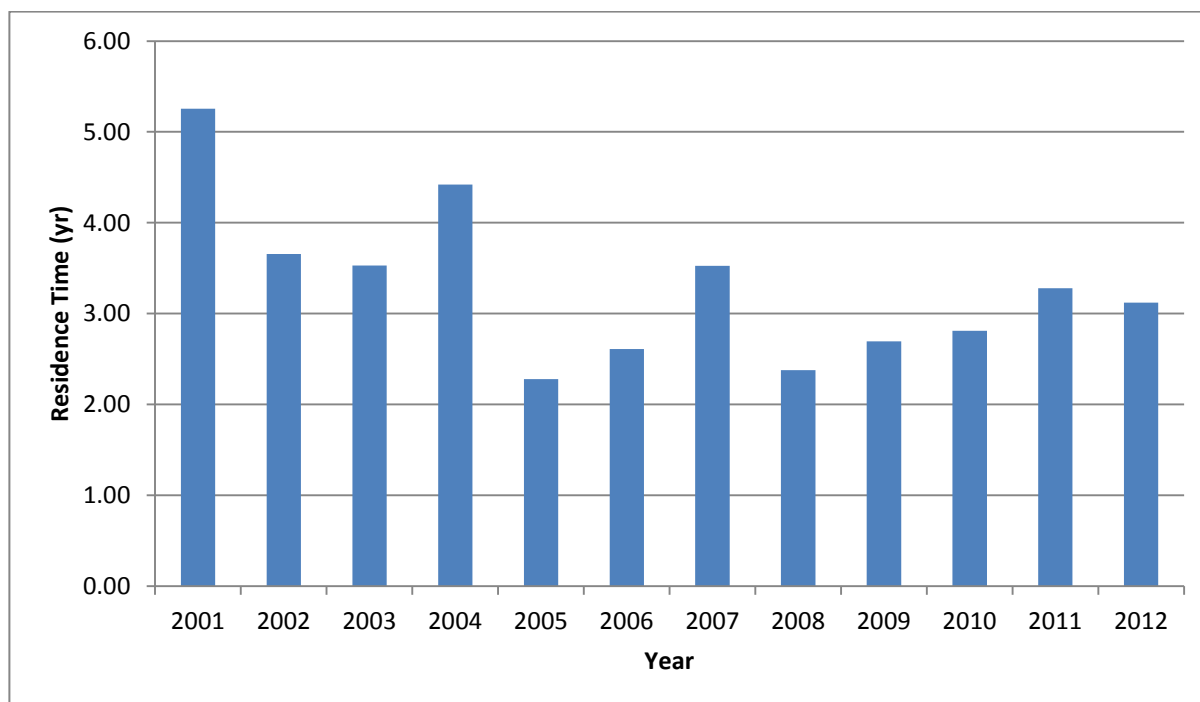


Figure 3-9. Residence Time in Lake Auburn

Consistent with precipitation data, 2001 – 2004 and 2007 represent longer retention times, while the wetter periods of 2005, 2006 and 2008 – 2010 represent shorter flushing times. Again, the retention time will not fluctuate this drastically from year to year, but can influence the retention time over a given period.

3.3 Nutrient Budget

3.3.1 Land Use Based Loads

GWLF-E was used to estimate annual phosphorus and nitrogen loads by source for the 2001-2012 time periods (Table 3-6 and Table 3-7). While the model was updated to include precipitation data from the Poland, Maine gage, which resulted in an increase in phosphorus loads for the 2001 – 2008 time period, it was not recalibrated to adjust loads to match in-pond concentrations. The new precipitation data resulted in an average annual increase in



phosphorus loads of 272 pounds/year. Using the Reckhow Phosphorus Lake Model, this phosphorus loading predicts an average in-lake phosphorus concentration of 11.2 ug/l for the 2001-2008 period. This falls within the range of average observed in-lake concentrations in the epilimnion layer, which ranged between a concentration of 7 ug/l in the summer to 11.1 ug/l in the winter. Note that the higher winter concentrations are a result of turnover and mixing of the phosphorus-rich hypolimnion layer with the lower concentrated epilimnion layer.

Further refinement of model loads can be achieved with a greater level of in-lake data on which to calibrate, and collection of outflow data to further refine inflows.

Specific land based runoff, baseflow, and streambank erosion were all estimated using GWLF-E. The septic system, precipitation, and internal recycling load contributions estimated in the 2010 Lake Auburn Watershed Management Plan (Appendix B) were carried over into the updated model. There was little development in the watershed between 2009 and 2012 that would significantly increase septic system loadings. Precipitation loadings on the lake are based on the size of the lake and internal recycling loads have been kept constant at the average rates calculated in the 2010 plan. These latter loads can be updated upon CDM-Smith's assessment and estimate of internal recycling contributions.

Note that the agricultural land uses (e.g., hay/pasture and cropland) assume the application of manure, primarily in the fall. This application will result in higher agricultural loadings for those years when there are significant fall rain events. The Auburn Water District has confirmed that hen manure is applied to select hay/pasture fields in the fall based on soil testing. There is no information on the remaining fields, however, it is assumed they are harvested for hay since they have not turned into woodlands. Manure application was assumed to occur on all properties. Additional data could be collected to adjust the assumptions if a more accurate break out by land use is needed. However, the overall watershed loads fall within the expected range based on the observed in-lake concentrations.

3.3.2 Gulls as a Source of Phosphorus

Phosphorus loads from gull populations between 2006 and 2008 were also estimated using the data provided in the January 2009 USDA report⁴ and a phosphorus loading factor of 115 mg/day/gull⁵. This period represents gull populations under implementation of the gull harassment program and resulted in a range of 6 to 13 lbs/year of phosphorus from gulls. This is considered to be insignificant compared with other loads.

⁴ United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services. Gull Management on Lake Auburn, Maine. Annual Report. January 2009.

⁵ Gould and Fletcher 1978. Gull Droppings and Their Effects on Water Quality. Water Research 12: 665-672.



Table 3-6. Phosphorus Load by Source												
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Source	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr
Land-based Runoff												
<i>Hay/Pasture</i>	123	323	468	246	1,303	591	702	1,041	507	808	581	519
<i>Cropland</i>	62	125	146	98	367	224	201	317	199	234	189	189
<i>Forest</i>	8	13	31	20	89	35	43	63	33	64	31	54
<i>Wetland</i>	3	5	6	4	12	9	7	12	8	9	7	8
<i>Low Intensity Development</i>	19	29	24	23	34	36	23	36	37	28	31	33
<i>High Intensity Development</i>	233	288	273	267	344	354	257	335	354	300	332	320
Land-based Runoff Subtotal	<u>448</u>	<u>784</u>	<u>949</u>	<u>658</u>	<u>2,150</u>	<u>1,249</u>	<u>1,233</u>	<u>1,804</u>	<u>1,138</u>	<u>1,443</u>	<u>1,171</u>	<u>1,124</u>
Other Land-based												
<i>Streambank Erosion (sediment)</i>	8	11	11	9	14	14	10	15	14	13	12	12
<i>Baseflow</i>	407	573	556	441	794	793	507	818	782	656	627	589
<i>Septic Systems</i>	293	293	293	293	293	293	293	293	293	293	293	293
Other Land-based Subtotal	<u>708</u>	<u>876</u>	<u>860</u>	<u>743</u>	<u>1101</u>	<u>1099</u>	<u>810</u>	<u>1126</u>	<u>1088</u>	<u>962</u>	<u>932</u>	<u>894</u>
Land-based Runoff & Other Land-based Subtotal	1,156	1,661	1,809	1,402	3,251	2,348	2,043	2,930	2,226	2,404	2,103	2,018
Other Sources												
<i>Atmospheric Deposition</i>	444	444	444	444	444	444	444	444	444	444	444	444
<i>Internal Recycling</i>	911	911	911	911	911	911	911	911	911	911	911	911
Other Sources Subtotal	<u>1,355</u>	<u>1,355</u>	<u>1,355</u>	<u>1,355</u>	<u>1,355</u>	<u>1,355</u>	<u>1,355</u>	<u>1,355</u>	<u>1,355</u>	<u>1,355</u>	<u>1,355</u>	<u>1,355</u>
Total	2,511	3,016	3,164	2,757	4,606	3,703	3,398	4,285	3,581	3,759	3,458	3,373

Note: Atmospheric deposition is based on a loading factor that is based on the size of the lake. It may fluctuate year to year based on precipitation amounts.

Table 3-7. Nitrogen Load by Source												
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Source	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr	lbs/yr
Land-based Runoff												
<i>Hay/Pasture</i>	1,018	2,369	4,231	2,161	9,436	4,951	5,027	8,273	4,447	6,525	4,131	5,419
<i>Cropland</i>	475	899	1,223	780	2,611	1,766	1,421	2,435	1,620	1,815	1,330	1,735
<i>Forest</i>	63	170	684	317	1,957	470	892	1,308	526	1,487	644	1,049
<i>Wetland</i>	69	134	169	105	329	236	181	324	213	226	179	208
<i>Low Intensity Development</i>	113	176	143	138	204	214	140	217	219	168	189	196
<i>High Intensity Development</i>	1,813	2,236	2,121	2,071	2,675	2,748	1,995	2,603	2,749	2,333	2,576	2,489
Land-based Runoff Subtotal	<u>3,550</u>	<u>5,984</u>	<u>8,571</u>	<u>5,572</u>	<u>17,212</u>	<u>10,385</u>	<u>9,657</u>	<u>15,159</u>	<u>9,775</u>	<u>12,555</u>	<u>9,048</u>	<u>11,095</u>
Other Land-based												
<i>Streambank Erosion (sediment)</i>	18	24	24	21	32	31	23	33	31	30	27	27
<i>Baseflow</i>	1,130	1,591	1,545	1,226	2,205	2,203	1,409	2,273	2,171	1,821	1,743	1,636
<i>Septic Systems</i>	427	427	427	428	427	427	427	428	427	427	427	427
Other Land-based Subtotal	<u>1,575</u>	<u>2,042</u>	<u>1,996</u>	<u>1,674</u>	<u>2,664</u>	<u>2,660</u>	<u>1,859</u>	<u>2,734</u>	<u>2,629</u>	<u>2,277</u>	<u>2,196</u>	<u>2,091</u>
Land-based Runoff & Other Land-based Subtotal	5,125	8,026	10,568	7,247	19,876	13,045	11,515	17,893	12,404	14,832	11,244	13,186
Other Sources												
<i>Atmospheric Deposition</i>	15,022	15,022	15,022	15,022	15,022	15,022	15,022	15,022	15,022	15,022	15,022	15,022
<i>Internal Recycling</i>												
Other Sources Subtotal	<u>15,022</u>	<u>15,022</u>	<u>15,022</u>	<u>15,022</u>	<u>15,022</u>	<u>15,022</u>	<u>15,022</u>	<u>15,022</u>	<u>15,022</u>	<u>15,022</u>	<u>15,022</u>	<u>15,022</u>
Total	20,148	23,049	25,590	22,269	34,899	28,067	26,537	32,915	27,426	29,855	26,267	28,208

Note: Atmospheric deposition is based on a loading factor that is based on the size of the lake. It may fluctuate year to year based on precipitation amounts.

3.3.3 Landfills as a Source of Phosphorus

Landfills produce a liquid leachate that can move through or drain from the landfill. The leachate is often formed as rainwater filters down through the landfill and aids bacteria in the process of decomposition. It can enter groundwater and migrate off-site in the direction of groundwater flows. The level of contamination and migration of landfill leachate is typically incorporated into a long-term monitoring program after the landfill is closed.

The Gracelawn Landfill in Auburn, Maine is located in close proximity to Lake Auburn. This landfill has been extensively studied to determine leachate migration and flow paths and whether leachate could be reaching Lake Auburn. The City also performs landfill monitoring and maintains an annual monitoring report as part of a long-term monitoring program.

The Auburn and Lewiston Water Districts reviewed and summarized landfill data as part of this study to rule out any potential pollutant contributions to the lake. The findings found that groundwater flows from the landfill travel in an easterly and southerly direction, away from the lake. This is supported by ongoing monitoring which shows low and diminishing levels of leachate indicators in wells between the lake and landfill, while monitoring wells on the southerly side, away from the lake, has had increases in these same leachate indicators. The summary of findings from this analysis is included in Appendix D.

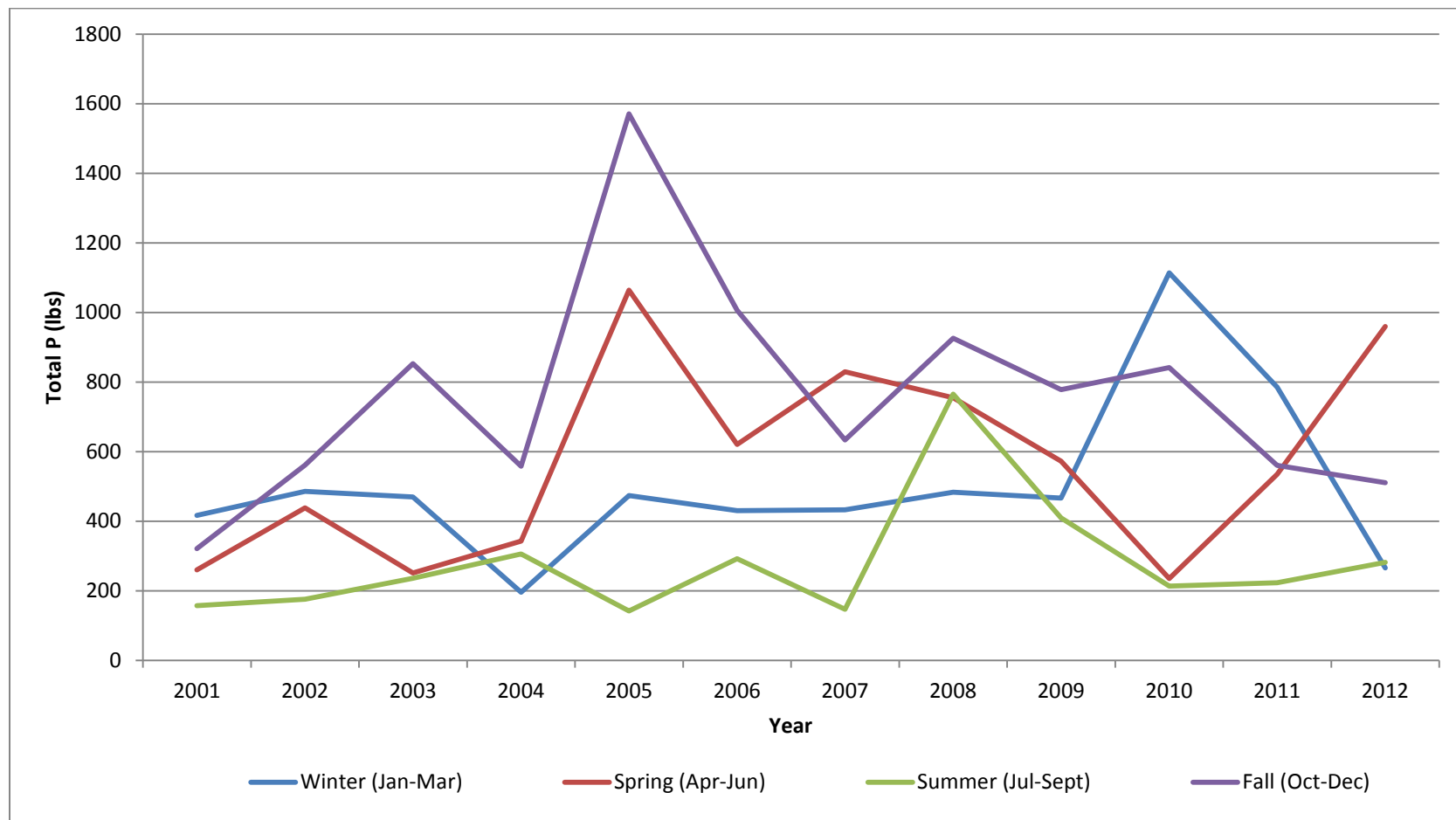
3.3.4 Nutrient Trends

As previously discussed, the model outputs lose accuracy as the output period is reduced. The model is calibrated based on an average eight year period of record, thus on a yearly basis, the data is expected to fall above and below this average based on the amount of precipitation and inflow. However, the model outputs can still be used to evaluate trends and changes from year to year that may influence in-lake water quality.

There was a notable increase in phosphorus loads beginning in 2005, consistent with the increased precipitation and inflows into the lake. As expected, 2005 and 2008 contributed the greatest land use based pollutant loads from the watershed. The 2005 through 2008 period contributed the highest loads on a four consecutive year basis, despite 2007 having considerably lower loads in comparison with the rest of this period. Loads between 2009 and 2012 decreased slightly from those between 2005 and 2008, however, were still considerably higher than the 2001 through 2004 period. It may take a few years for the lake to respond to these higher loadings, which may help to explain the notable changes in water quality beginning in 2010 (lower clarity) and continuing through 2012 (algal blooms).

A comparison of seasonal phosphorus loads to the lake (refer to Figure 3-10) shows the highest winter contributions in 2010 and 2011, the highest spring contributions in 2005, 2012, and 2007, the highest summer contributions in 2008 and 2009, and the highest fall contributions in 2005, 2006 and 2008.





Note: The total phosphorus inputs to the lake are from the watershed only. They exclude phosphorus loads from direct precipitation on the lake and internal recycling of phosphorus from bottom sediments.

Figure 3-10. Seasonal Total Phosphorous Inputs in Lake Auburn

The higher winter loads in 2010 and 2011 combined with the higher lake elevations during those periods may have provided a greater available food source within the lake for algae growth. The higher spring loads in June, 2012 with increasing residence times, from 2008, may have contributed to a greater food supply contributing to excess algae growth.

3.4 Lake Response

The health of a lake is often defined by its trophic state. Table 3-8 defines the proposed relationship among phosphorus concentration, trophic state and lake use for north temperate lakes. Based on this table, Lake Auburn is bordering between oligotrophic and mesotrophic. According to the 2003 Source Water Assessment prepared by Maine DEP, Lake Auburn has been classified as mesotrophic by the State. The trophic state of the lake was also calculated using the estimated hydrologic and phosphorus loadings from the model and the Dillon-Rigler Permissible Loading Model and the Vollenweider Model.

Table 3-8. Proposed Relationships Among Phosphorus Concentration, Trophic State, and Lake Use for North Temperate Lakes (Adapted from Chapra and Reckhow, 1979; Dillon and Rigler 1975)			
Phosphorus Concentration (µg/l)	Trophic State	Description	Lake Use
<10	Oligotrophic	Bodies of water that contain relatively little plant life or nutrients and are rich in dissolved oxygen.	Suitable for water-based recreation and propagation of cold water fisheries, such as trout. Very high clarity and aesthetically pleasing.
10-20	Mesotrophic	Bodies of water having a moderate amount of dissolved nutrients.	Suitable for water-based recreation but often not for cold water fisheries. Clarity less than oligotrophic lake.
20-50	Eutrophic	Bodies of water that are rich in nutrients, resulting in increased plant life (e.g., algal blooms). The bottoms of such waters typically have low dissolved oxygen.	Reduction in aesthetic properties diminishes enjoyment from body contact recreation. Generally very productive for warm water fisheries.
>50	Hypereutrophic	Bodies of water that are very rich in nutrients, resulting in frequent and severe nuisance algal blooms and low transparency.	A typical “old-aged” lake in advanced succession. Some fisheries, but high levels of sedimentation and algae or macrophyte growth may be diminishing open water surface area.

Source: Reckhow, Kenneth H. and Chapra, Steven C. 1983. Engineering Approaches for Lake Management. Volume 1: Data Analysis and Empirical Modeling. Butterworth Publishers. Boston. p. 275.



The Dillon-Rigler Permissible Loading Model is expressed as:

$$\text{Phosphorous Concentration} = LT(1-R)$$

L = annual areal phosphorus loading ($\text{g}/\text{m}^2\text{-yr}$), $L = W/A_s$
 W = total phosphorus mass loading (includes stormwater, internal recycling, baseflow) (g/yr)
 A_s = lake surface area (m^2)
 T = water retention time (yr)
 R = phosphorus retention coefficient
 $R = 0.426e^{-0.271(z/T)} + 0.574e^{-0.00949(z/T)}$
 Z = mean depth (m)

The Vollenweider Model is expressed as:

$$\text{Phosphorus Concentration} = L_p/q_s * (1/(1 + \text{square root } z/q_s))$$

L_p = annual areal phosphorus loading ($\text{g}/\text{m}^2\text{-yr}$), $L_p = W/A_s$
 W = total phosphorus mass loading (includes stormwater, internal recycling, baseflow) (g/yr)
 q_s = areal water loading (m/yr), $q_s = Q/A_s$
 z = mean depth (m)
 Q = inflow water volume to lake (m^3/yr), $Q = (A_d \times r) + (A_s \times P_r)$
 A_d = watershed area (land surface) (m^2)
 A_s = lake surface area (m^2)
 r = total annual unit runoff (m/yr)
 P_r = total precipitation (m/yr)

The results are shown in Figure 3-11 (Dillon-Rigler Permissible Loading Model) and Figure 3-12 (Vollenweider Model). Both models use phosphorus loads and hydrologic inputs to the lake to determine the trophic status of the lake.

The results of the Dillon-Rigler model showed that each year's estimated lake trophic status fell within the lower end of the mesotrophic state. These results were consistent with the Vollenweider model output which also predicted the lake's trophic status to fall within the lower end of the mesotrophic state. As expected, fluctuations from year to year follow the fluctuations in phosphorus load and hydrologic inputs (e.g., 2005 through 2008 show the worst trophic state and highest phosphorus loads).



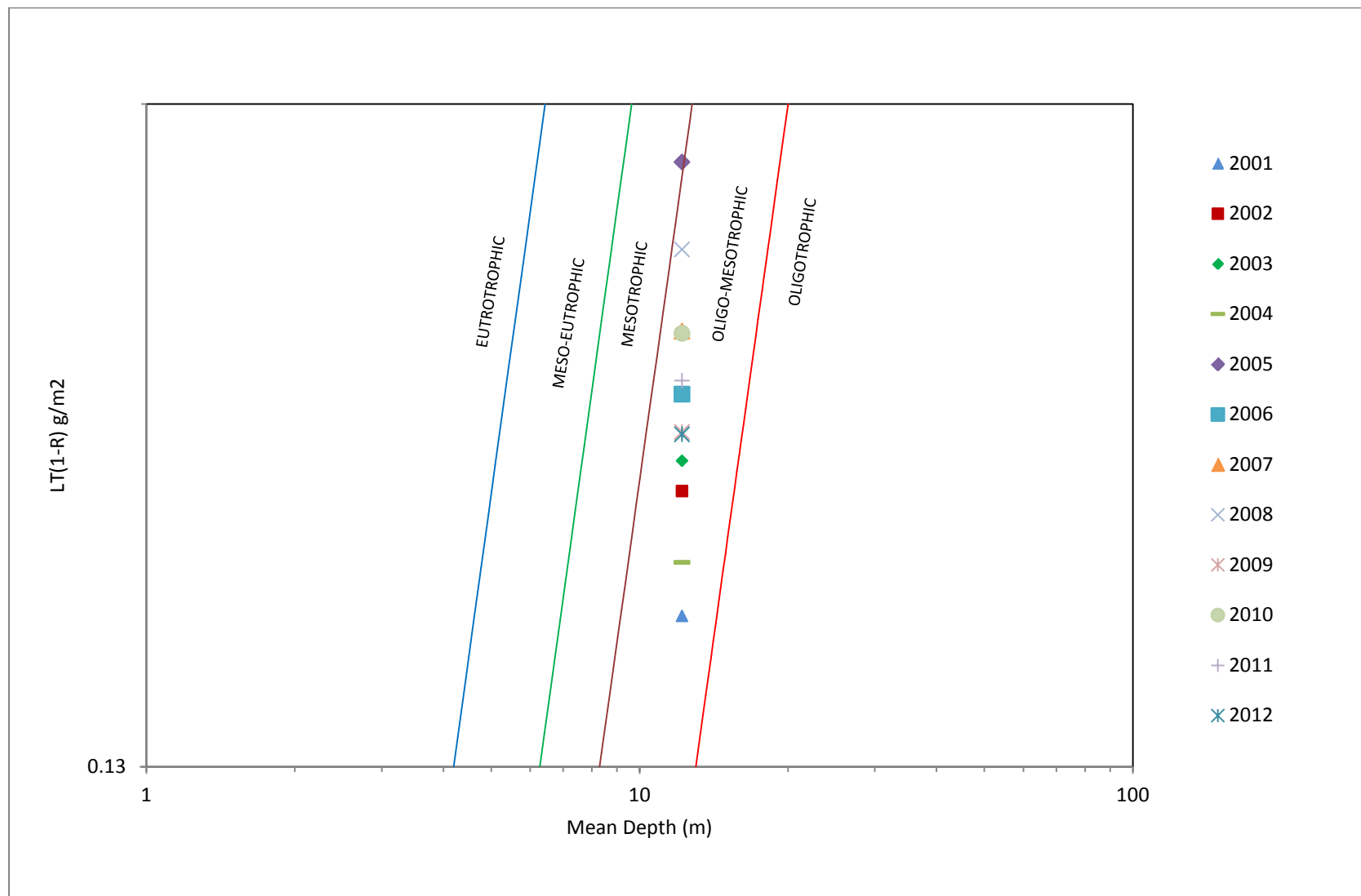


Figure 3-11. Dillon-Rigler Trophic Status for Lake Auburn Watershed with Internal Recycling

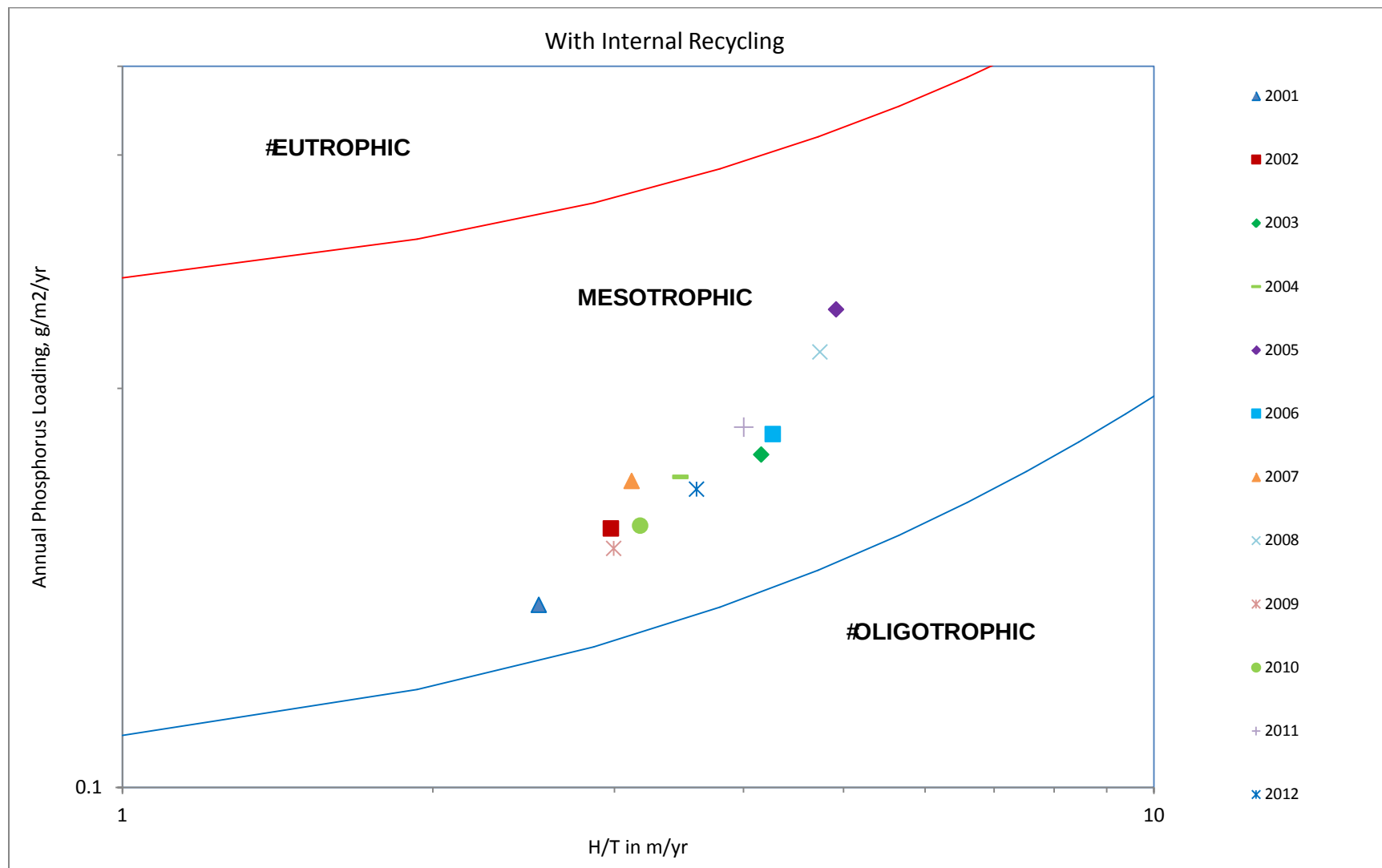


Figure 3-12. Vollenweider Trophic Status for Lake Auburn Watershed with Internal Recycling

3.5 Uncertainty in Data

The hydrologic and nutrient budgets developed for this study were based on the best available data given the constraints of time and budget. The purpose of this section is to explain some of the limitations in the data and how they may impact the accuracy of the budgets. Note that generally, longer-term estimates are more accurate than shorter-term estimates to do a larger data set and averaging of long-term trends.

3.5.1 Uncertainty in Water Budget

The lake elevation was the primary factor used in the water budget to identify the net gain or loss of water volume in the lake over a given period. This is based on direct measurement using a transducer. This is converted to a lake volume using the existing bathymetric map of the lake. The bathymetric map is based on depths in the lake, however is not tied to a surface elevation that can be related directly to the lake elevations collected. It was assumed that the surface of the lake represented on the bathymetric map was 260 feet. The associated surface area was extrapolated out using 3:1 side slopes to represent greater elevations common after rain events. Note that some staff at the Auburn Water District have questioned the accuracy of the lake elevation data within the more recent years, indicating that it may be over reading. This would impact the calculations for these periods, showing less outflow than the existing calculations.

The water budget is also based on modeled inflows to the lake, which were calibrated against measured streamflows in Townsend Brook between 2001 and 2003 and found to be within five percent of measured volumes. The model was run to represent the entire watershed as a whole, therefore may not adequately account for buffering associated with ponds and wetlands in the watershed. This could be refined in the future by breaking out these areas and calibrating them individually. Actual measurement of outflows over the dam, through logging of dam operations, could also be used to refine the overall water budget.

Evaporation was also estimated using the Hamon method, which is one of several methods that can be used to estimate evaporation. This was the same method used by USGS for the 2001-2003 watershed budget. USGS assumed values calculated with this method to be within 20 percent of the actual evaporation on an annual basis, with a greater error associated with monthly periods.

3.5.2 Uncertainty in Nutrient Budget

The nutrient budget is based on modeled phosphorus loads into the lake and estimates of phosphorus contributions from internal recycling.

Phosphorus loads will be based on the amount of inflow to the lake associated with precipitation events, stormwater runoff and groundwater baseflow as predicted by the model. As discussed in 3.5.1, the inflows are based on calibration to one gage in the watershed and extrapolation of this to other areas of the watershed may lead to some inaccuracies due to varying conditions between subwatersheds (e.g., more wetland/retention in some areas than others).



The loads are also based on default pollutant loading factors for land use and septic system loadings. Septic systems within 300 feet of the lake or its tributaries were assumed to contribute phosphorus load to the lake. Literature sources vary on this assumption, with some recommending the use of systems within 50 feet and other sources showing data to support contributions at greater distances.

Assumptions were made on fertilization of hay fields with manure in the watershed. The actual fertilization application, frequency and locations were not investigated for each parcel, and actual application rates may vary from the assumptions.

All default loads were adjusted similarly to develop a load that predicted an in-lake concentration similar to what was observed. These individual factors could be refined with further information.

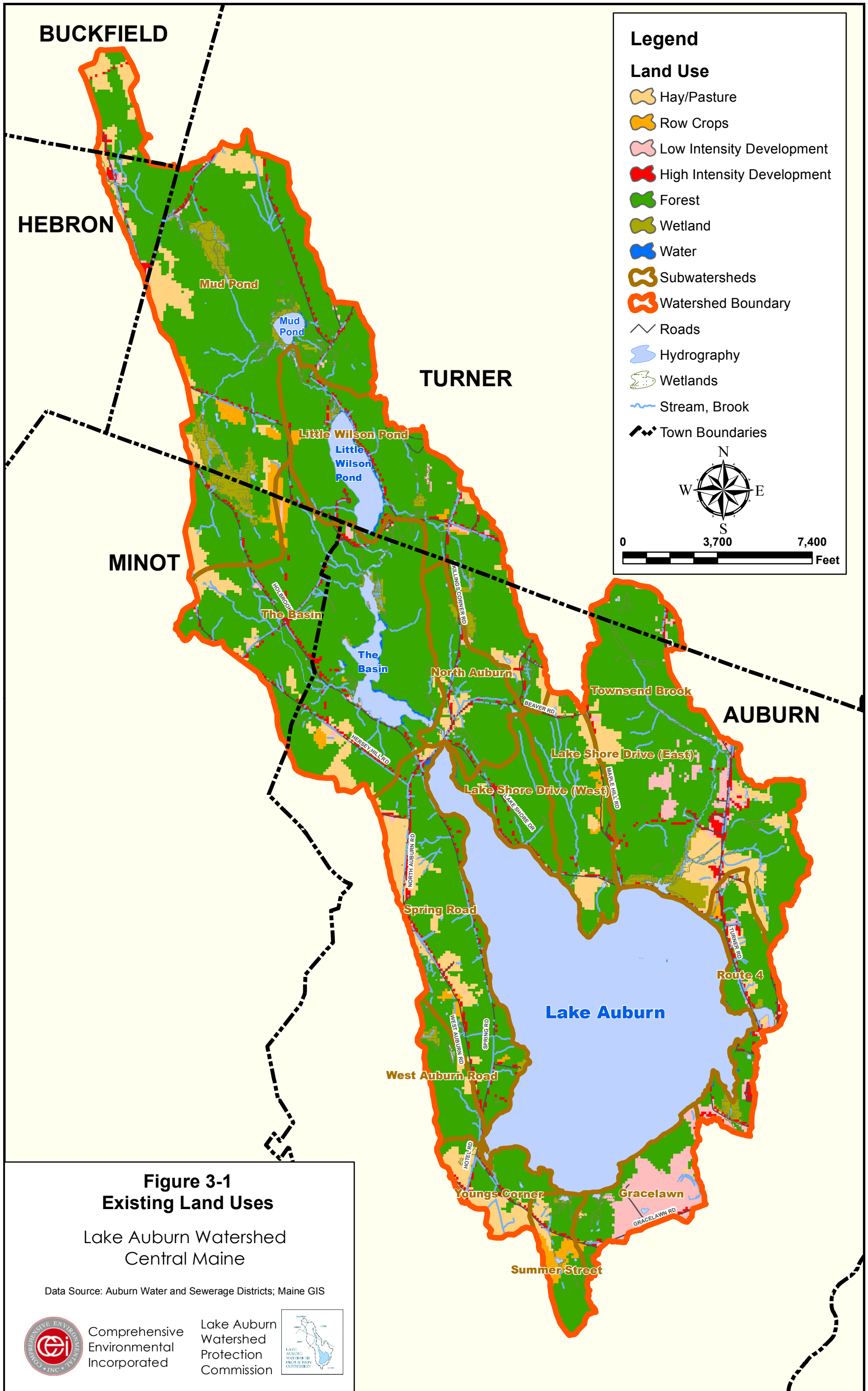
The Reckhow Phosphorus Load Model was used to predict in-lake concentrations based on these loads. Note that Dillon-Rigler and Vollenweider models can also be used to predict in-lake concentrations and typically generate higher predicted concentrations, so there is some variability in the method used for this prediction.

Internal recycling was estimated using two different methods and will be checked against calculations being performed by CDM Smith in a parallel study of the lake.

3.5.3 Uncertainty Summary

The model provided good estimates of inflows and nutrient loads to the lake for analysis of trends. The water and nutrient budgets are based on several parameters that each come with a level of uncertainty that can impact the overall results of the budgets. Further data collection can be used to refine the dataset and results, but this introduces a greater level of cost. The need for detailed accuracy must be weighed against the use of the results and how they would impact the outcome for which the data is being used.





Section 4 Next Steps

4.1 Summary of Findings

A combination of field investigations, imagery review, sampling, and pollutant and hydrologic load modeling were performed to identify possible threats to the lake in light of recent water quality issues. The following summarizes the key findings of these investigations:

- Land use changes since 2006 were highlighted by comparing orthophoto imagery from 2006 as used in the 2010 Watershed Management Plan to the most recent 2011 orthophotos. The comparison revealed that a total of 13 acres of new development occurred within the subwatersheds of Gracelawn, Mud Pond and Little Wilson. This additional development increases the amount of runoff and pollutant loadings entering Lake Auburn from larger areas of impervious surfaces, but the increases are not significant to the overall load.
- There are several potential ‘hot-spot’ areas in the watershed that contribute potentially high loads of sediment and nutrients to Lake Auburn. Many are associated with significant erosion of steep slopes, which is worsened by the recent intense, high volume storms. Potential high-load areas include:
 - Route 4 – contaminants directly enter the lake from untreated stormwater runoff, lack of buffer and erosion of steep slopes.
 - Spring Road – contaminants directly enter the lake from significant erosion of steep slopes and alterations to natural drainage patterns. Steep slopes on Spring Road and along Johnson Road should be restricted from activity and may need additional controls that will be discussed in more detail in Phase 2 of this project.
 - Discharges from The Basin, especially under the more severe weather events and two historical events that discharged a high nutrient laden sediment to the lake.
 - Lake Shore Drive – contaminants directly enter the lake from untreated stormwater runoff and lack of buffer. A driving range and golf course on the shoreline may contribute higher loads of nutrients.
 - Erosion along the Ice House Wetland tributary.
 - Land application of manure without best management practices can also be a contributor.
- The field crews noted evidence of clear cutting by private entities in the northern part of Lake Auburn Watershed along Gauthier Hill Road and East Hebron Road. Some of these areas may be of greater concern than in the past due to intense rainfall events where sediments may be washed in to the lake.
- Sediment samples collected from sediment deltas along the shoreline show that the watershed has provided a sustained contribution of elevated phosphorus and other nutrients to the lake, probably relatively recently.
- Both external and internal phosphorus loads need to be addressed, as initial estimates show internal recycling to contribute a significant portion of the total nutrient load to the lake.



