Total Maximum Daily Load
for
Total Phosphorus

Honeoye Lake
Ontario County, New York

August 2019

U.S. Environmental Protection Agency
Region 2
290 Broadway
New York, NY 10007

New York State Department of Environmental Conservation
625 Broadway, 4th Floor
Albany, NY 12233

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BACKGROUND/PROBLEM STATEMENT

INTRODUCTION

Section 303(d) of the Federal Clean Water Act (CWA) requires US states and territories to identify waters within their boundaries that are not meeting state or territorial water quality standards. Section 303(d) further requires EPA, states, and territories to develop a Total Maximum Daily Load (TMDL) for any pollutant violating or causing violation of an applicable water quality standard for each impaired waterbody. A TMDL defines the maximum amount of a pollutant that a waterbody can receive while continuing to meet water quality standards. A TMDL also allocates the maximum allowable pollutant load between point and nonpoint sources of the pollutant. A TMDL provides a framework for EPA, states, and territories to establish and implement pollution control and management plans, with the goal described in Section 101(a)(2) of the CWA: "water quality which provides for the protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water, wherever attainable" (USEPA, 1991a).

This report presents a TMDL for total phosphorus for Honeoye Lake in Ontario County, New York.

WATERBODY AND POLLUTANTS OF CONCERN

Honeoye Lake (WI/PWL ID 0402-0032) is in Ontario County, New York, within the Towns of Richmond and Candice. Honeoye Lake is included on the *2014 New York State Section 303(d) List of Impaired/TMDL Waters* (NYSDEC 2014). The List of Impaired/TMDL Waters is maintained by the New York State Department of Environmental Conservation (NYSDEC) and, as required by the Federal Clean Water Act, specifies which waterbodies in New York do not meet the state's surface water quality standards. Waters on the List of Impaired/TMDL Waters require development of a Total Maximum Daily Load (TMDL) that addresses the pollutants causing nonattainment of water quality standards. A TMDL defines the pollutant loading capacity of a waterbody, or the maximum allowable amount of a pollutant that the waterbody can receive and still meet water quality standards. A TMDL also allocates the maximum allowable pollutant load between pollutant sources.

The 2014 List of Impaired/TMDL Waters identifies phosphorus and oxygen demand as the pollutants causing nonattainment of water quality standards in Honeoye Lake, based on monitored values above the guidance value for Phosphorus. Phosphorus is a key plant nutrient and is typically the limiting nutrient for aquatic plant growth in freshwater lakes. Inputs of excess phosphorus to a lake can have several negative effects on water quality and ecosystem health. For example, high phosphorus levels often spur algae blooms and overgrowth of rooted aquatic plants. As these algae and aquatic plants are decomposed by microorganisms, dissolved oxygen levels become depressed, creating conditions that are unsuitable for fish and other wildlife. Excess aquatic plant growth also reduces the recreational and aesthetic value of a lake.

Table 1- 2014 New York State 303(d) list Honeoye Lake Information

Water Index Number	Waterbody Name (WI/PWL ID)	Class	Cause/Pollutant	Source	TMDL Priority
Ont 117- 27-P57	Honeoye Lake (0402-0032)	AA	Phosphorus; Oxygen Demand	Unknown	Low

APPLICABLE WATER QUALITY STANDARDS

Under New York surface water quality standards, all waters in New York State are assigned a letter classification that denotes their best uses. Honeoye Lake is designated as a Class AA waterbody. The following water quality standards apply to Class AA waters (6 NYCRR 701.5):

a) The best usages of Class AA waters are: a source of water supply for drinking, culinary or food processing purposes; primary and secondary contact recreation; and fishing. The waters shall be suitable for fish, shellfish and wildlife propagation and survival.
b) This classification may be given to those waters that, if subjected to approved disinfection treatment, with additional treatment if necessary to remove naturally present impurities, meet or will meet New York State Department of Health drinking water standards and are or will be considered safe and satisfactory for drinking water purposes.

New York water quality standards establish criteria for water quality that correspond to attainment of best uses. The criterion for phosphorus is narrative and states that phosphorus shall not be present within the waterbody *“in amounts that will result in growths of algae, weeds and slimes that will impair the waters for their best usages”* (6 CRR-NY 703.2).

NUMERIC WATER QUALITY TARGET

To determine the pollutant loading capacity of a waterbody, one or more numeric water quality targets must be selected that describe in-lake conditions which correspond to attainment of water quality standards. As noted in Section 1.3, New York water quality standards establish a narrative criterion for phosphorus. For Class AA waterbodies, NYSDEC has identified an in-lake growing season average chlorophyll-a concentration of less than or equal to 4 micrograms per liter (µg/L) as corresponding to attainment of the phosphorus narrative criterion (See Appendix C). Chlorophyll-a is an indicator of algal growth within a lake and is therefore a measure of ecosystem response to phosphorus loading.

LAKE MORPHOMETRY

Honeoye Lake is an 1,880-acre waterbody at an elevation of approximately 800 feet above mean sea level. Figure 1 shows a bathymetric map for Honeoye Lake based on lake contour maps developed by NYSDEC. Table 2 summarizes key morphometric characteristics for Honeoye Lake.

Figure 1- Bathymetric Map of Honeoye Lake

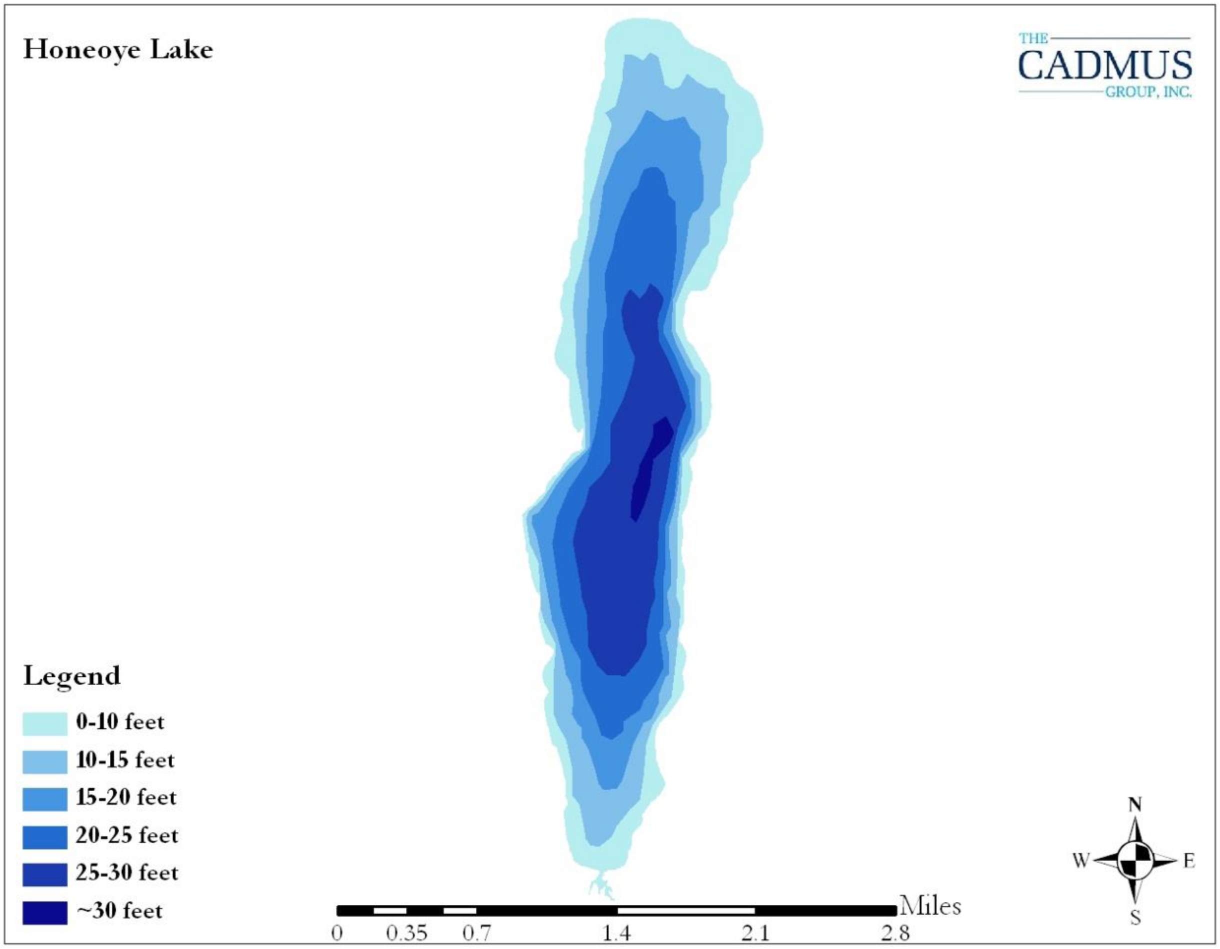


Table 2- Honeoye Lake Characteristics

Surface Area (acres)	1,880
Elevation (ft AMSL)	800
Maximum Depth (ft)	30
Mean Depth (ft)	16.1
Length (ft)	22,604
Width at widest point (ft)	4,539
Shoreline perimeter (ft)	56,593
Direct Drainage Area (acres)	24,500
Watershed: Lake Ratio	13:1
Mass Residence Time (years)	0.7
Hydraulic Residence Time (days)	300

ASSESSMENT OF PHOSPHORUS SOURCES

POINT SOURCES

Point sources of pollution, as defined by the NYS ECL 17-0105(17) and implementing regulations 6 NYCRR 750-1.2(a)(67), include any discrete conveyance that discharges pollutants to a waterbody, such as pipes or ditches discharging wastewater from a sewage treatment plant or industrial facility. Point sources of pollution are regulated by the NYSDEC State Pollutant Discharge Elimination System (SPDES) permit program. There are no point sources of phosphorus discharging to Honeoye Lake or its watershed.

