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 College[1] 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.

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- 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.

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- 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.

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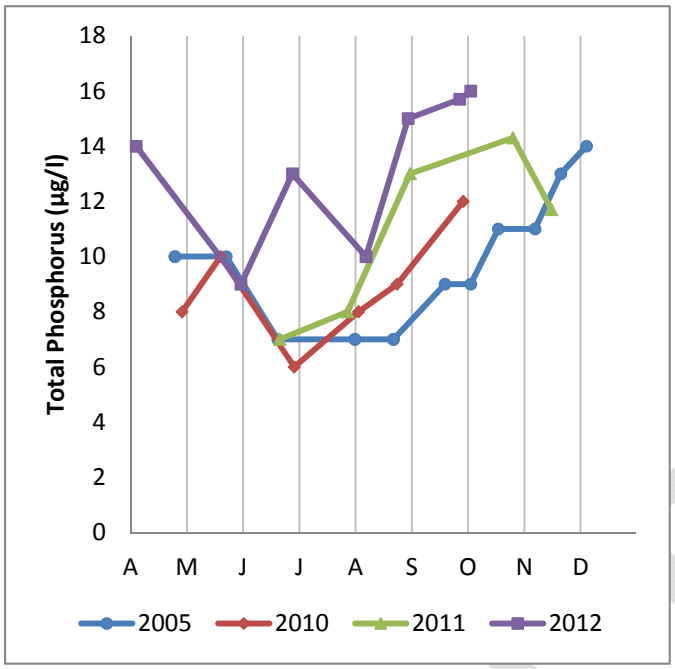

Figure 1: Concentration of Total Phosphorus in Surface Water at Deep Hole (0 to 5 meter depth)