- Recent above average precipitation since 2001 were evident and appear to have increased the phosphorus loads to the lake as described below:
 - The 2005 through 2008 period had the highest precipitation, inflows and pollutant loads into the lake with higher than average rainfall during this period. This may have been a precursor to existing water quality conditions.
 - Six large storm events, each contributing more than four inches of precipitation, were noted between October 2005 and June 2012 (i.e., six large storm events over a period of eight years). Conversely, historical typical weather patterns usually produce only one storm of this size over this same period. These larger storm events cause greater occurrences of erosion and can increase pollutant loads to the lake.
- Lake elevations were higher beginning in 2008. Prior to 2008, the lake would undergo long periods with water levels below the outlet dam elevation. This may have some impact on in-lake phosphorus concentrations if nutrient rich waters associated with internal recycling are mixed into the water column at fall turnover and retained over the winter and into spring, supplying a bountiful food source to algae in the spring.
- Higher winter phosphorus loads, compared with other seasons, were estimated in 2010 and 2011. This combined with the apparent higher lake elevations (additional confirmation of lake elevation may be needed) during those periods may have provided a greater available food source within the lake for algae growth. The phosphorus loads from June 2012 rainfall may also have contributed to a greater food supply contributing to excess algae growth, which can result in a decrease in dissolved oxygen levels when the algae die and decompose on the lake bottom.

Watershed sediment sample locations were selected based on visual observations that included stormwater sediment deltas, depositional areas in the upper chain ponds and along the shore of Lake Auburn. As expected from deposited sediments, all samples show some level of elevated TP content and also showed corresponding elevated TKN values. However, comparing these showed several areas that exhibited TP above 1,000 mg/kg, which in most cases also exhibited extremely high TKN values, in some cases a full order of magnitude larger than TP.

Above average precipitation and phosphorus contributions from the watershed likely played an important role in the recent algal blooms and increasing in-lake phosphorus concentrations in Lake Auburn. Pollutant load is directly correlated with precipitation, with greater precipitation over the watershed contributing greater pollutant loads. This is further exacerbated by the intense, high volume storms that are occurring at a much greater frequency than historically, leading to eroded areas that were previously more stable.

Since Lake Auburn is a seasonally stratified lake, it can be assumed that in addition to the watershed contributions, internal phosphorus loading within the lake is largely, but not completely, attributed to iron bound sediment phosphorus below the thermocline and under anoxic conditions. However, the flux of phosphorus between the sediments and the



water column interface is an equilibrium function and depends on the affinity of soluble phosphorus for the available inorganics like aluminum, calcium and iron in the sediments (i.e., the phosphorus storage capability of the sediments). However, given the available water quality data, concentrations of phosphorus in the 30-35 meter range was high in 2011 and 2012. Although the data set is limited, the increase in hypolimnetic total phosphorus concentrations contribute to increases in total phosphorus in the upper water column, particularly during the turnover of the reservoir.

4.2 Next Steps

The findings of this report will be used to develop recommendations, building on those included in the 2010 Lake Auburn Watershed Management Plan. Recommendations may include:

- Controls for identified ‘high-load’ areas of phosphorus;
- Regulatory actions that would strengthen lake protection;
- Changes, if needed, to the on-going watershed monitoring programs;
- An outreach program to educate property owners within the overlay district; and
- A contingency set of recommendations for future extreme events.

In lake mitigation measures will be addressed in a separate memorandum by CDM Smith.



Appendix A

Lake Auburn Watershed Field Review Summary

LAKE AUBURN WATERSHED - FIELD REVIEW SUMMARY

FALL 2012

Site 1: No Issues

Site 2: No Issues

Site 2A: No Issues

Site 3: Slight roadside erosion

Site 4: No Issues

Site 5: No Issues

Site 6: No Issues

Site 7: Slight outlet erosion

Site 7A: Stabilization installed, no issues

Site 8 –Spring Road

Issues:

- Historical erosion problems
- Steep shoulders alongside major tributary
- Moderate sediment build-up
- Bank erosion downstream from crossing

Photo:



Armored 30 inch HDPE Inlet. Note accumulated sediment right before standing water

Recommendations: Some stabilization installed but should be reinforced and expanded. Remove built up sediments.

Site 8A: No Issues

Site 8B: No Issues

Site 8C: No Issues

Site 8D: Slight inlet erosion

Site 8E: No Issues

Site 8F: No Issues

Site 8G – Spring Road

Issues:

- Considerable channel and roadside erosion
- Built up sediments
- Partially clogged structure

Photo:



Roadside erosion and partially clogged box inlet. Near a residential house

Recommendations: Bank stabilization, Remove built up sediments. Potential best management practices (BMP) location. Road should be prepared and properly graded to prevent future erosion.

Site 8H: Moderate slope, no issues

Site 8I – Spring Road

Issues:

- Major road bank and hillside erosion
- Moderate sediment and debris build-up
- Road eroded in places

Photo:



Steep slope from forested area heading into inlet. Note the runoff scouring

Recommendations: Stabilize/Armor roadside, remove accumulated sediment. Filter fabric on hillside. Roadway should be repaired and graded with a proper crown to prevent future erosion issues.

Site 8J –Spring Road

Issues:

- Major roadside bank erosion
- Tributary dried up, maybe evidence of diverted flow upstream
- Potentially high stormwater runoff

Photo:



Eroded roadside flowing south to box culvert inlet at bottom left

Recommendations: Stabilize/Armor area, hay bales or filter fabric in channel to slow down stormwater velocity.

Site 8K: No Issues

Site 8L: Armored, plunge pool. no issues

Site 8M: Armored, no issues

Site 8N: No Issues

Site 8O: Possible buried culvert

Site 9 –Spring Road

Issues:

- Considerable erosion from channel along road (both sides) and from forest
- Steep slope at outlet
- High potential sediment source to Lake Auburn

Photo:



Eroded channels from road and forest flowing to armored inlet, road itself has significant erosion

Recommendations: Potential best management practices (BMP) location. Channel (both sides) was armored at one time but could use maintenance. Filter fabric, rip-rap or earthen dams could be used to slow down stormwater velocity. New headwall should be considered for this location if other options do not provide enough protection.

Site 9A: Sediment at outlet

Site 9B: Armored, plunge pool

Site 9C: Armored

Site 9D –Spring Road

Issues:

- Large amounts of accumulated sediment
- Considerable erosion along banks
- Historical erosion based on installation of rock stabilization

Photo:



Outlet delta filled with sediment and leaves. Note the apparent high flow erosion around base of the trees

Recommendations: Remove accumulated sediment, expand stabilization along banks and around culvert. Potential best management practices (BMP) location.

Site 9E: No Issues

Site 10 –Spring Road

Issues:

- Major amounts of accumulated sediment
- Erosion along dried-up stream
- Historical erosion problems based on existence of rock stabilization
- Potential increased runoff from nearby logging

Photo:



Outlet plunge pool filled with sediment. Inlet also contains heavy sediment deposits

Recommendations: Remove accumulated sediment and control runoff from logging operation. Expand plunge pool to accommodate future sediment volumes.

Site 10A –Spring Road

Issues:

- Structure no longer appears to be working, buried pipe
- Considerable erosion from nearby logging operation

Photo:



Mostly buried inlet pipe and eroded roadside. Drainage no longer effective in this area

Recommendations: Uncover pipe and rebuild structure. Control logging erosion.

Site 10B –Spring Road

Issues:

- Major erosion along steep banks and in channel
- Accumulated sediment in roadway
- Road damaged by erosion

Photo:



Steep forested slope leading to 24 inch roadside inlet. Outlet has scoured channels

Recommendations: Stabilize area, remove sediment from roadway. Potential best management practices (BMP) location. Road repair and proper regrading may be necessary

Site 10C –Spring Road

Issues:

- Potential major nutrient source from large sediment delta present
- Large erosion potential from steep slope
- Historical erosion problem based on installed rock stabilization

Photo:



In Lake delta formed after outlet. Coming from a deep channel across the road

Recommendations: Remove sediment delta, increase/expand stabilization along banks. Potential best management practices (BMP) location.

Site 10D –Spring Road

Issues:

- Steep banks on both sides of the road
- High runoff potential from western slope

Photo:



Armored inlet with some sediment accumulation around the outlet. Channel coming out of forest to the right

Recommendations: Increase stabilization and armor along banks and extend along channel onto the western slope, install filter fabric or earthen dams to slow stormwater velocity

Site 11 –Spring Road

Issues:

- Evidence of major sediment source and outlet delta
- Large possible nutrient source to Lake Auburn
- Major historical erosion, very deep channel
- Contributing upstream logging operation

Photo:



New BMP construction not yet completed. outlets to a plunge pool before the lake

Recommendations: Remove sediment delta from lake and evaluate effectiveness of erosion reduction from previous plunge pool and rock stabilization (very new). Finish armoring the remaining upstream channel and control contributions from logging operation.

Site 11A –Spring Road

Issues:

- Considerable erosion source from steep hill
- Roadway runoff goes directly into lake

Photo:



Deep runoff channel coming down steep forested hillside causing considerable in-road erosion before outlet

Recommendations: Stabilize upstream channel and install barriers to slow water velocity down steep slope. Good location for a plunge pool or other Best Management Practice (BMP) on the lake side of the road.

Site 11B: Moderate erosion around outlet

Site 12: Minor erosion

Site 12A: No Issues

Site 13: Armored, no issues

Site 14: No Issues

Site 14A: Minor erosion

Site 14B: No Issues

Site 15: Armored, no issues

Site 16: No Issues

Site 18: No Issues

Site 19: No Issues

Site 20 –Lake Shore Drive

Issues:

- Moderate amount of sediment accumulation
- Major erosion along steep banks
- Potential nutrient source from nearby driving range

Photo:



Tributary which borders a driving range and outlets to Lake Auburn. Sampled delta contained 270 mg/kg TP

Recommendations: Remove accumulated sediment and stabilize steep banks. Evaluate runoff and nutrient input potential from driving range

Site 20A: No Issues

Site 20B: Minor erosion, outfalls directly to lake

Site 20C: Outfalls directly to lake

Site 21: Road drainage, potential nutrient source

Site 22: No Issues

Site 22A – Lakeshore Drive / RT 4 Intersection

Issues:

- Heavy sediment accumulation
- Heavy erosion at outfall to lake

Photo:



Tributary has scoured a deep channel into a Lake Auburn beach from its outlet crossing Lake Shore drive

Recommendations: Install sediment forebay to capture sediments and remove excess material. Stabilize banks at the outfall. Potential best management practices (BMP) location.

Site 23: No Issues

Site 23A: Steep banks, armored

Site 24: No Issues

Site 25 –Skillings Corner Road

Issues:

- Considerable sediment accumulation
- Major erosion from large tributary
- Evidence of previous bank collapse

Photo:



Eventually outlets to Little Wilson Pond. Outlet delta sampled and came back with 160 mg/kg TP

Recommendations: Remove sediment accumulation and stabilize bank. Evaluate size and effectiveness of culvert to minimize overtopping of the road.

Site 26: Armored, plunge pool

Site 26A: Armored channel, sediment delta

Site 27: Armored, no issues

Site 28: Armored roadside, blue-green algae present

Site 29: No Issues

Site 30: No Issues

Site 31: No Issues

Site 31A – Bailey Road

Issues:

- Major erosion source from steep rocky slope
- Decent flow
- Moderate sediment accumulation

Photo:



Steep roadside causing erosion. Tributary eventually outlets along the western shoreline of The Basin

Recommendations: Stabilization along banks, armor the channel on steep sections. Remove minor sediment accumulation

Site 32: Minor erosion

Site 32A – Bailey Road

Issues:

- High storm flows
- Major erosion source, deep channel

Photo:



Armored inlet flows across the road to deep outlet channel. Outlets to The Basin.

Recommendations: Stabilize and/or armor area. Plunge pool at the outfall would be ideal.

Site 32B: Minor channel erosion and sediment buildup

Site 33 –Holbrook Road

Issues:

- Moderate sediment source
- Major erosion from large tributary

Photo:



Historical tributary which eventually flows into The Basin and originates from a large wetland to the northwest

Recommendations: Stabilize area and remove sediment accumulation. Roadside slope needs protection

Site 34: No Issues

Site 35 –Holbrook Road

Issues:

- Moderate erosion from steep banks
- Major sediment source
- Increased runoff potential from nearby residential housing

Photo:



Armored inlet receives roadside flows and outlets to The Basin across the road.

Recommendations: Stabilize steep banks to prevent increased erosion. Increase amount of pervious surfaces near residential housing to enhance infiltration.

Site 35A –Holbrook Road

Issues:

- Large flow from major tributary contributing to moderate erosion and sediment accumulation

Photo:



Major tributary crossing which outlets to The Basin. Sample taken at delta returned 1500 mg/kg TP

Recommendations: Stabilize area, reduce velocity of flow by creating more pervious areas to divert runoff. Remove sediment accumulation. Downstream of 2 large culvert crossings which were removed. Also downstream of possible beaver dam breach/wash out.

Site 36: Armored inlet and outlet, no issues

Site 36A –Holbrook Road

Issues:

- Major sediment accumulation, both sides of the road
- Pipe partially buried

Photo:



Sediment accumulation along roadside, other side is in similar condition. Outlets along The Basin shoreline

Recommendations: Remove accumulated sediment and unclog pipe. Road needs a swale or ditch to collect runoff and a plunge pool at the outlet to trap sediments.

Site 36B: Lightly armored, no issues

Site 37 –Holbrook Road

Issues:

- Major sediment accumulation on both sides of tributary
- Major erosion source upstream from site

Photo:



Plunge pool at the inlet receives flows from channel coming out of forested area. Outlets to The Basin

Recommendations: Remove sediment accumulation from tributary and stabilize banks upstream.
Structure itself seems to be working properly but could use maintenance

Site 37A: Same general design as site 37, no issues

Site 37B: Minor erosion and sediment

Site 38: Recently armored, upgrades need evaluating

Site 39 – Robinson Road

Issues:

- Major erosion on steep banks
- Heavy storm flows
- Channel erosion downstream

Photo:



Outlet down steep roadside slope. Inlet is a minor tributary which ends at Little Wilson Pond

Recommendations: Both sides of the road need stabilization along the roadside. Barriers such as rip-rap or earthen dams should be installed to slow water velocity during heavy rain events.

Site 40: Moderate erosion on steep slope

Site 41: Minor erosion

Site 42: Major tributary to Mud Pond

Site 43: Minor erosion

Site 43A – Little Wilson Road

Issues:

- Moderate sediment source during storm events
- Increased runoff from nearby residential housing

Photo:



Runoff channel down moderate forested slope which outlets to Little Wilson Pond

Recommendations: Install barriers to slow water during high flows to allow infiltration and create buffer between the moderate slope and Little Wilson Pond.

Site 43B: Moderate erosion, see Site 43A

Site 44: Minor erosion

Site 45: Major tributary into Little Wilson Pond

Site 46:

Issues:

- Moderate channel erosion
- Moderate sediment accumulation
- Steep roadside banks also causing significant erosion

Photo:



Moderate roadside slope causing some minor channeling and erosion problems. Outlets to a small wetland

Recommendations: Armor or stabilize banks to prevent roadside erosion from going into stream channel. Channel should also be armored on steep sections where scouring is prevalent.

Site 46A – Johnson Rd / Dillingham Rd Intersection

Issues:

- Signs of livestock pasture and tributary within enclosure
- Potential heavy nutrient loading source

Photo:



Electric fencing follows roadside making an apparent livestock pen. Crossing structure relatively new

Recommendations: The interior of the enclosure was not investigated but an active livestock pasture could cause significant nutrient loading to the tributary, which ends up in Lake Auburn. Install fencing to prevent livestock from accessing tributary and provide a buffer between animal enclosures and tributary. Further investigation is recommended.

Site 46B: Small tributary flowing into a small wetland, no issues

Site 47 – Rt 4

Issues:

- Moderate sediment source, pipe partially filled in
- Possible phosphorous source from nearby field runoff
- Steep bank from roadside also an erosion source

Photo:



Standing water is caused by sediment clogging inlet pipe. Outlets to Townsend Brook

Recommendations: Reduce runoff from field and stabilize roadside slope. Remove accumulated sediment. The land use history of the field would help determine the priority ranking for this site as it does outfall directly to Lake Auburn

Site 48 – Rt 4

Issues:

- Possible phosphorous source from livestock pasture and golf course runoff

Photo:



6 ft diameter inlet culvert shown. Two major drainage channels for the area converge here

Recommendations: Divert high nutrient runoff from entering outfall. The 6 ft diameter pipe indicates this location has historically received large flows although this was not the case at the time of inspection. Determining the storm flows this site receives is recommended in order to rank its priority as it does outfall directly to Lake Auburn.

Site 49 –Route 4 Drainage

Issues:

- Major erosion at outfall to lake
- Deep outlet channel

Photo:



Deep outlet channel leading to Lake Auburn shown. Receives mostly roadside storm flows from Route 4

Recommendations: Repair side slopes of drainage channel and provide armoring at outfall. The channel is very deep but it is difficult to determine if this was manmade or caused by historical stormwater scouring. The latter would mean this outfall is a major sediment input to Lake Auburn and make it a high priority for rebuild. Recommend further investigation

Site 49A: Moderate sediment accumulation

Site 49B – Rt 4

Issues:

- Partially buried culvert preventing proper flow
- Moderate sediment accumulation

Photo:



Partially clogged inlet shown. Most likely flows to site 22A but this was not confirmed

Recommendations: Remove sediment and stabilize banks, possibly replace or clean pipe. Space available for Best Management Practices (BMP).

Site 50: No Issues

Site 51 –Route 4 Drainage

Issues:

- Direct discharge to lake without treatment
- Upstream channel shows signs of heavy storm flows
- Potential heavy sediment source

Photo:



Runoff channel down moderate slope. Outlets to steep shoreline with evidence of a sediment delta

Recommendations: Armor upstream slope to prevent runoff erosion. Potential Best Management Practices (BMP) location to provide stormwater treatment prior to entering lake. Examine drainage options to divert flow if space is unavailable for a BMP at the current location

Site 52 – Rt 4

Issues:

- Major roadside and shoreline erosion
- Drains directly to lake

Photo:



Outfall on steep roadside slope shown. Note the extensive shoreline erosion below

Recommendations: Stabilize roadside and eliminate direct discharge, re-direct runoff to area to provide treatment if necessary.

Site 53: No Issues

Site 53A: No Issues

Site 53B: No Issues

Site 54: Armored, No Issues

Site 54A: Steep slope, minor erosion

Site 54B: Steep slope, minor erosion

Site 55: Steep slope, No issues

Site 55A –Hersey Hill Road

Issues:

- Moderate roadside and channel erosion
- Installed filter fabric has failed
- Moderate sediment accumulation

Photo:



Some outlet channeling erosion shown. There is substantial roadside scouring directly above the outfall

Recommendations: Remove sediment and stabilize/armor area. Replace failed filter fabric with new fabric or earthen dams to slow water velocity

Site 56: No Issues

Site 57: Moderate channel erosion

Site 57A – East Hebron Road

Issues:

- Moderate roadside erosion
- Pipe clogged with tires, debris

Photo:



Tires are wedged at the road crossing inlet. Note the roadside erosion and channeling

Recommendations: Armor roadside along channel. Remove debris and unclog inlet pipe.

Site 59: No Issues

Site 60: No Issues

Site 61 – Rt 4 Sand Pit

Issues:

- Culvert blocked with debris
- Moderate erosion
- Possible major nutrient source from industry (sand pit) nearby

Photo:



Wetland pond near operational sandpit. Sticks and debris has partially dammed the outlet

Recommendations: Uncover clogged pipes. Improve buffering between pond and roadside/sandpit

Site 62: Armored, No Issues

Site 63: Armored, No Issues

Site T-1: No Issues

Site T-2: No Issues

Site T-3: Sheen on standing water. Golf course nearby

Site T-4: Erosion from nearby ATV trail

Site T-5 –Townsend Brook

Issues:

- ATV bridge has partially blocked and dammed stream
- Bypass pipe is too high to work effectively

Photo:



Stone ATV crossing, powerlines are also crossing above the picture. Note the difference in water elevations.

Recommendation: Remove structure to allow normal flow or install culvert. Review options to stabilize ATV trail approach and crossing strategies such as bridges

Site T-6: Pallet, tires and old car dumping ground

Site T-7 – Townsend Brook Manmade Pond

Issues:

- Evidence of pond flooding its banks during heavy rain events
- Failed outlet structure
- Highly turbid water
- Possibly used by commercial greenhouse uphill from site

Photo:



Recommendations: Divert flow upstream to reduce the high volume of runoff to this tributary and replace failed outlet structure so that actual treatment and storage occurs. Repair damage to side banks caused by pond overflowing

Site T-8: Moderate erosion along stream

Site T-9 –Townsend Brook

Issues:

- Nearby livestock pasture, tributary used as watering hole
- Beaver dam actively blocking water flow
- Runoff erosion coming from pasture

Photos:



Recommendations: Remove beaver dam. Work with landowner to determine a better way to water livestock. Reduce or prevent pasture runoff from reaching tributary.

Site T-10: ATV crossing, Beaver dam creating small pond.

Site LAT (1-5) – Spring Road

Issues:

- Heavy erosion from steep banks
- Heavy logging could contribute increased sediment runoff to tributary

Photos:



Recommendations: Increase soil stabilization around site to reduce sediment runoff. Improve logging practices to prevent impacts associated with heavy equipment use. Armor channel section upstream of outfall

Site LAT (6-7) – Spring Road

Issues:

- Heavy erosion from steep slope
- Nearby logging has increased erosion potential of area

Photos:



Recommended: Improve erosion controls and stabilize area. Finish armoring channel both upstream and downstream of recent rip-rap install. Install filter fabric or earthen/rip-rap dams to slow water velocity down steep channel slope.

Site UB-1 – Unnamed Basin

Issues:

- Heavy erosion potential during high water events

Photos:



Recommendations: Armor this section of the channel to stabilize banks. Prevent high flow velocities through this section during rain events.

Site UB-2: Old breached beaver dam

Site UB-3: Some bank erosion

Site UE-1: No Issues

Site UE-2: Runoff channel, minor erosion

Site UE-3 – Unnamed East

Issues:

- Bend in stream eroding large portion of hillside
- Hillside partially collapsed into stream, uprooted trees

Photos:



Recommendations: Stabilize hillside and armor the bend in stream to prevent further collapse.

Site UE-4 – Unnamed East

Issues:

- Bend in stream eroding large portion of collapsed hillside

Photos:



Recommendations: Armor bend in stream to prevent further collapse. Stabilize hillside to prevent runoff and erosion potential.

Site UE-5 and UE-6 – Unnamed East

Issues:

- UE-5 algae growth present (late November) at outlet of minor stream entering major brook
- Upstream potential nutrient source from UE-6 orchard and house with old farm for pasture or livestock

Photos:



Recommendations: Reduce high nutrient runoff from orchard. Unknown if past or current uses of the upstream orchard is causing high nutrient loading. Further investigation is recommended

Site UE-7: Moderate erosion on section with steep slope

Site JB-1:

Issues:

- Heavy erosion area during storm events
- Sediment accumulation in places

Photos:



Recommendations: Armor steep section with high runoff potential. Stabilize area

Site JB-2: Minor erosion

Site JB-3: No Issues

Site JB-4: Armored, No Issues

Site SK-1: No Issues

Site SK-2: Moderate erosion

Appendix B

2010 Pollutant Load Analysis (Section 2.0 of 2010 Lake Auburn Watershed Management Plan)

2.0 Pollutant Source Analysis

Determining a best course of action for maintaining existing water quality requires an understanding of pollutant loadings and how the water quality in Lake Auburn responds to them. The pollutant most commonly used as an indicator of lake health and for planning lake management activities is phosphorus since excess levels can create increased algal blooms, which can contribute to other water quality problems such as increased turbidity, taste and odor problems, which may require expensive treatment. Data on phosphorus loadings associated with stormwater runoff and other pollution sources and how lakes respond to these loadings is also readily available. As such, phosphorus was selected as the overall indicator of lake health for Lake Auburn.

To assist with the estimation of phosphorus loadings from the watershed, CEI selected the Generalized Watershed Loading Function – Enhanced (GWLF-E) Version 7.2.3 model with ArcView Generalized Watershed Loading Functions (AVGWLF) Version 7.1 geographical information systems (GIS) interface to assist with the development of phosphorus estimates. In combination with this software, CEI used the Reckhow Phosphorus Lake Model to predict in-lake phosphorus concentrations based on the projected loadings and to calibrate these loadings to match observed in-lake concentrations.

Although used to represent overall Lake health and for Lake management purposes, phosphorus is not the only indicator of Lake health. Fecal coliform is an extremely important indicator of water quality and is used to demonstrate that the raw water meets the filtration avoidance criteria of the Surface Water Treatment Rule. Excess levels of fecal coliform above the criteria could require the use of filtration to treat the raw water. In fact, elevated fecal coliform levels in 2004 nearly resulted in an EPA order to install filtration as a form of treatment. Fortunately, Auburn Water District and Lewiston Water Division were able to trace the coliform to a gull and waterfowl population and institute a program to mitigate the heavy gull influx on Lake Auburn. Turbidity is also an indicator of water quality and is often used to help determine disinfection requirements. So although phosphorus is used to quantitatively manage watershed controls, these other indicators are still an important consideration and recommendations are included to address coliform and sediment contributions to the Lake.

2.1 Input Data and Assumptions

Inputs to the combined model include land use and lake data. CEI focused on the outputs of estimated pollutant loadings and the corresponding impact on in-lake pollutant concentrations. To be consistent with references used in this analysis and to maintain consistency between Lake concentrations that are provided in metric units and pollutant loadings, the metric system is used to present calculations pertaining to phosphorus loadings (e.g., kg) and in-lake concentrations (e.g., µg/l). Once the correlation between loadings and Lake concentrations under existing conditions has been established, the phosphorus loadings to the Lake are presented in English units (e.g., pounds), as this is a more common unit of measure in the United States. The data used in the model along with a description of its purpose is described below.



Subwatersheds

The Lake Auburn watershed was divided into thirteen major subwatersheds (Figure 1-4), which are further divided into two categories: 1) direct subwatersheds to Lake Auburn, and 2) indirect subwatersheds. Direct subwatersheds drain stormwater runoff directly into Lake Auburn and its tributaries and include: North Auburn; Lake Shore Drive (West); Lake Shore Drive (East); Spring Road; Townsend Brook; West Auburn Road; Route Four; Youngs Corner; Summer Street; and Gracelawn. Indirect subwatersheds include land areas that drain to another pond or lake before entering Lake Auburn, providing some level of treatment before reaching Lake Auburn. Indirect subwatersheds include: Mud Pond; Little Wilson Pond; and The Basin. Each subwatershed represents the drainage area to a tributary or area of direct discharge to the Lake. This provides localized information to allow for prioritization of future remedial actions through identifying areas with the greatest pollutant loadings.

The subwatershed boundaries are natural boundaries dictated by the local topography. These boundaries generally follow ridgelines or high points and represent the area that drains to the farthest downgradient point, which is typically the location where a stream enters the lake. Further subdivision was performed where best management practices (BMPs) were proposed to evaluate specific pollutant loadings to and removals associated with the BMP. Table 2-1 shows the land area for each subwatershed, excluding major ponds and lakes.

Table 2-1. Land Area by Subwatershed	
Subwatershed	Land Area (acres)
Gracelawn	334
Lake Shore Drive (East)	450
Lake Shore Drive (West)	240
Little Wilson Pond	838
Mud Pond	2214
North Auburn	537
Route 4	346
Spring Road	803
Summer Street	189
The Basin	1587
Townsend Brook	1470
West Auburn Road	176
Youngs Corner	229
Total	9413



Land Use and Land Cover

Land use and land cover within the watershed relate directly to the amount of runoff and pollutant loadings to the lake. Generally, more intensely developed land uses with larger impervious area will produce more runoff and pollutant loadings than undeveloped forested areas. Land use data in the watershed was used to estimate stormwater runoff and pollutant loads from the watershed under existing and buildout conditions.

Existing land use data within the Lake Auburn watershed was obtained from datasets provided by the New England Interstate Water Pollution Control Commission, and developed by Penn State Institutes of the Environment specifically for AVGWLF application¹. Some modifications were made to the mapped land use data to reflect actual land uses within the watershed based on a comparison with orthophoto imagery. Specifically, the available spatial land use data showed several low-intensity developed areas as forested. Study of the orthophoto imagery reflected an average disturbance area of approximately 1.25 acres per lot in the Lake Auburn watershed, including the house, driveway and lawn area in each lot. Using a count of houses on land designated as “forested,” modifications were made to the GWLF-E model land use inputs to include the corresponding disturbed areas designated as “low intensity development”. Additionally, a 32-acre quarry area in the Upper Townsend Brook subwatershed and a 21-acre agricultural area in the Gracelawn subwatershed were mapped as forested. The quarry was converted to low-intensity urban development and the agricultural area was converted to cropland.

Table 2-2 shows the type and quantity of each land use by subwatershed as mapped and adjusted for use in the model to reflect actual conditions. Table 2-3 shows the percentage of land area in each subwatershed. Table 2-4 shows the type and quantity of each land use by Town. Table 2-5 shows the percentage of land area by Town. Figure 2-1 shows the existing land uses throughout the watershed (this does not reflect the adjustments discussed above).

¹ Penn State Institutes of the Environment. February 2007. Summary of Work Undertaken Related to Adaptation of AVGWLF for Use in New England and New York.



Table 2-2. Land Use Area by Subwatershed

	Land Use Area (acres)						
Subwatershed	Hay/ Pasture	Cropland	Forested	Wetland	Low- Intensity	High Intensity	Total
Gracelawn	2	23	249	0	56	4	334
Lake shore Drive, East	70	14	348	5	4	9	450
Lake Shore Drive, West	2	0	224	1	3	10	240
Little Wilson Pond	11	11	737	12	27	39	838
Mud Pond	231	47	1708	148	23	56	2214
North Auburn	57	0	434	14	11	20	537
Route 4	42	6	200	16	38	44	346
Spring Road	141	12	580	5	19	46	803
Summer Street	21	38	122	4	0	4	189
The Basin	100	22	1361	25	27	52	1587
Townsend Brook	180	0	1096	54	82	58	1470
West Auburn Road	8	0	159	8	1	1	176
Youngs Corner	94	0	119	3	1	12	229
Total	960	173	7337	296	292	356	9413



Table 2-3. Land Use by Percent Subwatershed Area

	Land Use Area (Percent Subwatershed Area)						
Subwatershed	Hay/ Pasture	Cropland	Forested	Wetland	Low- Intensity	High Intensity	Total
Gracelawn	1%	7%	74%	0%	17%	1%	4%
Lake shore Drive, East	16%	3%	77%	1%	1%	2%	5%
Lake Shore Drive, West	1%	0%	93%	0%	1%	4%	3%
Little Wilson Pond	1%	1%	88%	1%	3%	5%	9%
Mud Pond	10%	2%	77%	7%	1%	3%	24%
North Auburn	11%	0%	81%	3%	2%	4%	6%
Route 4	12%	2%	58%	5%	11%	13%	4%
Spring Road	18%	1%	72%	1%	2%	6%	9%
Summer Street	11%	20%	65%	2%	0%	2%	2%
The Basin	6%	1%	86%	2%	2%	3%	17%
Townsend Brook	12%	0%	75%	4%	6%	4%	16%
West Auburn Road	5%	0%	90%	4%	1%	0%	2%
Youngs Corner	41%	0%	52%	1%	1%	5%	2%
Total	10%	2%	78%	3%	3%	4%	100%

Table 2-4. Land Use by Town

	Land Use Area (acres)						
Town	Hay/ Pasture	Cropland	Forested	Wetland	Low- Intensity	High Intensity	Total
Auburn	675	100	4315	139	229	233	5691
Buckfield	55	0	96	0	1	6	158
Hebron	21	0	140	0	8	13	182
Minot	70	21	716	39	8	31	885
Turner	139	52	2070	117	47	73	2497
Total	960	173	7337	296	292	356	9413



Table 2-5. Land Use by Percent Town Area

	Land Use Area (acres)						
	Hay/ Pasture	Cropland	Forested	Wetland	Low- Intensity	High Intensity	Total
Town							
Auburn	12%	2%	76%	2%	4%	4%	60%
Buckfield	35%	0%	61%	0%	0%	4%	2%
Hebron	11%	0%	77%	0%	4%	7%	2%
Minot	8%	2%	81%	4%	1%	4%	9%
Turner	6%	2%	83%	5%	2%	3%	27%
Total	10%	2%	78%	3%	3%	4%	100%

Soils

GWLF-E employs soils data to determine the permeability of soils throughout the watershed. Soil permeability helps in determining runoff coefficients, as well as feasibility of implementing infiltration techniques.

The Natural Resource Conservation Service (NRCS) classifies soils into four Hydrologic Soil Groups (HSG) based on the soil's runoff potential. The four HSGs are A, B, C and D, where A soils generally produce the smallest runoff and allow for the greatest infiltration and D soils generally have the greatest runoff potential. Following is a brief description of the four HSGs:

- HSG A is sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission.
- HSG B is silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.
- HSG C soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.
- HSG D soils are clay loam, silty clay loam, sandy clay, silty clay or clay. This HSG has the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious material.

Figure 2-2 shows the hydrologic soil groups throughout the watershed.



Precipitation

Precipitation data is necessary to determine groundwater seepage, stormwater runoff and evapotranspiration volumes in the model. GWLF-E processes daily precipitation data to simulate watershed streamflow on a daily basis.

The Auburn Water District provided daily precipitation data used in the GWLF-E model for calendar years 2001 through 2008. The City of Lewiston Department of Public Services, in Maine, maintains the rainfall gage. The New England Interstate Water Pollution Control Commission provides data sets for AVGWL, including precipitation records. Daily precipitation data from the National Weather Station in Gardiner, Maine, included in these data sets, was used to fill in local precipitation data gaps. Based on the revised data, the average precipitation over the 2001 to 2008 period was approximately 45 inches per year.

Temperature

GWLF-E uses outdoor temperature data to determine whether precipitation occurs as rainfall or snow to then estimate snowmelt and evapotranspiration in the watershed. The Auburn Water District also provided daily maximum, minimum and mean temperatures for the period 2001 through 2008.

Evapotranspiration

Evapotranspiration represents the volume of precipitation that evaporates from the watershed or is taken up by plants and then recycled back into the atmosphere. The losses associated with evapotranspiration are used in the estimation of streamflows into the Lake. The GWLF-E model estimates evapotranspiration based on land use and temperature data. Evapotranspiration in the Lake Auburn watershed was estimated as 31% of the annual precipitation.

Flow Data

In 2004, the United States Geologic Survey published a water budget² for Lake Auburn, using measured streamflow at three points in the watershed. The report included estimates of total inflows to and outflows from Lake Auburn. The published surface water inflows to Lake Auburn used a combination of direct measurements and estimation methods. Continuous streamflow gage data was available for The Basin Outlet and Townsend Brook to Lake Auburn, as well as outflows from Lake Auburn at Bobbin Mill Brook, for the period of water-budget years 2001 through 2003. The Townsend Brook streamflow measurements were used to calibrate flows generated by the GWLF-E model as described later in this section.

² Dudley, Robert. Water Budget for Lake Auburn, Maine, May 1, 2000 through April 30, 2003, Scientific Investigations Report 2004-5106.



Septic Systems

While septic systems throughout the watershed, including those at greater distances from the Lake, can contribute pollutants such as nitrates, phosphorus contributions from septic systems are more likely to occur from systems located within 300 feet of the Lake.³ Counts of septic systems within 50 feet and between 50 feet and 300 feet of the lake, upstream ponds and major tributaries were determined under the assumption that the number of dwellings within the buffer represented the number of septic systems. Estimates of loadings associated with septic systems are made using these pieces of information.

Land Use Phosphorus Loadings

GWLF-E models pollutant loadings as a function of land use and pollutant load values, as compiled by Haith et al.⁴. The model provides default pollutant loading values as stormwater concentrations for rural land uses, such as agricultural and forested areas. The model uses a pollutant buildup and washoff function for urban areas. The buildup and washoff function is used for urban areas due to the greater impervious surfaces and behavior of pollutants on these surfaces. Pollutants will accumulate exponentially between storms in these areas and the buildup and washoff function accounts for this buildup over time (e.g., high intensity development accumulates 0.00445 kilograms of phosphorus per acre of land per day, which is adjusted exponentially for long dry periods) to estimate the anticipated loading from each storm event. This helps account for the differences in concentrations measured in stormwater (e.g., based on the timing from the last storm). The more pervious areas show more consistent stormwater runoff concentrations, therefore a straightforward concentration in stormwater runoff (e.g., assumes forested lands always produce a concentration of 0.006 mg/L in stormwater runoff for every storm) is used by the model. Table 2-6 shows the initial pollutant loads by land use used in the model for total phosphorus.

Table 2-6. Initial Phosphorus Loading Coefficients by Land Use		
Source	Phosphorus Loading Coefficient	Units
Hay/Pasture	0.206	mg/L
Cropland	0.206	mg/L
Forest	0.006	mg/L
Wetland	0.006	mg/L
High Intensity Development	0.00445	kg/acre/d
Low Intensity Development	0.00081	kg/acre/d

³ Special issue: fate of phosphorus in septic tanks (autonomous waste water treatment systems). *Scope Newsletter*. Number 63. January 2006.

⁴ Haith, Douglas A., Ross Mandel and Ray Shyan Wu. Generalized Watershed Loading Functions, Version 2.0, User's Manual. December 15, 1992.