NONPOINT SOURCES

Nonpoint sources of pollution include any sources that do not meet the definition of a point source. A key nonpoint source of phosphorus to a waterbody is runoff of precipitation from the watershed. Watershed runoff carries phosphorus deposited on the land surface and subsurface into a waterbody. Watershed runoff can originate from naturally vegetated areas (forest, grassland, etc.) or from developed lands (residential lots, agricultural fields, etc). The quantity and chemical quality of runoff is highly dependent on watershed characteristics such as land use, soils, and slopes. Land use in the Honeoye Lake watershed is described in Table 3 and in Figure 2. The watershed is predominantly forested (70% of watershed area). Rural residences are distributed throughout the upper portions of the watershed and higher density residential areas occur along the Honeoye Lake shoreline. Agriculture is not widely practiced.

Table 3- Land use in the Honeoye Lake watershed

From 2014 Ontario County Ecological Communities land cover dataset.

Land Use	Acres	Percent of Watershed
Forest	18,109	70%
Open Water	1,924	7%
Grassland	1,452	6%
Mowed Lawn	1,394	5%
Cropland	1,012	4%
Wetland	960	4%
Shrubland	774	3%
Other	356	1%
Total	**25,979**	**100%**

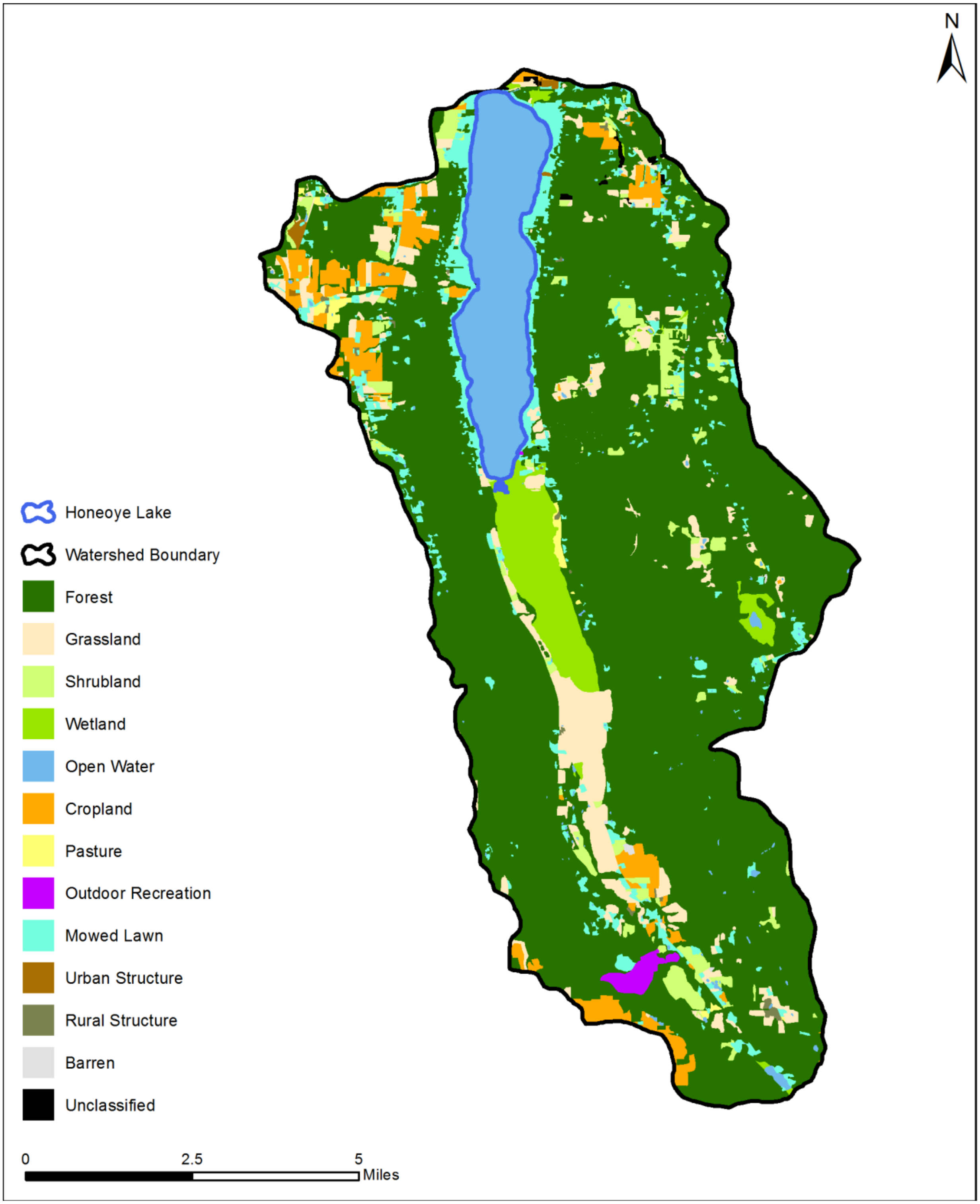
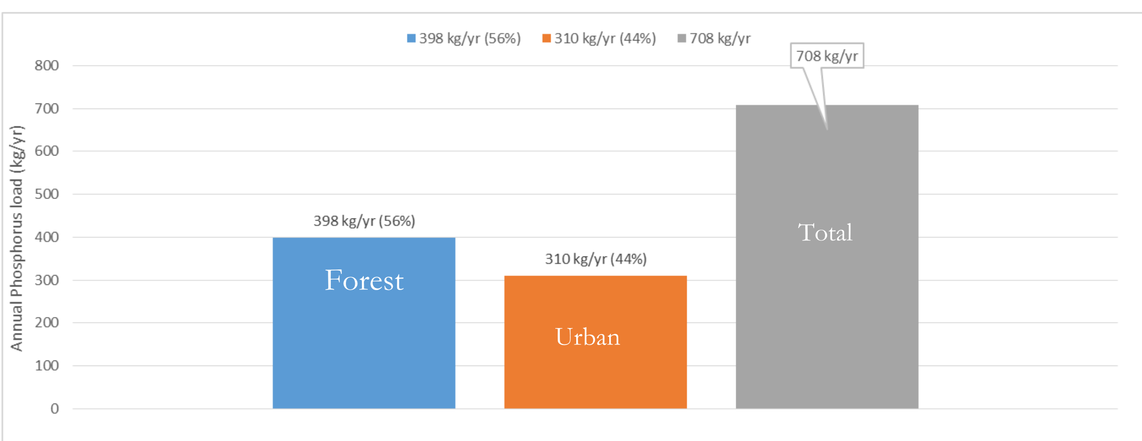


Figure 2- Map of land use in the Honeoye Lake watershed.

Phosphorus loads from Honeoye Lake watershed runoff for the period 2007 through 2014 were estimated using the Soil and Water Assessment Tool (SWAT). SWAT is a watershed model that uses information on watershed characteristics, weather records, and mathematical equations describing runoff generation and water quality processes to generate daily predictions of watershed runoff and pollutant loads (Neitsch et al. 2011). The SWAT model used to estimate phosphorus loads from the Honeoye Lake watershed was originally developed by researchers at SUNY Brockport as part of a larger effort to model the Genesee River watershed. Details of the Genesee River watershed SWAT modeling study and model configuration are provided in Makerewicz et al. (2013a, b). The SWAT model developed by SUNY-Brockport researchers was modified for this effort to extend the simulation period to include the years 2013 and 2014. No modifications were made to model parameters that affect nonpoint source phosphorus outputs.

SWAT represents a watershed as a collection of Hydrologic Response Units (HRUs). Each HRU is a land area with a unique land use-soil-slope combination. The SWAT model of the Honeoye Lake watershed includes HRUs for two land use types: forest and urban. SWAT-estimated loads of total phosphorus from HRUs in the Honeoye Lake watershed are displayed in Figure 3. The average total phosphorus load over 2007 through 2014 is 398 kg/year for forest HRUs (56% of the total load) and 310 kg/year from urban HRUs (44% of the total load). Note that other land use types were not represented as separate HRUs in the SWAT model because they did not meet the minimum area threshold applied to non-urban land uses (10% of the watershed area; Makarewicz et al. 2013b). Average total phosphorus loading over 2007 through 2014 is estimated to be 708 kilograms per year (kg/year).