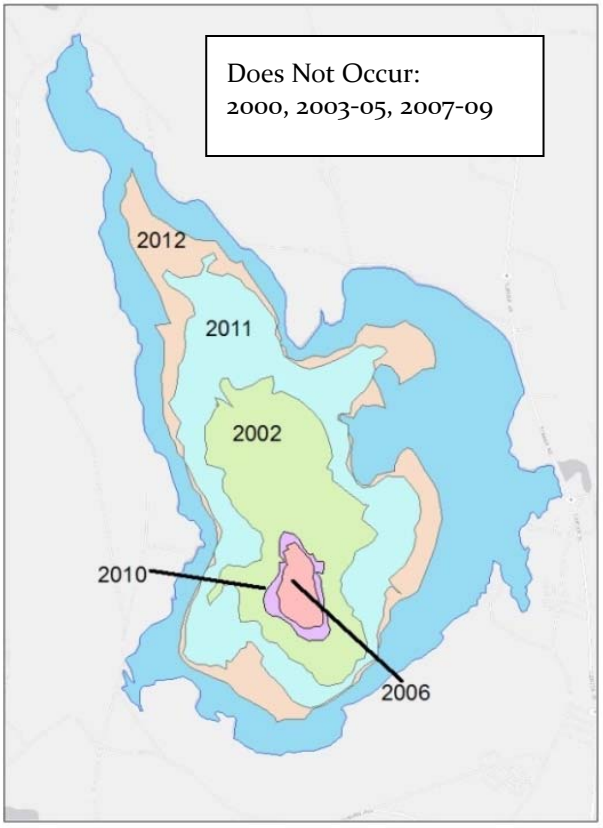

Figure 2: Bottom Area of Lake Auburn with Dissolved Oxygen < 2 mg/l

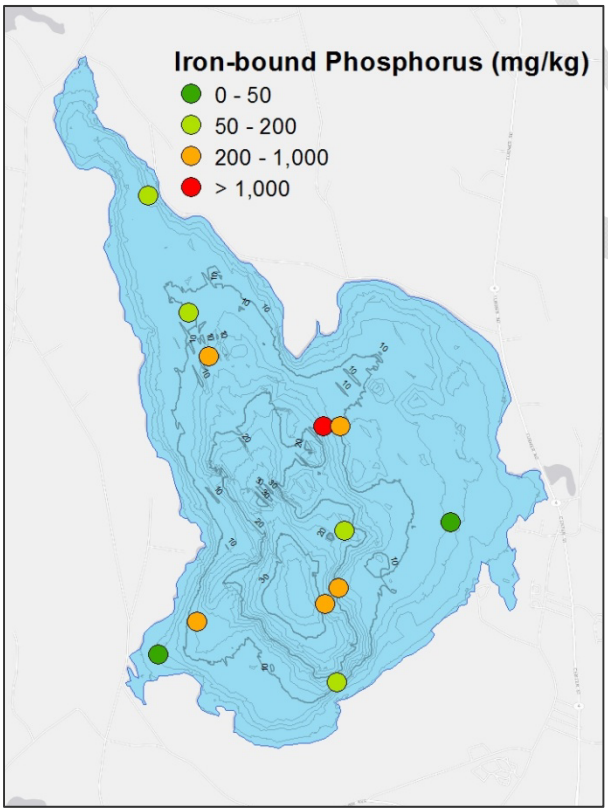

Figure 3: 2012 Iron-Bound Phosphorus in Sediment

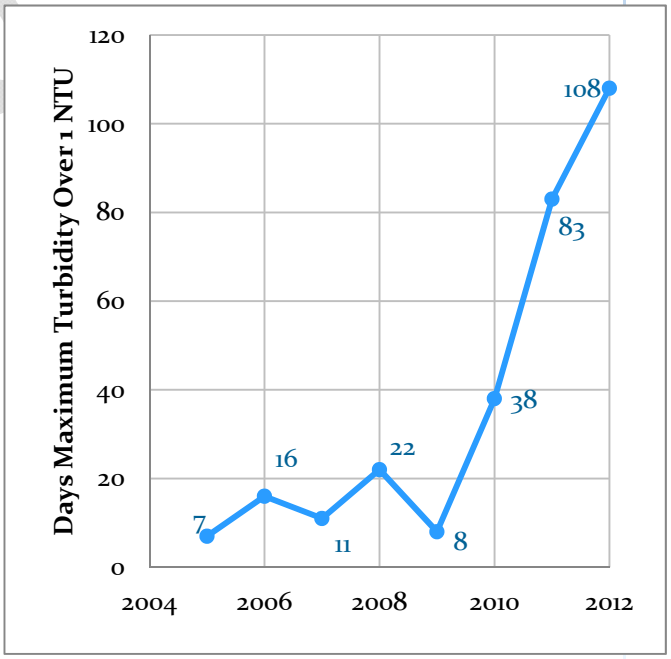

Figure 4: Days per Year When Maximum Turbidity in Raw Water Intake is Over 1 NTU

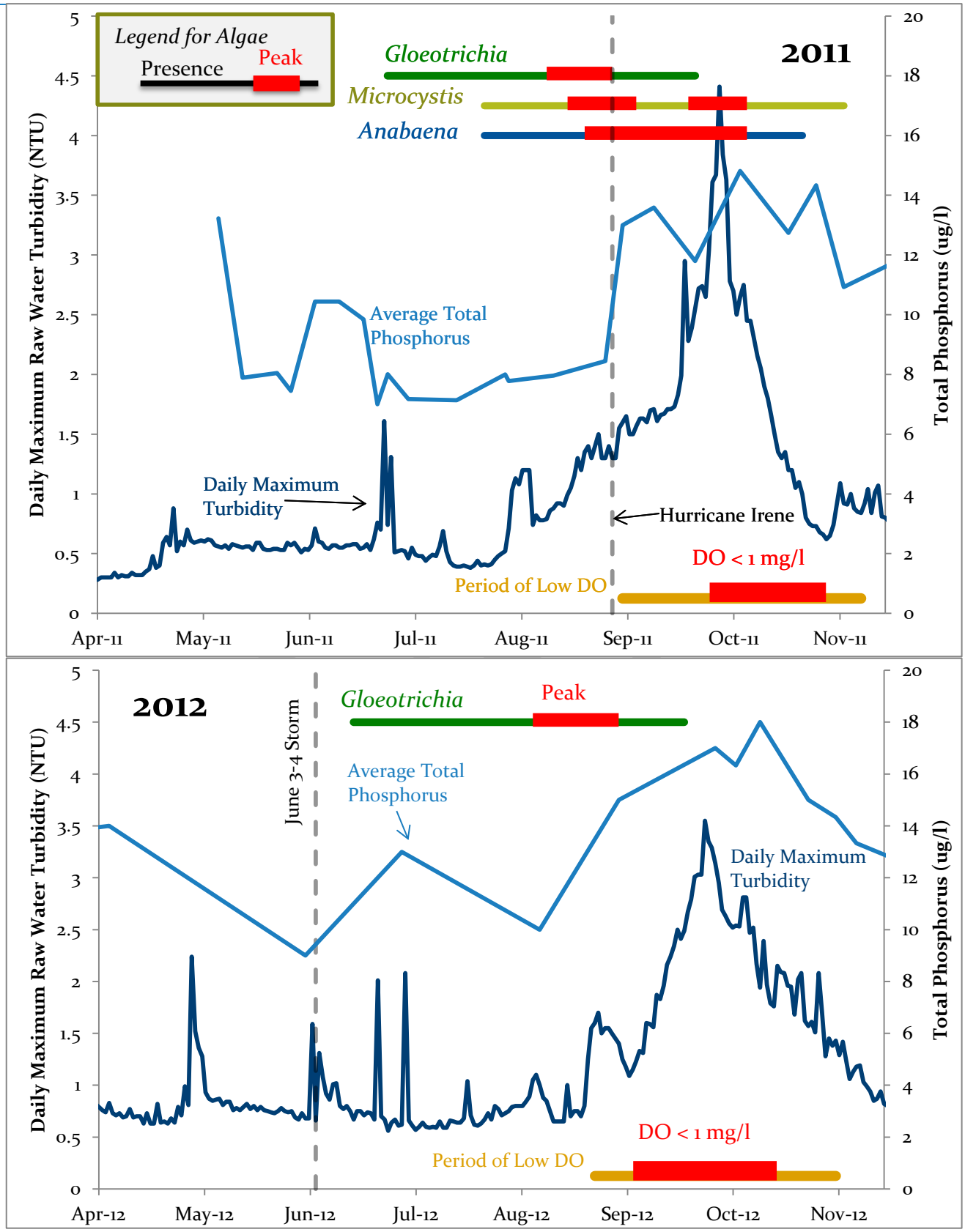

Figure 5: Average Surface Water Total Phosphorus, Algal Succession, Daily Maximum