Bathymetric Data

The Auburn Water District provided bathymetry information for Lake Auburn, included as Figure 2-3. The bathymetry was used to estimate water volumes associated with the stratified layers of the Lake. Stratification occurs when temperature variations are experienced at different depths in the Lake, with warmer waters near the surface and cooler waters at the bottom (warm water is less dense than cool water and generally floats, while cold water sinks). When the Lake thermally stratifies, it separates into three layers: epilimnion, (top-most layer), the metalimnion or thermocline (middle layer denoted by a rapid decrease in temperature with depth), and the hypolimnion (dense, bottom-most layer). Seasonal stratification is common as weather patterns change and ice forms and melts on lakes. These volumes contributed towards calculations of average in-lake phosphorus concentrations and estimates of internal phosphorus recycling. The bathymetry also showed the deepest area of the Lake, used for sampling.

2.2 Water Quality

The Auburn Water District (AWD) and Lewiston Water Division (LWD) maintain an extensive database of water quality data collected from Lake Auburn and the watershed, dating as far back as 1979 with temperature and dissolved oxygen profiles in the deep spot of the lake. AWD and LWD performed most of the data collection. The data focuses on raw water quality at the intake for compliance purposes and raw water quality at the deep hole of the lake to evaluate water quality trends and the overall health of the Lake. The two agencies also performed some lake shore sampling, primarily at locations where tributaries enter the Lake. The AWD/LWD maintains a large database of the information collected. A map of the sampling locations is shown in Figure 2-4 and Figure 2-5.

In-Lake Sampling

For the purposes of this study, the water quality collected from the deep spot of the lake (sample ID DEEP HOLE) was the primary focus to assess water quality under stratified lake conditions (Figure 2-4). This data was the most useful for determining the trophic status, or health, of the lake and for calibrating phosphorus loadings calculated in the model as it allowed for a direct comparison of modeled phosphorus concentrations to observed phosphorus concentrations.

Dissolved oxygen and temperature data from profile samples at the deep spot of the Lake were collected between 1979 and the present. These profile data revealed the stratification characteristics of the Lake, which were used to determine differences in water quality amongst these layers. Studies showing the relationship between dissolved oxygen and temperature helped define where the lake stratifies at different times of the year, as indicated by significant changes in temperature and dissolved oxygen gradients. Appendix A contains the graphs created for these efforts.



Generally, the stratification patterns are seasonal; stratification begins in the spring and becomes more defined through fall, with little to no stratification in the winter. When the Lake thermally stratifies, it separates into three layers: the epilimnion, or top-most layer; the metalimnion or thermocline, the middle layer denoted by a rapid decrease in temperature with depth; and the hypolimnion, the dense, bottom-most layer. Table 2-7 summarizes the average depths of these three layers during each season. Note that actual depths in a given year vary depending on the weather.

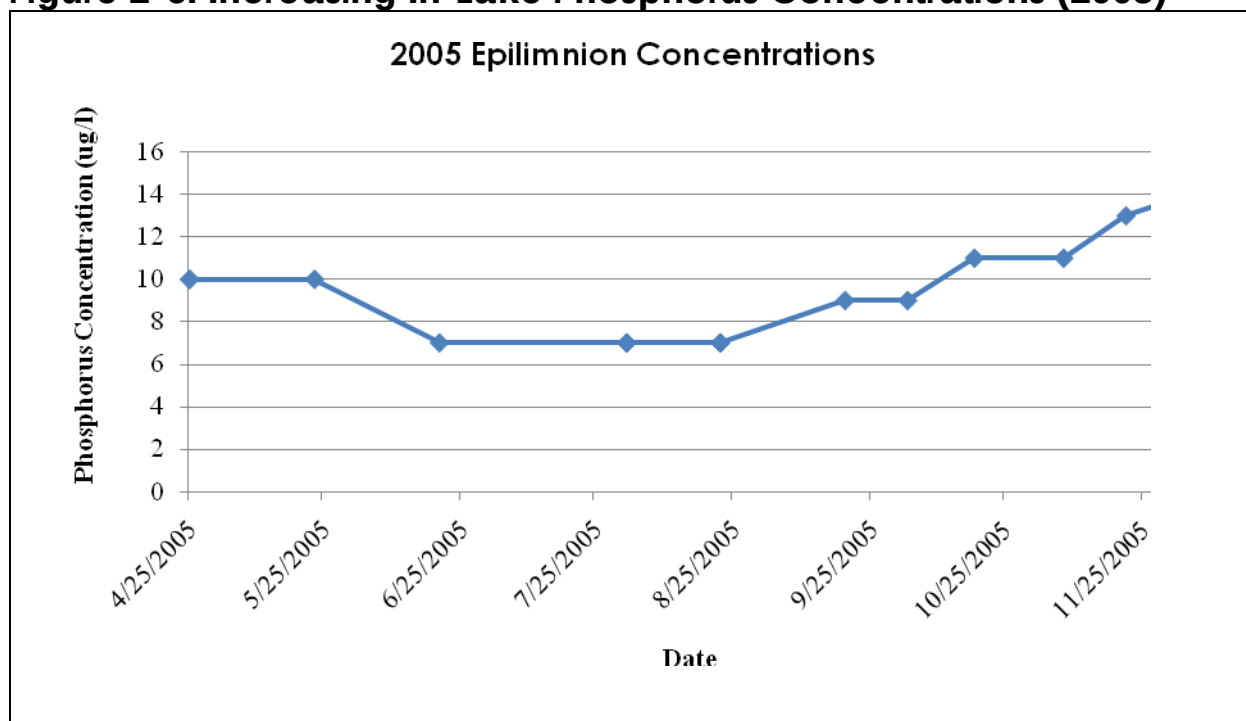
Table 2-7. Stratification by Season				
		Depth of Stratified Layers (feet)		
Season	Months in Season	Epilimnion	Metalimnion	Hypolimnion
Spring	May	0-20	20-30	30-bottom
Summer	June – August	0-23	23-36	36-bottom
Winter	November – April	No Stratification	No Stratification	No Stratification
Fall	September – October	0-43	43-49	49-bottom

The lake stratification provides significant information for determining how phosphorus concentrations behave within the Lake, namely, quantifying the potential for pollutant contributions from lake-bottom sediments. Table 2-8 provides a summary of the available phosphorus data from water column samples at the deep spot of the Lake, categorized by epilimnion, metalimnion and hypolimnion.

As expected, under stratified conditions the hypolimnion typically has a much higher phosphorus concentration than the epilimnion. Low oxygen levels allow for the release of phosphorus from bottom sediments back into the water column. Stratification of the Lake keeps these higher concentrations at the bottom of the lake until mixing, or turnover occurs; therefore, the sediments released from the bottom of the Lake only mix with the full lake volume during spring and fall turnover when temperatures are more consistent throughout the water column. Although limited, phosphorus data from 2005 shows an increase in in-lake phosphorus concentrations in the epilimnion layer in the fall and winter, with the lowest concentrations in the summer (Figure 2-6). This indicates an increase in concentrations after fall turnover, however, there is not enough phosphorus sampling data throughout the water column profile to determine whether this is the result of high concentrations in the hypolimnion from sediment release or the result of a suspended layer of phosphorus-laden decaying plants above the thermocline. Even with this mixing, the average annual concentration in the epilimnion layer remains relatively low at 9.8 µg/l, with average spring levels at 10.3 µg/l.



Table 2-8 Observed In-Lake Phosphorus Concentrations (µg/l)					
Date	Epilimnion	Metalimnion	Hypolimnion	CORE 0-9m	Full CORE
11/17/1986	10	8	18		
2/19/1987	1	9	124		
4/24/1987	11	70	18		
1/30/1990	<10	10	21		
10/25/1990			42		
12/6/1990			10		
2/20/1991	20	<10	10		
5/29/1991	<10	<10	10		
9/24/1991	<10	<10	34		
11/7/1991	12	10	12		
2/18/1992	<10	<10	<10		
10/21/1999	62				
10/21/1999			37		
10/21/1999			12		
10/4/2000			57		
10/23/2001					10
10/23/2001			38		
6/26/2002					12
6/26/2002			21		
9/26/2002					9
5/30/2003			11		
5/30/2003			14		
6/26/2003					10
6/26/2003			12		
7/31/2003				7	
7/31/2003			17		
9/3/2003			20		
6/3/2004			13		
6/3/2004					10
7/1/2004					8
7/1/2004			18		
4/25/2005	10				
8/1/2005	7				
8/22/2005	7				
4/25/2005	10				
5/23/2005	10				
6/20/2005	7				
8/1/2005	7				
8/22/2005	7				
9/19/2005	9				
10/3/2005	9				
10/18/2005	11				
11/7/2005	11				
11/21/2005	13				
12/5/2005	14				
8/29/2006				9	
9/25/2006				9	
6/21/2007				6	
6/25/2008					9
7/23/2008					6
9/24/2008					10
Average In-Lake Concentrations by Season					
Spring	10.3	10.0	13.3		
Summer	7.0		16.2	7.3	9.2
Winter	11.1	9.8	12.6		
Fall	9.8	9.0	32.3	9.0	9.7
Average Annual In-Lake Concentration	9.8	9.6	16.8		
Notes: (1) Average seasonal concentrations represent the average of all data for a particular season (months included in each season are included in Table 2-7) exclusive of the hypolimnion concentration of 124 on 2/19/87, the metalimnion concentration of 70 on 4/24/87 and the epilimnion concentration of 62 on 10/21/99, which are anomalous data sets that skew the average. (2) Average Annual In-Lake Concentrations by stratified layer represent a weighted average based on the number of months in each season as follows: Average Annual In-Lake Concentration = (Spring Conc.*1 month + Summer Conc.*3 months + Winter Conc.*6 months + Fall Conc.*2 months)/12 months					

Figure 2-6. Increasing In-Lake Phosphorus Concentrations (2005)

In comparison to other lakes, it is difficult to find a lake and watershed that is exactly equivalent to Lake Auburn in terms of depth, area, volume, watershed land uses, etc. Compared to other public water supply watersheds in Maine, Lake Auburn has less forest cover, and more developed/disturbed land (over 10%), and is under continuing development pressure. Given that water quality impacts start to appear at 7 to 10% developed, the current level of development and disturbance is a management challenge and requires attention. The water quality data reviewed for the Source Water Assessments indicated that the Lake is at risk from development and other activities that increase nutrient inputs.⁵ Thus, it is important to maintain a strong water supply protection program to maintain the water quality of the lake.

In addition to phosphorus sampling, the AWD and LWD sample numerous other parameters to assess the water quality of the Lake and to show compliance with the conditions of the filtration waiver. Among these parameters are pathogens, sampled as fecal coliform. High fecal coliform levels above water quality conditions permitted by the filtration avoidance criteria were discovered in the raw water in 2004, nearly resulting in an EPA order to install filtration to treat the raw water. AWD and LWD quickly traced the source to an influx of gulls and other waterfowl and instituted an annual gull control program that has successfully kept the lake within permitted source water quality conditions and allowed AWD and LWD to keep their filtration waiver. Records of these and other sampling parameters are kept by the AWD and LWD. This incident demonstrates the significance and importance of other pollutants in monitoring the health of the lake. As such, these other key pollutants including pathogens and turbidity are also addressed in this plan.

⁵ Tolman, Andrews L., Maine CDC Drinking Water Program, (personal email communication, March 24, 2010)
 Lake Auburn Watershed Management Plan
 Final Report, April 19, 2010



The highest epilimnion phosphorus concentrations occur during the winter, when algal and plant growth does not occur. Because of this and the depth of the Lake, the average spring concentration of 10.3 $\mu\text{g/l}$ in the epilimnion layer, instead of the highest evident concentration, was used to assess phosphorus loadings to the Lake with the lake response model.

Tributary/Inlet Sampling

Tributaries to the Lake have historically been sampled for phosphorus and other parameters. A map of tributary sampling locations is shown on Figure 2-5. A summary of the phosphorus results is included in Table 2-9.

The results show the greatest phosphorus concentrations along the northeast side of the lake from First Brook and Townsend Brook, which contains some developed areas along the brook. These areas also showed higher pathogen concentrations (Fecal Coliform and Enterococci) than other locations on many occasions. Townsend Brook is also one of the larger tributaries to the Lake, with greater flows carrying greater overall pollutant loads.

However, flow data was not collected at the time of sampling, therefore the data cannot be used to determine loads associated with streamflows.

2.3 Flow Calibration

GWLF-E estimates surface runoff and infiltration to model the resulting hydrology within the watershed. Precipitation falls on the ground surface and either evapotranspires, infiltrates into the soil or runs over the ground depending on several variables (e.g., land use, soil type, temperature). The infiltrate that does not evapotranspire, evaporating directly or through plant transpiration, either moves through soil to surface waters as baseflow or seeps downward into a deep aquifer.

AVGWLF, the GIS interface, calculates the necessary model parameters based on the spatial data inputs. The GWLF-E model then generates daily flow data based on precipitation, land use, soil conditions and other environmental characteristics. GWLF-E provides some flexibility to adjust calculated parameters, allowing for adjustments to calculated flow information.

As previously discussed, the USGS prepared a water budget for Lake Auburn in 2004, representing flows between 2000 and 2003. As part of this budget, gages were used to measure continuous streamflows during this period at two inlets to Lake Auburn, including The Basin Outlet and Townsend Brook to Lake Auburn, and the outlet from Lake Auburn, Lake Auburn at Bobbin Mill Brook.



Table 2-9. Tributary Phosphorus Concentrations (ug/l)

	Outlet of Lake, Site #1	Townsend Brook, Site #2	Brook Near Tabor's, Site #3	Culvert on Lake Shore Dr., Site #4	North Auburn Bridge, Site #13	Basin - Before Dam, Site #16	Outlet to Little Wilson Pond, Site #17	Inlet to Little Wilson Pond, Site #18	Horse Pond on Lake Shore Dr., Site #23	First Brook on Lake Shore Dr., Site #25	Tot Lot, Site #26	Johnson Road, Site #27	Milfoil Bouy Line (Lake)
10/21/1999		2			9								
5/31/2000	11	22	6	5	16	19	10	13	9	26	22		
4/12/2000	10	16	5	8	11	13	15	10	7	25	14		
6/28/2000	17	30	10	9	24	10	12	18		28	22		
8/9/2000	16	21	11	11	18	12	11	16			20		
8/30/2000	10	16	12		16	11	12	14			15		
10/4/2000		26	21			12	16	16			24		
4/3/2001	7	21	5	5	8		8				20	8	
4/25/2001	10	18	7	9	10	10	21	13	10	23	100	10	
5/17/2001	16												
5/17/2001	11												
5/23/2001	24	27	7	7	19	11	11	18	17	31	17	8	
6/28/2001	16	28	16	8	26	16	25	28			27	9	
7/31/2001	11	18	14		18	23	20	19			20		
9/12/2001	12	21	15		13	18	22	22			18		
10/23/2001	15	15	18		13	12	26	18			16		13
3/20/2002	19	11	9	4	11	8	11	9	9	26	10	4	
4/24/2002	14	14	4	5	12	20	11	13	9	13	14	6	
5/30/2002	18	21	5	7	54	10	11	13	36	18	26	6	
6/27/2002	23	30	8	7	20	12	13	21	25	21	29	8	
7/31/2002	13	15	10		17	12	23	21			24		
8/29/2002	14	12	12		30	54	40	30			21		
9/25/2002	13	17	13		18	11	20	14			24		
10/23/2002	16	12	7		12	9	14	14			18		
4/24/2003	26	16	6	8	8	9	11	10	15	31	16	7	
6/25/2003	16	26	10	9	16	10	12	24	24	25	25	10	
7/30/2003	16	21	14		34	9	25	20			22		
8/28/2003	12	14	14		14	11	11	18			14		
5/26/2004	11	22	7	11	15	12	11	15	14	26	26	16	
6/30/2004	15	28	19	8	20	21	12	18		33	23	7	
8/25/2004	13	19	9	12	14	10		15		23	29	7	
4/13/2005	9	15	5	6	8	8	11	10	8	20	15	6	
5/16/2005	<1	16	5	7	10	9	10	10		25	4	6	
6/13/2005	1	22	7	13	1	36	14	17		34	6	8	
7/11/2005	19	28	10	15	14	10	12	19		3	8	11	
8/9/2005	1	20	11		24	<1	23	17			5		
9/12/2005	36	18	18		15	35	12	16			23		
10/4/2005	16	22	12		13	12	13	9			19		
11/7/2007						8							
4/3/2008						3							
4/16/2008						6							
Averages	14.49	19.44	10.34	8.29	16.60	14.22	15.56	16.41	15.25	23.94	21.03	8.06	13.00

The GWLF-E model generated daily inflow to the Lake based on input created with AVGWLF, as discussed above. GWLF-E estimated flows for the model period 2001 through 2008. To calibrate the model, Townsend Brook gaging data (USGS Gage Number 01056480) was compared to model generated flows in Townsend Brook for the period of record. This helped to determine the extent of correlation between the modeled and observed flows, and to then make adjustments as needed to better fit modeled flows with observed flows. Because storage impoundments upstream of other available gages buffer the streams' reactions to precipitation events, the model calibration considered only the Townsend Brook gage. For example, matching records collected at The Basin Outlet gage would be difficult because flows are controlled by factors not predicted in the model (i.e., the outlet structure and water levels within The Basin).

The key flow calibration parameters within the model include curve numbers, a recession coefficient and a seepage coefficient. These parameters have the greatest influence on the shapes of modeled hydrographs, which indicate the streamflow peaks due to stormwater runoff and the baseflow between storm events.

The AVGWLF interface determines curve numbers for watershed areas based on soil type and land use data. However, comparison to TR-55⁶ revealed that the model predicted high curve numbers, resulting in greater runoff. Table 2-2c in the TR-55 Manual was used to adjust the curve numbers downwards, providing a better fit to observed flows.

AVGWLF also calculates a groundwater recession coefficient, which represents the “lag time” for subsurface flow to reach streams. Higher recession coefficients correspond to high flows appearing more quickly in the streamflow whereas lower values correspond to greater subsurface storage and slower release of baseflows to streamflow.

The seepage coefficient represents the fraction of infiltrated groundwater that is lost to an underlying aquifer or deep saturated zone. Allowing for seepage shifts the entire hydrograph curve towards zero, reducing overall model-predicted inflows.

The main intent of the GWLF-E model is not accurate prediction of watershed hydrology, rather, the model focuses primarily on the prediction of annual average pollutant loads from the watershed based on stormwater runoff. The model is limited to using average daily precipitation values to predict average daily, monthly and annual flows, while the gaged streamflow data represents stream responses to actual hourly rain events. Therefore, it is difficult to accurately match the model predicted curve with the gaged data. Within these limitations, the model tended to over-predict flows for some periods and under-predict for others. A close fit of the hydrograph curve for the entire period proved unrealistic based on the limited changes allowed within the model. As a result, calibration focused on obtaining the best fit such that total average annual flow volumes estimated by the model matched as well as possible with those observed by the USGS gage. The results reveal that average annual precipitation for the modeled period was 19% higher than the average annual precipitation for the three year USGS study, thus, one would expect the modeled streamflows to be roughly 19% higher than USGS gaged data. Modeled

⁶ US Department of Agriculture, Natural Resources Conservation Service. Urban Hydrology for Small Watersheds: Technical Release 55. June 1986.



average annual inflows were 18% higher than USGS measured average annual flows, which correlates to a 1% difference when accounting for differences in precipitation. This provides a reasonable estimation to determine pollutant loads from the watershed under various land use scenarios. Appendix B contains the final calibration curve and estimated flow volumes for the period of calibration.

Model results including direct precipitation, baseflow and runoff (streamflow) contributed to an estimate of average annual water budget for Lake Auburn. These components together make up the inflow to the Lake and evaporation, while withdrawals and outlet flows make up the outflows. Table 2-10 lists these volumes, as discussed below.

Table 2-10. Water Budget	
Precipitation (inches)	44.81
Inflows (million ft³)	
Direct Precipitation	367
Streamflow	594
<i>Baseflow</i>	<i>486</i>
<i>Runoff</i>	<i>108</i>
Total	961
Outflows (million ft³)	
Outlet	413
Evaporation	190
Withdrawals	358
Total	961

Inflows

Direct precipitation – Direct precipitation comprises average annual precipitation of 44.81 inches multiplied by the lake surface area of 2,259 acres. Direct precipitation contributes approximately 367 million cubic feet to the lake inflow.

Baseflow – Baseflow represents the volume of water that enters the lake or its tributaries as groundwater flow. GWLF-E calculated baseflow volume as 486 million cubic feet.

Runoff – Runoff represents the volume of water that enters the lake or its tributaries as stormwater flow over land in the watershed. GWLF-E calculated runoff volume as 108 million cubic feet.



Outflows

Evaporation – CDM estimated average annual evaporation from the Lake Auburn watershed in the 1987 study as 23.5 inches per year. USGS also estimated average annual evaporation in the 2004 water budget study as 22.8 inches per year. Because evaporation is a function of temperature data, it is not anticipated to change significantly from the previous studies. An average evaporation rate of 23.15 inches per year was applied to the surface area of the lake, resulting in an average evaporation loss of 190 million cubic feet.

Withdrawals – The Auburn Water District provided withdrawal information for the eight-year period 1994 through 2008. The average annual withdrawal from Lake Auburn for water supply over the 2001 through 2008 period was 358 million cubic feet.

Outlet flows – Outlet flows represent the water leaving the Lake through the Bobbin Mill Brook outlet. Because there is no longer a gage at this outlet, flows are assumed as the difference between inflows and evaporation and withdrawals, or 413 million cubic feet. This compares reasonably well with estimates from the 1987 CDM Plan of 471 million cubic feet, but is considerably higher than the USGS measured average outlet flows.

Lake Residence Time

Lake residence time, also known as flushing rate) is the amount of time that water spends in a lake. It is calculated by dividing the lake volume by the flow in or out of the lake. For Lake Auburn, the residence time was calculated as follows:

Residence Time = Lake Volume/Inflow

Where:

Lake Volume = 3,920 million ft³
Inflow = 961 million ft³/yr

Residence Time = 3,920/961 = 4.08 years

2.4 Pre-Calibration Phosphorus Load Estimates

Phosphorus loads from various sources within the watershed were modeled, including direct precipitation, stormwater runoff, baseflow, septic systems, streambank erosion and internal recycling, as described below.



Direct Precipitation

Phosphorus loadings from direct precipitation into the Lake were estimated by multiplying the lake area by a loading coefficient of 0.081 kg/acre-yr⁷. This results in an annual phosphorus load of 182.8 kg (403 pounds) per year.

Stormwater Runoff

Phosphorus loadings from stormwater runoff were predicted using the GWLF-E model. Initial default land use loading coefficients were used to predict a load from stormwater runoff of 374.7 kg (826 pounds) per year.

Baseflow

Phosphorus loadings from baseflow were predicted using the GWLF-E model. Baseflow was predicted to contribute 228.2 kg (503 pounds) of phosphorus per year.

Septic Systems

GWLF-E also estimates phosphorus loadings from septic systems based on the model developed by Mandel. The model divides septic system loads into four types: normal, short-circuited, ponded, and direct discharge systems. These are defined as follows in the GWLF User Manual:

“Normal System. A normal septic system is a system whose construction and operation conforms to recommended procedures such as those suggested by the EPA design manual for on-site wastewater disposal systems (U.S. Environmental Protection Agency, 1980). Effluents from such systems infiltrate into the soil and enter the shallow saturated zone. Effluent nitrogen is converted to nitrate, and except for removal by plant uptake, the nitrogen is transported to the stream by groundwater discharge. Conversely, phosphates in the effluent are adsorbed and retained by the soil and hence normal systems provide no phosphorus loads to streamflow.

Short-Circuited Systems. These systems are located close enough to surface waters (~ 15 m) so that negligible adsorption of phosphorus takes place. The only nutrient removal mechanism is plant uptake...

Ponded Systems. These systems exhibit hydraulic failure of the tank’s absorption field and resulting surfacing of the effluent. Unless the surfaced effluent freezes, ponding systems deliver their nutrient loads to surface waters in the same month that they are generated through overland flow. If the temperature is below freezing, the surfaced effluent is assumed to freeze in a thin layer at the ground surface. The accumulated frozen effluent melts when the snowpack disappears and the temperature is above freezing.

Direct Discharge Systems. These illegal systems discharge septic tank effluent directly into surface waters.”

⁷ Reckhow, Kenneth H. and Chapra, Steven C. 1983. Engineering Approaches for Lake Management. Volume 1: Data Analysis and Empirical Modeling. Butterworth Publishers. Boston.



GWLF-E estimates septic system phosphorus loadings using the following equation:

$$SL = 0.001 * a * d * (e - u)$$

where:

SL = phosphorus septic load

a = the number of people

d = the number of days in the month

e = the per capita tank effluent, a default of 2.5 grams/day of phosphorus

u = the per capita growing season phosphorus uptake, a default of 0.4 grams/day

0.001 = conversion factor for grams to kilograms

Other methods for estimating phosphorus loadings from septic systems assume that all septic systems within a specific buffer (e.g., 65 to 656 feet) to the lake and/or tributaries contribute some phosphorus load. These methods apply a soil retention coefficient, representing the fraction of phosphorus retained by the soils.

Septic contributions for the Lake Auburn Watershed were calculated using a combination of methods. Orthophoto imagery and spatial parcels and building data were used to estimate the number of dwellings within 300 feet of the lake, upstream ponds and major tributaries. Each dwelling within this buffer was assumed to represent a septic system. GWLF-E was used to calculate phosphorus loadings from septic systems within 50 feet of each waterbody and tributary under the assumption that these systems were short-circuiting with no removal of phosphorus. Phosphorus loadings from septic systems located between 50 feet and 300 feet were calculated by multiplying the number of homes by persons per dwelling (2.6 persons per dwelling based on 2000 US Census data) and kilograms of phosphorus contributed by each person (0.7 kg per person⁸). A soil retention coefficient of 0.8, as applied in the 1987 Watershed Management Study, was applied to these loads.

Septic systems were estimated to contribute an average of 120.7 kg (266 lbs) per year of phosphorus.

Internal Recycling

During thermal stratification of the Lake, elevated phosphorus concentrations in the hypolimnion layer indicate that internal recycling of phosphorus is likely occurring through sediment mixing. There is the possibility for this to be released to the water column during fall turnover. Internal recycling was calculated using two methods for comparison. The first method considered the average concentration in the hypolimnion layer under stratified conditions in the fall (September-October), just before turnover would occur. This method rests on the assumption that the entire hypolimnion water volume is at this concentration (this may be conservative since the sample is collected close to the bottom, which is likely higher than concentrations at shallower depths

⁸ Litke, David W. Review of Phosphorus Control Measures in the United States and Their Effects on Water Quality. U.S. Geological Survey. Water-Resources Investigations Report 99-4007. 1999.



within the hypolimnion layer) and that all phosphorus in the hypolimnion will mix with the remaining lake volume at turnover, as discussed and shown with the water quality data. Both of these assumptions are conservative and more water quality data is needed to accurately estimate internal recycling loads.

Water quality data records in the month of October show an average phosphorus concentration in the hypolimnion layer of 32.3 µg/l. When multiplied by the hypolimnion volume, this translates to 540 kg (1,190 pounds) of phosphorus in this layer. Concentrations of phosphorus during periods without internal recycling were assumed to be representative of those in the epilimnion layer (9.8 µg/l in the fall, representing the same period of high concentrations in the hypolimnion layer). The amount of phosphorus in the hypolimnion volume using the concentration of 9.8 µg/l was calculated as 164 kg (362 pounds). The difference between the two values was assumed to represent the phosphorus loading associated with internal recycling, or 376 kg (829 pounds) of phosphorus.

This was checked against a second method, which used an equation estimate the sediment-water exchange rate under aerobic conditions. The equation, based on the results of an investigation by Kamp-Nielsen⁹, is shown below.

$$\Delta P/\Delta t = -1.38 \log P + 1.88$$

Where:

$\Delta P/\Delta t$ is in mg PO₄/m²/day

P is in µg PO₄/l

With this equation, an equilibrium (no exchange) occurs for a water column phosphorus concentration of about 30 µg/l. A net phosphorus release from sediments occurs when concentrations above aerobic sediments is less than 30 µg/l. Kamp-Nielsen found that aerobic release of phosphorus is independent of the sediment composition.

Assuming the entire lake bottom contributes to an internal load, a phosphorus contribution of 627 kg (1,383 pounds) per year was determined based on this second method. It is unlikely that the entire lake bottom releases phosphorus to the water column, thus, the lesser value of 376 kg (829 pounds) of phosphorus was used to represent internal loadings of phosphorus.

Streambank

Streambank erosion and phosphorus loads attached to the resulting sediment particles were estimated with GWLF-E. Streambank erosion was estimated to contribute 4.5 kg (10 pounds) of phosphorus per year.

⁹ Reckhow, Kenneth H. and Chapra, Steven C. 1983. Engineering Approaches for Lake Management. Volume 1: Data Analysis and Empirical Modeling. Butterworth Publishers. Boston. p. 141-142.



2.5 Phosphorus Loads Calibration

The pre-calibrated phosphorus loadings and model predicted runoff rates and baseflow for the period between 2001 and 2008 were input to the Reckhow steady-state lake response model to determine the predicted in-lake concentration associated with these loadings. Due to the limited data on the upstream ponds, it was assumed that all loads entered Lake Auburn directly. While some retention is likely occurring from settling in upstream ponds, the “big-picture” application of the lake response model associates total loads to the lake with an actual in-lake concentration. Thus, the overall loading and needed reductions for each scenario are still valid and applicable for evaluating recommendations. The same holds true regarding the choice of lake response model. All models will not generate the same exact loading results, but the correlation between loads and in-lake concentrations allow for an accurate assessment of percent reductions needed to achieve goals and the actions that will result in these reductions.

The results of this modeling effort showed that initial pollutant loads were underestimated by about 11%. As a result, all pollutant load estimates were increased by 10 to 15% to match predicted in-lake phosphorus concentrations with observed in-lake phosphorus concentrations. This involved adjusting the phosphorus loading factors in the model.

The use of the Reckhow steady-state lake response model requires that the simulated water body is representative of the model basis, shown on Table 2-11. This table shows the minimum and maximum data set levels for the model alongside corresponding levels for Lake Auburn. As shown in Table 2-11, this model is appropriate for Lake Auburn.

Table 2-11. Reckhow Model Minimum and Maximum Loading Values		
	Reckhow Acceptable Range	Lake Auburn
Phosphorus Concentration – P (µg/l)	4 – 135	9.8
Annual Areal Phosphorus Loading – L (g/m ² -yr)	0.07 – 31.4	0.157
Areal Water Loading – q _s (m/yr)	0.75 - 187	3.0

The Reckhow steady-state lake model is expressed as:

$$P = L / (11.6 + 1.2q_s)$$

Where:

L = annual areal phosphorus loading (g/m²-yr), $L = W / A_s$

W = total phosphorus mass loading (includes stormwater, internal recycling, baseflow) (g/yr)

q_s = areal water loading (m/yr), $q_s = Q / A_s$

Q = inflow water volume to lake (m³/yr), $Q = (A_d \times r) + (A_s \times Pr)$

A_d = watershed area (land surface) (m²)

A_s = lake surface area (m²)

r = total annual unit runoff (m/yr)



Pr = mean annual net precipitation (m/yr)

The predicted in-lake phosphorus concentration using the Reckhow steady-state in lake model after calibration is included in Table 2-12.

Table 2-12. Reckhow Steady-state Phosphorus Model Results After Calibration	
Parameter	Value
Lake area – A_s (km ²)	9.1
Mean Depth (m)	12.2
Watershed area – A_d (km ²)	48.2
Phosphorus Loads	
Stormwater runoff phosphorus loadings (kg/yr)	425
Streambank erosion phosphorus loadings (kg/yr)	5
Septic system phosphorus loadings (kg/yr)	133
Phosphorus loadings from direct precipitation (kg/yr)	201
Phosphorus loadings from internal recycling (kg/yr)	413
Phosphorus loadings from baseflow (kg/yr)	255
Total phosphorus loadings – W (kg/yr)	1432
Total phosphorus loadings – L (g/m ² -yr)	0.157
Runoff (m/yr)	0.3
Baseflow (m/yr)	1.5
Direct Precipitation (m/yr)	1.1
Areal Water Loading – q_s (m/yr)	3.0
Predicted In-lake Phosphorus (mg/l)	0.0103
Predicted In-lake Phosphorus (µg/l)	10.3
Average Observed In-lake Phosphorus (µg/l)	10.3

2.6 Calibrated Phosphorus Loadings

Based on the calibration performed modeling runs, the phosphorus loadings by subwatershed were estimated. These are presented in Table 2-13. Phosphorus loadings were also determined by town as shown in Table 2-14. Phosphorus loadings by source, including a breakout by land use are included in Table 2-15.



Table 2-13. Phosphorus Load by Subwatershed	
Subwatershed	Phosphorus Load (lbs/yr)
Gracelawn	65
Lake shore Drive, East	87
Lake Shore Drive, West	26
Little Wilson Pond	186
Mud Pond	360
North Auburn	103
Route 4	121
Spring Road	218
Summer Street	67
The Basin	242
Townsend Brook	235
West Auburn Road	19
Youngs Corner	73
Total	1802

Table 2-14. Phosphorus Load by Town	
Town	Phosphorus Load (lbs/yr)
Auburn	1130
Buckfield	43
Hebron	35
Minot	167
Turner	427
Total	1802



Table 2-15. Phosphorus Load by Source

Source	Phosphorus Load (lbs/yr)
Land-based Runoff	
<i>Hay/Pasture</i>	451
<i>Cropland</i>	153
<i>Forest</i>	28
<i>Wetland</i>	6
<i>High Intensity Development</i>	274
<i>Low Intensity Development</i>	25
Land-based Runoff Subtotal	937
Other Land-based	
<i>Streambank Erosion (sediment)</i>	10
<i>Baseflow</i>	562
<i>Septic Systems</i>	293
Other Land-based Subtotal	865
Land-based Runoff & Other Land-based Subtotal	1802
Other Sources	
<i>Precipitation</i>	444
<i>Internal Recycling</i>	911
Other Sources Subtotal	1355
Total	3157

2.7 Buildout

A gross buildout was evaluated to determine potential pollutant loadings and in-lake concentrations assuming a worst-case scenario. The buildout evaluation may be used for planning purposes to mitigate phosphorus loadings associated with new development.

Three scenarios were evaluated for buildout as described below.

Scenario 1. Buildout Under Existing Zoning

Under this scenario, all developable land was modeled as developed to its maximum potential based on existing zoning regulations. Figure 2-7 shows the existing zoning map for the watershed. The following assumptions were applied to the analysis:

- No development within 300 feet of the shoreline in sandy soils in accordance with the current Lake Auburn Watershed Overlay District Ordinance, which does not allow septic systems within this buffer;



- No development on properties with less than 36 inches to groundwater as based on soil maps from the Natural Resources Conservation Service (Figure 2-8), in accordance with Lake Auburn Watershed Overlay District Ordinance, which does not allow septic systems on sites with less than 36" of suitable soil;
- No development within 100 feet of shoreland buffers from streams, ponds and wetlands;
- Protected lands would remain forested (Figure 1-3);
- The above undevelopable land areas were subtracted from the total land area within each zoning district to determine developable land area by zoning district. This evaluation did not consider existing lot frontage and setbacks, which requires a more detailed parcel level analysis. This evaluation, rather, represents a worst-case buildout condition considering that land ownership and construction of new roadways can alter a parcel by parcel analysis;
- Existing zoning densities were applied to total land estimates for residentially zoned areas;
- Agricultural Resource Protection (AR) zoning would be developed assuming one residence per 10 acres with the 88% of remaining land developed as crops;
- Phosphorus loads from low and high intensity areas were limited to those allowed by existing State and local ordinances, whichever is more stringent (see Table 2-16); and
- All new development would be served by septic systems.

Table 2-16. State and Local Per Acre Phosphorus Allocation Requirements

Waterbody	Town	State Total P Allocation (lbs/acre/yr)	Existing Local Total P Allocation (lbs/acre/yr)	Recommended Total P Allocation Requirement (lbs/acre/yr)
Lake Auburn	Auburn	0.072	0.047	0.036
	Turner	0.082	0.082	0.082
Little Wilson Pond	Auburn	0.025		0.025
	Minot	0.038		0.038
	Turner	0.031	0.031	0.031
Mud Pond	Minot	0.033		0.033
	Turner	0.033	0.025	0.025
Mud Pond (in Turner)	Buckfield	0.025		0.025
The Basin	Minot	0.043		0.043
	Turner	0.027	0.02	0.02

These land use changes were input into GWLF-E to predict phosphorus loadings to the Lake under this scenario. Total phosphorus contributions to Lake Auburn under this scenario were 5,043 pounds (3,688 pounds land based) of phosphorus per year, which results in an in-lake concentration of 16.2 $\mu\text{g/l}$. The results of the analysis are summarized in Tables 2-17 by subwatershed, 2-18 by Town and 2-19 by source.



**Table 2-17. Buildout Scenario 1
Phosphorus Load by Subwatershed**

Subwatershed	Phosphorus Load (lbs/yr)
Gracelawn	140
Lake shore Drive, East	209
Lake Shore Drive, West	122
Little Wilson Pond	258
Mud Pond	464
North Auburn	247
Route 4	132
Spring Road	447
Summer Street	145
The Basin	606
Townsend Brook	632
West Auburn Road	118
Youngs Corner	169
Total	3688

**Table 2-18. Buildout Scenario 1
Phosphorus Load by Town**

Town	Phosphorus Load (lbs)
Auburn	2831
Buckfield	46
Hebron	40
Minot	172
Turner	598
Total	3688



**Table 2-19. Buildout Scenario 1
Phosphorus Load by Source**

Source	Phosphorus Load (lbs)
Land-based Runoff	
<i>Hay/Pasture</i>	449
<i>Cropland</i>	1812
<i>Forest</i>	5
<i>Wetland</i>	6
<i>High Intensity Development</i>	274
<i>Low Intensity Development</i>	180
Land-based Runoff Subtotal	2725
Other Land-based	
<i>Streambank Erosion (sediment)</i>	74
<i>Baseflow</i>	442
<i>Septic Systems</i>	447
Other Land-based Subtotal	963
Land-based Runoff & Other Land-based Subtotal	3688
Other Sources	
<i>Precipitation</i>	444
<i>Internal Recycling</i>	911
Other Sources Subtotal	1355
Total	5043

Scenario 2. Buildout Under Existing Zoning With Less Stringent Septic Requirements

Scenario 2 is identical to Scenario 1 with one exception: this scenario assumes that septic systems can be built on land with shallow depths to groundwater. The same assumptions as outlined above apply, with the exception that development may occur on properties with less than 36 inches to groundwater. This scenario was evaluated to determine the impacts of less stringent septic requirements within the Lake Auburn watershed.