Figure 3- Annual Honeoye Lake Watershed phosphorus loads
2007 - 2014 (SWAT watershed model)



The digital elevation model map in Figure 4 further defines source loads by sub-watershed area. Relative TP exported by these subwatershed areas is given in Table 4:

Fig. 4 - Honeoye Lake Sub-watershed Boundaries

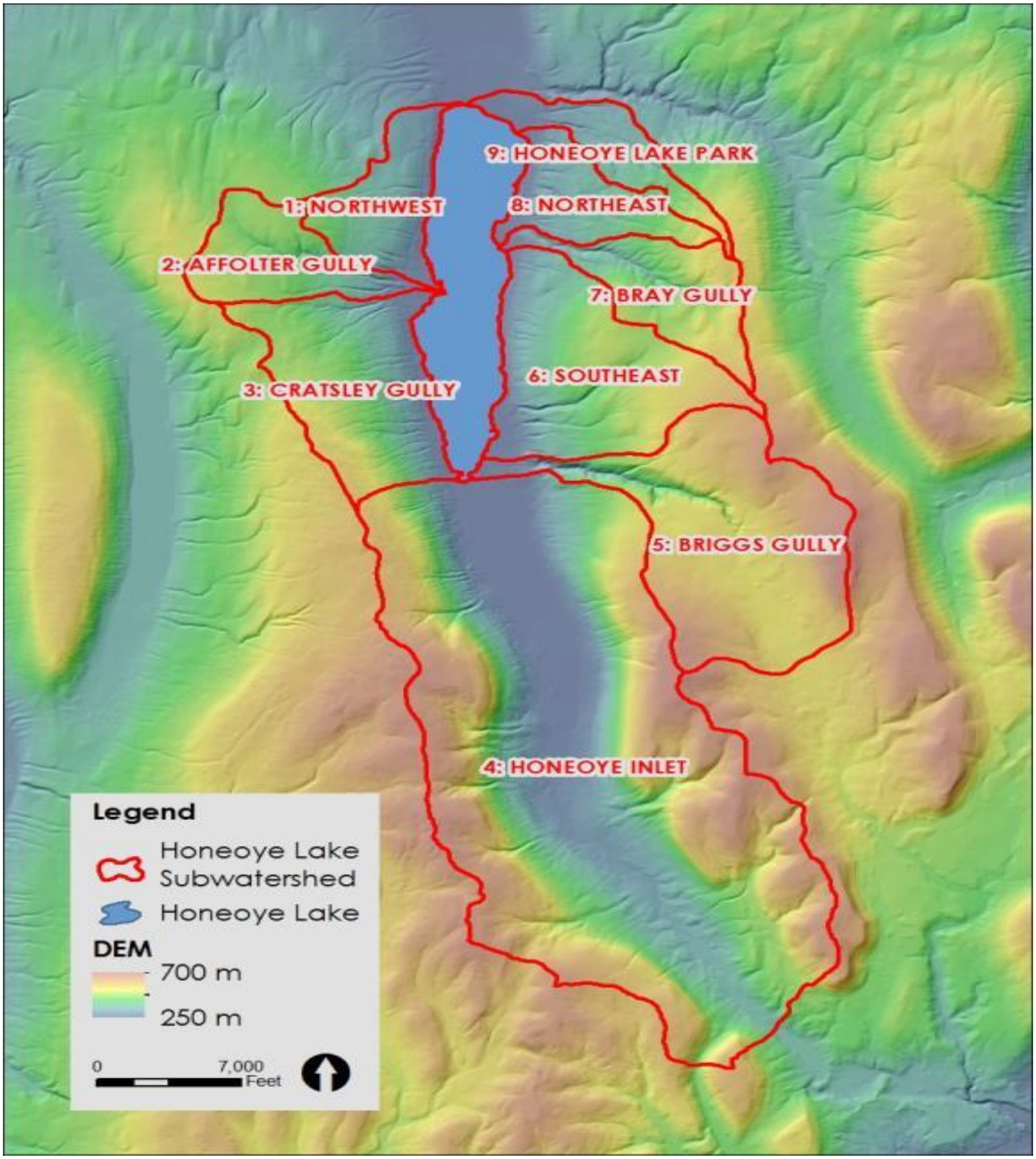


Table 4 - Honeoye Lake – Phosphorus Load by Sub-watershed

Subwatershed	No.	Area	TP (%)
Northwest	1	384	11
Affolter Gully	2	403	8
Cratsley Gully	3	781	12
Honeoye Inlet	4	4,572	47
Briggs Gully	5	1,307	7
Southeast	6	926	6
Bray Gully	7	439	3
Northeast	8	356	4
Honeoye Lake Park	9	285	3

INTERNAL LOADING

Estimates of phosphorus release in Honeoye Lake from bottom sediments were derived from the CE-QUAL-W2 lake model. CE-QUAL-W2 is a two-dimensional (longitudinal and vertical) hydrodynamic water quality model developed by the US Army Corps of Engineers and the Water Quality Research Group at Portland State University (Cole and Wells, 2014). Details of the CE-QUAL-W2 lake model set-up and calibration are provided in Appendix A. CE-QUAL-W2 utilizes two methods to simulate anoxic and oxic nutrient transport from the sediment to the water column. Both methods were employed in the Honeoye Lake TMDL:

Anoxic nutrient release

The model uses a constant, zero-order release and demand approach to simulate organic sediment decay under anaerobic conditions. Anoxic nutrient release from bottom sediment occurs when dissolved oxygen concentrations in the overlying water column are below a specified minimum value. When anoxic conditions develop, typically in the summer months, nutrient release is a function of modeled sediment oxygen demand (grams of oxygen per square meter per day), anoxic release rates for nutrients, and water temperature.

Oxic nutrient release

The model tracks accumulation of organic bottom sediments and their decay under oxic conditions. The first-order sediment compartment tracks organic matter delivery to the sediments via particulate organic matter and dead algal cells, and the subsequent water column oxygen demand that is exerted. Nutrient releases and oxygen demand are dependent on sediment accumulation, a first-order process. Oxic nutrient release from bottom sediment does not occur when the overlying water column is anoxic, since the first-order sediment compartment represents labile, oxic decay of organic sediment.

Estimates of nutrient release from bottom sediments are displayed in Figure 5 below. Average nutrient release over 2007 to 2014 is 8,554 kg/year.

It should be noted that a fundamental coupling exists between external sources (watershed runoff, point sources, etc.) and loading from bottom sediments. The magnitude of phosphorus loading from bottom sediments is influenced by the amount of phosphorus entering a lake in any given year as well as by historical phosphorus loading.

Figure 5 - Phosphorus Sources to Honeoye Lake

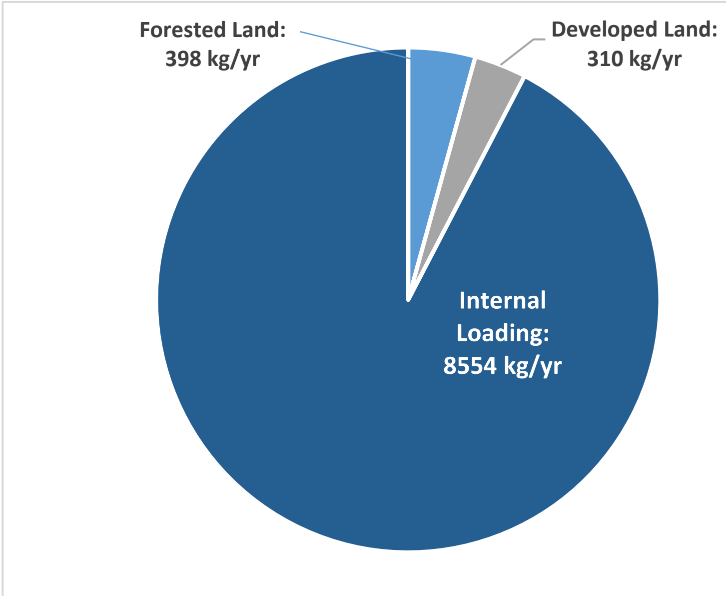


Table 5 - Growing season modeled mean ChlA concentrations

Year	ChlA (ug/l)	TP (ug/l)
2007	14	13
2008	13	10
2009	13	19
2010	55	30
2011	39	37
2012	42	41
2013	44	38
2014	38	69

It is important to note that the ChlA and TP values from 2007 to 2009 that are shown in Table 5 are lower, influenced by the fact that there was a previous, successful, Alum application in 2006 and 2007. The data following the Alum application further supports the fact that internal load is the dominant P source for Honeoye Lake.

PHOSPHORUS LOADING CAPACITY ANALYSIS

The phosphorus loading capacity of Honeoye Lake is the maximum phosphorus load to the lake that results in attainment of the chlorophyll-a target listed in Section 3. The phosphorus loading capacity of Honeoye Lake was analyzed using the CE-QUAL-W2 lake model described in Appendix A. The Honeoye Lake CE-QUAL-W2 model simulates in-lake physical, chemical, and biological processes based on user-supplied inputs related to lake bathymetry, tributary inflows, lake outflows and meteorological conditions.

Analysis of the phosphorus loading capacity of Honeoye Lake was completed by developing a TMDL scenario from the calibrated Honeoye Lake CE-QUAL-W2 model to predict the lake response to a modeled reduced phosphorus loading scenario.

Development of the TMDL scenario model included running the model with watershed stormwater phosphorus loading reduced to undeveloped (forested) conditions, to determine if the target Chl-a concentration could be met via external watershed load reductions only, i.e. without addressing the internal load. These model results did not meet the Chl-a water quality target, so the model was run with internal loading eliminated, and with a 10% watershed stormwater reduction. This scenario resulted in predicted growing season mean Chl-a concentrations to fall substantially below the 4 µ/gl target in all 8 years of the simulation period, and below 1.0 ug/l in all but one year.

Evaluation of the chlorophyll-a target was completed by:

1. Extracting daily model predictions of chlorophyll-a concentrations for the model segment in the middle of Honeoye Lake (segment 15);
2. Calculating the growing season (June to September) mean chlorophyll-a concentration in the surface model layer for each year in the simulation period (2007 through 2014).
3. Comparing predicted growing season mean chlorophyll-a concentrations to the 4 µg/L chlorophyll-a target.

Table 6 – Simulated growing season mean ChlA concentrations
(with internal P load eliminated & 10% watershed P reduction)

Simulation Year	ChlA (ug/l)	TP (ug/l)
Year 1	1.1	2
Year 2	1.0	3
Year 3	0.5	6
Year 4	0.1	9
Year 5	0.1	7
Year 6	0.0	6
Year 7	0.5	10
Year 8	1.1	11

The TMDL scenario CE-QUAL-W2 model estimates that the chlorophyll-a target of 4 μg/L is achieved in all 8 years, given a 10% reduction in watershed TP loads, (reduced to 637 kilograms per year), and elimination of internal loading. The model results for Chla and TP for the TMDL scenario are shown in Table 6.