Turbidity, and Low Dissolved Oxygen Conditions, 2011 and 2012. Algal and 2011 TP data from Drs. Ewing, Weathers, and Cottingham under NSF grants NSF DEB-0749022 NSF EF-0842112m NSF EF-0842125, NSF EF-084226

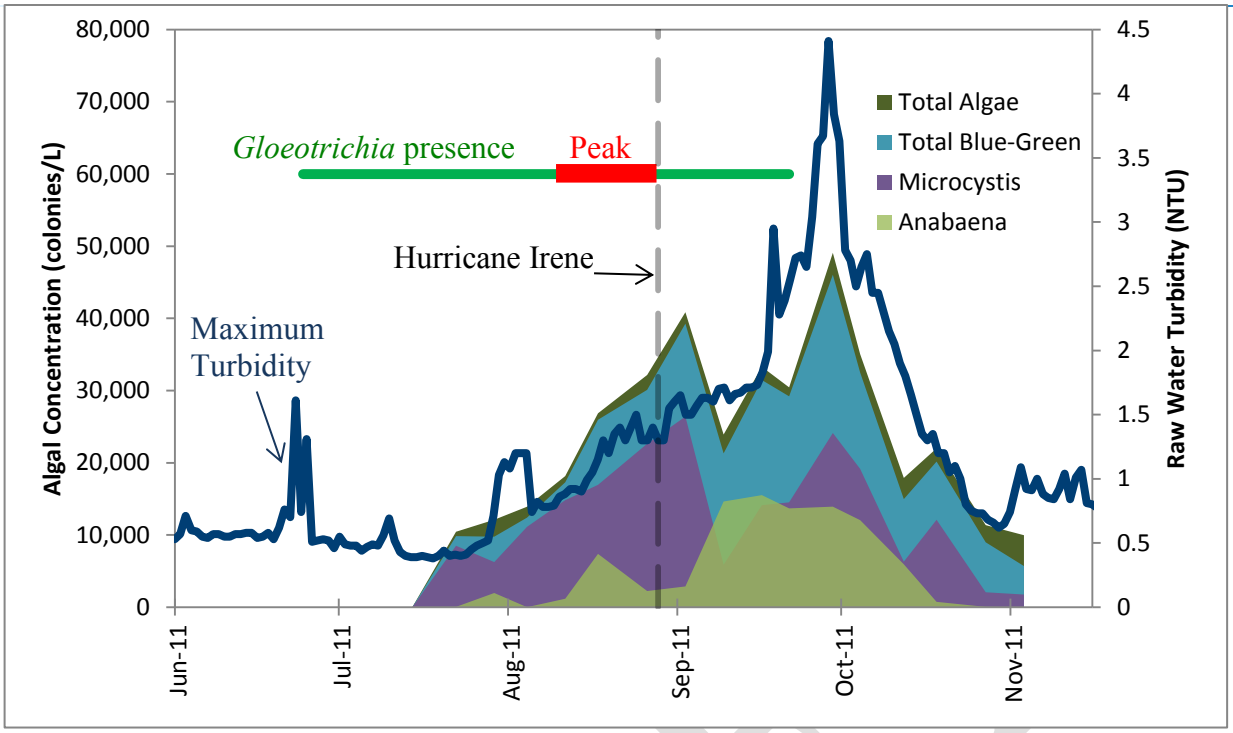

Figure 6: 2011 Maximum Daily Turbidity and Algal Succession. Algal data from Drs. Ewing, Weathers, and Cottingham under NSF grants NSF DEB-0749022 NSF EF-0842112m NSF EF-0842125, NSF EF-084226