Under this scenario, an additional 264 acres of land can be developed. Overall development under this scenario includes an existing 41 homes located within 50 feet of the shoreline, an existing 39 homes between 50 and 100 feet of the shoreline and 383 homes between 100 and 300 feet of the shoreline (207 existing homes, 176 additional homes during buildout).



The increased phosphorus loading from septic systems from Scenario 1 is 225 pounds of phosphorus. The increased loading from other sources, associated with the development of these properties (e.g., surface runoff, streambank erosion, etc.) is 125 lbs of phosphorus, resulting in a total phosphorus loading to Lake Auburn of 5,395 lbs. This corresponds with an in-lake concentration of 17.3 µg/l in Lake Auburn. The results of the analysis are summarized in Tables 2-20 by subwatershed, 2-21 by source and 2-22 by Town.

Table 2-20. Buildout Scenario 2 Phosphorus Load by Subwatershed	
Subwatershed	Phosphorus Load (lbs)
Gracelawn	142
Lake shore Drive, East	221
Lake Shore Drive, West	126
Little Wilson Pond	262
Mud Pond	463
North Auburn	447
Route 4	129
Spring Road	475
Summer Street	145
The Basin	658
Townsend Brook	683
West Auburn Road	142
Youngs Corner	147
Total	4041

Table 2-21. Buildout Scenario 2 Phosphorus Load by Town	
Town	Phosphorus Load (lbs)
Auburn	3183
Buckfield	44
Hebron	40
Minot	173
Turner	599
Total	4041



**Table 2-22. Buildout Scenario 2
Phosphorus Load by Source**

Source	Phosphorus Load (lbs)
Land-based Runoff	
<i>Hay/Pasture</i>	449
<i>Cropland</i>	1931
<i>Forest</i>	4
<i>Wetland</i>	6
<i>High Intensity Development</i>	274
<i>Low Intensity Development</i>	186
Land-based Subtotal	2850
Other Land-based	
<i>Streambank Erosion (sediment)</i>	82
<i>Baseflow</i>	438
<i>Septic Systems</i>	671
Other Land-based Subtotal	1191
Land-based Runoff & Other Land-based Subtotal	4041
Other Sources	
<i>Precipitation</i>	444
<i>Internal Recycling</i>	911
Other Sources Subtotal	1355
Total	5395

Scenario 3. More Likely Buildout Scenario

A third buildout scenario was evaluated to represent more likely buildout conditions considering that agricultural in Maine are declining rather than increasing making it unlikely that all of the agriculturally zoned land will be deforested for farming purposes. Under this scenario, the same assumptions as in Scenario 1 were applied, including one house per 10 acres in the agriculturally zoned areas, however, it was assumed that only half of the remaining (e.g., not occupied by the residence) land would be developed as agricultural with the other remaining as forested. This is still believed to be a conservative assumption considering farm lands are declining, however, does anticipate that some of the forested land will be cleared, which is likely to happen in the future whether for agriculture or another use.

Based on this scenario, the lake will receive 4,192 pounds of phosphorus per year, which results in an in-lake phosphorus concentration of 13.4 µg/l. The results of the analysis are summarized in Tables 2-23 by subwatershed, 2-24 by Town and 2-25 by source. This scenario will be used as the basis for future recommendations.



**Table 2-23. Buildout Scenario 3
Phosphorus Load by Subwatershed**

Subwatershed	Phosphorus Load (lbs)
Gracelawn	92
Lake shore Drive, East	147
Lake Shore Drive, West	73
Little Wilson Pond	251
Mud Pond	463
North Auburn	199
Route 4	132
Spring Road	332
Summer Street	89
The Basin	419
Townsend Brook	443
West Auburn Road	71
Youngs Corner	124
Total	2837

**Table 2-24. Buildout Scenario 3
Phosphorus Load by Town**

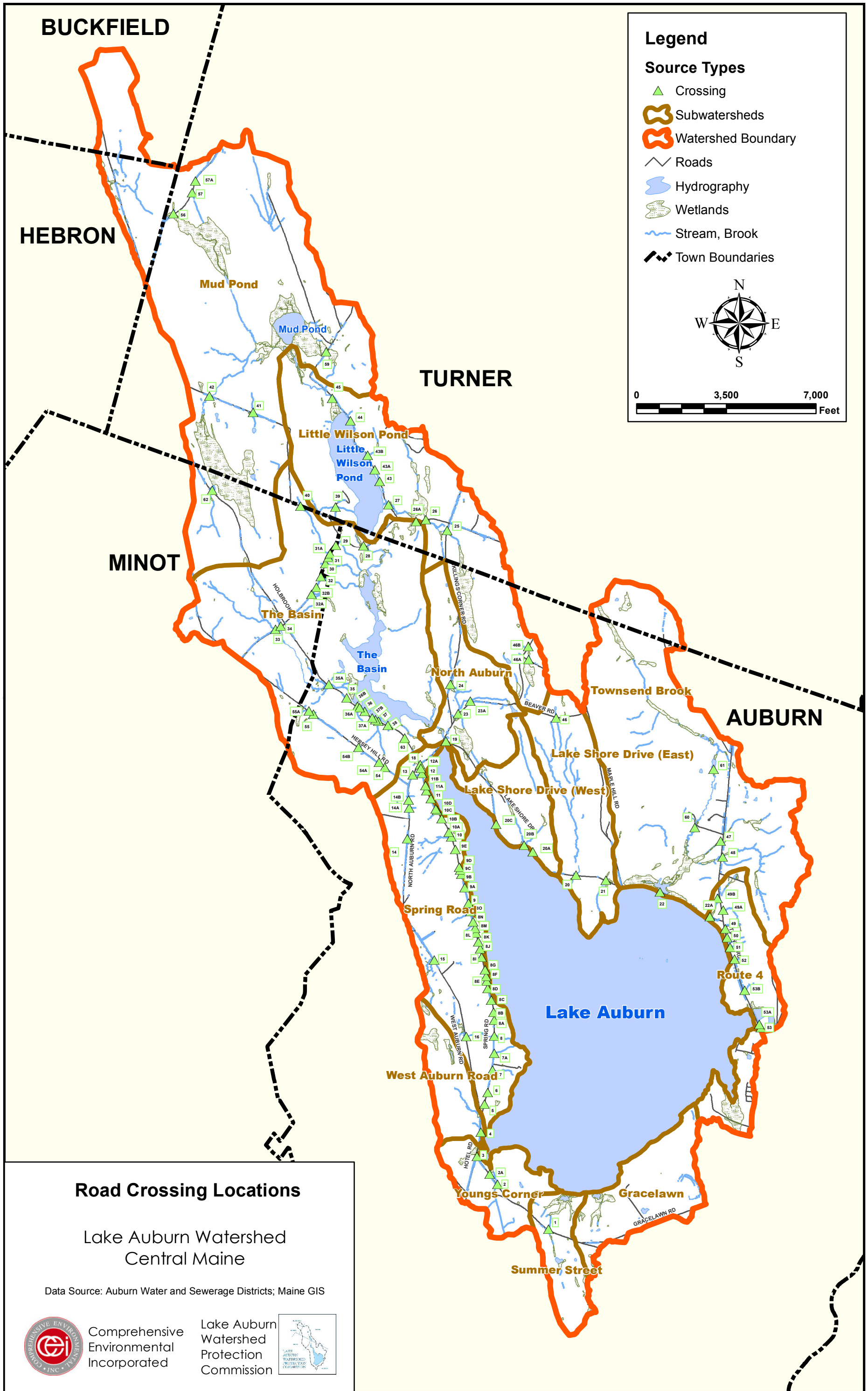
Town	Phosphorus Load (lbs)
Auburn	1980
Buckfield	46
Hebron	40
Minot	172
Turner	599
Total	2837

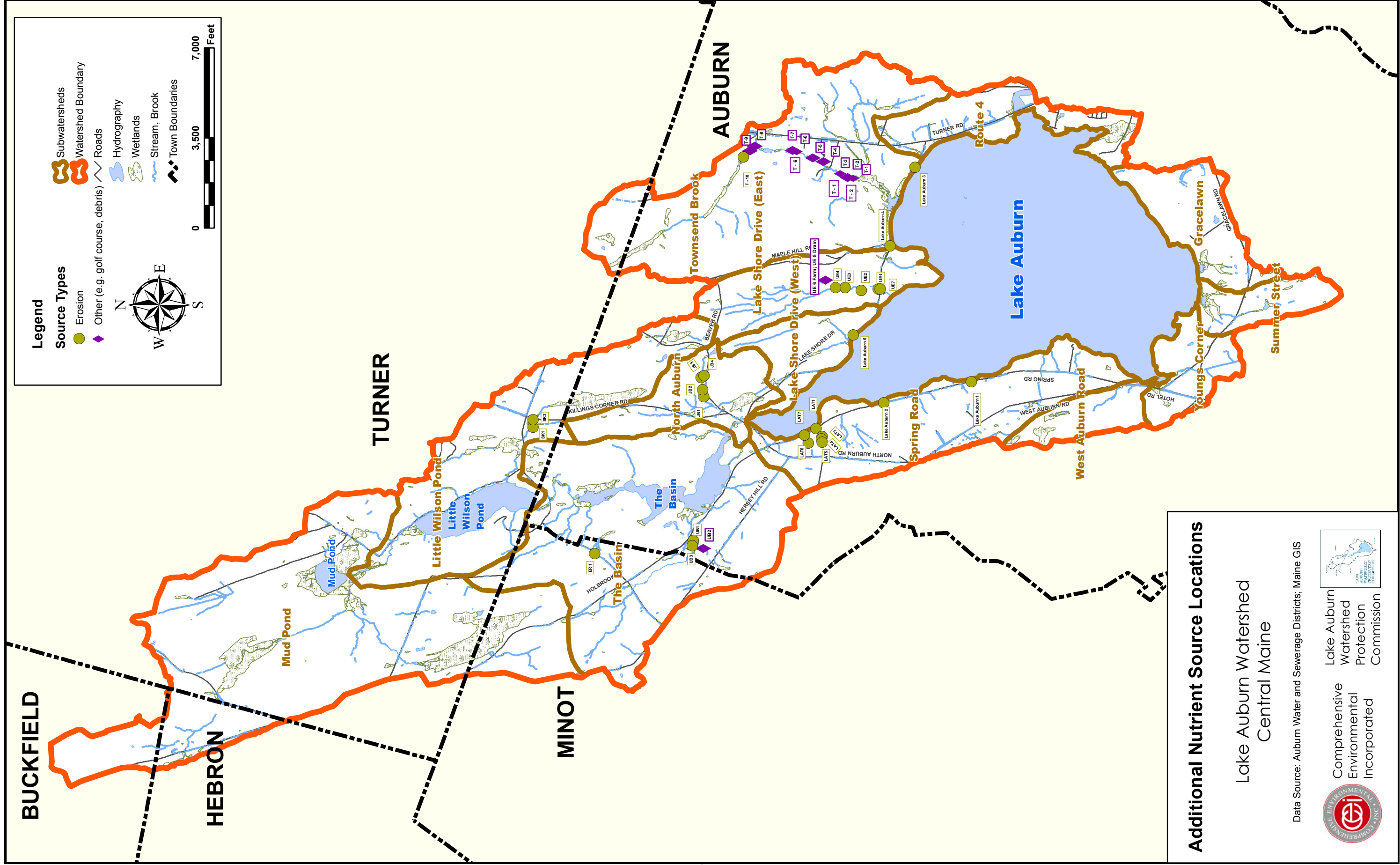


**Table 2-25. Buildout Scenario 3
Phosphorus Load by Source**

Source	Phosphorus Load (lbs)
Land-based Runoff	
<i>Hay/Pasture</i>	449
<i>Cropland</i>	938
<i>Forest</i>	9
<i>Wetland</i>	6
<i>High Intensity Development</i>	274
<i>Low Intensity Development</i>	180
Land-based Runoff Subtotal	1855
Other Land-based	
<i>Streambank Erosion (sediment)</i>	79
<i>Baseflow</i>	456
<i>Septic Systems</i>	447
Other Land-based Subtotal	981
Land-based Runoff & Other Land-based Subtotal	2837
Other Sources	
<i>Precipitation</i>	444
<i>Internal Recycling</i>	911
Other Sources Subtotal	1355
Total	4192







Additional Nutrient Source Locations

Lake Auburn Watershed
Central Maine

Data Source: Auburn Water and Sewerage Districts; Maine GIS



Comprehensive
Environmental
Incorporated

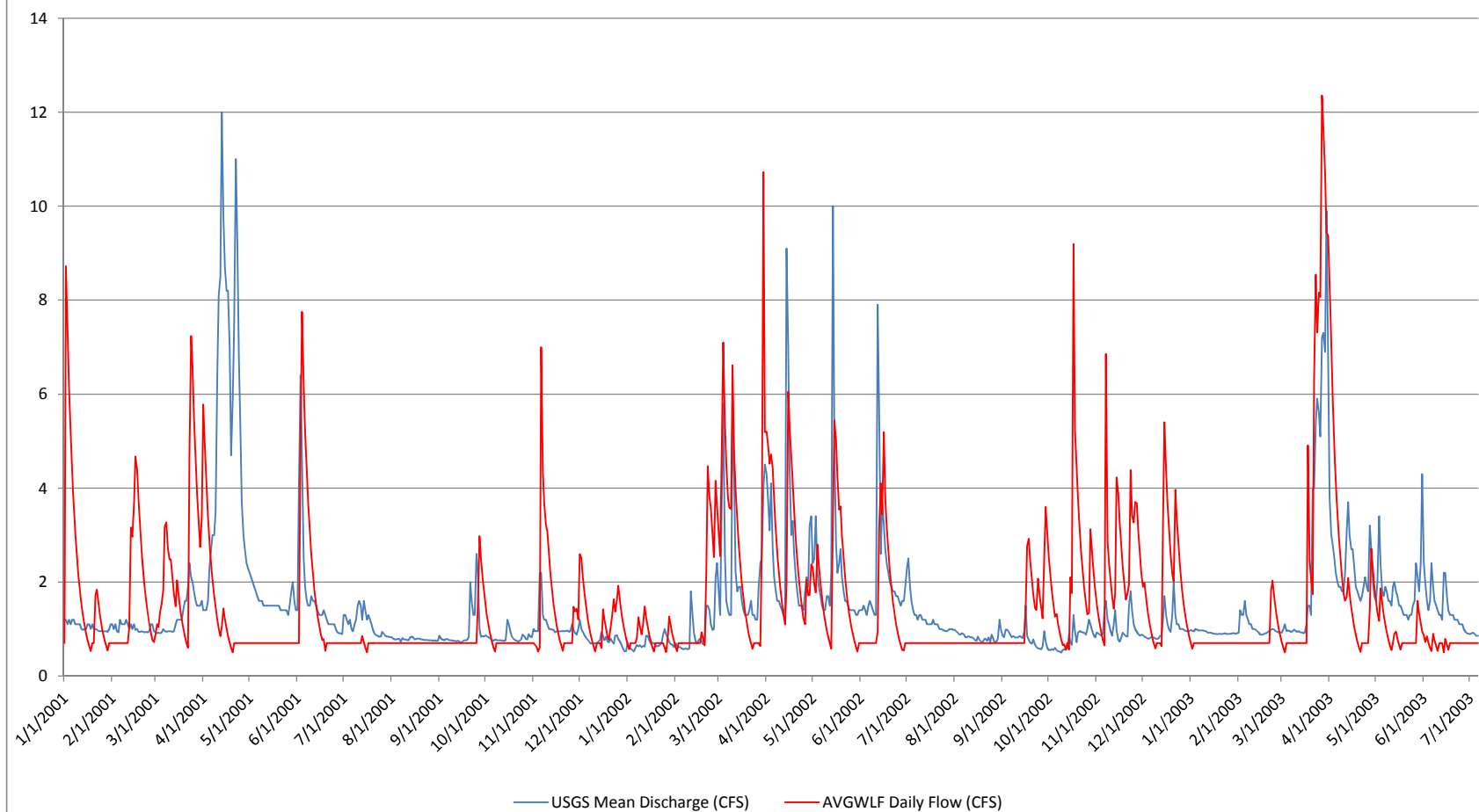


Lake Auburn
Watershed
Protection
Commission

Appendix C

Flow Calibration Curve and Volumes

Daily Discharge at Townsend Brook



Average Streamflow Volume		
Data Source	Storm Period: 3/1/2002 to 7/1/2002 (10^6 ft^3)	Entire Period: 1/1/2001 to 7/6/2003 (10^6 ft^3)
Observed (USGS)	24.60	117.9
Modeled (AVGWLF)	24.24	91.44
Percent Difference	-1%	-5%

Appendix D

Landfill Analysis Summary

Potential for contamination of Lake Auburn from adjacent landfills

Summary of Findings

There are four closed landfills in proximity to Lake Auburn: The Gracelawn Landfill, Interim Sanitary Landfill and Asbestos disposal area, Pionite Sawdust Disposal Area, and an old burning brush dump and demolition debris landfill.

Given the value of Lake Auburn as a drinking water supply for Auburn and Lewiston, studies have been conducted over the years to determine if leachate from the landfills could be reaching the lake. As our consultants continue to look for causes for the recent algae blooms, the questions has arisen once again whether or not the landfills could be affecting the Lake.

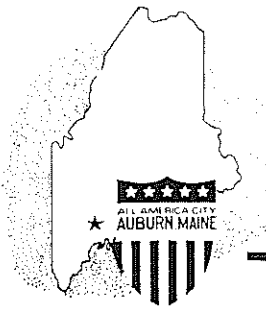
A study was conducted in 1990 by EC Jordan. They installed groundwater monitoring wells and developed groundwater contour maps, as well as bedrock maps. As a result of sampling the wells over a period of years, they determined that the groundwater flow travels in an Easterly and Southerly direction – away from the Lake. A summary of their findings is attached.

A similar study was conducted in 1995 by Woodard and Curran, which reached the same conclusion.

In accordance with Maine Department of Environmental Protection rules, the wells continue to be sampled today. For the past three years, Summit Environmental has taken over the sampling and reporting for the City of Auburn. Data on the wells goes back to 1995. The most relevant leachate indicators include specific conductance, chlorides, and total suspended solids. The two wells between the Lake and landfills (MW- 201, and MW- 301) have had low levels of these indicators, and they continue to diminish. On the other hand, monitoring well 101, which is on the southerly side of the Gracelawn landfill (away from the lake), has had increases in all landfill leachate indicators. Copies of the data are attached.

Further investigation may be warranted; however, available data shows that the landfills are not contaminating the Lake.

*And Hazeltan P.E.,
District Engineer
Auburn Water District
3/7/13*



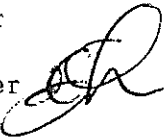
CITY OF AUBURN, MAINE

"MAINE'S CITY OF OPPORTUNITY"

45 SPRING STREET · AUBURN, MAINE 04210

786-2421

ROBERT F. BELZ
PUBLIC WORKS DIRECTOR

MEMO TO: Paula Valente, City Manager
FROM: Steven Ranney, City Engineer 
DATE: June 11, 1990
RE: Hydrogeologic Investigation for Gracelawn Road area landfills

I received 8 copies of the report from ABB Environmental (i.e. E.C. Jordan Company) entitled Hydrogeologic Investigation, Gracelawn Landfill/Lake Auburn, Auburn, Maine. The report includes the results of last year's expansion of the existing groundwater quality monitoring program.

Results indicate that Lake Auburn is not receiving contaminants from the area landfills. However, a potential pathway for contaminants from the brush dump and the old burning dump area may exist between the area high ground and CMVTI. The new well installed in that area was vandalized and plugged and thus groundwater samples could not be taken. Therefore, the consultant recommends replacing the well and performing additional monitoring to determine if contaminants are in fact moving in that general direction.

Dave Gulick, senior environmental geologist for ABB Environmental and project manager, will give a brief presentation of the report at the June 18, 1990 City Council meeting.

Copies of the complete report will be on file with the City Manager, Engineering Division, and Auburn Water District.

cc: Robert Belz, Director of Public Works

FIGURE 5-1 **GROUNDWATER CONTOUR MAP** **HYDROGEOLOGIC INVESTIGATION** **GRACELAWN LANDFILL** **CITY OF AUBURN, MAINE**

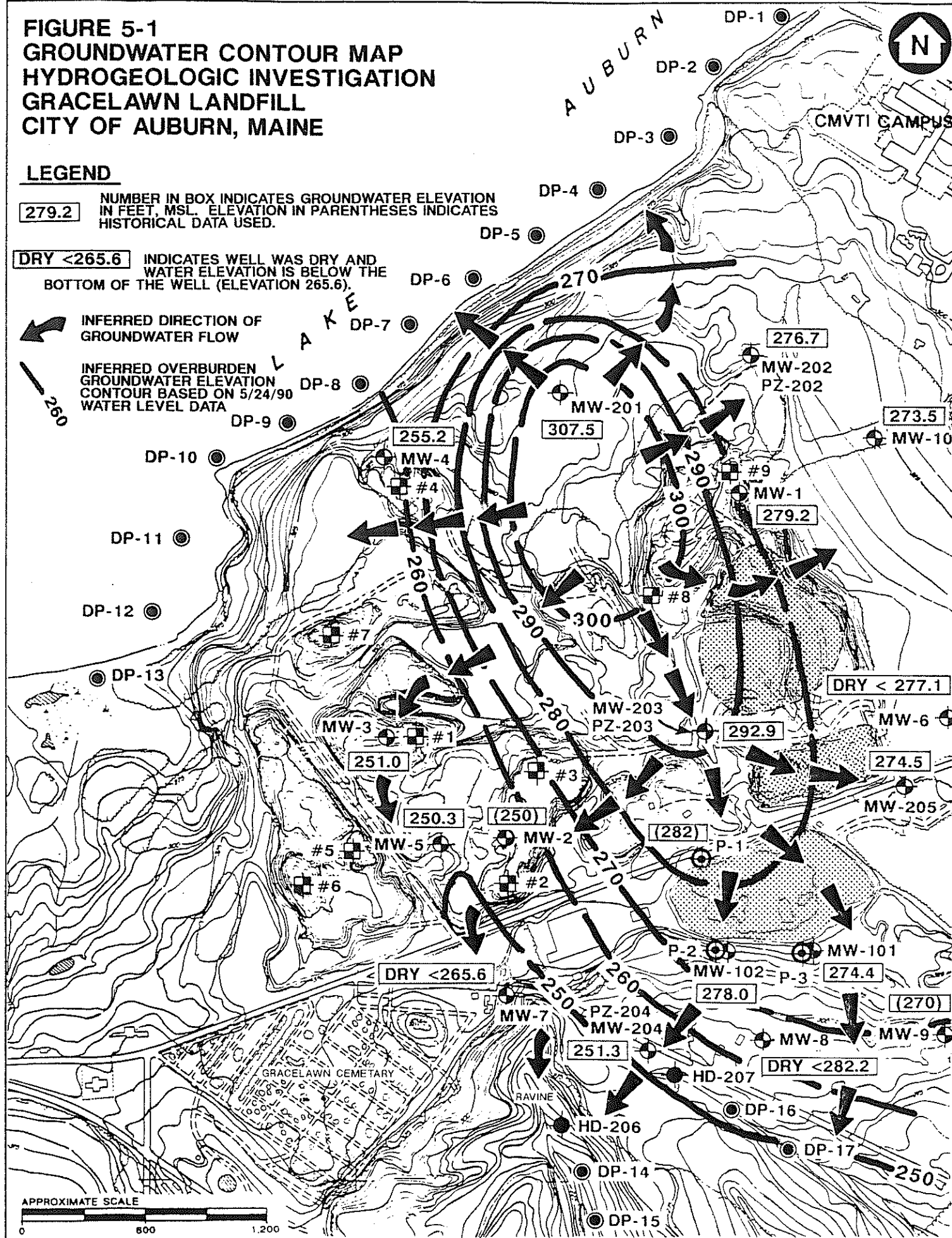
LEGEND

279.2 NUMBER IN BOX INDICATES GROUNDWATER ELEVATION IN FEET, MSL. ELEVATION IN PARENTHESES INDICATES HISTORICAL DATA USED.

DRY <265.6 INDICATES WELL WAS DRY AND WATER ELEVATION IS BELOW THE BOTTOM OF THE WELL (ELEVATION 265.6).

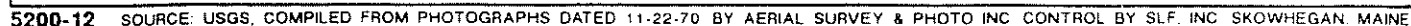
INFERRED DIRECTION OF GROUNDWATER FLOW

INFERRED OVERBURDEN GROUNDWATER ELEVATION CONTOUR BASED ON 5/24/90 WATER LEVEL DATA



LEGEND

**INFERRED BEDROCK ELEVATION
CONTOUR IN FEET MSL**



7.0 FINDINGS AND CONCLUSIONS

The hydrogeological investigation of the Gracelawn Landfill area has been conducted in phases beginning with a seismic survey in 1976 and the installation of 10 monitoring wells and nine test pits in 1980. Each succeeding investigation program has been designed to address the increasing level of understanding of the site area and obtain more useful and definitive information. Each new exploration program has added locations and explorations to fill specific data gaps and assisted in the interpretation of groundwater movement. Hydrogeological investigations are most effectively conducted with this type of phased approach.

The most recent investigations, conducted in the fall of 1989, have added significantly to the understanding of the site area. The new information is reflected in a greatly modified groundwater contour map and knowledge of the extent of the bedrock contours. Historical and recent laboratory analytical data is much more meaningful in light of our revised understanding of groundwater movement, although the loss of MW-202 has influenced our ability to assess groundwater movement and water quality in the area east of the knob.

Based on our current understanding of the geology and hydrogeology in the vicinity of the city landfills and Lake Auburn, the following conclusions have been reached:

- o The bedrock knob in the north-central portion of the site appears to be the area of highest groundwater elevations in the overburden soils and shallow bedrock.
- o Groundwater movement in both the overburden soils and shallow bedrock is radially away from the bedrock knob.
- ✓ o The bedrock knob does appear to act locally as a barrier to groundwater movement from the landfills towards Lake Auburn.
- o A bedrock low is present between the bedrock knob and the CMVTI Campus (identified in MW-202) providing a potential pathway for groundwater to reach Lake Auburn.
- o Saturated permeable sands overlying highly-fractured bedrock were encountered in the bedrock low at MW-202 indicating a groundwater pathway does exist east of the knob to the lake.
- ✓ o Based upon currently available water level data, the Old Burning Dump and the Brush/Demolition Debris Dump appear to be the only potential landfills or disposal areas that could contribute contaminants to the groundwater that may be reaching Lake Auburn by passing between the bedrock knob and CMVTI.
- ✓ o Groundwater impacted by the Interim Sanitary Landfill, the Asbestos Disposal Site, the Pionite Disposal Site and Gracelawn Landfill appears to be moving away from Lake Auburn to the east, southeast and south.

- o The greatest groundwater impacts have been detected in monitoring wells MW-101, MW-102 and MW-205 directly adjacent to and down gradient of Gracelawn Landfill and the Interim Sanitary Landfill.
- o Significantly elevated specific conductance measurements in groundwater, indicative of landfill leachate, have been detected in MW-9, MW-101, MW-102, and MW-205. Somewhat less elevated conductivity values have also been reported in MW-1, MW-203 and MW-204.
- o MW-102 and MW-205 contain the highest levels of VOC contamination. The highest detected levels of VOCs include 1,300 ug/l of acetone, 690 ug/l 2-butanone, and 40 ug/l of 4 methyl-2-pentanone in MW-205 in March 1990. Other significant detects include 86 ug/l of 1,1-dichloroethane, 130 ug/l of 1,2-dichloroethane, and 20 ug/l of vinyl chloride in February and March 1990.
- o Limited inorganic contamination of the groundwater has been identified to date.
- ✓ o It is recommended that MW-202 be replaced and additional monitoring at the site be undertaken to confirm or deny potential groundwater contamination moving from the Old Burning Dump and Brush/Demolition Debris Dump towards the lake. *replaced in 2006*

The conclusions presented in this report are based on interpretations of currently available data and may need to be modified if further investigations are performed at the site, or if additional information becomes available.

Sid Hazelton

From: Sue Yerina <syerina@summitenv.com>
Sent: Tuesday, March 05, 2013 8:59 AM
To: Sid Hazelton
Subject: RE: monitoring well results

Sid,

Here are some concentration trend graphs for monitoring well data at the Gracelawn landfill. I could not find water quality data in the database for MW-202 and data for MW-206 was limited. Historical and recent groundwater flow data shows that the lake is not downgradient of the landfill. Although this is counter-intuitive, it is consistent with data obtained from monitoring wells at the adjacent K&K gravel pit.

Wells MW-301 and MW-201 are considered upgradient to the landfill. Based on results for the 2012 sampling, groundwater quality at monitoring well MW-301 reported decreasing trends in specific conductivity, Sulfate, and TDS with no increasing trends. MW-201 is no longer sampled as part of the monitoring program. However, historical data shows that concentrations reported at MW-201 are similar or consistently lower than those reported at MW-301. In 2011, MW-201 reported one parameter as trending upward (temperature) and one parameter as trending downward (sulfate).

Historically, MW-101 has shown a trend of declining groundwater quality, which is consistent with its location directly downgradient from the original Gracelawn Landfill. In 2012, well MW-101 reported increasing trends for four parameters (Chloride, specific conductivity, sulfate, and TDS). These results are consistent with 2011. When comparing concentrations at MW-301 and MW-101, values at MW-301 are consistently lower than those reported at MW-101.

I have split the attachment into two files. If you find that you need additional information, let me know and I will do my best to get it to you before your meeting Wednesday.

Sue

From: Sid Hazelton [<mailto:shazelton@awsd.org>]
Sent: Wednesday, February 27, 2013 2:12 PM
To: Sue Yerina
Subject: monitoring well results

Sue,

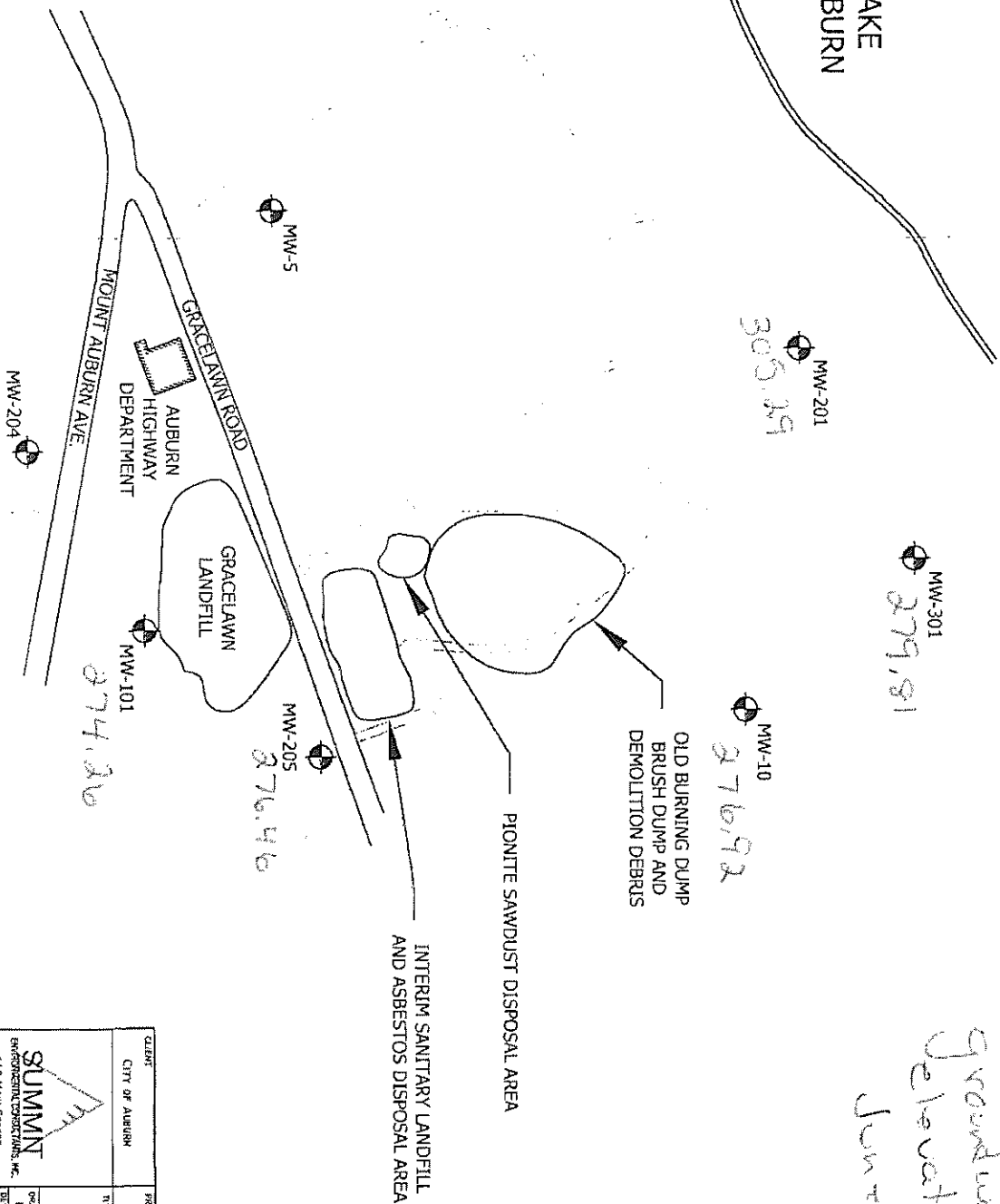
Thanks for taking the time to talk to me today. As we spoke, we are trying to correlate monitoring well results around the Gracelawn landfills to the potential for contamination of Lake Auburn. The 1990 EC Jordan study determined that most of the groundwater plume was headed away from Lake Auburn, and towards the Androscoggin River Basin, and Pettengill Park. The only area in question was monitoring well 202 which is between the Community College and the old burning /brush dump. MW 202 was subsequently replaced with MW 206, and then again by well number 301. Do you have any data for these wells, or others between the Lake and the old landfill?

Sid Hazelton, P.E.

Sid Hazelton, P.E.