The objective of a TMDL is to define the pollutant loading capacity of a waterbody and to allocate loads among pollutant sources. Wasteload allocations (WLAs) are assigned to point sources. Nonpoint source loads are assigned load allocations (LAs). A TMDL is expressed as the sum of all individual WLAs, LAs and an appropriate margin of safety (MOS) that factors in an estimated degree of uncertainty.

Equation 1. Calculation of the TMDL.

$$TMDL = \sum WLA + \sum LA + MOS$$

Because of a degree of uncertainty in the efficacy of a phosphorus inactivant application, an explicit margin of safety of 15% of the internal load has been added to the phosphorus loading capacity of Honeoye Lake, which results in a TMDL of 1,920 kg/yr.

This total was distributed as LAs and WLAs, with an implicit and an explicit MOS:

- The WLA is zero since there are no point sources in the watershed;
- The LAs for forested and urban lands are both reduced by 10%;
- The LAs for anaerobic and aerobic sediment release are set to zero;
- There is an implicit MOS, as LA were calculated using a Chla target of 1 ug/l rather than 4 ug/l/;
- An explicit MOS was also included to allow for uncertainty in the characterization of oxic internal load response to inactivant application;

With the application of an inactivant to the deeper areas of the lake, where anoxia occurs during the summer months, the anoxic load is reduced to zero. This anoxic loading occurs approximately at lake depths greater than 18 feet, and accounts for approximately 1,000 acres of lake bottom.

The oxic load is reduced as well to zero, as the application of an inactivant was modeled to include all areas of the lake. However, in areas of the lake where there is rooted weed growth, i.e. areas less than 12 feet deep, rooted macrophytes may impede the effective dispersion of inactivant, potentially preventing complete coverage of the lake bottom. Recently conducted bathymetry of the lake calculated 25% of the lake to be less than 12 feet deep. For this reason, the additional, explicit margin of safety has been added to the TMDL, to account for uncertainty in application effectiveness.

Table 7 - Phosphorus Total Maximum Daily Load (TMDL) for Honeoye Lake

Source	Existing Load (kg/year)	TMDL (kg/year)	Existing Load (kg/day)	TMDL (kg/day)	Reduction
Load Allocations (LA)	**-**	**-**	**-**	**-**	**-**
Forest	398	358	1.1	1.0	10%
Urban	310	279	0.9	0.8	10%
Internal Loading - Aerobic Sediment Release	1,074	0	2.9	0	100%
Internal Loading - Anaerobic Sediment Release	7,480	0	20.5	0	100%
Wasteload Allocation (WLA)	**0**	**-**	**0**	**-**	**-**
LA + WLA	**9,262**	**637**	**25.4**	**1.8**	**93%**
Margin of Safety (15% of internal load)	**-**	1283	**-**	**3.5**	**-**
Total	**9,262**	**1,920**	**25.4**	**5.3**	**-**

<u>CRITICAL CONDITIONS</u>

TMDLs must consider critical environmental conditions to ensure that water quality is protected during times when it is most vulnerable. Critical conditions for chlorophyll-a concentrations in Honeoye Lake are during the growing season months when temperatures are conducive to aquatic plant growth. The chlorophyll-a water quality target was evaluated during the growing season months (June through September) and critical conditions were therefore considered in the development of this TMDL.

<u>SEASONAL VARIATION</u>

TMDLs must consider seasonal variation in environmental conditions. Chlorophyll-a concentrations in Honeoye Lake vary seasonally, with higher concentrations occurring during growing season months. The chlorophyll-a water quality target was evaluated during growing season months and seasonal variation was therefore considered in the development of this TMDL.

TMDL IMPLEMENTATION

This TMDL requires reductions from internal loading as well as watershed sources. The following section enumerates some recommended strategies for achieving water quality standards.

INTERNAL LOADING

Algal growth can be controlled with algaecides or by decreasing the availability of the nutrients in the lake. Some of the most common methods are mentioned here, but some chemical additions can elicit or trigger toxicity, or necessitate other environmental considerations.

Algaecides

Algaecides are generally copper-based chemicals used to kill algae cells (although other products are registered for use in New York), and to reduce the use impairments associated with excessive algal growth. Copper sulfate is the most common algaecide and one of the most popular algae control techniques. There are, however, a variety of copper-based algaecides that may be chosen for various algal problems. Algaecides may be beneficial in treating the symptoms of eutrophication and can provide some short-term relief from the impacts associated with excessive algae growth, including reduced swimming opportunities, fish kills from die-off of large unmanaged blooms, additional water treatment costs and poor aesthetic conditions. These benefits are more likely if the water is treated immediately before blooms occur. Some algaecides, such as hydrogen peroxide-based products, break down into benign compounds and may break down toxins produced in some blue green algae (cyanobacteria) blooms.

Copper-based algaecides may impact the benthic organisms in lakes where these have been applied. The use of algaecides while a bloom peaks can also create oxygen deficits and may release algal toxins that are otherwise bound within algae cells, which are more likely to be controlled through conventional or expanded water treatment techniques. In addition, toxins in the absence of algae cells can leave swimmers vulnerable to toxin exposure in water recently cleared of these cells. Therefore, the timing and use of algaecides in Honeoye Lake would need to be very closely evaluated and approved by DEC. Perhaps most importantly, the use of algaecides will not result in the attainment of the required phosphorus targets (and therefore are unlikely to result in long-term reductions in algae growth).

Nutrient Inactivation

Nutrient precipitation and inactivation is a common lake management technique in other states, where a chemical agent, such as alum (aluminum sulfate), is used to remove phosphorus from the water column and prevent sediment release of additional phosphorus. Nutrient inactivation works by sealing the bottom sediments to prevent the release of phosphorus to the over-lying water with low oxygen concentrations. Alum may be less toxic than algaecides in many instances, less expensive than dredging, and aluminum toxicity is unlikely given the high alkalinity of Honeoye Lake (and can be further prevented with the use of buffered alum). If successful, alum may reduce migration of nutrients from bottom sediments into the lake, providing a long-term reduction in algae growth.

Alum was previously applied to Honeoye Lake in 2006 and 2007. A DEC-permitted Alum dose (DEC Permit #NY-0247421, effective date June 20, 2006) was applied to 1,000 acres of the lake, in areas where lake bathymetry indicated depths greater than 18 feet. These deeper areas become anoxic every summer. An application rate of 150 gallons per acre was applied to Honeoye Lake. The lake showed a reduction in severity of algae blooms and total phosphorus levels for two years, that may be attributed in part to the alum application but diminishing improvement the third year and thereafter. Table 5 shows values for ChlA and TP lower in 2007-2009 than in the subsequent years.

Success in many lakes is dependent on continuing reduction of external nutrient sources, and evaluation of potential side effects, and the cost of a whole lake inactivant treatment would be substantial. DEC and New York State Department of Health (DOH) should be consulted prior to consideration of any chemical treatment to Honeoye Lake.

Hypolimnetic Aeration or Destratification

When the hypolimnion has enough oxygen, the release of phosphorus (and other pollutants) from oxygen depleted bottom sediments will be minimized. Hypolimnetic aeration is used to increase oxygen circulation within a lake and increase oxygen concentration in the deep waters without causing enough disturbance to disrupt stratification. Aeration of the lake bottom waters uses an air-lift device to pump or lift the deep, stagnant water layer for exposure to the atmosphere. This results in aeration and the loss of some gases such as carbon dioxide and methane. Then the water sinks back to the hypolimnion. Hypolimnetic aeration may also be accomplished by injecting pure oxygen or air into the bottom waters or by using an air-lift device along with the injection. With more vigorous aeration and water movement, the hypolimnion can be broken down (destratified), mixing the entire water column and increasing oxygen levels from both the aeration and increased exposure to the atmosphere.

Hypolimnetic withdrawal

Hypolimnetic withdrawal can be accomplished through the installation of a pipe or siphon along the bottom of the lake, usually at the outlet. Water flows out of the hypolimnion by gravity, past the outlet to the receiving waters. If there is insufficient elevation for gravity flow, an auxiliary pump can be installed. Summertime hypolimnetic withdrawal serves to remove the high nutrient waters, thus reducing the potential for algal blooms during fall turnover. Oxygen deficits and elevated phosphorus concentrations are decreased.

WATERSHED MANAGEMENT

Watershed management is needed to reduce the external loading which has created and continues to contribute to the internal loading problem. The Honeoye Lake report: *"Update of the Hydrologic and Nutrient Budgets of Honeoye Inlet and Honeoye Lake"*

(Report), by Princeton Hydro, 2014, and attached to this report as Appendix D, provides in-depth detail on the relative magnitude of phosphorus loading for the various sub-watersheds of Honeoye Lake. The report articulates techniques to address runoff and stormwater loading impacts associated with the lake's subwatersheds. The subwatersheds contributing the greatest pollutant loads are identified. Those identified as having the *"greatest stormwater management net return on the investment"*, because the predominant land use (residential) produces higher phosphorus load per unit area, were the Northwest, Affolter Gully, Cratsely Gully and Northeast subwatersheds.

Among the potential projects articulated in this Report, the report recommended retrofitting the Honeoye Lake Inlet. This project (Honeoye Lake Inlet Restoration Project) has now been completed, with DEC funding, as part of its Round 12 WQIP Grant Program.

Additionally, all thirty-five (35) of the direct tributaries to Honeoye lake should be studied to determine where and how to reduce the sediment and nutrients that they contribute to the lake. For example; Briggs Gully, Bray Gully, and the Honeoye Lake Inlet wetlands and tributaries north of the Inlet Restoration Project are all major contributors of phosphorus loading to the lake and should be assessed for possible stormwater BMP implementation.