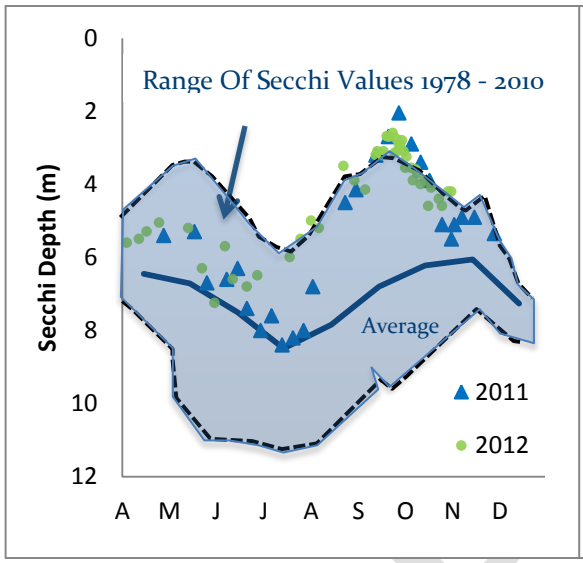

Figure 7: 2011-12 Secchi Depths Compared to Long-term Range and Average

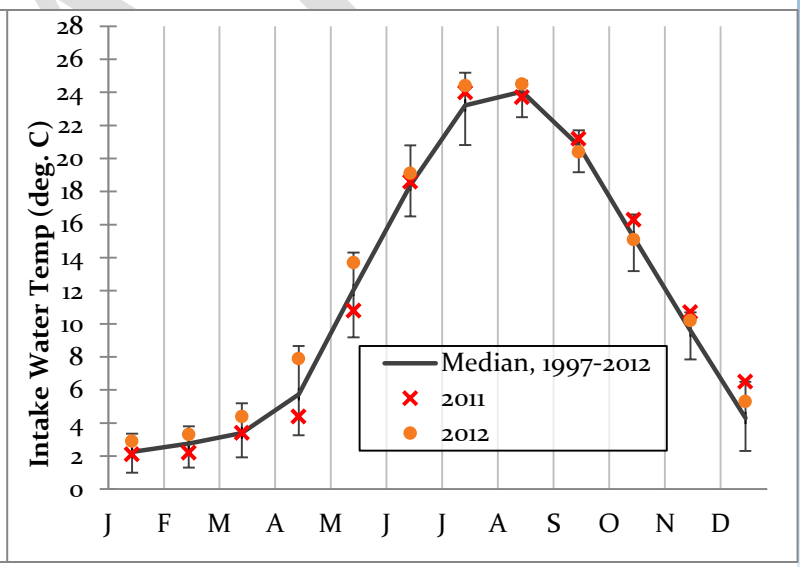

Figure 8: 2011-12 Water Temperature Compared to Long-Term Median

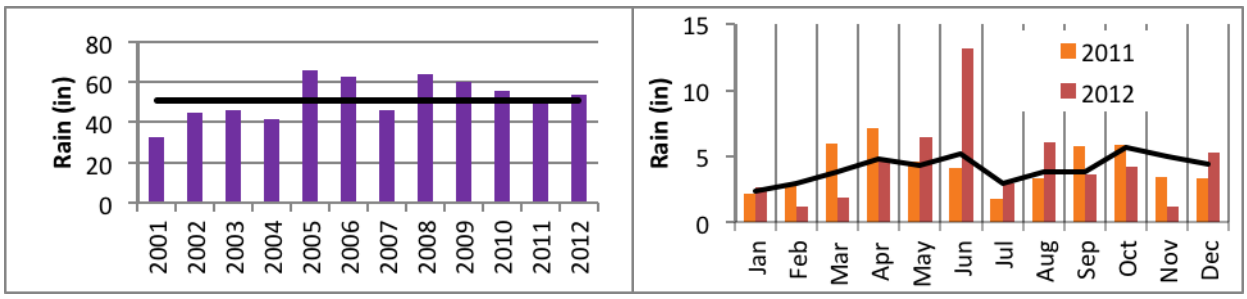

Figure 9: 2011-12 Annual and Monthly Rainfall Compared With 1998–2012 Average, Poland, ME