LAKE
AUBURN

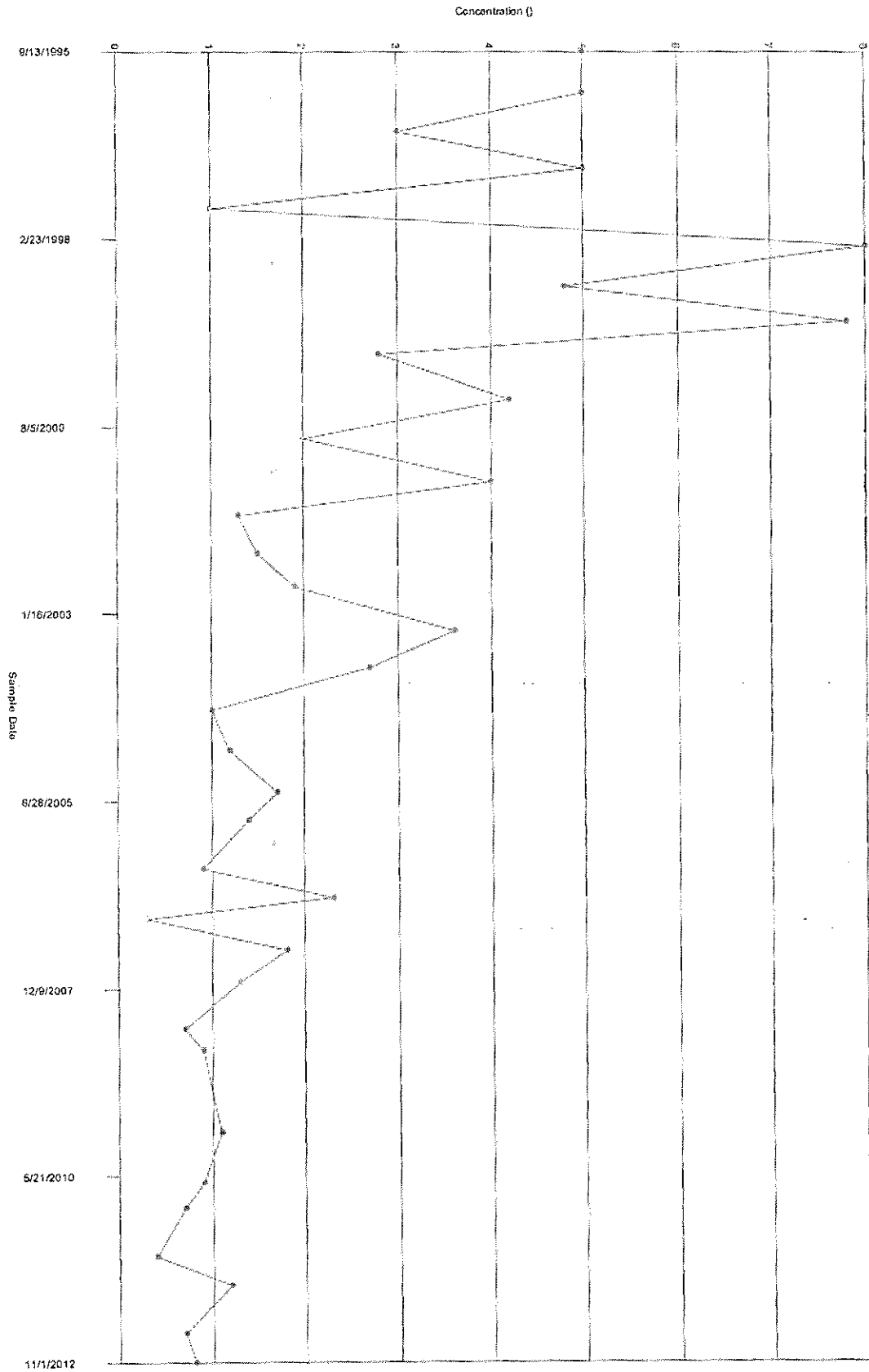


Note: All locations are Approximate

Groundwater
Elevations
June 2013

CLIENT		PROJECT	
CITY OF AUBURN		GRACECLAWN LANDFILL AUBURN, MAINE	
TITLE		SAMPLING LOCATION PLAN	
DRAWN B.N.C.		SCALE Not to Scale	
CHECKED S.Y.C.		DATE 01/07/10	
PROJECT NO. 15902		FILE NO. 1002	

CHLORIDE Time-Series Graph of MW-301



2000

1500

1000

500

Concentration (l)

Specific Conductance
Time-Series Graph of MW-301

9/13/1995

2/23/1999

8/5/2000

1/18/2003

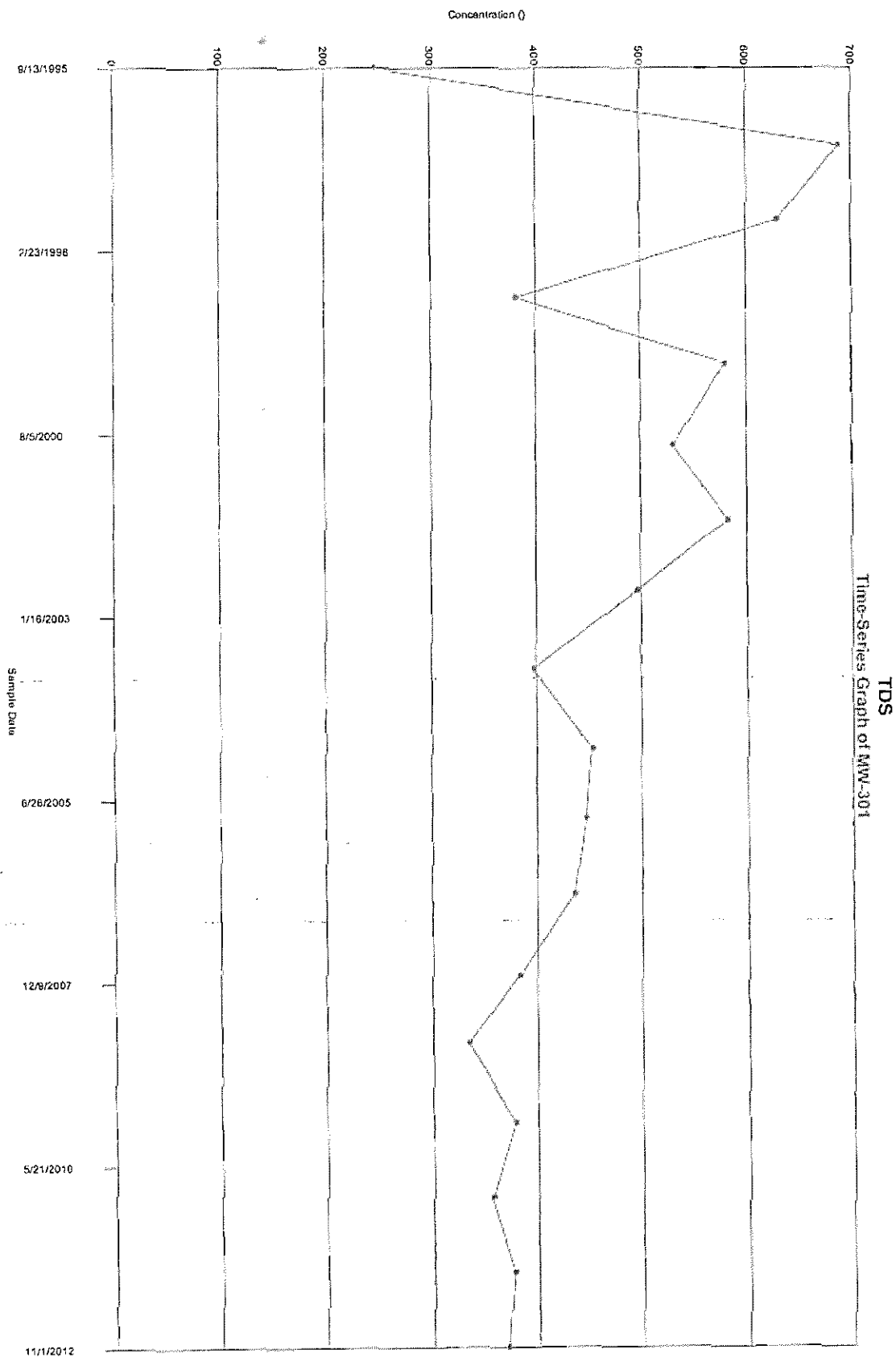
6/28/2005

12/9/2007

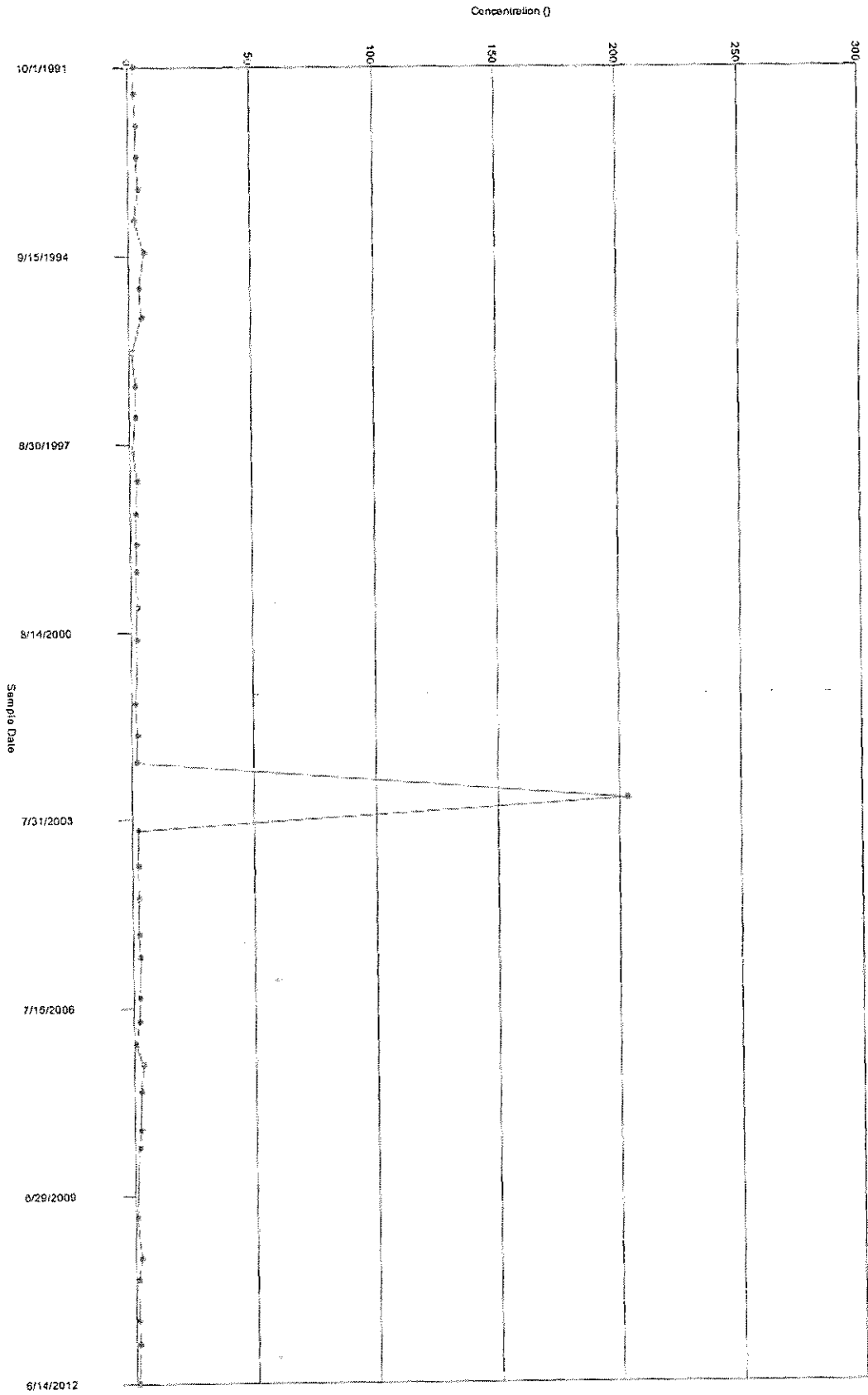
5/21/2010

11/1/2012

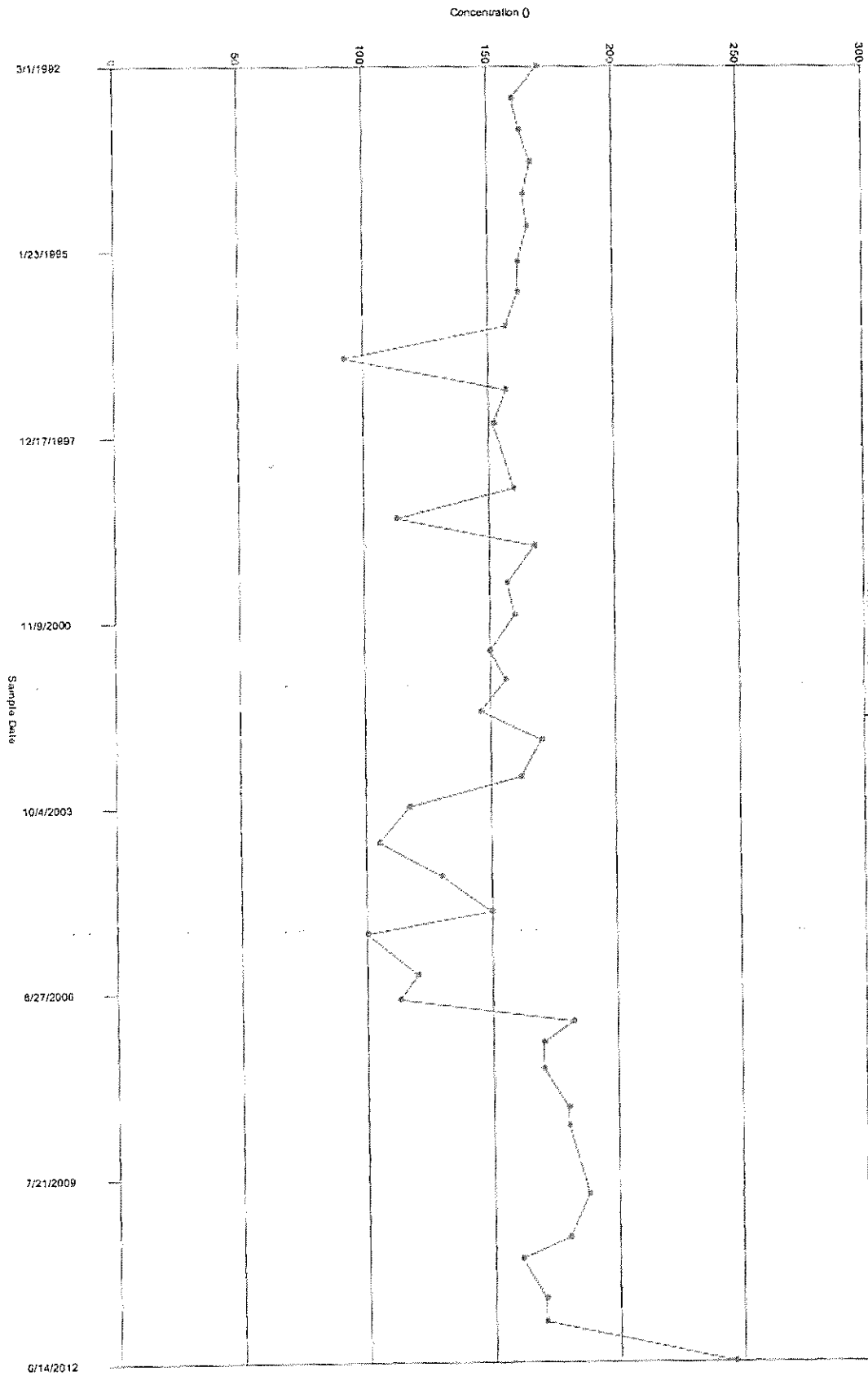
Sample Date



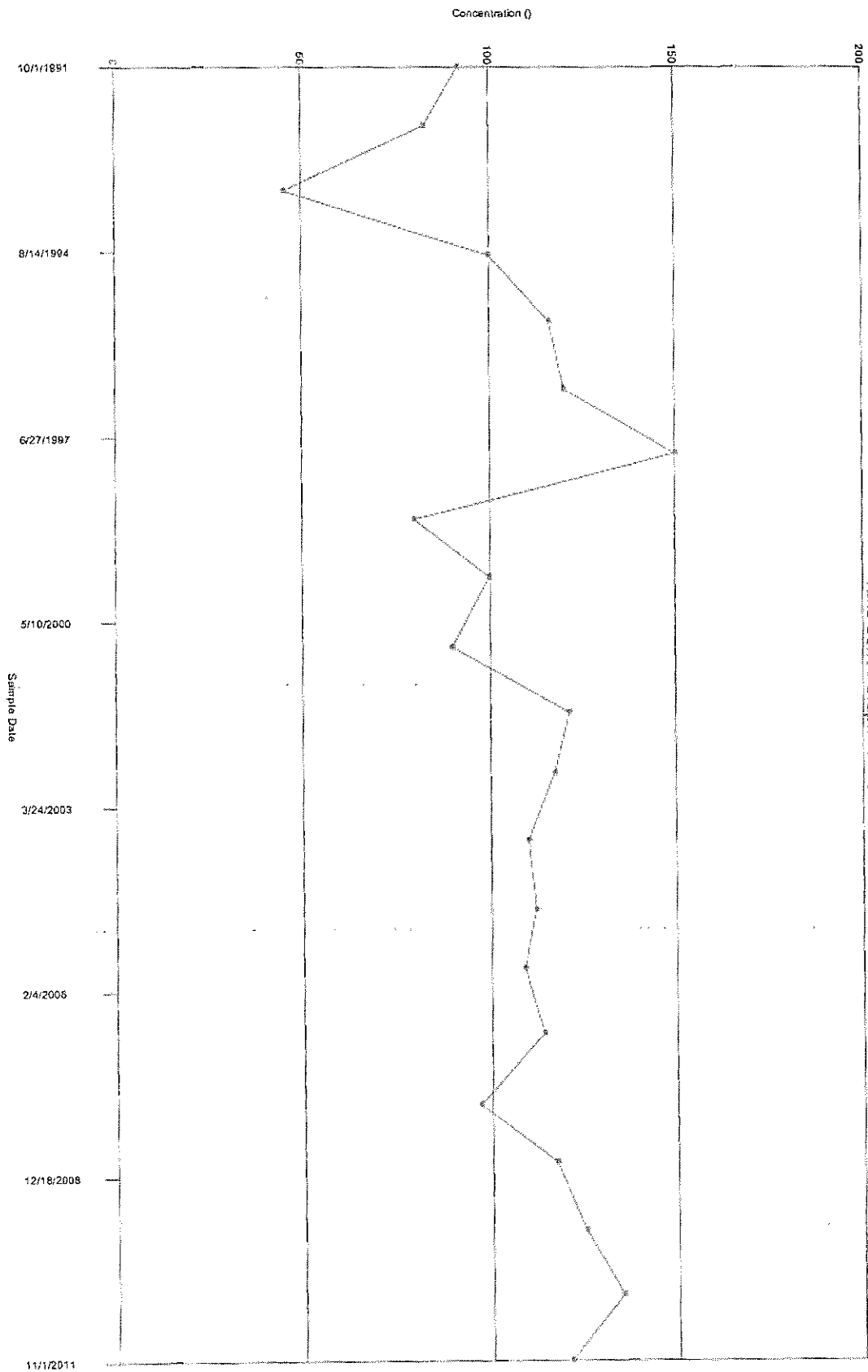
CHLORIDE
Time-Series Graph of MW-201



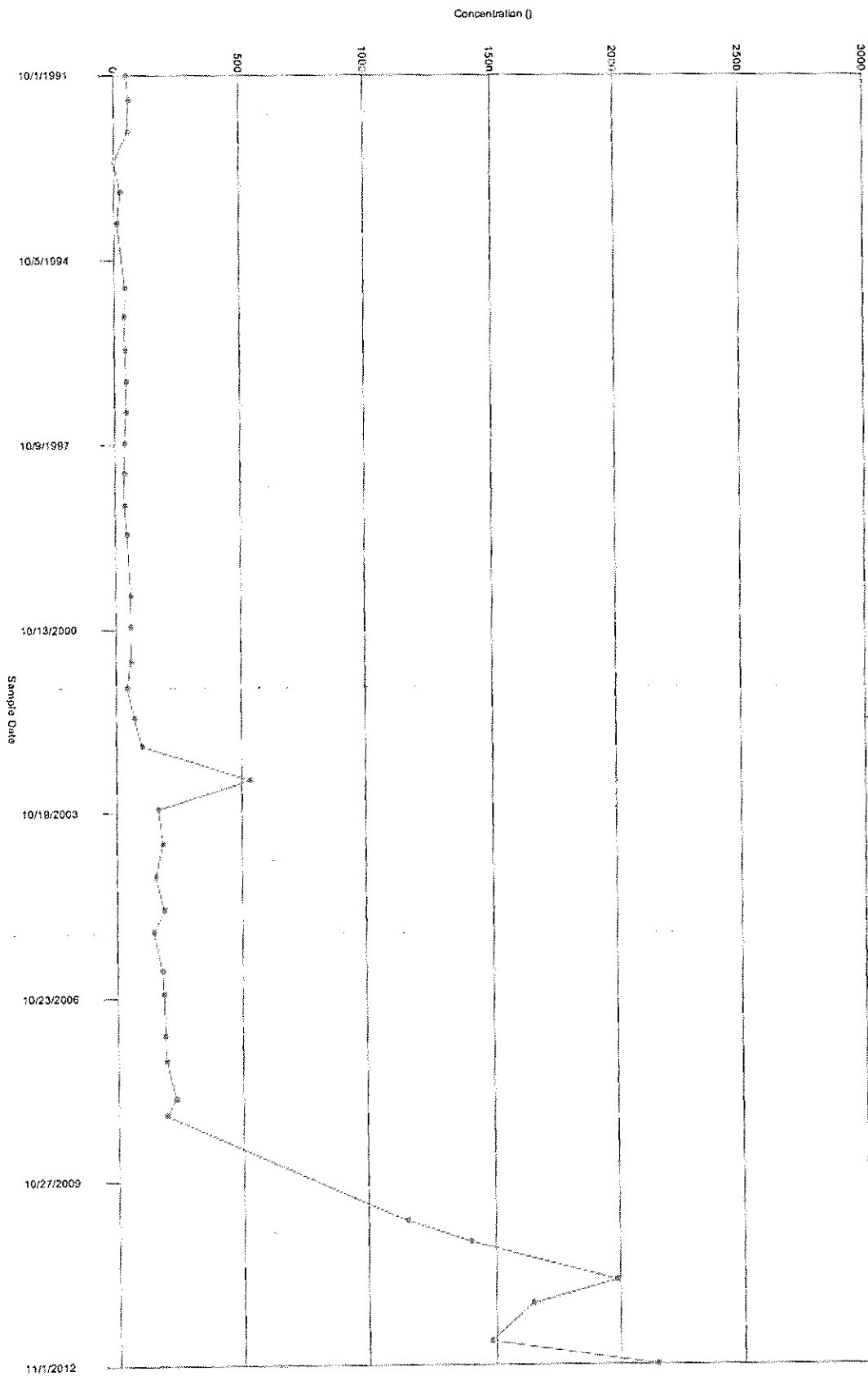
Specific Conductance
Time-Series Graph of MW-201



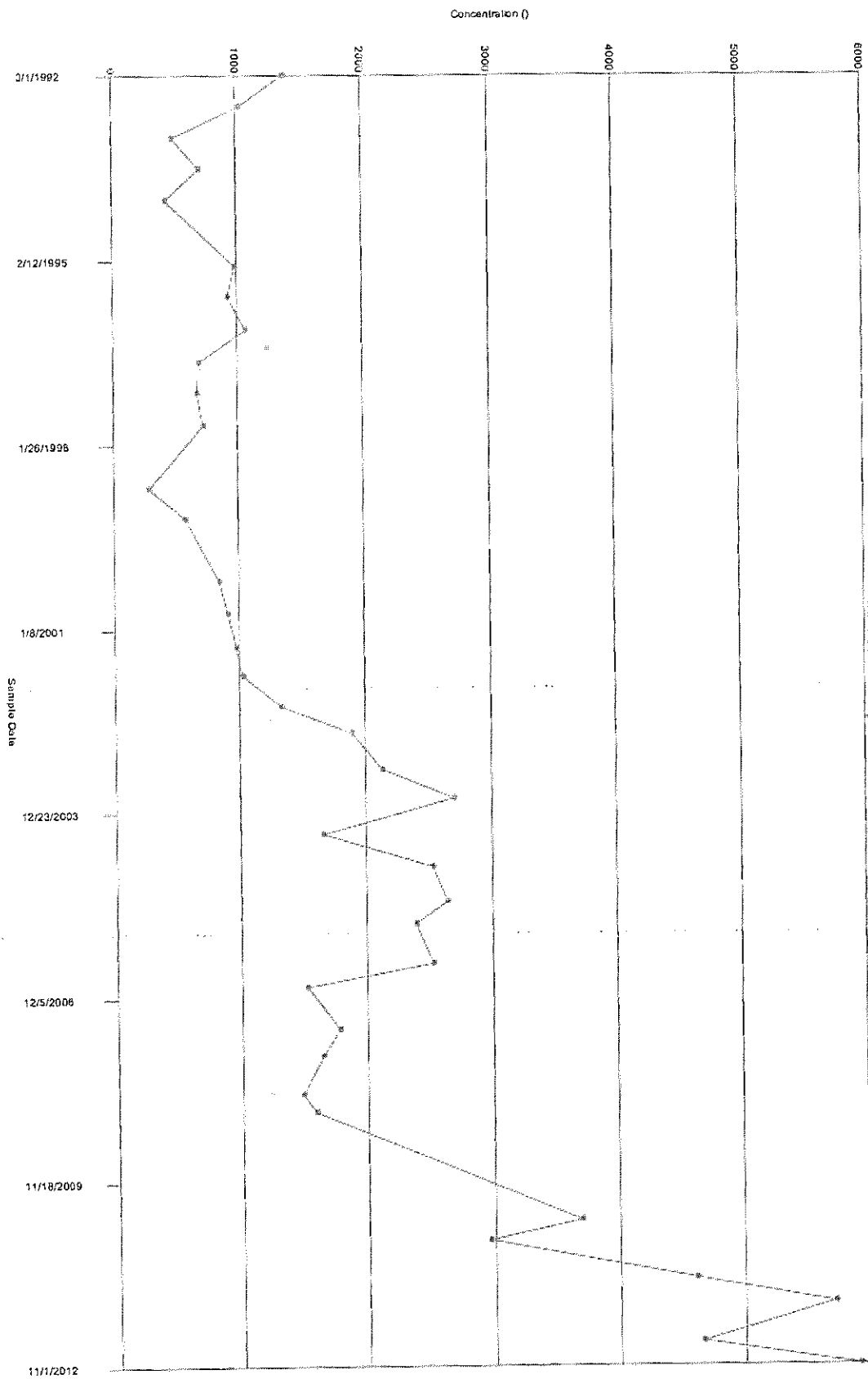
TDS
Time-Series Graph of MW-201



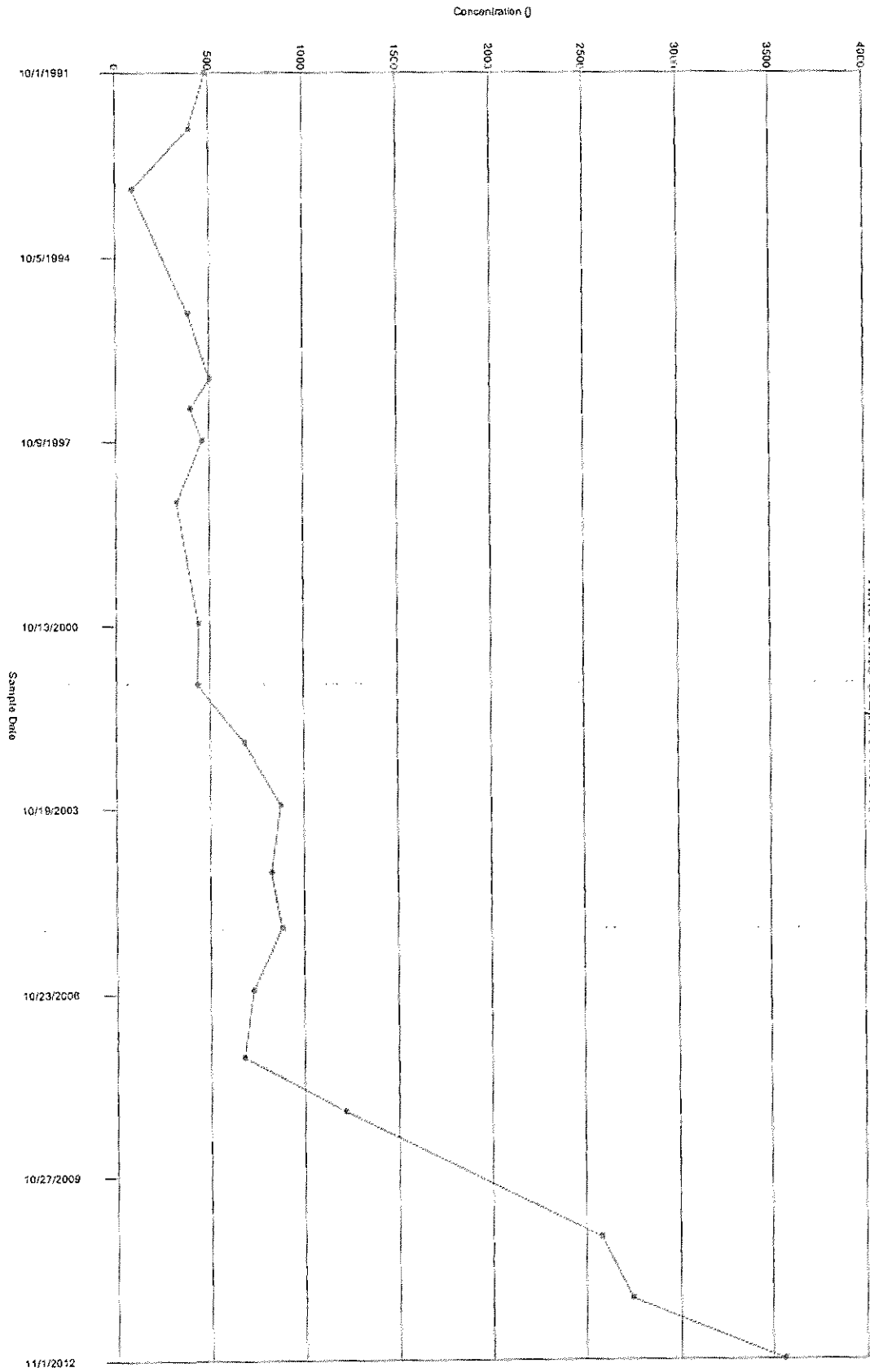
CHLORIDE Time-Series Graph of MW-101



Specific Conductance Time-Series Graph of MW-101



TDS
Time-Series Graph of MW-101



Appendix B

Data Inventory

[illegible]

Table B-1[illegible]

[illegible]

Table B-1

[illegible]

[illegible]

Table B-2[illegible]

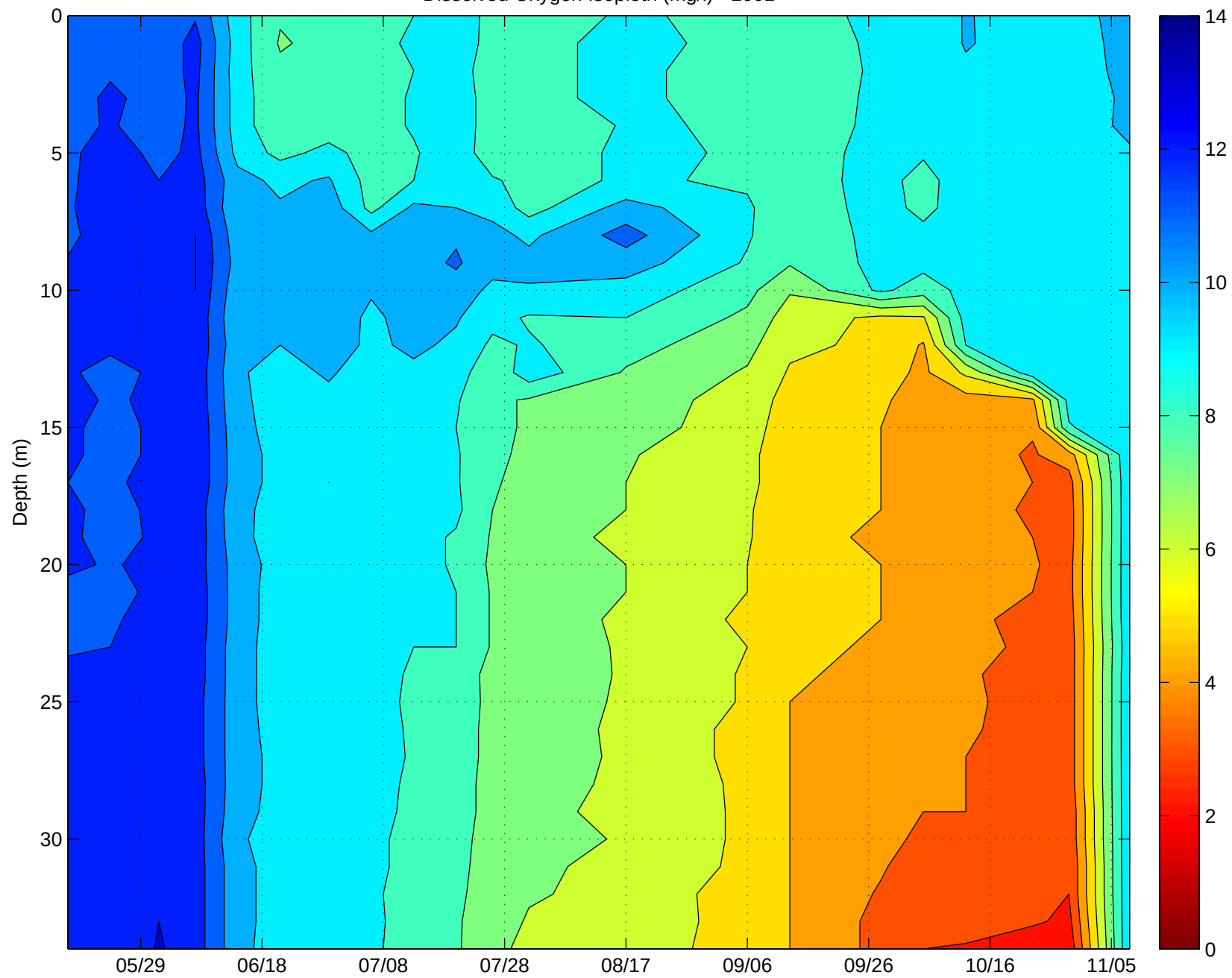
Table B-2

	pH																Temperature												Turbidity																
Sample Location	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012					
1 - OUTLET																																													
6 - NEAR SHORE - 2m									30	13	23	20	22	22	21	21					30	14	23	21	23	24	21	22					28	14	23	20	23	24	21	22					
7 - OFF BIRD ISLAND									18	12	23	20	22	24	21	19					18	14	23	21	23	24	21	20					16	14	23	21	23	24	21	20					
8 - DEEP HOLE - SURFACE					2				9	11	22	20	22	22	21	21	2	1			9	13	20	20	23	24	21	22	2				8	13	23	20	23	24	21	22					
8 - DEEP HOLE - 1m						1	4	1										1	4	1							1		1	3	1														
8 - DEEP HOLE - 3m					3	1	2	1									3		2	1								3		2	1														
8 - DEEP HOLE - 4m									29	12	4	4	6	4	6	6					28	14	5	4	6	6	6	8					28	14	5	3	6	6	6	8					
8 - DEEP HOLE - 5m					3	1	1										3	2	1								1	3	1																
8 - DEEP HOLE - 6m						1																																							
8 - DEEP HOLE - 8m									8	11	4	4	6	4	6	1					8	13	5	4	6	6	6	2					7	13	5	3	6	6	6	2					
8 - DEEP HOLE - 10m					3												3	1									1	3																	
8 - DEEP HOLE - 12m									8	11	4	4	6	4	6	1					8	13	5	4	6	6	6	2					7	13	5	3	6	6	6	2					
8 - DEEP HOLE - 15m					3		1										3	1	1								2	3		1															
8 - DEEP HOLE - 16m									8	11	4	4	6	4	6	1					8	13	5	4	6	6	6	2					7	13	5	3	6	6	6	2					
8 - DEEP HOLE - 20m					3				8	11	4	4	6	4	6	1	3	1			8	13	5	4	6	6	6	3	3					7	13	5	3	6	6	6	2				
8 - DEEP HOLE - 24m									8	11	4	4	6	4	6	1					8	13	5	4	6	6	6	2					7	13	5	3	6	6	6	2					
8 - DEEP HOLE - 25m					3												3	1									1	3																	
8 - DEEP HOLE - 28m									8	11	4	4	6	4	6	1					8	13	5	4	6	6	6	2					7	13	5	3	6	6	6	2					
8 - DEEP HOLE - 30m					3												3	1									1	3																	
8 - DEEP HOLE - 32m									8	11	4	4	6	4	6	1					8	13	5	4	6	6	6	2					7	13	5	3	6	6	6	2					
8 - DEEP HOLE - 33m																		1									1																		
8 - DEEP HOLE - 34m					3	1	4	1									3	1	4	1									3	1	4	1													
8 - DEEP HOLE - CORE							3	1		1												1									3	1		1											
8 - DEEP HOLE - CORE 9m										1	1											1	1										1	1											
8 - DEEP HOLE - CORE 10m																											1																		
8 - DEEP HOLE - CORE 15m																											1																		
9 - SURFACE									18	12	23	20	22	22	21	21					18	14	23	21	23	24	21	22					16	14	23	20	23	24	21	22					
9 - 4m									20	11	5	4	6	4	6	1					20	13	5	4	6	6	6	2					19	13	5	3	6	6	6	2					
9 - 12m									8	11	5	4	6	4	6	1					8	13	5	4	6	6	6	2					7	13	5	3	6	6	6	2					
9 - 16m																					1												1												
9 - 21m									7	11	5	4	6	4	6	1					7	13	5	4	6	6	6	2					6	13	5	3	6	6	6	2					
10 - STANDBY INTAKE											23	20	22	22	21	21							23	21	23	24	21	22							23	20	23	24	21	22					
10 - STANDBY INTAKE - 3m									30	13											30	14											28	14											
11 - SURFACE									18	12	23	20	22	22	6	21					18	14	23	21	23	24	6	22					16	14	23	20	23	24	6	22					
11 - 4m									20	11	5	4	6	4	6	1					20	13	5	4	6	6	6	2					19	13	5	3	6	6	6	2					
11 - 12m									8	11	5	4	6	4	21	1					8	13	5	4	6	6	21	2					7	13	5	3	6	6	21	2					
11 - 16m									7	11	5	4	6	4	6	1					7	13	5	4	6	6	6	2					6	13	5	3	6	6	6	2					
11 - 21m									1												1												1												
12 - CURRENT INTAKE - 4m									30	12	23	20	22	21	20	25					30	13	23	21	23	23	20	26					29	12	23	21	23	23	20	26					
12 - CURRENT INTAKE - CORE 4m																2											3																2		
29 - NORTH END																1											1																1		
29 - NORTH END - CORE 9m																1											3																1		
30 - CORE 9m																1											3																1		
31 - CORE 10m																											1																		
31 - CORE 11m																1											1																1		
31 - CORE 15m																											1																		
32 - CORE 10m																											1																		
32 - CORE 11m																1											1																1		
32 - CORE 15m																											1																		
SALMON POINT										12	23	20	22	23	21	21						14	23	21	23	24	21	22						14	23	21	23	24	21	22					
Raw Water Quality - Unknown Location	36	36	36	36	36	36	36	36	36	36	36	36	36	36	15																														