RECOMMENDATIONS FOR WATERSHED RESIDENTS

Practice Fertilizer Management:

Over-application of fertilizers during application on residential lawns can cause runoff of fertilizer to the nearest drainage course, which eventually drains into the lake. Homeowners and lawn care services should be reminded to test their lawns, as in many cases there is sufficient phosphorus in the soil and no additional fertilizer is necessary. It should also be noted that, under New York law (effective January 1, 2012), phosphorus-containing fertilizer may only be applied to lawns or non-agricultural turf when:

1. A soil test indicates that additional phosphorus is needed for growth of a lawn or non-agricultural turf, or

2. The fertilizer is used for newly established lawns or non-agricultural turf during the first growing season.

The application of fertilizers should be timed to anticipate rain storms, and applied after, rather than before rain events. Nutrients are needed more in the spring, rather than throughout the summer, so fertilizer application should be limited to the spring season. Fertilizer uptake and retention is promoted by proper soil pH (lime application) as well as by aeration to reduce compacting of soil, and to promote better infiltration and reduce runoff.

Create Riparian Buffers:

Riparian vegetation slows stormwater to maintain stable streambanks and protect downstream property. By slowing down runoff, the riparian vegetation allows more water to soak into the ground and recharge groundwater. Slowing runoff allows the riparian zone to function as a site of sediment deposition, trapping sediments that build stream banks and would otherwise degrade our streams and rivers.

Acquire Sensitive Lands:

Conservation easements should be established where possible on high- priority, water quality-sensitive lands within the watershed. Work with the Honeoye Lake Watershed Task Force (HLWTF) and other organizations to preserve and restore critical resource areas including wetlands and floodplains targeted at sediment reduction.

Install Vegetative Swales:

Vegetated swales are shallow ditches that convey and treat stormwater runoff. Some swales infiltrate runoff as well. Vegetated swales perform best relatively flat (<3%) land. Pollutant removal effectiveness is a function of slope, swale length and the roughness and composition of the vegetation.

Revegetate Shoreline:

The Honeoye Lake watershed is largely (over 80%) undeveloped, with land use as either forest or wetland. The remaining watershed land is developed, as either residential, commercial or farmland. The shoreline, where developed, no longer has an adequate shoreline buffer. The shoreline has by now mostly been converted to lakeshore housing, with its associated nutrient pollution (animal waste, fertilizer runoff, erosion). The removal of this shoreline vegetation causes increased water temperatures and decreased dissolved oxygen. The loss of shade exposes soils to drying out by wind and sunlight and reduces the water storage capacity of the riparian area. The shoreline should be re-vegetated wherever possible, a task only possible with the support of shoreline property owners.

Terrestrial Invasive Species:

Evaluate the presence of terrestrial invasive species, including forest pests that affect hemlock, ash, and other tree species that are currently integral to watershed stabilization. Disruption by these pest species could exacerbate erosion and nutrient loading to Honeoye Lake. Forest research and management should be implemented to extent feasible to identify and control these and other pests as a proactive means to minimize impacts. Strategic planting of species less susceptible to impacts of infestation or other forest management measures may be considered in areas where canopy loss will result in significant system destabilization.

Stabilize Steep Slopes

Many of the streams, gullies, ditches that drain into Honeoye Lake, especially from the west and east sides of the lake drain steep slopes, contributing pollutant-laden sediment into the lake. The creation of riparian buffers near these streams, with vegetation such as

grasses, flowers and trees along the stream banks, can help to prevent sediment and nutrient pollution from reaching these streams and the lake.
Rehabilitating riparian buffers is key to restoring natural stream functions and aquatic habitats. There are many economic benefits derived from increased riparian habitat, channel stabilization, improved water quality, improved wildlife and fish populations, improved aesthetics, and other associated values.

Install Small-scale BMPs:

Rain gardens are small bio-retention basins that treat impervious or slow-draining surfaces like driveways and rooftops. Rain gardens are constructed to can infiltrate intense runoff, reduce runoff volume, and reduce pollutant loading. Rain gardens should be constructed with permeable soils and plant material that can tolerate periodically wet as well as dry conditions.

Maintain Septic Systems:

The Honeoye Lake shoreline and near shore properties are served by a sewer system district that was installed in 1978. Although the near-shore properties are all connected to the Wastewater Treatment Facility (WWTF), there remain approximately 600 private septic systems in the Honeoye Lake watershed, and over 200 of those systems are located on properties within 250 feet of streams which discharge into Honeoye Lake. For residents near streams in the watershed, more frequent pump-out of those septic tanks is recommended. Where appropriate, the proper infrastructure should be installed to connect failing septic systems to the municipal system.

RECOMMENDATIONS FOR MUNICIPALITIES

Install BMPs to Reduce Streambank Erosion:

Soil erosion and stream bank erosion occur during stormwater runoff over exposed soil, through construction, drainage, road projects, and due to increases in stormwater runoff wherever new impervious surfaces are created in a watershed. The removal of streamside buffers reduces bank stability and increases stream bank erosion. Degraded streambeds create unstable, eroding banks. Streambank instability from these human development activities increases the sediment/pollutant load transported into Honeoye Lake. Some streambank stabilization techniques include:

Soil Bioengineering

Plant materials may be used to structurally reinforce/stabilize eroding streambanks. This technique utilizes dormant cuttings of willows, shrub dogwoods and other easily rooted plants. Practices range from simple live stakes to complex structures such as fabricated lifts incorporating erosion control blankets, plants and compacted soil.

Native Material Revetments

These practices use native materials, wood and stone, to armor streambanks and deflect flow away from them. Low rock walls and log cribwalls can be used to armor the bank.

Rootwads armor the bank and provide protection downstream by deflecting the flow away from the bank.

In-Stream Structures
Rock and logs can be used to construct a variety of structures that stabilize the streambed and banks. Cross vanes are rock structures that stabilize the streambed while aiding in streambank stabilization. Rock or log vanes redirect stream flow away from the toe of the streambank and help to stabilize the bank upstream and downstream from the structure. These practices can be used to allow vegetation to become established and create long term bank stability. The streamside vegetation improves habitat by providing shade, cover and food. Some streambank stabilization structures, e.g. root wads, are also excellent fish habitat improvement structures.

<u>Implement Timber Harvesting Local Laws:</u>
Timber harvesting causes the disturbance of soils which, when not stabilized properly, result in stormwater-related erosion to watercourses. Erosion of exposed soil increases the sediment load into Honeoye Lake. If a timber harvest requires crossing a stream, it is possible an Article 15 NY State Stream Disturbance Permit may be required. Depending on the level of harvesting and the extent of road building or other activities associated with a harvest, timber harvests taking place in a wetland may require an Article 24 state wetlands permit.

Soil compaction and rutting associated with timber harvesting can reduce the productivity of a site, disrupt surface drainage and infiltration, and contribute to sediment movement from erosion. During timber harvesting soil compaction results from an increase in soil bulk density, primarily due to the ground pressure of harvesting and construction equipment. Compaction may occur over broad areas, where it would not necessarily result in the visible depressions associated with rutting.

Timber harvesting BMPs and associated educational outreach, including updating of Towns local laws to include restrictions on the development of access roads, haul roads, skid trails, and landings in wet, disturbed or muddy areas, the prevention of excess rutting, the reseeding of skid trails after use, and other measures to reduce soil erosion from the harvesting site are recommended.

<u>Control Aquatic Plant Growth:</u>
Aquatic plants are an important part of lake ecosystems, as fish and wildlife cannot survive without them. Honeoye Lake contains excessive weeds and algae which interfere with swimming, boating and fishing in the lake. While aquatic plants naturally go through cyclical growth patterns, excessive weeds point to a larger problem such as excessive sedimentation and nutrients as well as the potential introduction of invasive species, most of which cannot be eradicated. Consideration should be given to selecting actions with lesser side effects. For more detail on the aquatic plants in Honeoye Lake see *Appendix F: Thirty Years Monitoring the Fall Standing Crop Biomass.* For more detail on aquatic plant control options see *Appendix G: Honeoye Lake Macrophyte Management Plan.*

Honeoye Lake Wastewater Treatment Facility:
The perimeter sanitary sewer line that collects sewage from the near-shore properties includes lift stations that pump the sewage upgradient as required to the Wastewater Treatment Facility (WWTF), where the treated sewage discharges downstream of the Lake. It has been reported that approximately twelve lift stations do not have dedicated back-up generators, and that portable generators are utilized during power outages as necessary to prevent station overflows. A lift station overflow could discharge into the lake. Consideration should be given to installation of dedicated back-up generators for each lift station.

RECOMMENDATIONS FOR TOWN & COUNTY HIGHWAY DEPARTMENTS

Three recent 100-year storms, occurring in two successive years, have accentuated a change in weather patterns and increasing intensity of storms. The storms cause runoff that carries wooden debris, gravel and shale bars, creating overtopping of Town and County roadway culverts, and resultant debris in roadways. Highway Departments are responsible for maintaining the stormwater conveyances, including under road culverts and roadside ditches that accept stormwater from the direct tributaries to Honeoye Lake to maintain safe roadways and stream functionality.

Along with post-storm clean-up, annual ditch maintenance should include reshaping ditches, and hydro seeding to decrease erosion of disturbed soils from the ditch, and where required to slow the velocity of stormwater, the installation of check dams.

Other Lake Management Resources

Diet for a Small Lake (http://www.dec.ny.gov/chemical/82123.html)

- Chapter 6 discusses each aquatic plant management option in detail
- Chapter 7 discusses each algae control option in detail

Harmful Blue-green Algae Blooms

- General information— http://www.dec.ny.gov/chemical/77118.html
- Bloom Notices— http://www.dec.ny.gov/chemical/83310.html
- Frequently Asked Questions— http://www.dec.ny.gov/chemical/91570.html

Invasive Species

- General information - http://www.dec.ny.gov/animals/265.html
- Aquatic invasive species in NYS— http://www.dec.ny.gov/animals/50121.html
- How to prevent the spread of aquatic invasive species— http://www.dec.ny.gov/animals/48221.html Citizens Statewide Lake Assessment Program (CSLAP)

- Need to be a member of the NY Federation of Lake Associations— http://www.nysfola.org/
- No spots available in 2014 program, but can apply to NYSFOLA for 2015
- General information about CSLAP— http://www.dec.ny.gov/chemical/81576.html

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PUBLIC PARTICIPATION

Public participation has helped inform the development of the Honeoye Lake TMDL and has involved stakeholders including the Ontario County Soil and Water Conservation District and the Honeoye Lake Watershed Task Force.

The public outreach efforts prior to the public presentation of the draft TMDL included:

- DEC Presentation of the TMDL concept and development at a Public Town Meeting in December of 2014; and
- Public meeting in August of 2015 providing the initial modeling information and responding to input received from the public and other watershed stakeholders.

The Department made the draft Honeoye Lake TMDL available for public comment and review on January 16, 2019. A 30-day public review period was established for soliciting written comments from stakeholders. The Department held a public meeting on February 4, 2019 in the Town of Honeoye, to provide an overview of the draft TMDL and answer questions about the Honeoye Lake TMDL. Comments were accepted until close of business on February 19, 2019. Written comments that were received, and the Department's responses are below:

Q1: Would it be possible to add the four Honeoye Lake HABs Action Plan recommendations below as Honeoye Lake TMDL recommendations?

1. Acquisition of land and/or establish conservation easements on high priority, water quality sensitive lands within the watershed.
2. Evaluate the presence of terrestrial invasive species, including forest pests that affect hemlock, ash, and other tree species that are currently integral to watershed stabilization. Disruption by these pest species could exacerbate erosion and nutrient loading to Honeoye Lake. Forest research and management should be implemented to extent feasible to identify and control these and other pests as a proactive means to minimize impacts. Strategic planting of species less susceptible to impacts of infestation or other forest management measures may be considered in areas where canopy loss will result in significant system destabilization.
3. Provide funding for replacement of failing septic systems within 250 ft of the Honeoye Lake shoreline and tributaries.
4. Work with the Honeoye Lake Watershed Task Force (HLWTF) and other organizations to preserve and restore critical resource areas including wetlands and floodplains targeted at sediment reduction.

A: Recommendations 1, 2 and 4 have been added to the Honeoye Lake TMDL Implementation section. Funding recommendations are outside the scope of a TMDL.

Q2: The draft Honeoye Lake TMDL has the anaerobic and aerobic phosphorus estimates reversed in the table on page 15.

A2: This typo has been corrected.

Q3: When will the feasibility studies be complete and will those studies be available for public review? Please define the process for obtaining those documents if they will not be publicly posted.

A3: The feasibility studies have not been completed at the time of this response. Once the feasibility studies have been finalized, they may be obtained by contacting the Division of Water at: DOWinfo@dec.ny.gov

Q4: I think it would be prudent to include data from years prior to the alum treatment if the (TMDL) report is to attest to the success or lack of success of the alum treatment.

A4: The lake response was modeled using chlorophyll and phosphorus data from 2007 through 2014 because that was the timeframe for the available data; that information is summarized in Table 5. The language in the TMDL regarding the 2006 inactivant application acknowledges a subsequent reduction in chlorophyll levels. DEC agrees that factors other than the alum treatment may have influenced the reduction. The success of any alum treatment depends on the proper application, dose and, as the TMDL states, *"success in many lakes is (also) dependent on continuing reduction of external nutrient sources…".*

Q5: HABs on Honeoye lake follow short-term temporary patterns that are only partially connected to legacy phosphorus. Legacy phosphorus comes into play in late summer when temp and oxygen levels are ideal, but the majority of HAB events are caused by temporary point loading (stormwater runoff carrying sediment). Would be nice if the DEC report addressed this issue, as it's the only way real progress will be made with improving water quality within a generation.

A5: The primary source of Honeoye Lake's internal phosphorus load is legacy sediment-bound, inorganic phosphorus resuspending in the water column. This legacy phosphorus is the result of years of stormwater runoff carrying sediment into the lake, which has resulted in a large amount of phosphorus in the sediment that now constitutes the internal load. Watershed loading due to rainfall, especially from more intense storms, is a persistent contributor to the phosphorus load to the lake, and so TMDL implementation recommendations also include watershed sediment and erosion control projects, in addition to the recommendations on mitigating the internal load.

Q6: 1st, the stagnant water levels in late summer prevent any outflow of surface water at North end of lake. If the weir were to have an operable gate or even a step or V-notch, water flow would continue during the dry season. Since the HAB is concentrated near the surface, an operable weir would allow the lake to shed/drain large portions of algae blooms before they become harmful.

2nd, Honeoye Lake has very high and often flood level water elevations in the Spring. Nutrients and sediment washed into lake from grassy shores. With an operable weir to control lake level, the added nutrient loading into lake every spring from high water level erosion could be eliminated.

3rd, the lack of natural variation in annual water level allows invasive Zebra mussels to have a much longer growing season. If we were to allow the lake water levels to be reduced another 2', closer to historic natural variations, than the Zebra Mussels would have to move their growing zone continuously over the season. This would significantly reduce Zebra Mussel populations, which tend to make HABs worse by disproportionately consuming non-toxic algae and putting toxic algae back into the water body.

A6: Due to the lake's long residence time (flushing rate) of 13 years, the large source of internal phosphorus loading, and the inherent nature of cyanobacteria growth and movement, (although the densest accumulations are at the surface, cyanobacteria live throughout the water column), it is unlikely that weir modifications would have a significant impact on bloom formation in Honeoye Lake.

The purpose of the TMDL is to calculate the maximum phosphorus loading to the lake that will allow water quality standards to be met, and to recommend management tools to accomplish the phosphorus reductions. The primary cause of blooms in the lake is excessive nutrients, and the TMDL and independent analyses show that most of these nutrients come from bottom sediments and internal nutrient loading. Addressing the internal loading source is therefore a primary recommendation. Water circulation and other factors are not the priority for managing water quality problems in the lake.

Q7: On page 21, the (TMDL) document states: *"It has been reported that approximately twelve lift stations do not have dedicated back-up generators, and that portable generators must be utilized whenever power outages occur."* This statement is not accurate. It is not practical to deploy portable generators whenever power outages occur. The part of the statement pertaining to portable generators should be reworded to the say to the effect that: …*portable generators are utilized during power outages as necessary to prevent lift station overflows.*

A7: The suggested language change has been added for clarity.

APPENDIX A-CE-QUAL-W2 MODEL SETUP AND CALIBRATION FOR HONEOYE LAKE

Prepared by The Cadmus Group, Inc. for U.S. Environmental Protection Agency Region 2

April 2016

A1 Introduction

This Appendix describes the setup and calibration of a CE-QUAL-W2 hydrodynamic and water quality model for Honeoye Lake in Ontario County, New York. The CE-QUAL-W2 lake model was developed by The Cadmus Group, Inc., and Dr. Scott Wells and Dr. Chris Berger of Wells and Associates. The model was used to support analysis of a phosphorus Total Maximum Daily Load (TMDL) for Honeoye Lake.

A2 Description of CE-QUAL-W2

CE-QUAL-W2 is a public domain two-dimensional (longitudinal and vertical) hydrodynamic and water quality model (Cole and Wells 2015). The model assumes lateral homogeneity within a waterbody and is therefore ideally suited for long and narrow waterbodies such as rivers or narrow lakes. CE-QUAL-W2 can predict water surface elevations, velocities, temperature, and several water quality constituents. The model represents a waterbody using multiple longitudinal segments and multiple vertical layers within each segment. Typical model longitudinal resolution is between 100 to 1000 meters and vertical resolution is typically between 0.5 and 2 meters. The model was originally developed by the US Army Corps of Engineers and has been maintained by Dr. Scott Wells of Portland State University in recent years. The user manual and documentation can be found at http://www.cee.pdx.edu/w2.

A3 Model Setup

Steps for setting up a CE-QUAL-W2 model include horizontal and vertical segmentation the lake, defining segment morphology, preparing weather inputs, preparing inflow and outflow data, selecting water quality constituents to model, and selecting initial parameter values. Data required to setup a CE-QUAL-W2 model are summarized in Table 2.

Table 2: Data needs for CE-QUAL-W2 lake modeling.

Data Type	Purpose
Bathymetric map of lake	Define dimensions of model segments and layers
Time series of inflow flow rates, water temperatures, and concentrations of water quality constituents for all inflows (tributaries, direct drainage, point sources, etc.)	Define upstream boundary conditions
Time series of outflow flow rates and locations of all outflows (outlets, withdrawals, etc.)	Define downstream boundary conditions.
Outlet structure details for spillways, including rating curves for the spillways	The centerline elevation of outlets and weir crest elevations are of importance in predicting vertical stratification in a lake and outflow during spill events
Hourly meteorological records (air temperature, dew point temperature, wind speed, wind direction, solar radiation, and cloud cover)	Define meteorological forcings
Water surface elevation records	Model calibration
In-lake water temperature and water quality records	Model calibration
Measured kinetic or estimated model coefficients from field data (if available)	Defining initial parameter values

Model Bathymetry

CE-QUAL-W2 represents a lake as a two-dimensional grid consisting of multiple longitudinal segments and multiple vertical layers within each segment. The model grid for Honeoye Lake was developed using geospatial bathymetric data for the lake (based on a 2014 bathymetric survey; acquired from the 014 bathymetric survey results provided by the Honeoye Lake Watershed Task Force) and Watershed Modeling System (WMS) software. The model grid was configured with segment lengths of approximately 200 meters and 20 active vertical layers (Figure 1). Characteristics of the model grid for Honeoye Lake are listed Table 3.