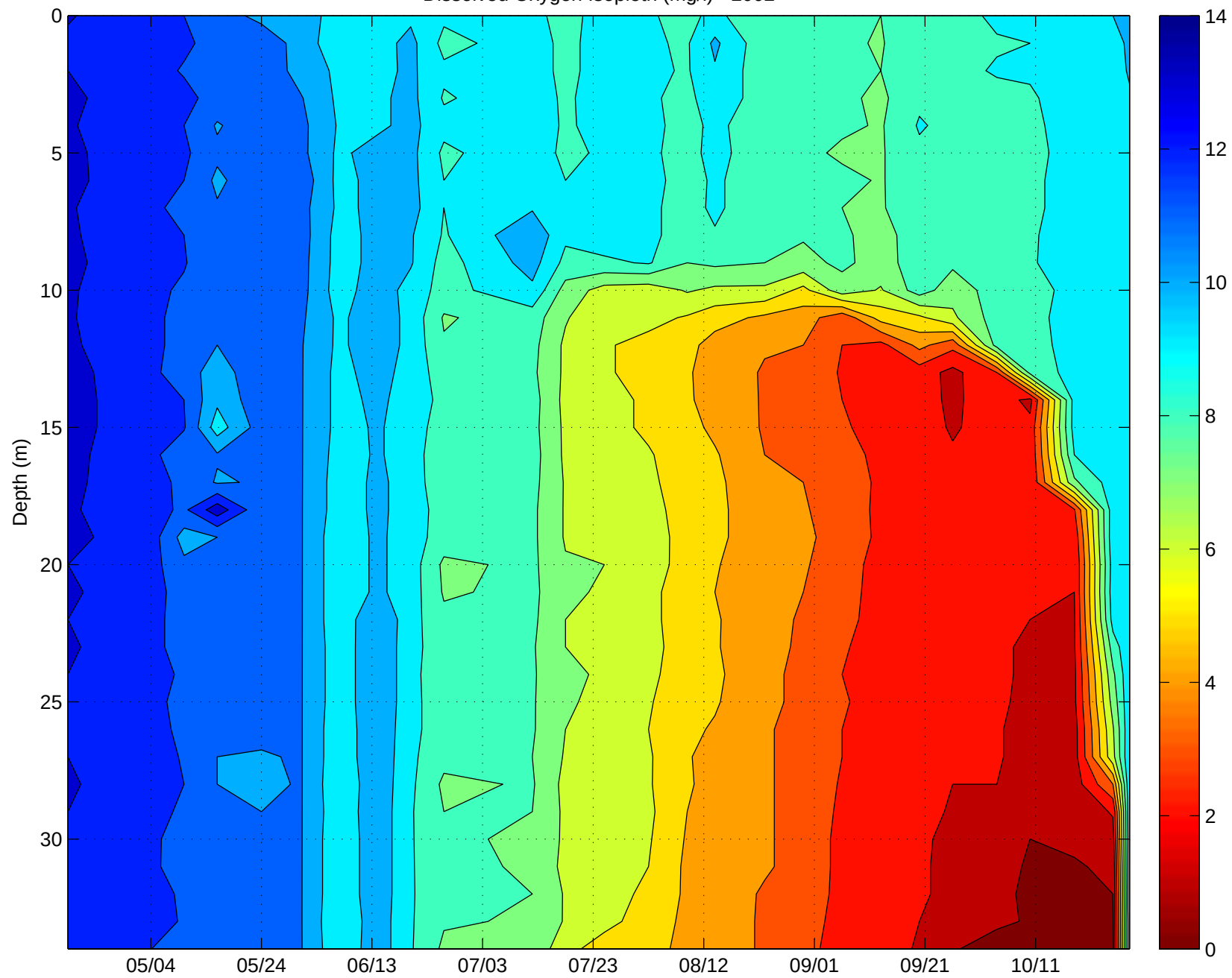
Appendix C

Temperature and Dissolved Oxygen Isopleths

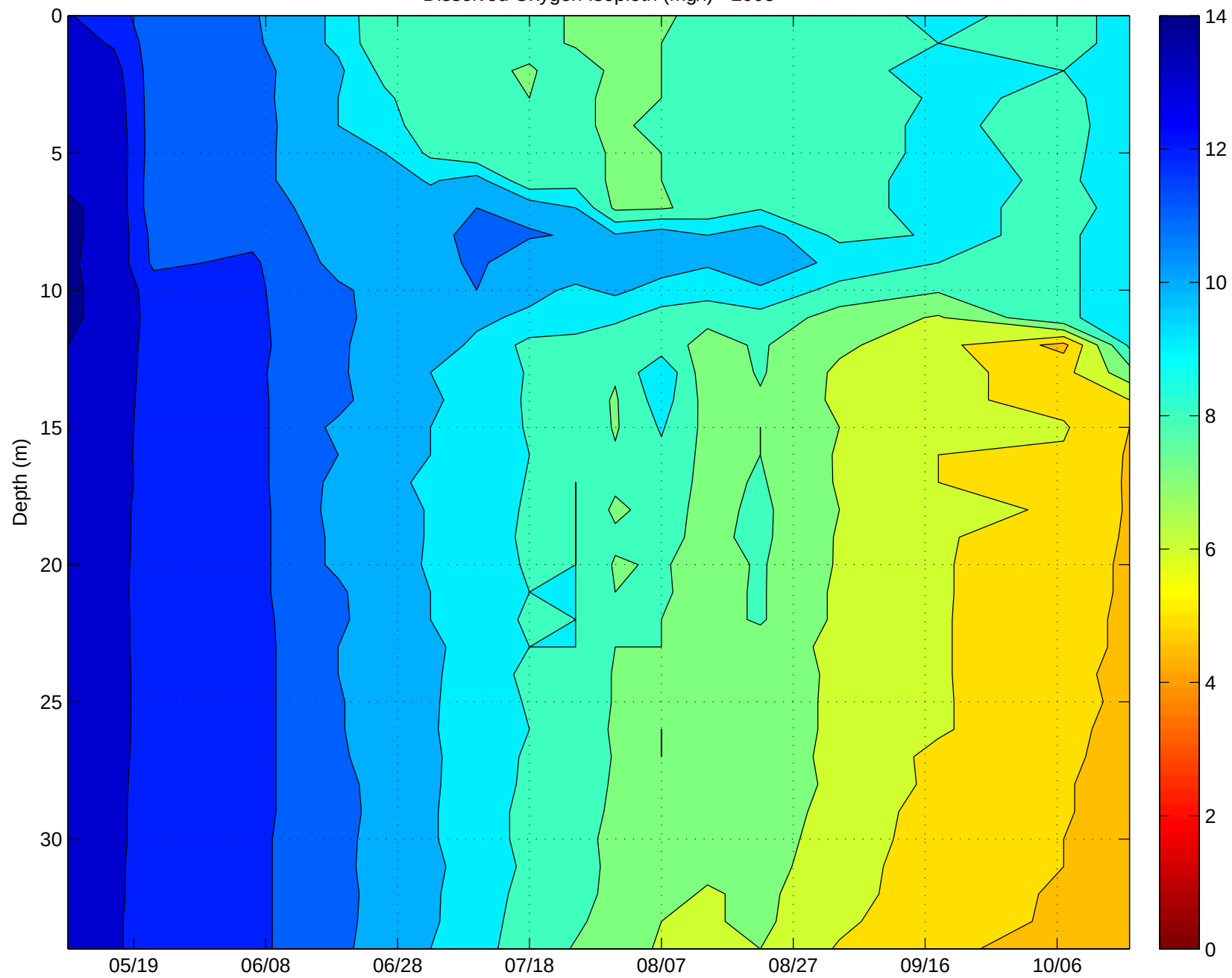
Dissolved Oxygen Isopleth (mg/l) - 2001



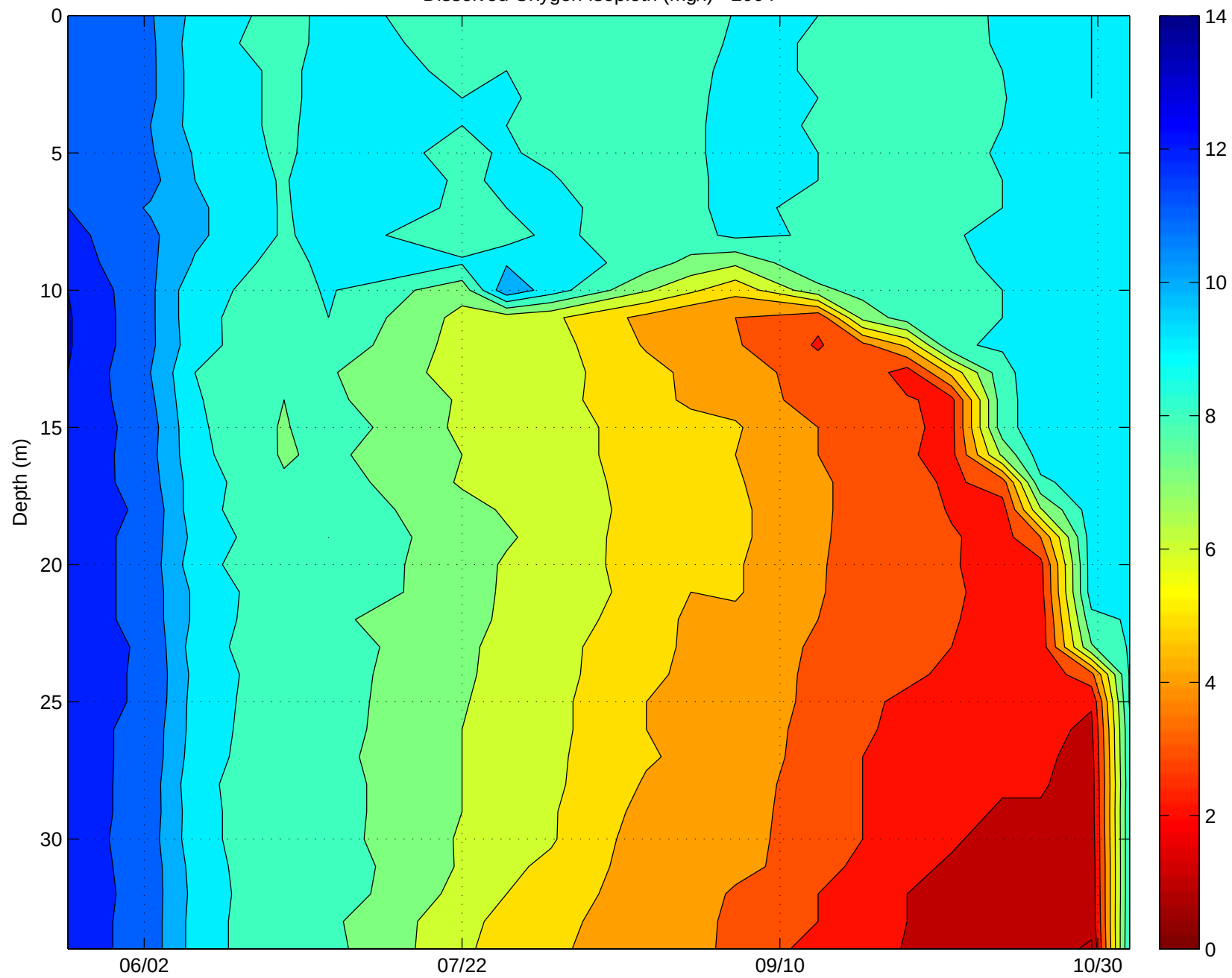
Dissolved Oxygen Isopleth (mg/l) - 2002



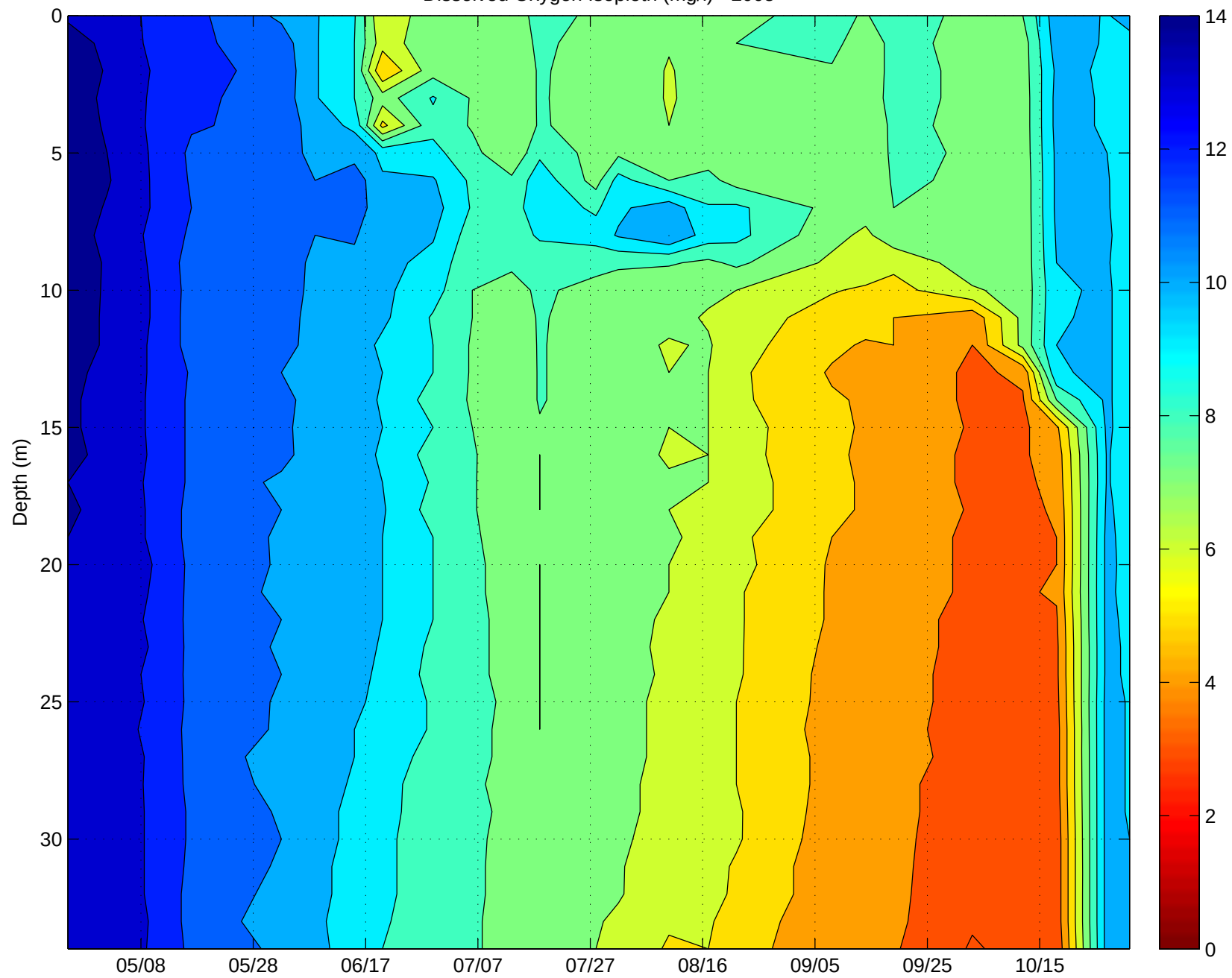
Dissolved Oxygen Isopleth (mg/l) - 2003



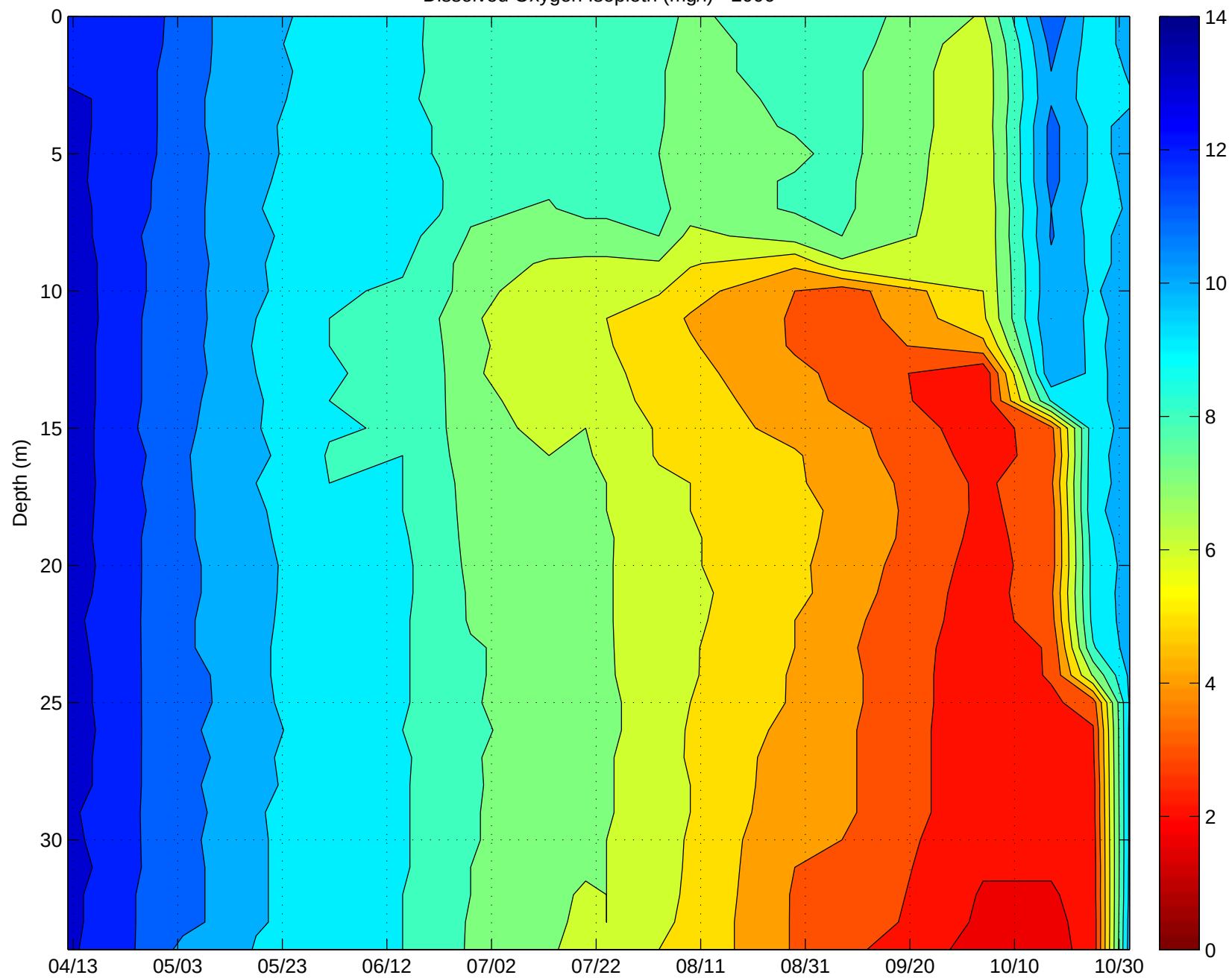
Dissolved Oxygen Isopleth (mg/l) - 2004



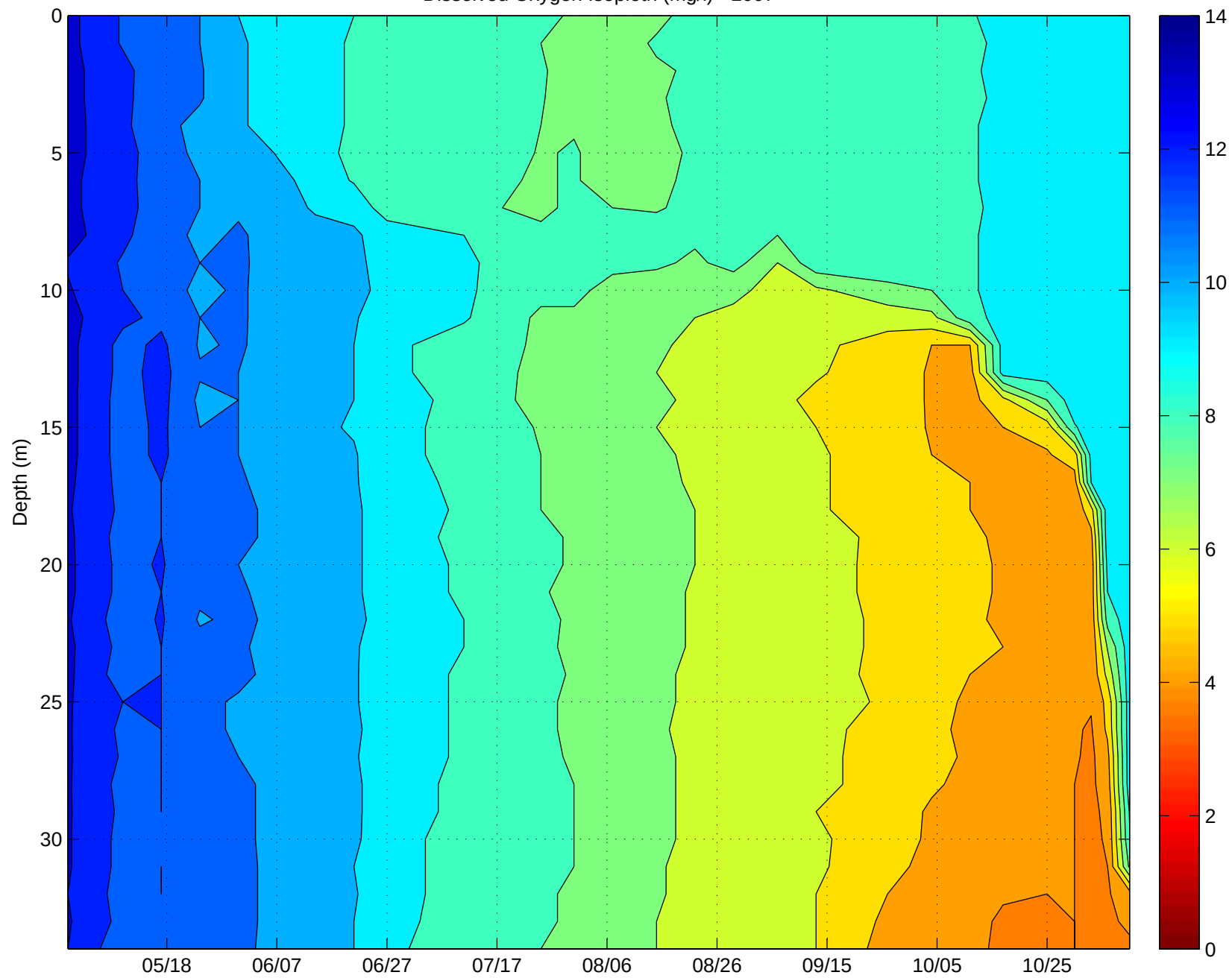
Dissolved Oxygen Isopleth (mg/l) - 2005



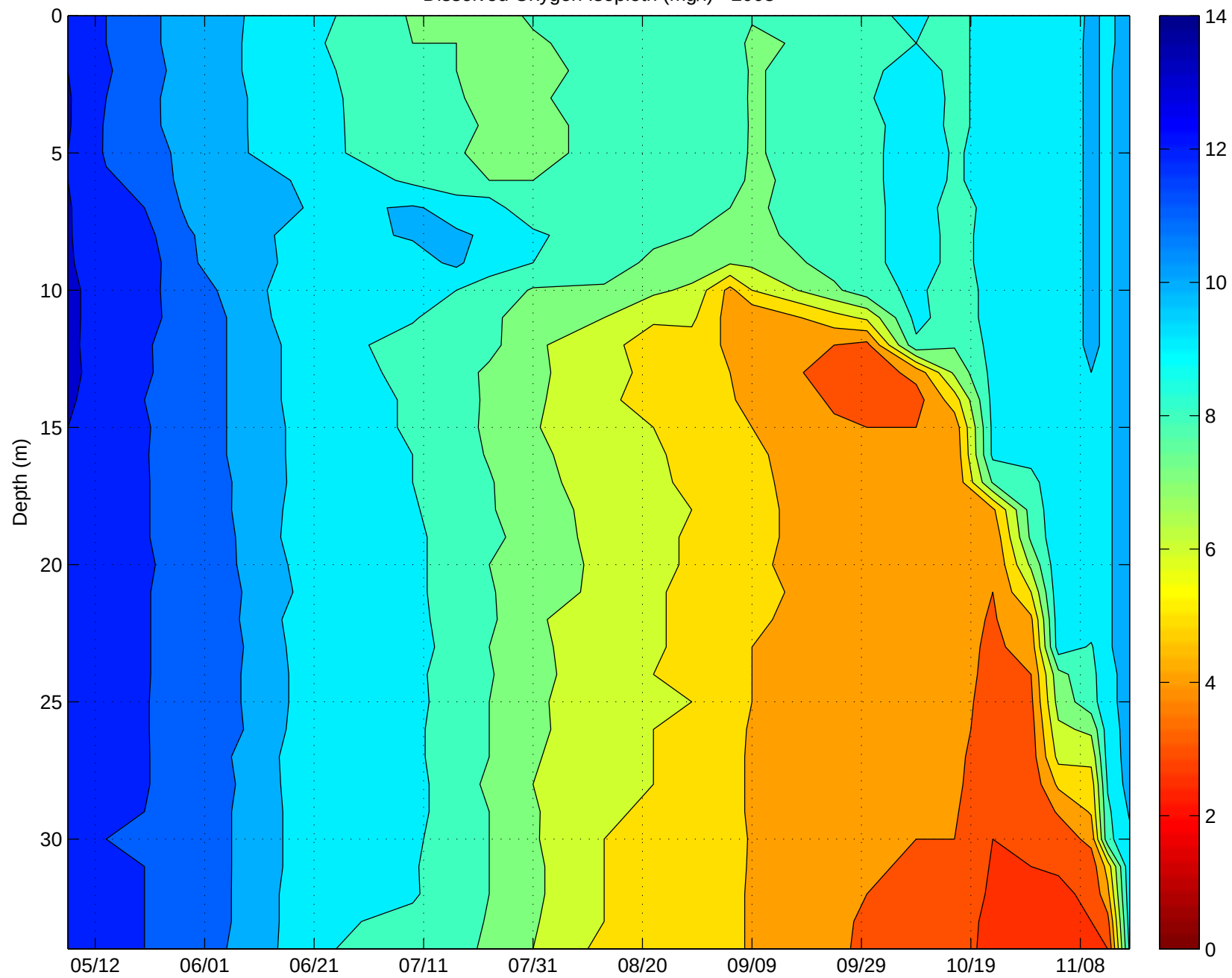
Dissolved Oxygen Isopleth (mg/l) - 2006



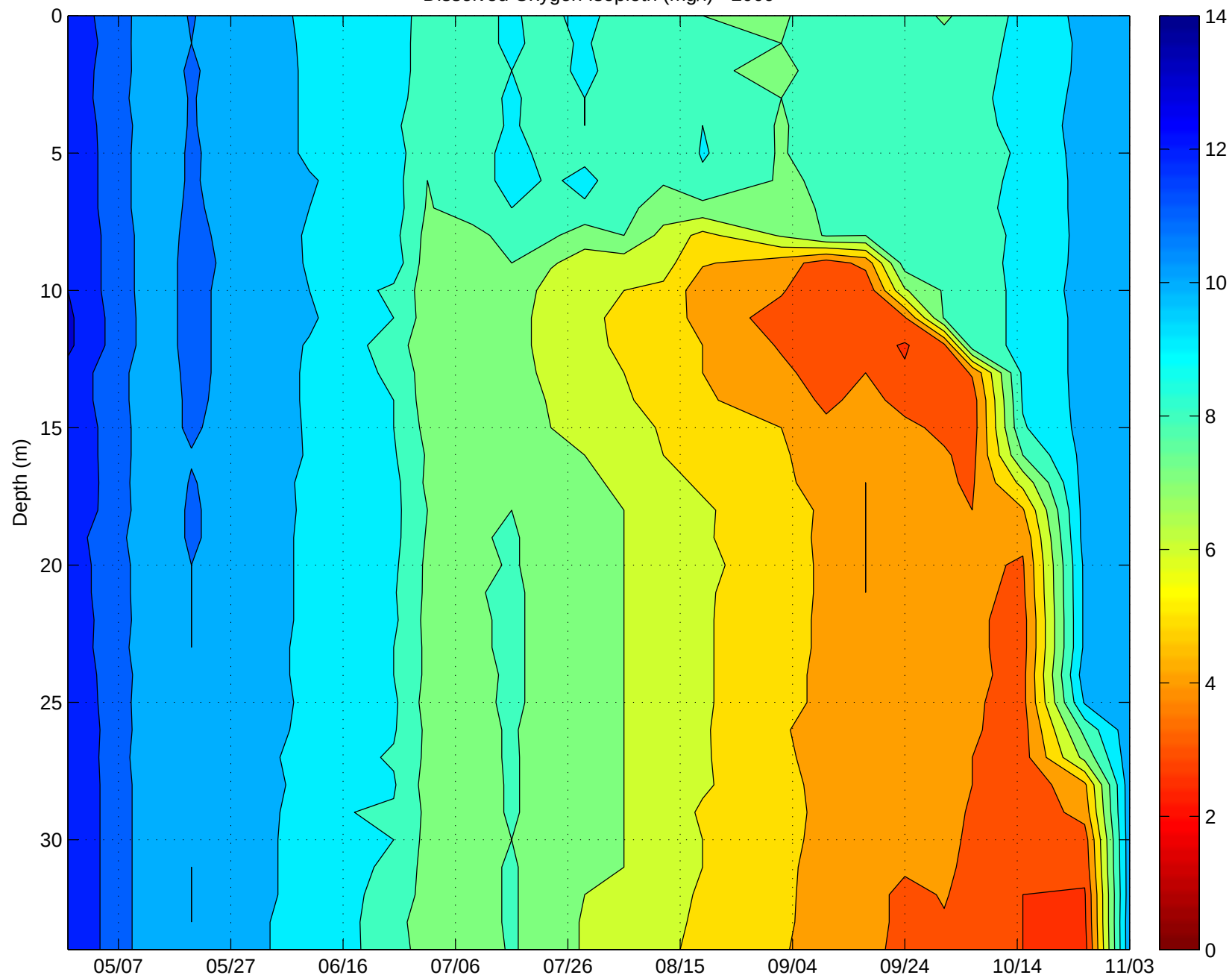
Dissolved Oxygen Isopleth (mg/l) - 2007



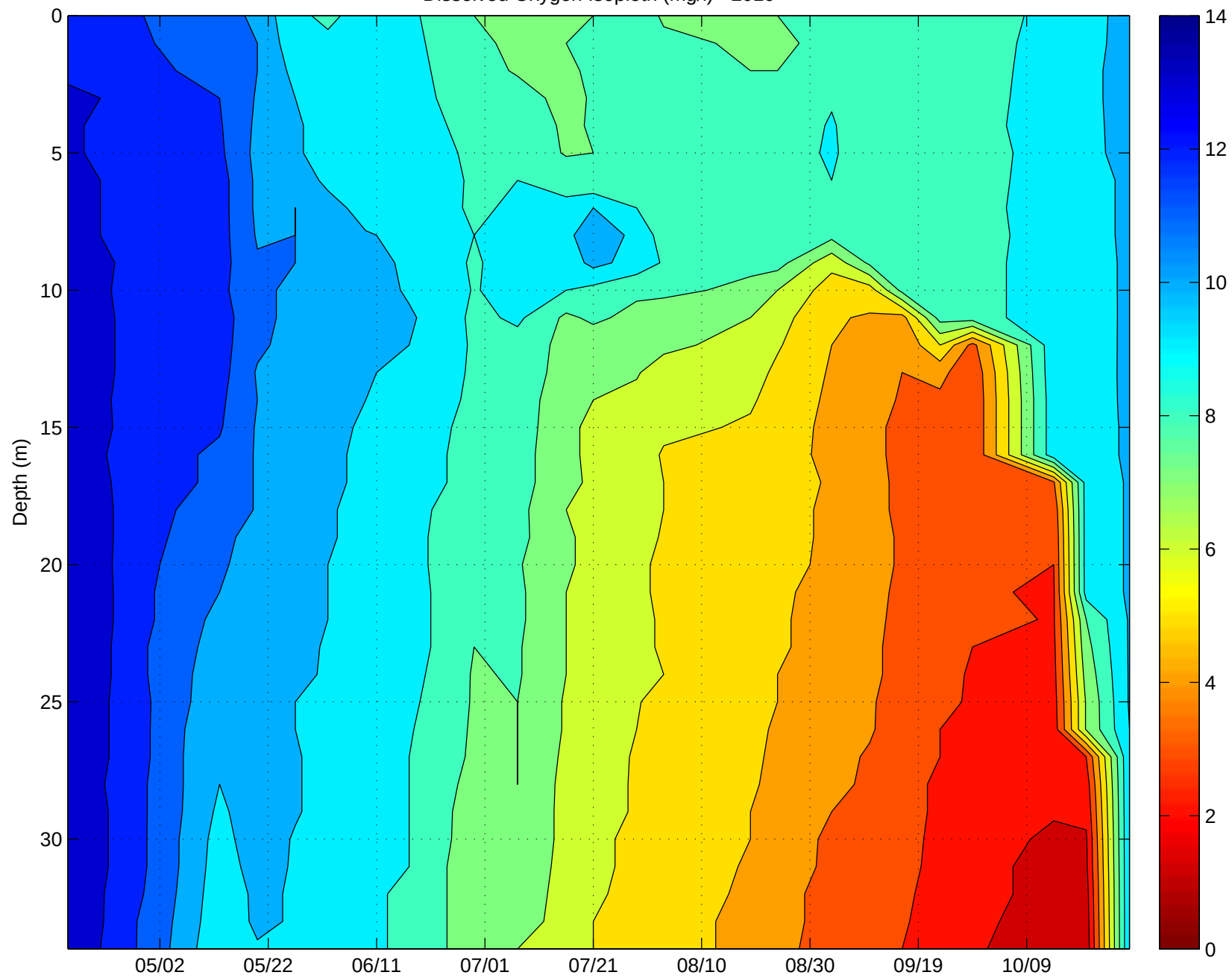
Dissolved Oxygen Isopleth (mg/l) - 2008



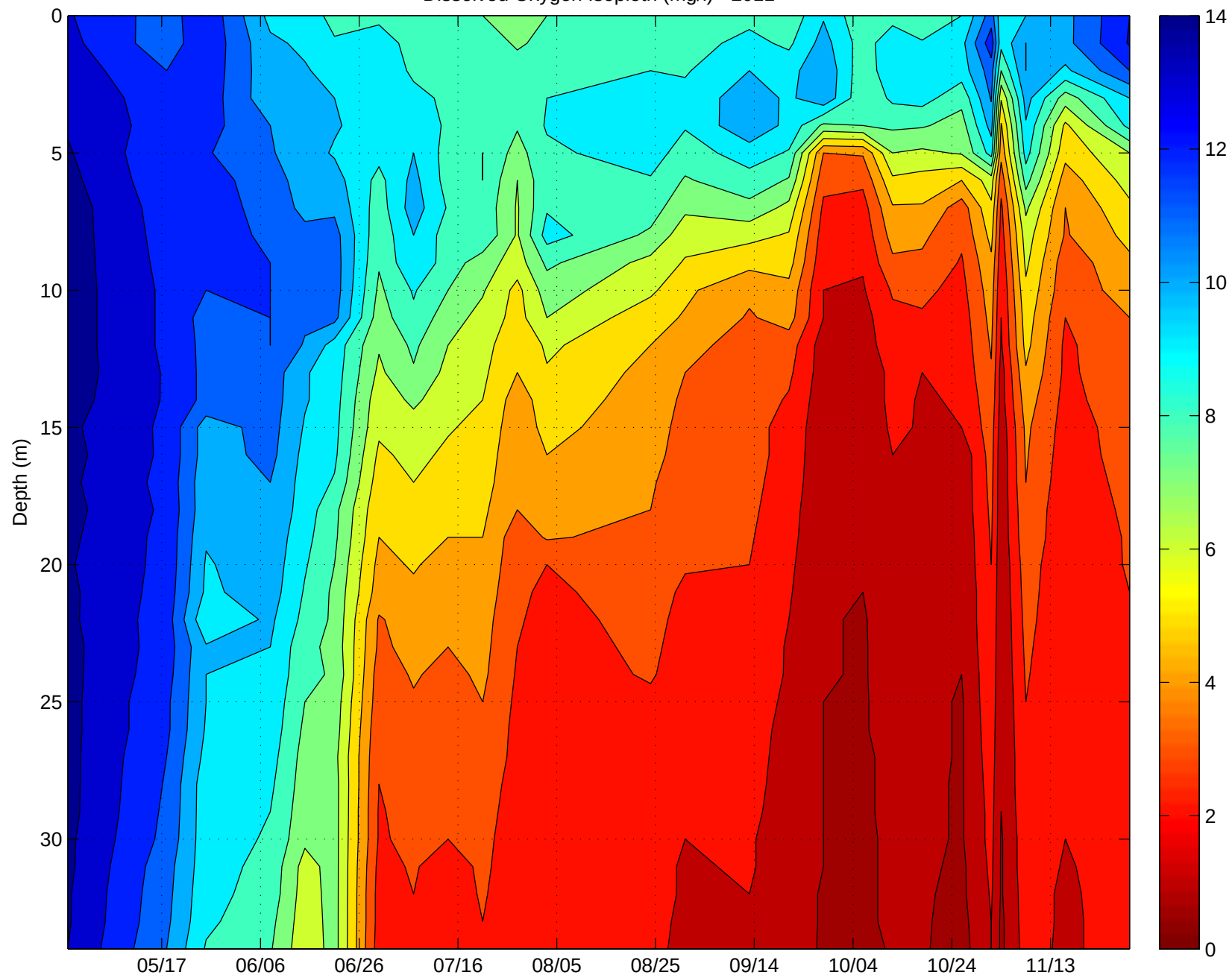
Dissolved Oxygen Isopleth (mg/l) - 2009



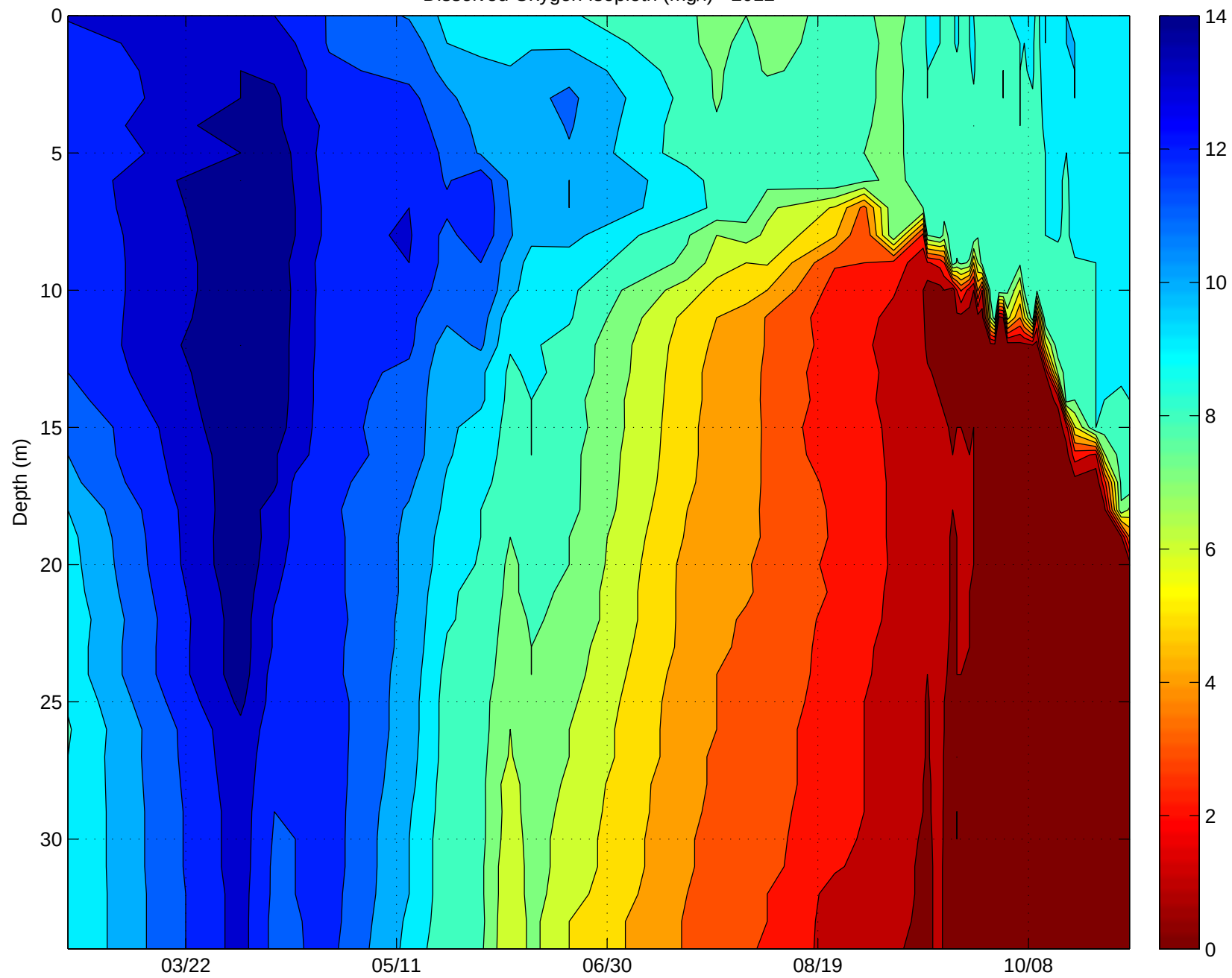
Dissolved Oxygen Isopleth (mg/l) - 2010



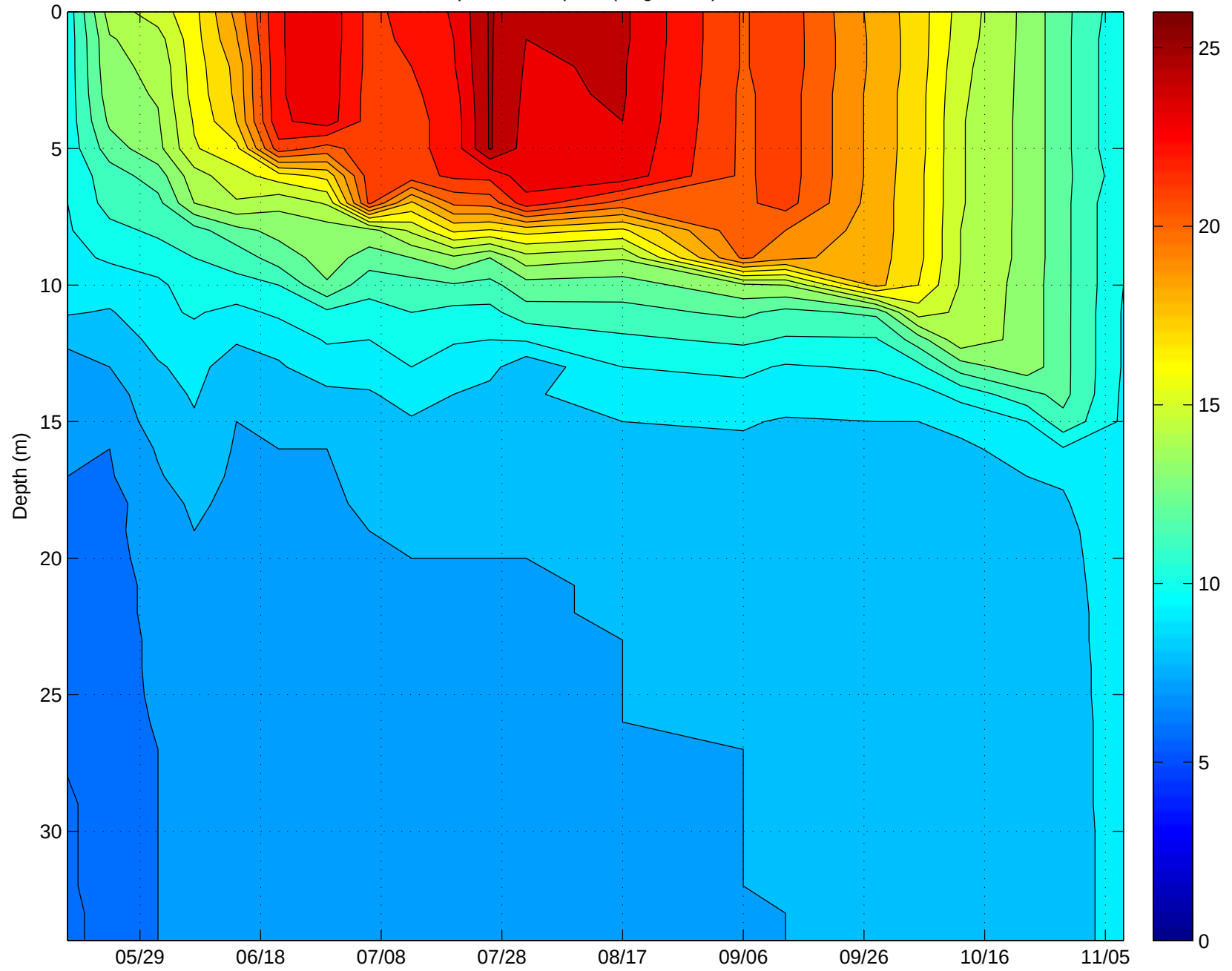
Dissolved Oxygen Isopleth (mg/l) - 2011



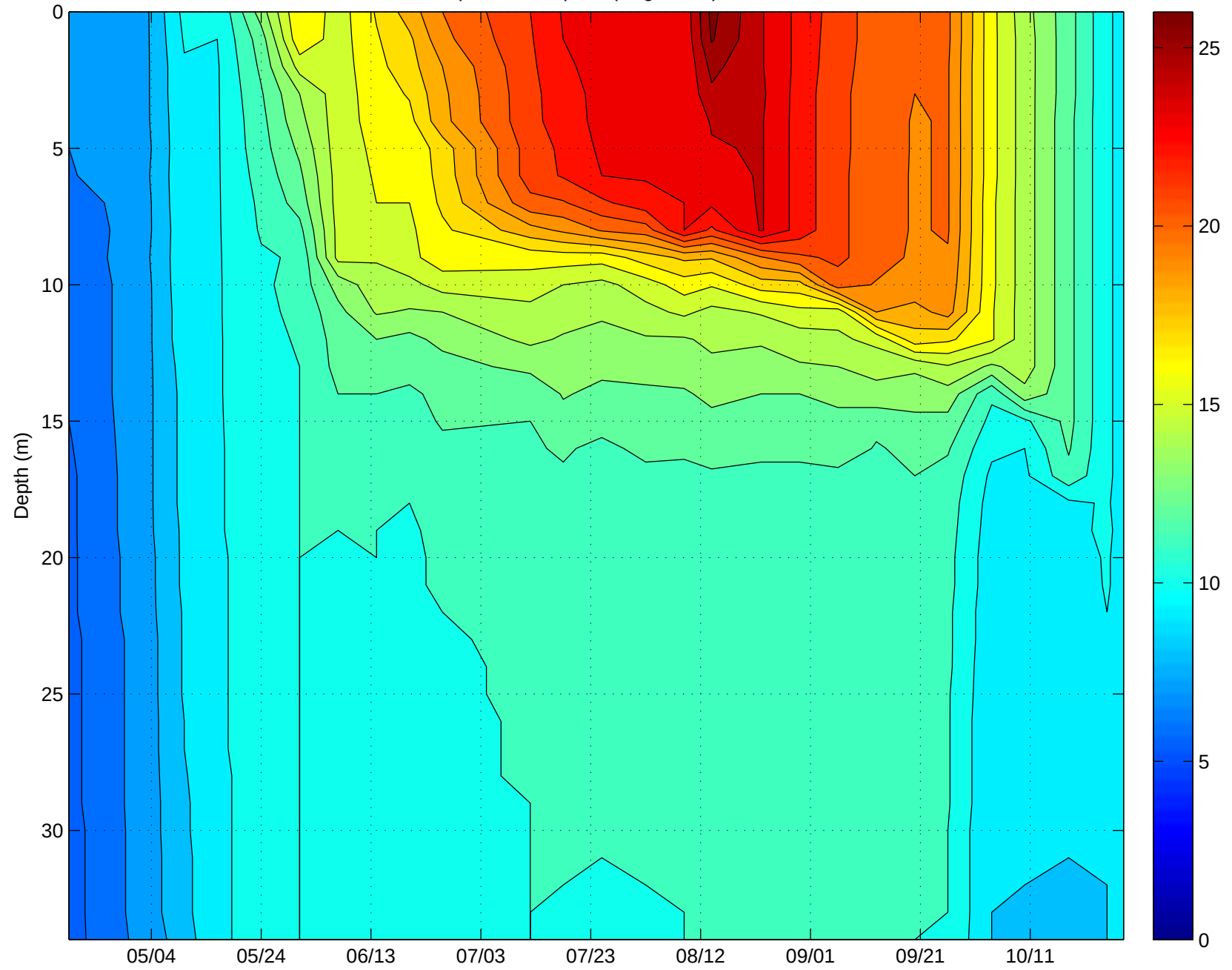
Dissolved Oxygen Isopleth (mg/l) - 2012

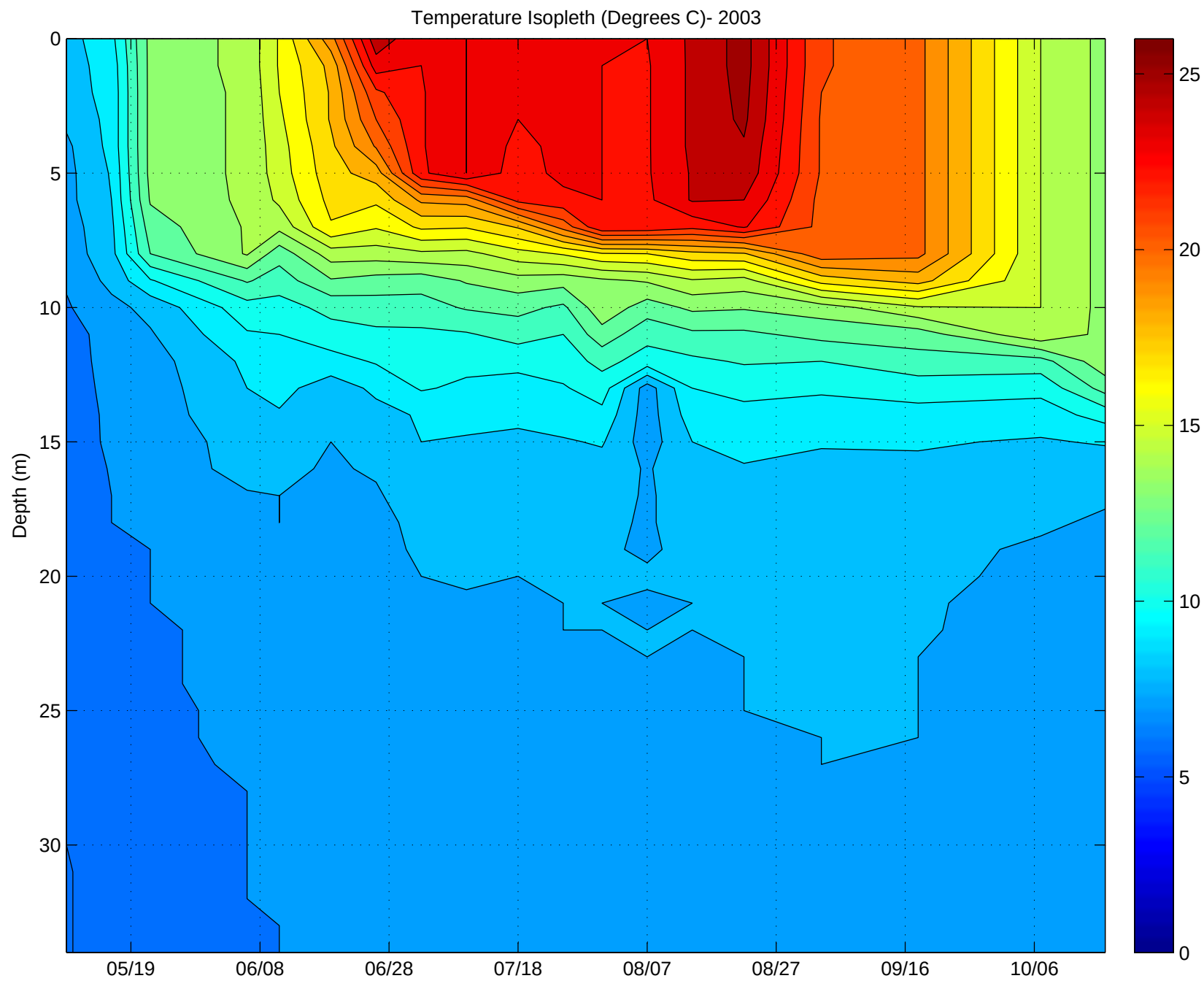


Temperature Isopleth (Degrees C)- 2001

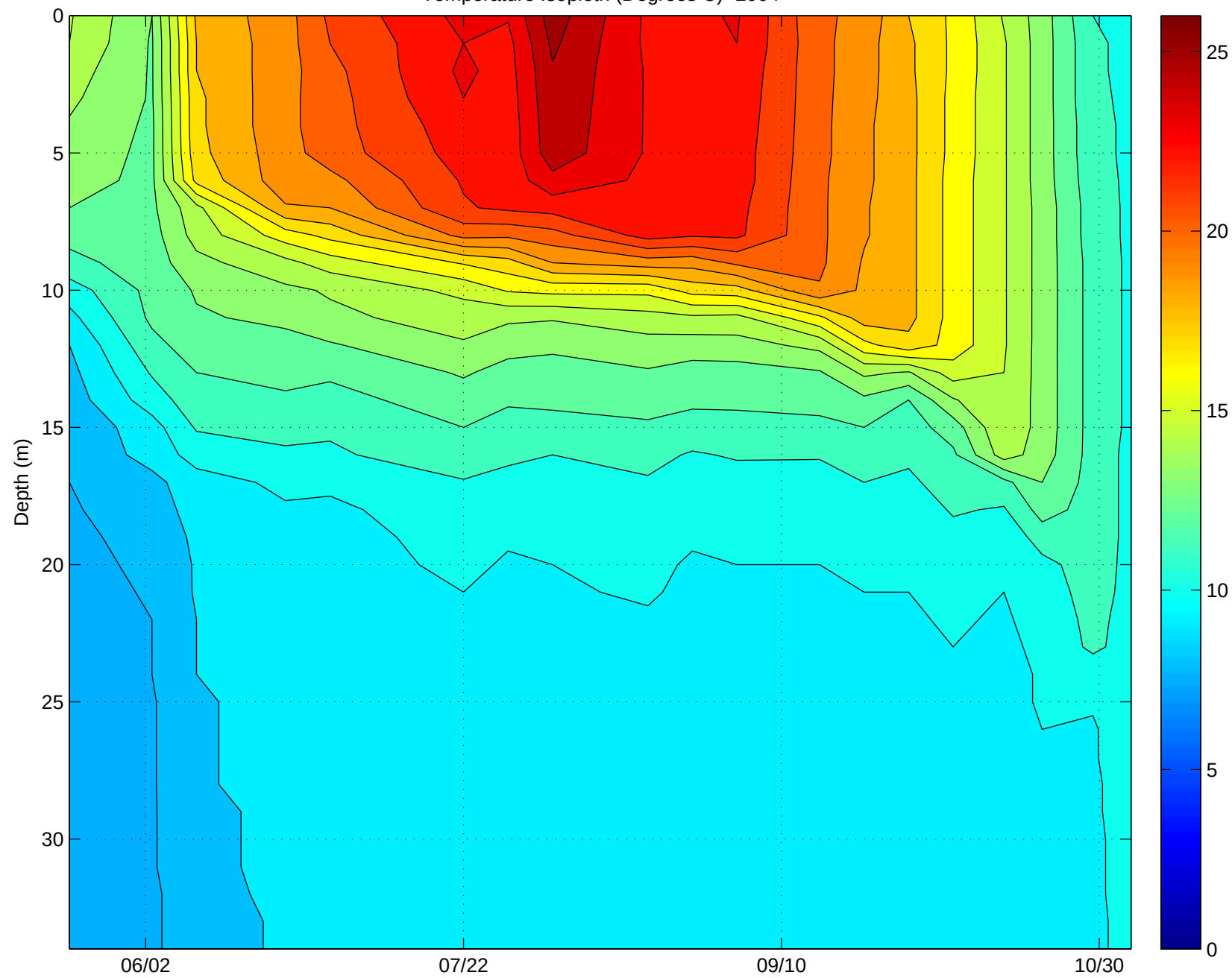


Temperature Isopleth (Degrees C)- 2002

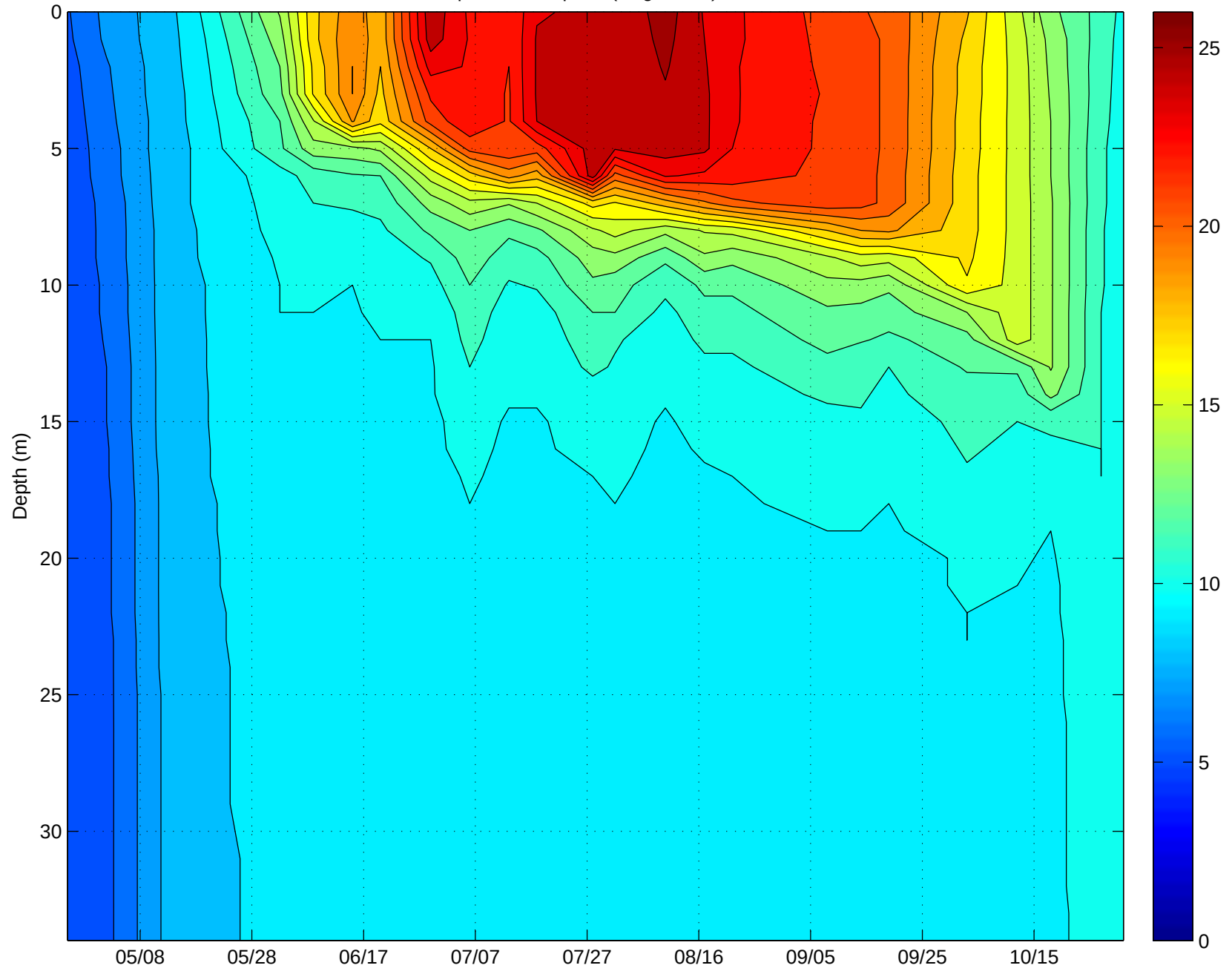




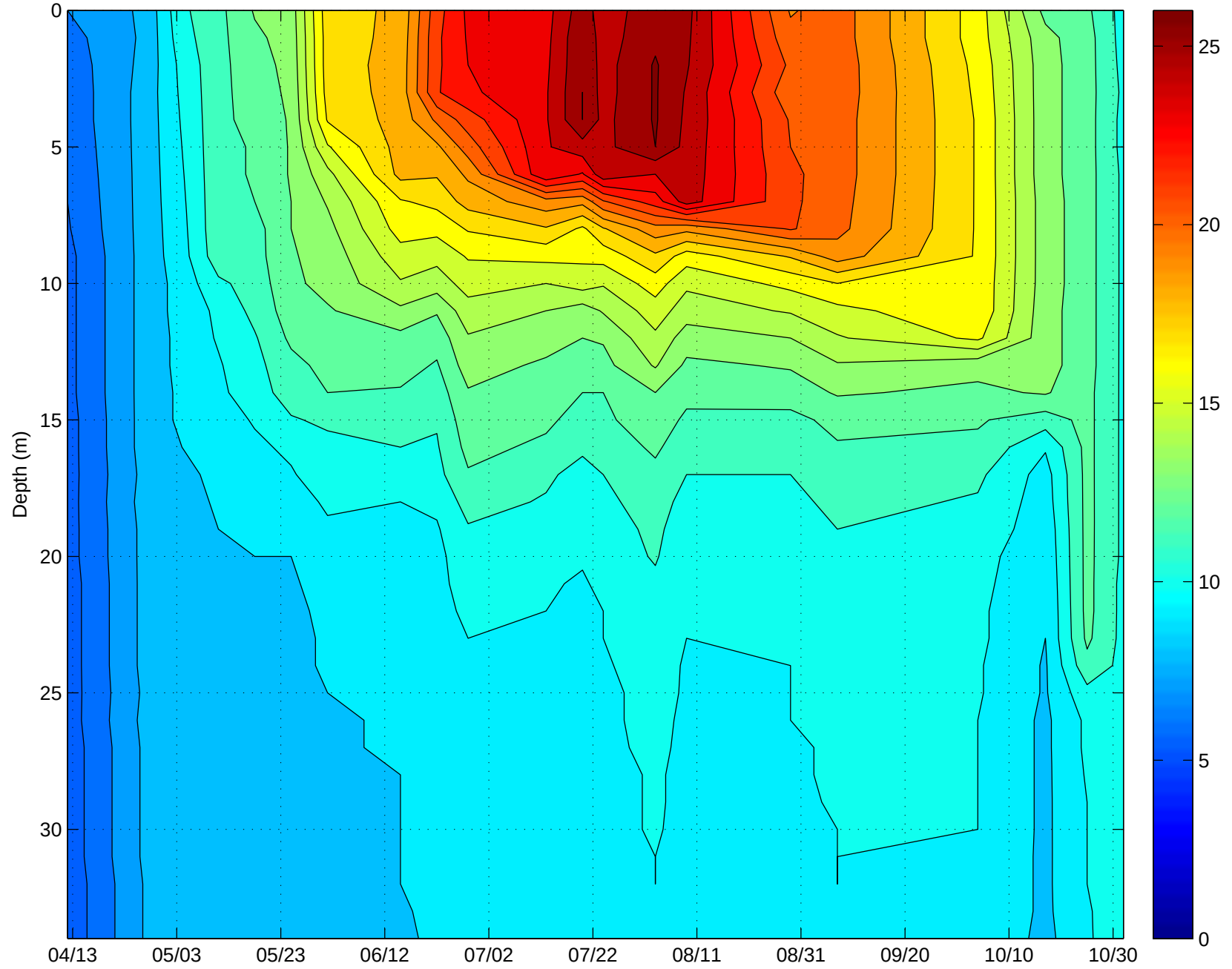
Temperature Isopleth (Degrees C)- 2004



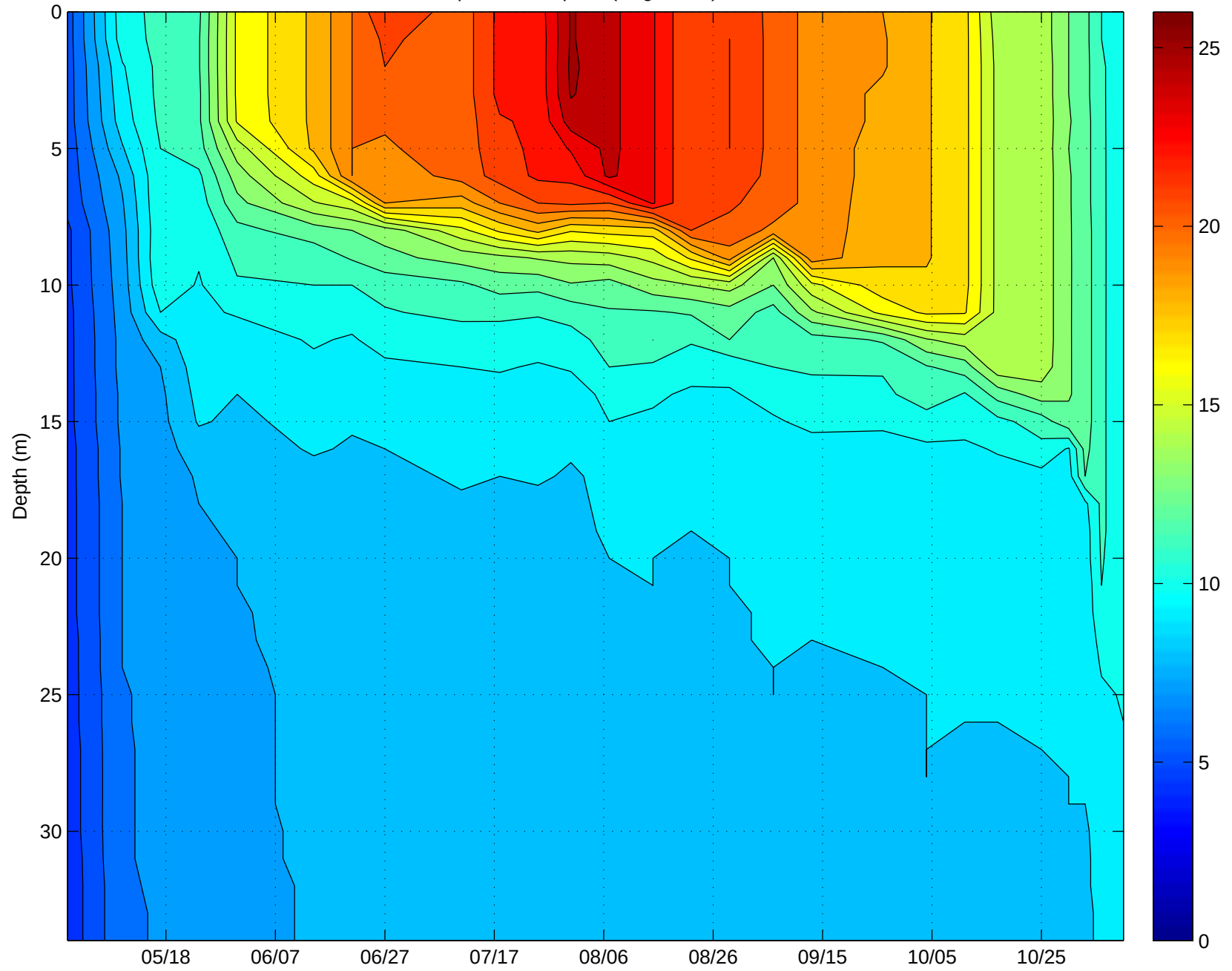
Temperature Isopleth (Degrees C)- 2005



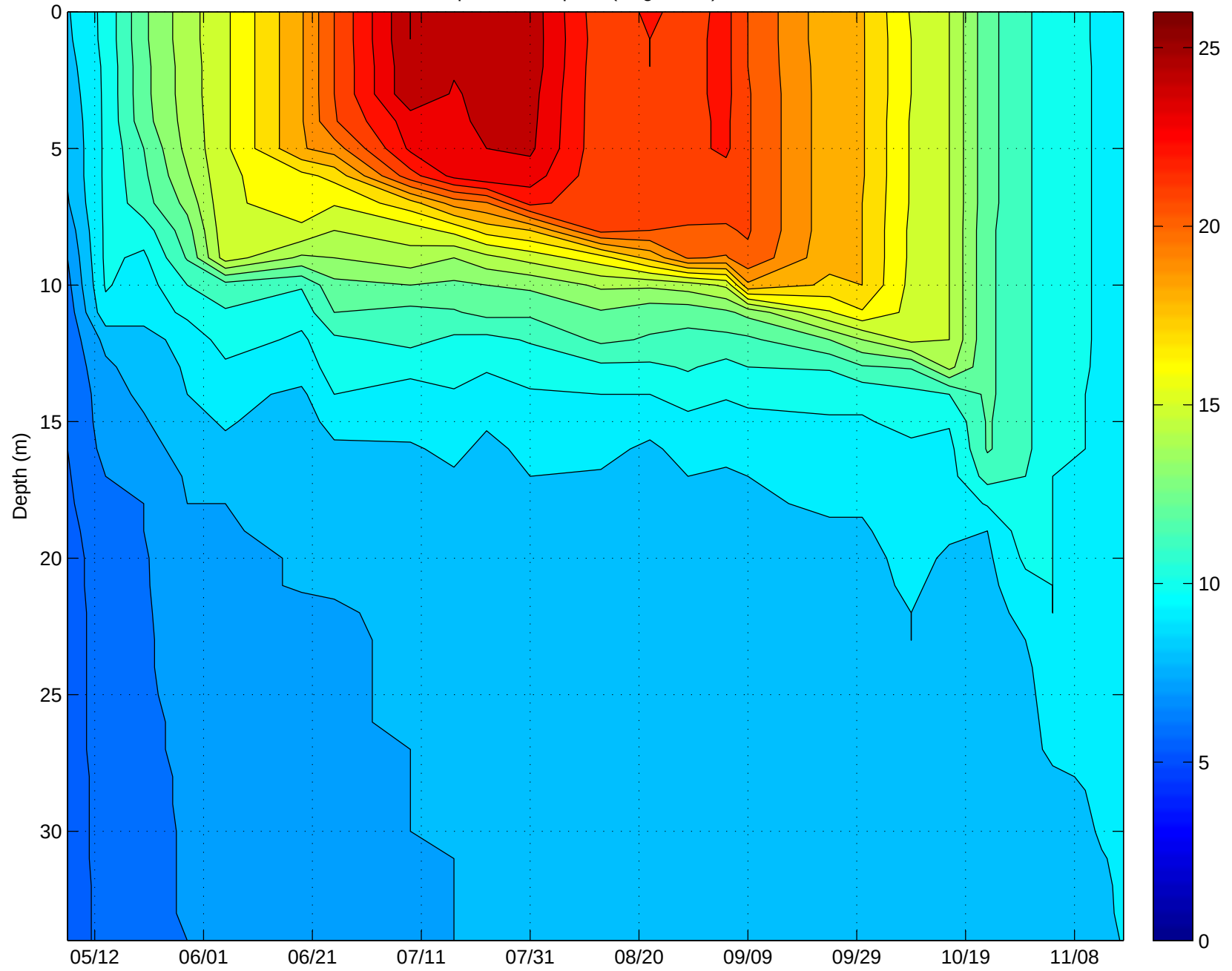
Temperature Isopleth (Degrees C)- 2006



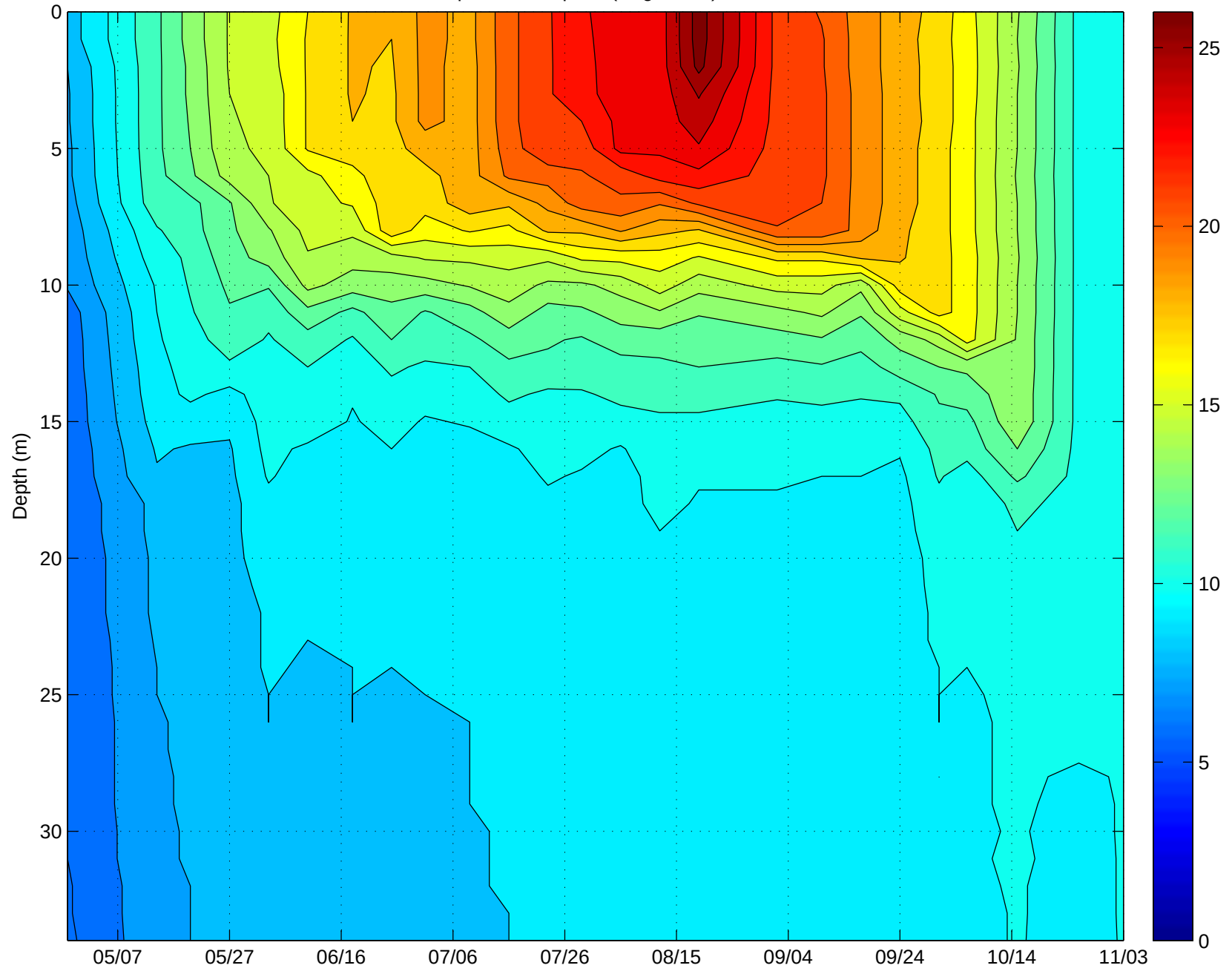
Temperature Isopleth (Degrees C)- 2007

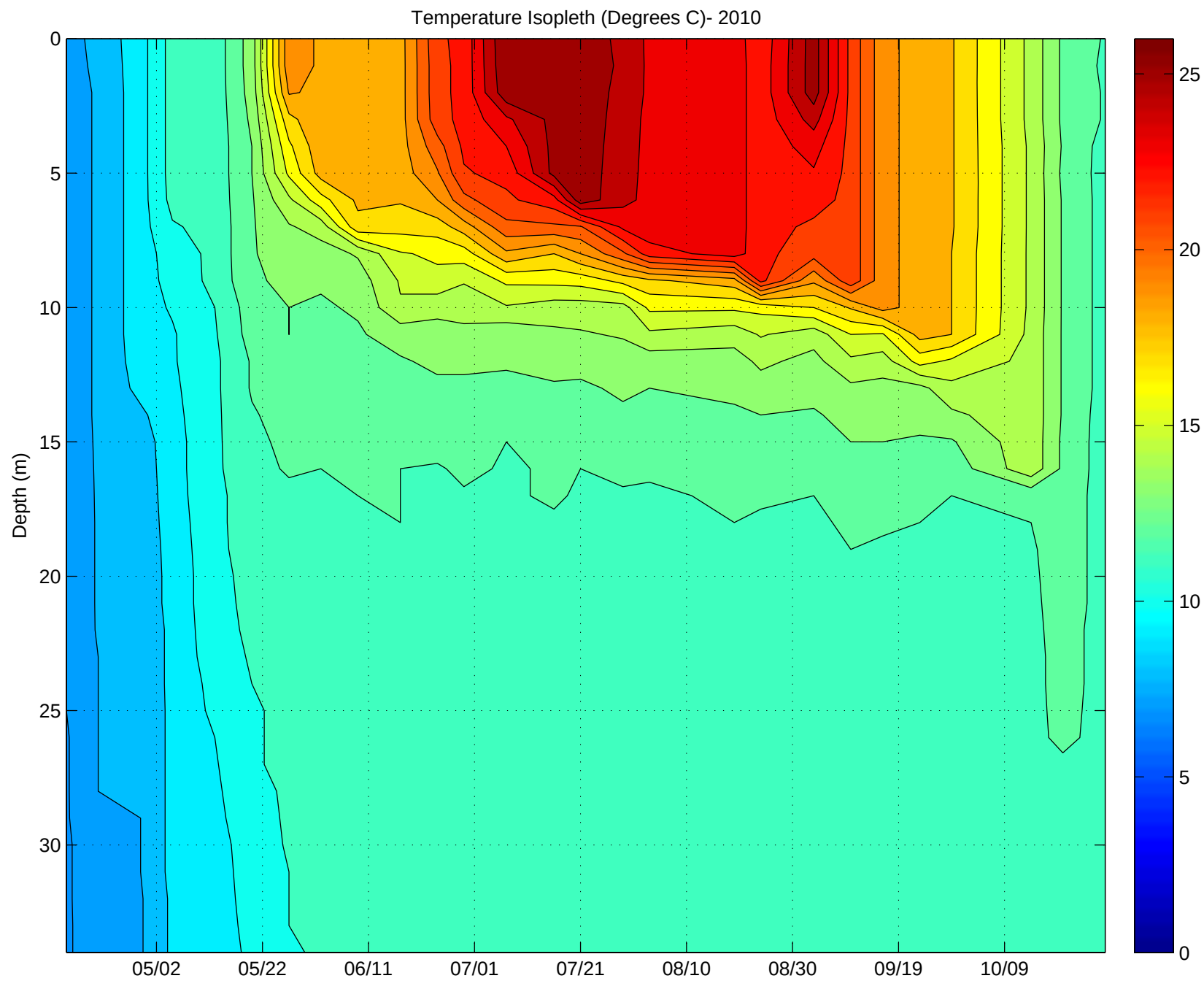


Temperature Isopleth (Degrees C)- 2008

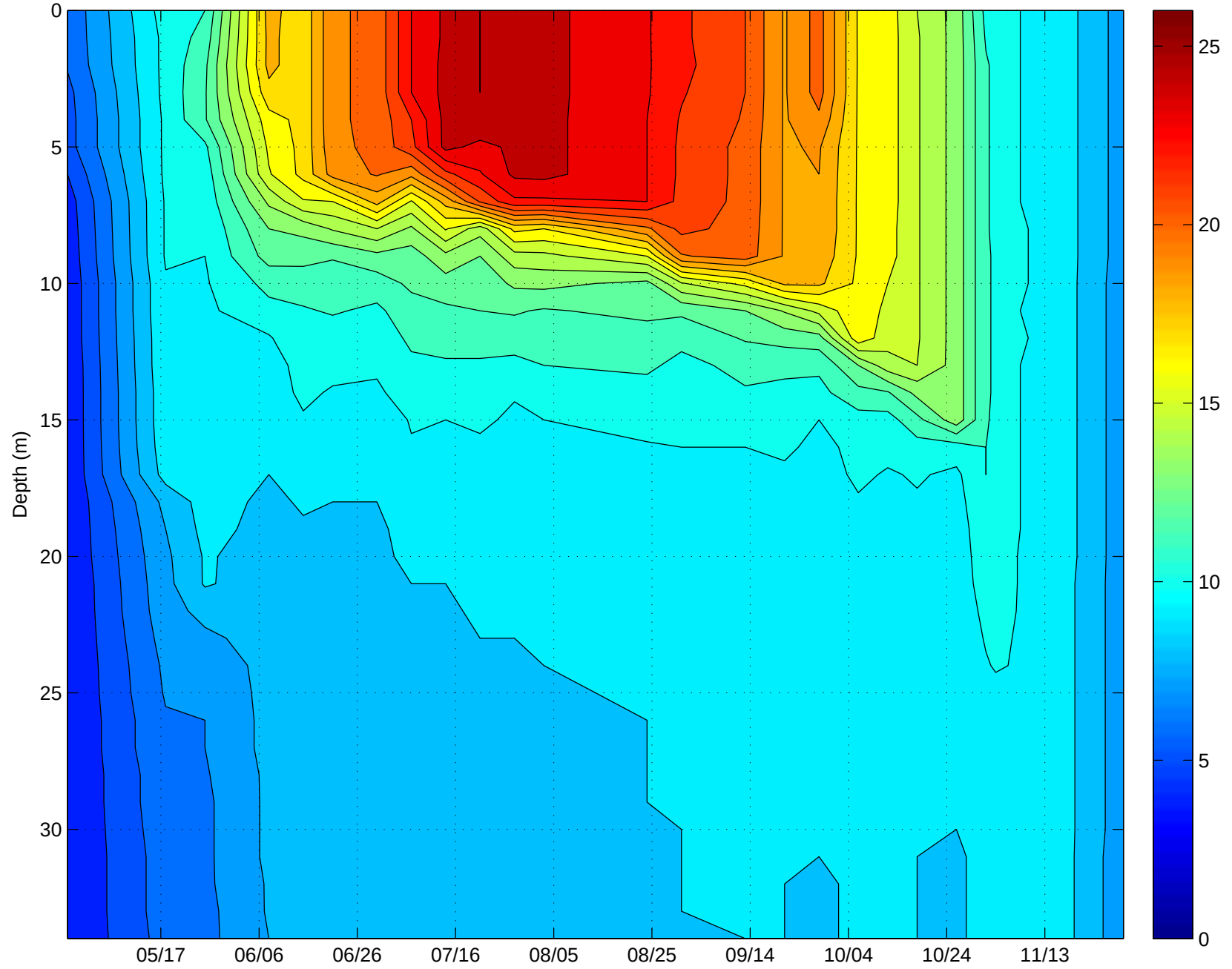


Temperature Isopleth (Degrees C)- 2009

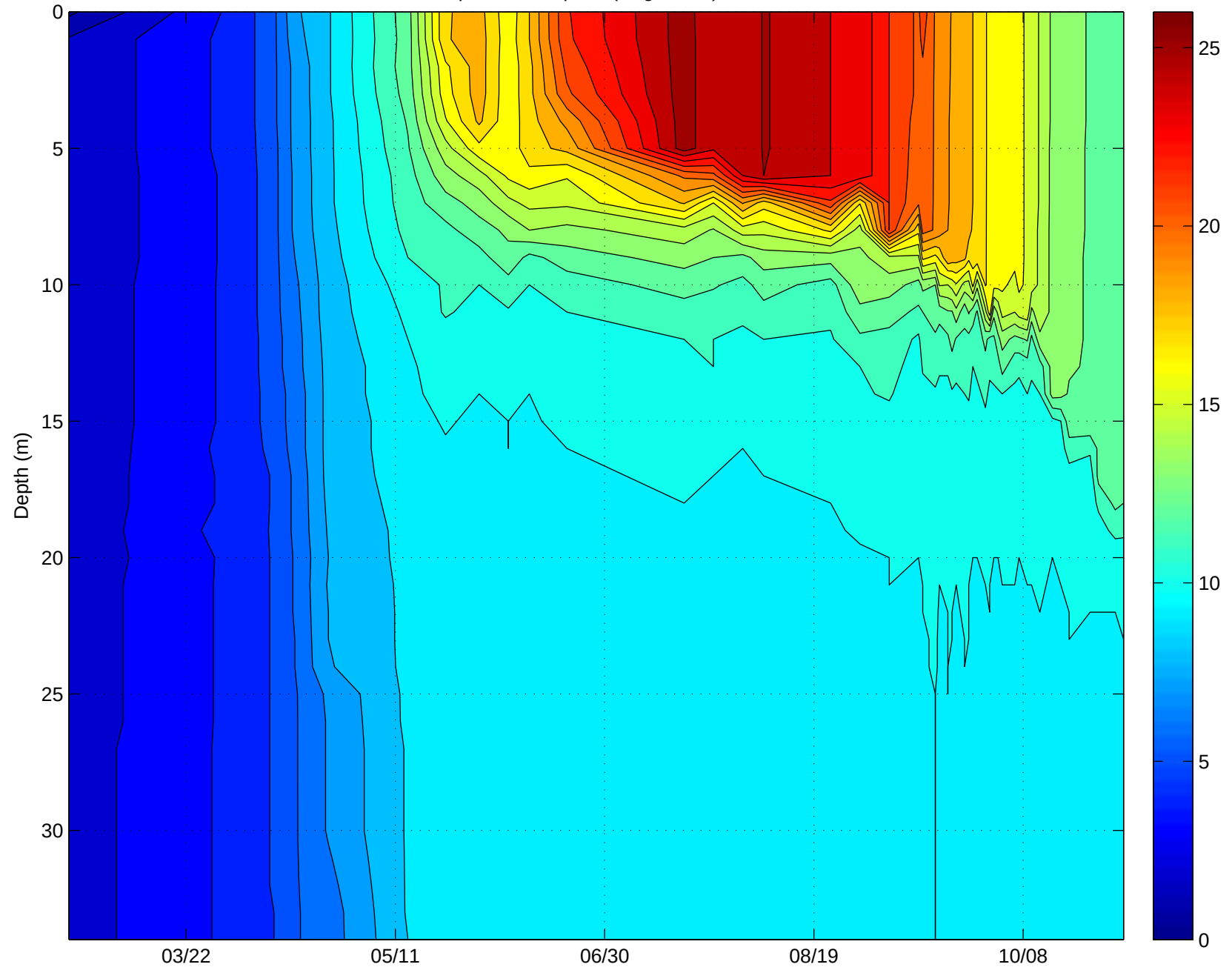




Temperature Isopleth (Degrees C)- 2011



Temperature Isopleth (Degrees C)- 2012



Appendix D

Relevant Maine Statutes

Maine Revised Statutes

Title 38: WATERS AND NAVIGATION
Chapter 3: PROTECTION AND IMPROVEMENT OF WATERS
Subchapter 1: ENVIRONMENTAL PROTECTION BOARD
Article 2: POLLUTION CONTROL

§414-A. Conditions of licenses

1. Generally. The department shall issue a license for the discharge of any pollutants only if it finds that:

A. The discharge either by itself or in combination with other discharges will not lower the quality of any classified body of water below such classification; [1973, c. 450, §15 (NEW).]

B. The discharge either by itself or in combination with other discharges will not lower the quality of any unclassified body of water below the classification which the board expects to adopt in accordance with this subchapter; [1973, c. 450, §15 (NEW).]

C. The discharge either by itself or in combination with other discharges will not lower the existing quality of any body of water, unless, following opportunity for public participation, the department finds that the discharge is necessary to achieve important economic or social benefits to the State and when the discharge is in conformance with section 464, subsection 4, paragraph F. The finding must be made following procedures established by rule of the board pursuant to section 464, subsection 4, paragraph F; [1989, c. 890, Pt. A, §40 (AFF); 1989, c. 890, Pt. B, §30 (AMD).]

D. The discharge will be subject to effluent limitations that require application of the best practicable treatment. "Effluent limitations" means any restriction or prohibition including, but not limited to, effluent limitations, standards of performance for new sources, toxic effluent standards and other discharge criteria regulating rates, quantities and concentrations of physical, chemical, biological and other constituents that are discharged directly or indirectly into waters of the State. "Best practicable treatment" means the methods of reduction, treatment, control and handling of pollutants, including process methods, and the application of best conventional pollutant control technology or best available technology economically achievable, for a category or class of discharge sources that the department determines are best calculated to protect and improve the quality of the receiving water and that are consistent with the requirements of the Federal Water Pollution Control Act, as amended, and published in 40 Code of Federal Regulations. If no applicable standards exist for a specific activity or discharge, the department must establish limits on a case-by-case basis using best professional judgment, after consultation with the applicant and other interested parties of record. In determining best practicable treatment for each category or class, the department shall consider the existing state of technology, the effectiveness of the available alternatives for control of the type of discharge and the economic feasibility of such alternatives; and [1997, c. 794, Pt. A, §22 (AMD).]

E. A pesticide discharge is unlikely to exert a significant adverse impact on nontarget species. This standard is only applicable to applications to discharge pesticides. [1989, c. 890, Pt. A, §40 (AFF); 1989, c. 890, Pt. B, §30 (AMD).]

[1997, c. 794, Pt. A, §22 (AMD) .]

1-A. License for copper sulfate applications in public water supplies. The commissioner may issue licenses to treat public water supplies with copper sulfate or related compounds. The commissioner may not issue more than 2 consecutive licenses for the same body of water.

A. A license may only be issued if the Department of Human Services, Division of Health Engineering has determined that:

(1) An abundant growth of algae producing taste or odor exists to such a degree that the water supply is in danger of becoming unhealthful or unpalatable;

(2) The abundance of algae is a sporadic event. For purposes of this section, "sporadic" means occurring not more than 2 years in a row; and

(3) The algae cannot effectively be controlled by other methods. [1997, c. 794, Pt. A, §22 (AMD).]

B. Any license issued under this subsection is for one application or series of applications not to exceed 6 months, as provided in the terms of the license. [1997, c. 794, Pt. A, §22 (AMD).]

C. The commissioner shall impose all conditions necessary to meet the requirements of this section and all other relevant provisions of law. [1989, c. 890, Pt. A, §40 (AFF); 1989, c. 890, Pt. B, §30 (AMD).]

D. [1997, c. 794, Pt. A, §22 (RP).]

[1997, c. 794, Pt. A, §22 (AMD) .]

1-B. Licensing of overboard discharges. The following provisions govern the licensing of overboard discharges.

A. The department shall find that the discharge meets the requirements of best practicable treatment under this section for purposes of licensing when it finds that there are no technologically proven alternative methods of wastewater disposal consistent with the plumbing code adopted by the Department of Health and Human Services pursuant to Title 22, section 42 that will not result in an overboard discharge.

(1) The department's finding must be based on documentation from a licensed site evaluator provided by the overboard discharge owner and approved by the department. The licensed site evaluator shall demonstrate experience in designing replacement systems for overboard discharges.

(2) If a technologically proven alternative system is identified and is eligible for grant funding according to the cost-share schedule under section 411-A and grant funding is available, the alternative system must be installed within 180 days of written notification from the department, unless soil conditions are

poor due to seasonal weather, in which case the alternative may be installed as soon as soil conditions permit.

(3) If a technologically proven alternative system eligible for grant funding according to the cost-share schedule is identified and funding is not available, then the owner of the overboard discharge is not required to install the system until grant funds are available or as provided in section 413, subsection 3. The department may determine that grant funds are not available when there are insufficient funds available for all alternative systems and the alternative system is not one of the systems identified as a priority for funding from available grant funds by the department.

(4) If a technologically proven alternative system for an overboard discharge from a residence is identified and is not eligible for grant funding according to the cost-share schedule under section 411-A, subsection 2-A and the overboard discharge is subject to a license that expires on or after July 2, 2010 and prior to July 2, 2012, the department may not require the alternative to be installed earlier than July 2, 2012.

(5) If a technologically proven alternative system for an overboard discharge from a commercial establishment is identified and is not eligible for grant funding according to the cost-share schedule under section 411-A, subsection 2-A and the overboard discharge is subject to a license that expires on or after July 2, 2010 and prior to July 2, 2012, the department may not require the alternative to be installed earlier than July 2, 2012. [2009, c. 654, §5 (AMD).]

B. For the purposes of this subsection, the department may not require the installation or use of wastewater holding tanks as a "technologically proven alternative method of wastewater disposal" except in the following cases:

(1) Seasonal residential overboard discharges that are located on the mainland or on any island connected to the mainland by vehicle bridge or by scheduled car ferry service, when the elimination of the discharge alone or in conjunction with the elimination of other discharges will result in the opening of a shellfish harvesting area or the removal of a public nuisance condition;

(2) All overboard discharges located within the boundaries of a sanitary or sewer district when the district has agreed to service and maintain the holding tank at an annual fee that does not exceed those fees charged to other similar users of the district's services who are physically connected to the sewers of the district; and

(3) All overboard discharges located within the municipality when the municipality has agreed to service and maintain the holding tank at an annual fee that does not exceed those fees charged to other similar users of the municipality's services who are physically connected to the sewers of the municipality. [2003, c. 246, §11 (AMD).]

C. [2003, c. 246, §12 (RP).]

D. [2003, c. 246, §13 (RP).]

E. At the time of each relicensing of an overboard discharge, the department shall impose all conditions necessary to meet the requirements of this section and all other relevant laws. [1989, c. 442, §3 (NEW); 1989, c. 890, Pt. A, §40 (AFF); 1989, c. 890, Pt. B, §30 (AMD).]

F. For the purposes of this subsection, the department may not require the installation or use of an identified technologically proven alternative system unless the department finds that the identified alternative constitutes best practicable treatment under subsection 1, paragraph D. [2009, c. 654, §5 (NEW).]

[2009, c. 654, §5 (AMD) .]

1-C. License for the use of algicides in Class GPA waters. The commissioner may issue a license to a municipality for the discharge of copper compounds or other materials registered by the Department of Agriculture, Food and Rural Resources to control excessive algae growth in Class GPA waters when the commissioner has determined that:

A. A lake restoration plan to reduce algae growth has been designed and implemented in cooperation with the department; [1995, c. 642, §5 (NEW).]

B. That plan has been found by the department to have failed to achieve the desired level of restoration in a reasonable period of time; [1995, c. 642, §5 (NEW).]

C. Because of technical or financial limitations, there is no further plan for restoration; [1995, c. 642, §5 (NEW).]

D. The affected water has a recent history of severe algae blooms of less than one meter Secchi disk transparency; [1995, c. 642, §5 (NEW).]

E. A watershed plan to further reduce phosphorus loading to the affected water is being implemented by responsible parties including the department and all affected municipalities; and [1995, c. 642, §5 (NEW).]

F. The Department of Inland Fisheries and Wildlife has found that the discharge will not have an adverse impact on the fishery management plan of that water body. [1995, c. 642, §5 (NEW).]