Table 3. CE-QUAL-W2 model grid characteristics for Honeoye Lake.

Lake	No. of Longitudinal Segments	Longitudinal Segment Length (meters)	Total Length (meters)	No. of Vertical Layers	Vertical Layer Depth (meters)
Honeoye	30 (28 active)	200-276	6,929	22 (20 active)	0.46

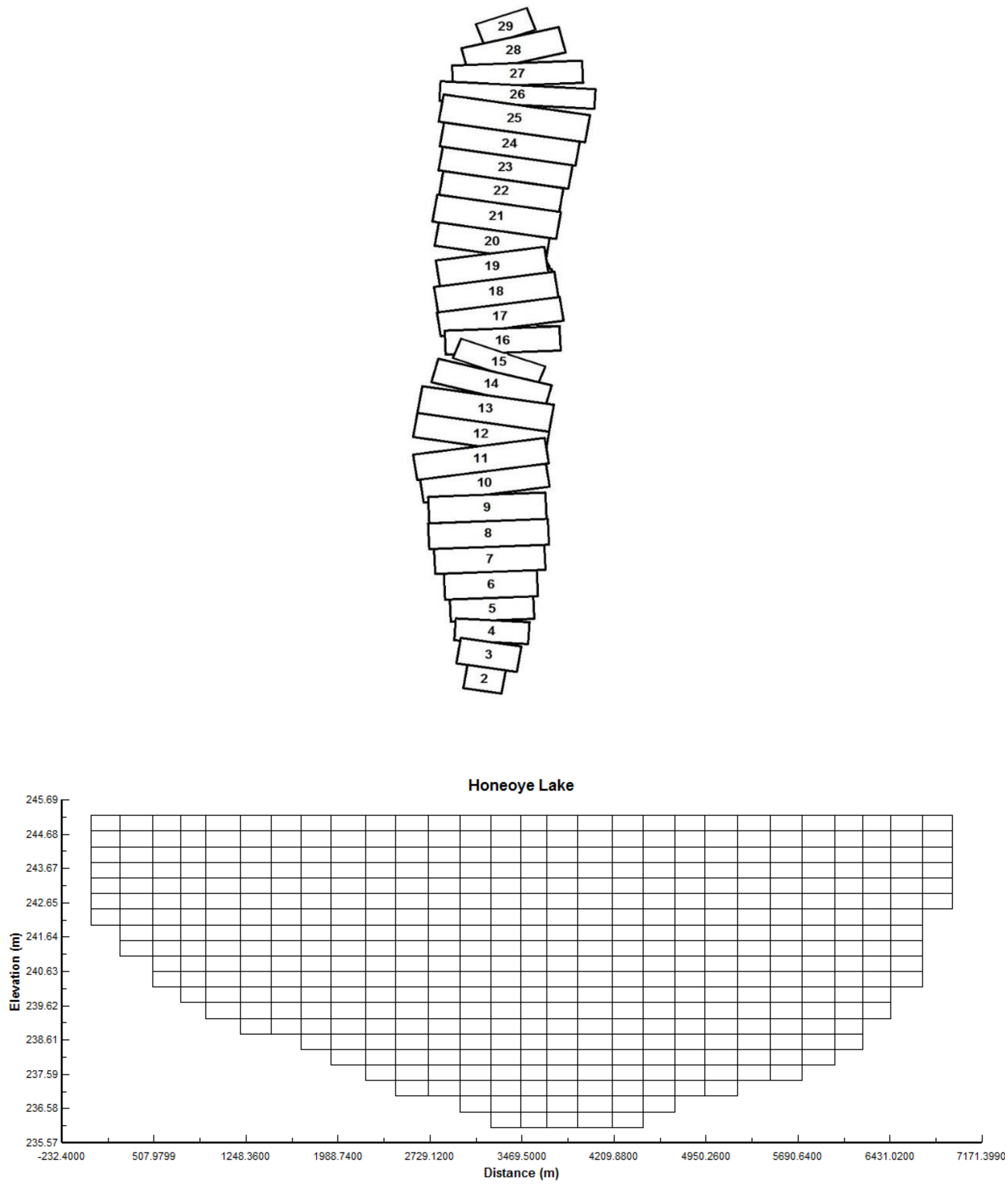


Figure 1. Top and side view of the Honeoye Lake CE-QUAL-W2 model grid.

Meteorological Data

CE-QUAL-W2 requires hourly records of the following meteorological variables: air temperature, dew point temperature, wind speed and direction, and cloud cover. Records of these variables were obtained from the National Climate Data Center (NCDC) website for Dansville Municipal Airport weather station (Table 4). The Dansville Municipal Airport station is located approximately 8.9 miles from Honeoye Lake. Gaps in the meteorological time series were filled as the average of the preceding and next available record with data.

Cloud cover ratings in the NCDC dataset were reported on a scale of zero (no clouds) to four (overcast), while CE-QUAL-W2 requires cloud cover on a scale of zero (no clouds) to ten (overcast). NCDC cloud cover ratings were translated to a zero to ten scale for input to CE-QUAL-W2 using values listed in Table 5. The NCDC dataset also includes a cloud cover rating of five for surface-based obscurations, such as fog, that were assumed to correspond to full cloud cover for input to CE-QUAL-W2.

CE-QUAL-W2 also allows users to input precipitation records. Daily precipitation records from the Hemlock Lake weather station (Table 4) acquired from the NCDC website and input to the Honeoye Lake model.

Table 4. Meteorological station summary.

Station Name	Latitude	Longitude	Elevation (meters)
Dansville Municipal Airport	42.57083°	-77.71333°	208.8
Hemlock Lake	42.7743°	-77.6083°	274.9

Table 5. Conversion table used to translate NCDC cloud cover to CE-QUAL-W2 cloud cover.

NCDC Cloud Cover	NCDC Cloud Cover Description	CE-QUAL-W2 Cloud Cover
0	Clear	0
1	Few Clouds	1.9
2	Scattered Clouds	4.4
3	Broken Clouds	7.5
4	Overcast	10
5	Obscured	10

Water Quality Constituents

Water quality constituents simulated in the CE-QUAL-W2 Honeoye Lake model are:

- Inorganic Suspended Solids (1 group)
- Algae (2 groups)
- Epiphyton (1 group)
- Macrophytes (1 group)
- Zooplankton (1 group)
- Phosphate Phosphorus
- Ammonium Nitrogen
- Nitrate + Nitrite Nitrogen
- Labile Dissolved Organic Matter (LDOM)
- Refractory Dissolved Organic Matter (RDOM)
- Labile Particulate Organic Matter (LPOM)
- Refractory Particulate Organic Matter (RPOM)
- Labile Dissolved Organic Matter – Phosphorus (LDOM-P)
- Refractory Dissolved Organic Matter – Phosphorus (RDOM-P)
- Labile Particulate Organic Matter – Phosphorus (LPOM-P)
- Refractory Particulate Organic Matter – Phosphorus (RPOM-P)
- Labile Dissolved Organic Matter – Nitrogen (LDOM-N)
- Refractory Dissolved Organic Matter – Nitrogen (RDOM-N)
- Labile Particulate Organic Matter – Nitrogen (LPOM-N)
- Refractory Particulate Organic Matter – Nitrogen (RPOM-N)
- Dissolved Organic Carbon (DOC)
- Total Organic Carbon (TOC)
- Total Nitrogen (TN)
- Total Phosphorus (TP)
- Chlorophyll-a

Bottom Sediments

CE-QUAL-W2 uses two methods to simulate the effects of bottom sediment on water column nutrient and dissolved oxygen concentrations. The first method uses a constant zero-order release and demand approach to simulate organic sediment decay under anaerobic conditions. Nutrient release from bottom sediment does not occur from the zero-order process when dissolved oxygen concentrations in the overlying water column are above a specified minimum value. When anoxic conditions develop, nutrient release from the zero-order process are a function of user-supplied sediment oxygen demand (grams of oxygen per square meter per day), anoxic release rates for nutrients, and water temperature.

The second method uses a sediment compartment to track accumulation of organic bottom sediments and allow their decay under oxic conditions. The first-order sediment compartment is not a true sediment diagenesis compartment as it does not keep track of organic nutrient delivery to the sediments, their decay, and subsequent release back into the water column during hypoxic/anoxic conditions. However, it does keep track of organic matter delivery to the sediments via particulate organic matter and dead algal cells, and the subsequent water column oxygen demand that is exerted. Nutrient releases and oxygen demand are dependent on sediment accumulation, a first-order process. There is no release of nutrients when the overlying water column is anoxic as the first-order sediment compartment represents labile, oxic decay of organic sediment. A description of zero-order & first-order sediment decay parameters is provided in Table 6.

Table 6. Description of bottom sediment parameters in the CE-QUAL-W2 model.