This license allows for no more than one application of copper compounds or other registered algicides per year for a period not to exceed 5 years. Algicides must be applied in an amount and in a manner that minimizes risk to nontarget organisms. The individual conducting the treatment must be certified by the Board of Pesticides Control for the use of aquatic pesticides. Application of an algicide may only occur after the Secchi disk transparency of the water is less than 2 meters. Relicensing is contingent upon an assessment of the water quality and the effectiveness of the phosphorus reduction plan for the watershed.

[1995, c. 642, §5 (NEW) .]

2. Schedules of compliance. Within the terms and conditions of a license, the department may establish a schedule of compliance for a final effluent limitation based on a water quality standard adopted after July 1, 1977. When a final effluent limitation is based on new or more stringent technology-based treatment requirements, the department may establish a schedule of compliance consistent with the time limitations

permitted for compliance under the Federal Water Pollution Control Act, Public Law 92-500, as amended. A schedule of compliance may include interim and final dates for attainment of specific standards necessary to carry out the purposes of this subchapter and must be as short as possible, based on consideration of the technological, economic and environmental impact of the steps necessary to attain those standards.

[1993, c. 501, §1 (RPR) .]

3. Federal law. When the Administrator of the United States Environmental Protection Agency ceases issuing permits for discharges of pollutants to waters of this State pursuant to the administrator's authority under Section 402(c)(1) of the Federal Water Pollution Control Act, as amended, the department shall refuse to issue a license for the discharge of pollutants which it finds would violate the provisions of any federal law relating to water pollution control, anchorage or navigation or regulations enacted pursuant thereto. Any license issued under this chapter after this determination must contain provisions, including effluent limitations, that the department determines necessary to carry out the purposes of this subchapter and any federal laws or regulations.

Notwithstanding the foregoing, the department is authorized to issue licenses containing a variance from thermal effluent limitations, or from applicable compliance deadlines to accommodate an innovative technology. The variances may be granted only in accordance with the Federal Water Pollution Control Act, Sections 316 and 301(k), as amended, and applicable regulations.

[1989, c. 890, Pt. A, §40 (AFF); 1989, c. 890, Pt. B, §30 (AMD) .]

4. License conditions affecting bypasses. In fashioning license decisions and conditions, the department shall consider the extent to which operation of the licensed facility will require an allowance for bypass of wastewater from any portion of a treatment facility when necessary for essential maintenance to assure efficient operation of the licensed facility, when unavoidable to prevent loss of life, personal injury or severe property damage and otherwise subject to applicable effluent limitations and standards. When the applicant demonstrates to the department that, consistent with best practical treatment requirements and other applicable standards, reasonably controlled and infrequent bypasses will be necessary for this purpose, and there is no feasible alternative to the bypass, such as the use of auxillary treatment facilities, retention of untreated wastes or maintenance during normal equipment downtime, the department shall fashion appropriate license allowances and conditions.

[1997, c. 794, Pt. A, §24 (AMD) .]

5. Modification, reopening and revocation. The following actions may be taken to reopen, modify or revoke and reissue waste discharge licenses. All actions taken under this subsection must be with notice to the licensee and all other interested parties of record and with opportunity for hearing. Actions may be appealed as set forth in sections 341-D and 346.

A. The department may reopen a license to add or change conditions or effluent limitations for toxic compounds identified in 40 Code of Federal Regulations, Section 401 or to include schedules of compliance to implement industrial pretreatment rules adopted by the board. Additionally, at the time of license issuance, the department may include as a condition of a license a provision for reopening the license for inclusion or change of specific limitations when facts available upon issuance indicate that changed circumstances or new information may be anticipated. [1997, c. 794, Pt. A, §25 (NEW).]

B. A request for modification of a license may be made by the licensee for any valid cause or changed circumstance. The department may initiate a license modification:

- (1) When necessary to correct legal, technical or procedural mistakes or errors;
- (2) When there has been or will be a substantial change in the activity or means of treatment that occurred after the time the license was issued;
- (3) When new information other than revised rules, guidance or test methods becomes available that would have justified different conditions at the time the license was issued;
- (4) When a pollutant not included in the license may be present in the discharge in quantities sufficient to require treatment, such as when the pollutant exceeds the level that can be achieved by the technology-based treatment standards appropriate to the licensee, or contribute to water quality violations;
- (5) When necessary to remove net limits based on pollutant concentration in intake water when the licensee is no longer eligible for them, consistent with federal law;
- (6) When necessary to make changes as a result of the failure of one state to notify another state whose waters may be affected by a discharge; or
- (7) When necessary to include pretreatment compliance schedules required pursuant to federal law. [1997, c. 794, Pt. A, §25 (NEW).]

C. Notwithstanding Title 5, section 10051, the board may modify, revoke or suspend a license when the board finds that any of the conditions specified in section 341-D, subsection 3 exist or upon an application for transfer of a license. [1997, c. 794, Pt. A, §25 (NEW).]

[1997, c. 794, Pt. A, §25 (NEW) .]

6. Cooling water intake structures. Any standard established by the department pursuant to section 413 or this section with respect to cooling water discharges and applicable to a point source must require that the location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impacts.

[2001, c. 232, §11 (NEW) .]

SECTION HISTORY

1973, c. 450, §15 (NEW). 1973, c. 788, §210 (AMD). 1979, c. 127, §209 (AMD). 1979, c. 281, §4 (AMD). 1979, c. 444, §§5-7 (AMD). 1979, c. 663, §230 (AMD). 1983, c. 566, §19 (AMD). 1987, c. 192, §11 (AMD). 1987, c. 394, §2 (AMD). 1989, c. 442, §3 (AMD). 1989, c. 856, §§1,7 (AMD). 1989, c. 890, §§A40,B30 (AMD). 1991, c. 66, §A43 (AFF). 1991, c. 66, §A7 (AMD). 1991, c. 483, §2 (AMD). 1993, c. 232, §§2,3 (AMD). 1993, c. 410, §G6 (AMD). 1993, c. 501, §1 (AMD). 1995, c. 642, §5 (AMD). 1997, c. 794, §§A22-25 (AMD). 2001, c. 232, §11 (AMD). 2003, c. 246, §§10-13 (AMD). 2003, c. 689, §B6 (REV). 2009, c. 654, §5 (AMD).

38 §465-A. STANDARDS FOR CLASSIFICATION OF LAKES AND PONDS

38 §465-A. STANDARDS FOR CLASSIFICATION OF LAKES AND PONDS

The department shall have one standard for the classification of great ponds and natural lakes and ponds less than 10 acres in size. Impoundments of rivers that are defined as great ponds pursuant to section 480-B are classified as GPA or as specifically provided in sections 467 and 468. [1989, c. 890, Pt. A, §40 (AFF); 1989, c. 890, Pt. B, §64 (AMD).]

1. Class GPA waters. Class GPA shall be the sole classification of great ponds and natural ponds and lakes less than 10 acres in size.

A. Class GPA waters must be of such quality that they are suitable for the designated uses of drinking water after disinfection, recreation in and on the water, fishing, agriculture, industrial process and cooling water supply, hydroelectric power generation, navigation and as habitat for fish and other aquatic life. The habitat must be characterized as natural. [2003, c. 227, §5 (AMD); 2003, c. 227, §9 (AFF); 2005, c. 561, §10 (AFF).]

B. Class GPA waters must be described by their trophic state based on measures of the chlorophyll "a" content, Secchi disk transparency, total phosphorus content and other appropriate criteria. Class GPA waters must have a stable or decreasing trophic state, subject only to natural fluctuations and must be free of culturally induced algal blooms that impair their use and enjoyment. The number of *Escherichia coli* bacteria of human and domestic animal origin in these waters may not exceed a geometric mean of 29 per 100 milliliters or an instantaneous level of 194 per 100 milliliters. [2007, c. 292, §23 (AMD).]

C. There may be no new direct discharge of pollutants into Class GPA waters. The following are exempt from this provision:

- (1) Chemical discharges for the purpose of restoring water quality approved by the department;
- (2) Aquatic pesticide or chemical discharges approved by the department and conducted by the department, the Department of Inland Fisheries and Wildlife or an agent of either agency for the purpose of restoring biological communities affected by an invasive species;
- (3) Storm water discharges that are in compliance with state and local requirements ; and
- (4) Discharges of aquatic pesticides approved by the department for the control of mosquito-borne diseases in the interest of public health and safety using materials and methods that provide for protection of nontarget species. When the department issues a license for the discharge of aquatic pesticides authorized under this subparagraph, the department shall notify the municipality in which the application is licensed to occur and post the notice on the department's publicly accessible website.

Discharges into these waters licensed prior to January 1, 1986 are allowed to continue only until practical alternatives exist. Materials may not be placed on or removed from the shores or banks of a Class GPA water body in such a manner that materials may fall or be washed into the water or that contaminated drainage may flow or leach into those waters, except as permitted pursuant to section 480-C. A change of land use in the watershed of a Class GPA water body may not, by itself or in combination with other activities, cause water quality degradation that impairs the characteristics and designated uses of downstream GPA waters or causes an increase in the trophic state of those GPA waters. [2007, c. 291, §5 (AMD).]

[2007, c. 291, §5 (AMD); 2007, c. 292, §23 (AMD) .]

SECTION HISTORY

1985, c. 698, §15 (NEW). 1989, c. 890, §§A40, B64, 65 (AMD). 1999, c. 243, §9 (AMD). 2003, c. 227, §5 (AMD). 2003, c. 227, §9 (AFF). 2005, c. 182, §6 (AMD). 2005, c. 561, §10 (AFF). 2007, c. 291, §5 (AMD). 2007, c. 292, §23 (AMD).

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38 §480-B. DEFINITIONS

38 §480-B. DEFINITIONS

As used in this article, unless the context otherwise indicates, the following terms have the following meanings. [1987, c. 809, §2 (NEW).]

1. Coastal sand dune systems. "Coastal sand dune systems" means sand and gravel deposits within a marine beach system, including, but not limited to, beach berms, frontal dunes, dune ridges, back dunes and other sand and gravel areas deposited by wave or wind action. Coastal sand dune systems may extend into coastal wetlands.

[1997, c. 603, §1 (AMD) .]

1-A. Community public water system. "Community public water system" has the same meaning as "community water system" has in Title 22, section 2660-B, subsection 2.

[2007, c. 353, §6 (NEW) .]

1-B. Community public water system primary protection area. "Community public water system primary protection area" means:

A. The area within 250 feet, measured horizontally, of a great pond that is a source for a community public water system; [2007, c. 353, §7 (NEW) .]

B. The area within 250 feet, measured horizontally, of a river, stream or brook that is a source for a community public water system for a distance of 1/2 mile upstream from the intake of the public water supply; or [2007, c. 353, §7 (NEW) .]

C. A source water protection area identified and mapped by the Department of Health and Human Services as described under Title 30-A, section 2001, subsection 20-A. [2007, c. 353, §7 (NEW) .]

[2007, c. 353, §7 (NEW) .]

2. Coastal wetlands. "Coastal wetlands" means all tidal and subtidal lands; all areas with vegetation present that is tolerant of salt water and occurs primarily in a salt water or estuarine habitat; and any swamp, marsh, bog, beach, flat or other contiguous lowland that is subject to tidal action during the highest tide level for the year in which an activity is proposed as identified in tide tables published by the National Ocean Service. Coastal wetlands may include portions of coastal sand dunes.

[2005, c. 330, §13 (AMD) .]

2-A. Dredge spoils. "Dredge spoils" means sand, silt, mud, gravel, rock or other sediment or material that is moved from coastal wetlands.

[1989, c. 656, §2 (NEW) .]

2-B. Forest management activities. "Forest management activities" means timber stand improvement, timber harvesting activities, forest products harvesting and regeneration of forest stands. For the purposes of this definition, "timber harvesting activities" means timber harvesting, the construction and maintenance of roads used primarily for timber harvesting, the mining of gravel used for the construction and maintenance of roads used primarily for timber harvesting and other activities conducted to facilitate timber harvesting. For the purposes of this definition, "timber harvesting" means the cutting or removal of timber for the primary purpose of selling or processing forest products.

[2011, c. 599, §11 (AMD) .]

2-C. Forested wetland. "Forested wetland" means a freshwater wetland dominated by woody vegetation that is 6 meters tall, or taller.

[1989, c. 838, §3 (NEW) .]

2-D. Floodplain wetland. "Floodplain wetland" means lands adjacent to a river, stream or brook that are inundated with floodwater during a 100-year flood event and that under normal circumstances support a prevalence of wetland vegetation typically adapted for life in saturated soils.

[1991, c. 214, §1 (NEW) .]

2-E. Footprint. "Footprint" means the outline of a structure on the ground, except that for a building "footprint" means the outline that would be created on the ground by extending the exterior walls of a building to the ground surface.

[2011, c. 538, §8 (AMD) .]

3. Fragile mountain areas. "Fragile mountain areas" means areas above 2,700 feet in elevation from mean sea level.

[1987, c. 809, §2 (NEW) .]

4. Freshwater wetlands. "Freshwater wetlands" means freshwater swamps, marshes, bogs and similar areas that are:

A. [1995, c. 460, §1 (RP); 1995, c. 460, §12 (AFF).]

B. Inundated or saturated by surface or groundwater at a frequency and for a duration sufficient to support, and which under normal circumstances do support, a prevalence of wetland vegetation typically adapted for life in saturated soils; and [1995, c. 460, §1 (AMD); 1995, c. 460, §12 (AFF) .]

C. Not considered part of a great pond, coastal wetland, river, stream or brook. [1987, c. 809, §2 (NEW) .]

[1995, c. 460, §1 (AMD); 1995, c. 460, §12 (AFF) .]

5. Great ponds. "Great ponds" means any inland bodies of water which in a natural state have a surface area in excess of 10 acres and any inland bodies of water artificially formed or increased which have a surface area in excess of 30 acres.

[1987, c. 809, §2 (NEW) .]

5-A. Mooring. "Mooring" means equipment, such as anchors, chains and lines, for holding fast a vessel, aircraft, floating dock or buoy.

[1993, c. 187, §1 (NEW) .]

5-B. Impervious area. "Impervious area" means an area that is a building, parking lot, roadway or similar constructed area. "Impervious area" does not mean a deck or patio.

[2011, c. 64, §2 (NEW) .]

6. Normal high water line. "Normal high water line" means that line along the shore of a great pond, river, stream, brook or other nontidal body of water which is apparent from visible markings, changes in the character of soils due to prolonged action of the water or from changes in vegetation and which distinguishes between predominantly aquatic and predominantly terrestrial land. In the case of great ponds, all land below the normal high water line shall be considered the bottom of the great pond for the purposes of this article.

[1987, c. 809, §2 (NEW) .]

6-A. Offshore wind power project. "Offshore wind power project" means a project that uses a windmill or wind turbine to convert wind energy to electrical energy and is located in whole or in part within coastal wetlands. "Offshore wind power project" includes both generating facilities as defined by Title 35-A, section 3451, subsection 5 and associated facilities as defined by Title 35-A, section 3451, subsection 1, without regard to whether the electrical energy is for sale or use by a person other than the generator.

[2009, c. 615, Pt. E, §6 (NEW) .]

7. Permanent structure. "Permanent structure" means any structure that is designed to remain at or that is constructed or erected with a fixed location or that is attached to a structure with a fixed location for a period exceeding 7 months within any 12-month period, including, but not limited to, causeways, piers, docks, concrete slabs, piles, marinas, retaining walls and buildings.

[2007, c. 290, §2 (AMD) .]

8. Protected natural resource. "Protected natural resource" means coastal sand dune systems, coastal wetlands, significant wildlife habitat, fragile mountain areas, freshwater wetlands, community public water system primary protection areas, great ponds or rivers, streams or brooks, as these terms are defined in this article.

[2007, c. 1, §20 (COR) .]

8-A. Transportation reconstruction or replacement project. "Transportation reconstruction or replacement project" means the improvement of an existing transportation facility to modern design standards without expanding its function or creating any additional roadways, facilities or structures. These projects are limited to:

- A. Highway or bridge alignment changes not exceeding a distance of 200 feet between the old and new center lines in any protected natural resource; [1989, c. 814, §1 (NEW) .]
- B. Replacement or rehabilitation of the roadway base, pavement and drainage; [1989, c. 814, §1 (NEW) .]
- C. Replacement or rehabilitation of bridges or piers; [1989, c. 814, §1 (NEW) .]
- D. The addition of climbing lanes, and turning lanes of less than 1,000 feet in length in a protected natural resource; and [1989, c. 814, §1 (NEW) .]
- E. Rehabilitation or repair of state-owned railroads. [1989, c. 814, §1 (NEW) .]

[1989, c. 814, §1 (NEW) .]

9. River, stream or brook. "River, stream or brook" means a channel between defined banks. A channel is created by the action of surface water and has 2 or more of the following characteristics.

- A. It is depicted as a solid or broken blue line on the most recent edition of the U.S. Geological Survey 7.5-minute series topographic map or, if that is not available, a 15-minute series topographic map. [1995, c. 92, §2 (NEW) .]
- B. It contains or is known to contain flowing water continuously for a period of at least 6 months of the year in most years. [2001, c. 618, §1 (AMD) .]

C. The channel bed is primarily composed of mineral material such as sand and gravel, parent material or bedrock that has been deposited or scoured by water. [1995, c. 92, §2 (NEW).]

D. The channel contains aquatic animals such as fish, aquatic insects or mollusks in the water or, if no surface water is present, within the stream bed. [1995, c. 92, §2 (NEW).]

E. The channel contains aquatic vegetation and is essentially devoid of upland vegetation. [1995, c. 92, §2 (NEW).]

"River, stream or brook" does not mean a ditch or other drainage way constructed, or constructed and maintained, solely for the purpose of draining storm water or a grassy swale.

[2001, c. 618, §1 (AMD) .]

9-A. Significant groundwater well. "Significant groundwater well" is defined as follows.

A. "Significant groundwater well" means any well, wellfield, excavation or other structure, device or method used to obtain groundwater that is:

(1) Withdrawing at least 75,000 gallons during any week or at least 50,000 gallons on any day and is located at a distance of 500 feet or less from a coastal or freshwater wetland, great pond, significant vernal pool habitat, water supply well not owned or controlled by the applicant or river, stream or brook; or

(2) Withdrawing at least 216,000 gallons during any week or at least 144,000 gallons on any day and is located at a distance of more than 500 feet from a coastal or freshwater wetland, great pond, significant vernal pool habitat, water supply well not owned or controlled by the applicant or river, stream or brook.

Withdrawals of water for firefighting or preoperational capacity testing are not applied toward these thresholds. [2009, c. 295, §1 (AMD) .]

B. "Significant groundwater well" does not include:

(1) A public water system as defined in Title 22, section 2601, subsection 8, except that "significant groundwater well" includes:

(a) A public water system used solely to bottle water for sale; and

(b) Any portion of a public water system that is:

(i) Constructed on or after January 1, 2009;

(ii) Used solely to bottle water for sale; and

(iii) Not connected to another portion of the public water system through pipes intended to convey water.

For purposes of this paragraph, a public water system that is used solely to bottle water for sale includes a public water system that bottles water for sale and may provide a de minimus amount of water for other purposes, such as employee or other use, as determined by the department;

(2) Individual home domestic supply;

(3) Agricultural use or storage;

(3-A) Dewatering of a mining operation;

(4) A development or part of a development requiring a permit pursuant to article 6, article 7 or article 8-A; or

(5) A structure or development requiring a permit from the Maine Land Use Planning Commission. [2009, c. 295, §1 (AMD); 2011, c. 682, §38 (REV) .]

[2009, c. 295, §1 (AMD); 2011, c. 682, §38 (REV) .]

10. Significant wildlife habitat. "Significant wildlife habitat" means:

A. The following areas to the extent that they have been mapped by the Department of Inland Fisheries and Wildlife or are within any other protected natural resource: habitat, as defined by the Department of Inland Fisheries and Wildlife, for species appearing on the official state or federal list of endangered or threatened animal species; high and moderate value deer wintering areas and travel corridors as defined by the Department of Inland Fisheries and Wildlife; seabird nesting islands as defined by the Department of Inland Fisheries and Wildlife; and critical spawning and nursery areas for Atlantic salmon as defined by the Department of Marine Resources; and [2009, c. 561, §37 (AMD).]

B. Except for solely forest management activities, for which "significant wildlife habitat" is as defined and mapped in accordance with section 480-I by the Department of Inland Fisheries and Wildlife, the following areas that are defined by the Department of Inland Fisheries and Wildlife and are in conformance with criteria adopted by the Department of Environmental Protection or are within any other protected natural resource:

- (1) Significant vernal pool habitat;
- (2) High and moderate value waterfowl and wading bird habitat, including nesting and feeding areas; and
- (3) Shorebird nesting, feeding and staging areas. [2005, c. 116, §2 (NEW).]

[2009, c. 561, §37 (AMD) .]

SECTION HISTORY

1987, c. 809, §2 (NEW). 1989, c. 430, §3 (AMD). 1989, c. 656, §2 (AMD). 1989, c. 814, §1 (AMD). 1989, c. 838, §3 (AMD). 1991, c. 214, §1 (AMD). 1991, c. 693, §1 (AMD). 1993, c. 187, §1 (AMD). 1993, c. 296, §1 (AMD). 1995, c. 92, §2 (AMD). 1995, c. 406, §13 (AMD). 1995, c. 460, §§1-3 (AMD). 1995, c. 460, §12 (AFF). 1995, c. 625, §A51 (AMD). 1997, c. 603, §1 (AMD). 1999, c. 243, §11 (AMD). 1999, c. 401, §BB17 (AMD). 2001, c. 618, §1 (AMD). 2005, c. 116, §§1,2 (AMD). 2005, c. 330, §13 (AMD). RR 2007, c. 1, §20 (COR). 2007, c. 290, §2 (AMD). 2007, c. 353, §§6-8 (AMD). 2007, c. 399, §10 (AMD). 2009, c. 295, §1 (AMD). 2009, c. 561, §37 (AMD). 2009, c. 615, Pt. E, §6 (AMD). 2011, c. 64, §§1, 2 (AMD). 2011, c. 538, §8 (AMD). 2011, c. 599, §11 (AMD). 2011, c. 682, §38 (REV).

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