Parameter	Applies To	Description
Sediment oxygen demand, grams per square meter per day (SOD)	Zero-Order Decay	Sediment oxygen demand for the zero-order sediment compartment.
Sediment release rate of phosphorus, as a fraction of SOD (PO4R)	Zero-Order Decay	Release rate of phosphorous from the zero-order sediment compartment under anaerobic conditions, specified as a fraction of sediment oxygen demand.
Lower temperature for sediment decay, degrees Celsius (SODT1)	Zero-Order & First-Order Decay	Lower temperature for decay rate multiplier curve.
Upper temperature for sediment decay, degrees Celsius (SODT2)	Zero-Order & First-Order Decay	Upper temperature for decay rate multiplier curve.
Fraction of SOD or sediment decay rate at lower temperature (SODK1)	Zero-Order & First-Order Decay	Decay rate multiplier at lower temperature.
Fraction of SOD or sediment decay rate at upper temperature (SODK2)	Zero-Order & First-Order Decay	Decay rate multiplier at upper temperature.
Initial sediment concentration, grams per square meter	First-Order Decay	Initial concentration of organic sediment in 1st-order bottom compartment, determines initial concentrations of N, P, and C in the 1st-order sediment compartment using stochiometric coefficients.
Sediment settling rate, per day (SEDS)	First-Order Decay	Settling rate of organic sediment from the water column to the 1st-order sediment compartment.
Sediment decay rate, per day (SEDK)	First-Order Decay	Maximum decay rate of organic sediment in the 1st-order sediment compartment.
Sediment burial rate, per day (SEDBR)	First-Order Decay	Burial rate of organic sediment in 1st-order sediment compartment. Organic sediment is not available for decay after burial.

Lake Inflows

CE-QUAL-W2 allows three types of lake inflows to be defined:

1. Branch inflow – Inflow to the most upstream model segment, such as inflow from an inlet stream or river;
2. Tributary inflow – Inflow to any model segment, such as inflow from a tributary stream to the middle/lower portion of a lake;
3. Distributed tributary inflow – Inflow that is distributed between all model segments, such as direct drainage from nearshore areas.

Rates of watershed inflow to Honeoye Lake were estimated using the Soil and Water Assessment Tool (SWAT). SWAT is a continuous, process-based watershed model that simulates runoff using information on watershed characteristics (land use, soils, slope, etc.) and weather records (Neitsch et al. 2011). SWAT models for the entire Genesee River watershed (including the Honeoye Lake watershed) were developed as part of a separate effort by researchers at the State University of New York at Brockport (SUNY Brockport) for the US Department of Agriculture. A summary of the Genesee River watershed SWAT modeling effort is provided in Makarewicz et al. (2013a, b). The project created multiple SWAT models that together cover the Genesee River watershed. The Honeoye Lake watershed is within the area covered by the “Honeoye Creek” SWAT model. The Honeoye Creek SWAT model includes the entire Honeoye Creek watershed from its headwaters to its confluence with the Genesee River.

SWAT model files for the Honeoye Creek model were acquired from SUNY Brockport for use in the Honeoye Lake modeling effort. Minor revisions were applied to the model after acquisition and review of model files. The simulation period was extended to cover January 1, 2006 through December 31, 2014. This required extending daily precipitation and air temperature records for weather stations in each model to include the years 2013 and 2014 using weather data from the NCDC website. The first year of the SWAT simulation period (2006) was considered a “warm-up” period for initial conditions to stabilize and was input to the CE-QUAL-W2 lake model.

Output from the Honeoye Creek SWAT model was used to derive daily branch inflow rates to Honeoye Lake over the period January 1, 2007 through December 31, 2014. Inflow rates were extracted from daily flow predictions in the SWAT Reach Output file. Branch inflow consisted of predictions for SWAT model reach 15 (

Figure 2). Because this reach includes the entire Honeoye Lake watershed no tributary or distributed tributary inflows were defined in the Honeoye Lake CE-QUAL-W2 model.

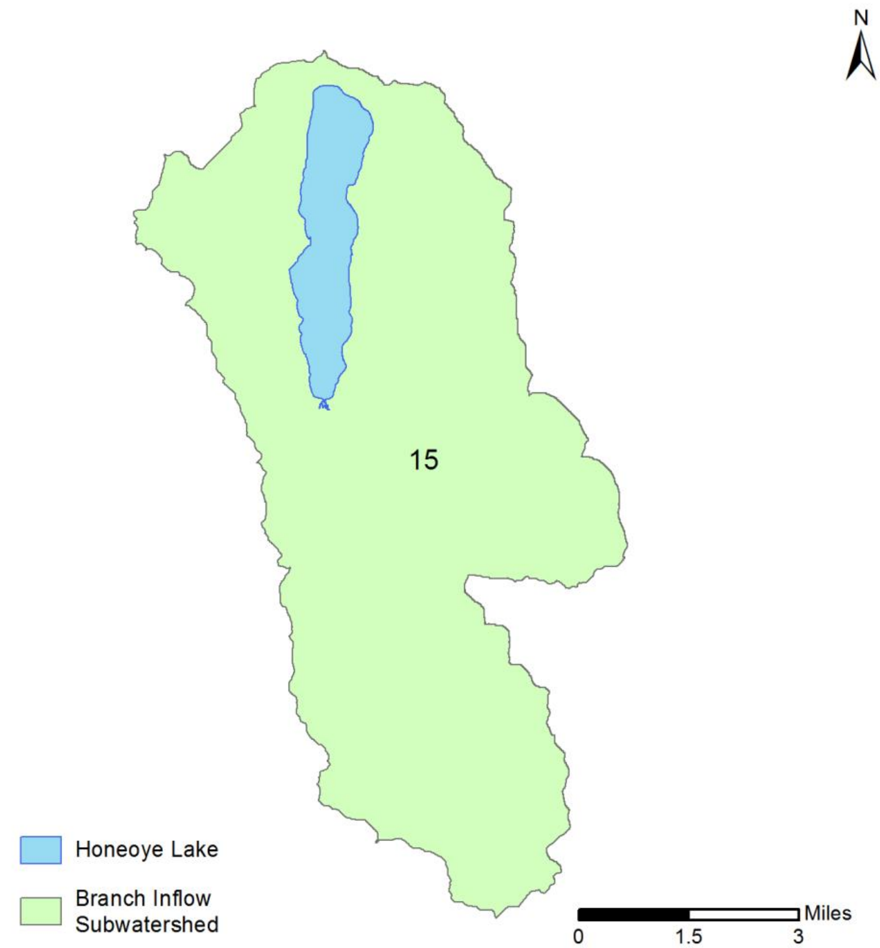


Figure 2. Honeoye Creek SWAT model subwatershed used to define branch inflow for the Honeoye Lake CE-QUAL-W2 model.

Lake Outflows

The Honeoye Lake CE-QUAL-W2 model was configured to predict outflow rates from Honeoye Lake internally using a weir stage-discharge equation. The Honeoye Lake outlet consists of a broad-crested weir that measures 107.0 meters in length with a crest elevation of 244.91 meters. If the upstream edge is well rounded, experiments have shown that discharge from a broad-crested weir can be estimated using the following equation (Streeter and Wylie, 1985):

$$Q = 1.67LH^{3/2}$$

where L is weir length in meters, H is upstream head in meters, and Q is discharge in cubic meters per second. Head (H) is calculated internally by the CE-QUAL-W2 model by subtracting the crest elevation from the predicted water surface elevation.

Watershed Water Quality Loadings

Daily time series of water quality constituent concentrations are needed for branch, tributary, and distributed tributary inflows in CE-QUAL-W2 models. Concentrations of most constituents were derived using the Honeoye Creek SWAT watershed model described in Section A8. SWAT-predicted daily loads reported in reach output files were divided by mean daily flows to estimate daily concentrations in branch inflows to Honeoye Lake. Below is a summary of methods applied to derive inflow concentrations for CE-QUAL-W2 state variables.

- Phosphate Phosphorus (PO4-P) – Set to SWAT mineral phosphorus (MINP);
- Nitrate + Nitrite Nitrogen (NOxN) – Calculated as SWAT nitrate (NO3) plus nitrite (NO2);
- Labile Dissolved Organic Phosphorus (LDOM-P), Refractory Dissolved Organic Phosphorus (RDOM-P), Labile Particulate Organic Phosphorus (LPOM-P), and Refractory Particulate Organic Phosphorus (RDOM-P) – Each calculated as SWAT organic phosphorus (ORGP) divided by 4;
- Labile Dissolved Organic Nitrogen (LDOM-N), Refractory Dissolved Organic Phosphorus (RDOM-N), Labile Particulate Organic Phosphorus (LPOM-N), Refractory Particulate Organic Nitrogen (RDOM-N) – Each calculated as SWAT organic nitrogen (ORGN) divided by 4;
- Labile Dissolved Organic Matter (LDOM), Refractory Dissolved Organic Matter (RDOM), Labile Particulate Organic Matter (LPOM), and Refractory Particulate Organic Matter (RPOM) – Each calculated as total organic matter divided by 4. Total organic matter was estimated using SWAT organic phosphorus (ORGN), organic nitrogen (ORGP), and methods described in Debele et al. (2007).
- Inorganic Suspended Solids (ISS) – Calculated as SWAT sediment (SED) minus labile and refractory particulate organic matter (LPOM + RPOM);
- Ammonium Nitrogen (NH4N) – Set to 0.1 milligrams per liter;
- Algae – Set to 0.02 milligrams per liter;

- Dissolved Oxygen (DO) – Calculated from average daily air temperature at the Hemlock weather station and equation 1:1.3.13 in SWAT Theoretical Documentation (Neitsch et al. 2011);
- Water Temperature – Calculated from daily water temperature estimates and equation 3 in Debele et al. (2007).

Atmospheric Water Quality Loadings

Atmospheric loading of water quality constituents to the surface of a lake are input in CE-QUAL-W2 as constituent concentrations in precipitation. The Honeoye Lake CE-QUAL-W2 was setup to simulate atmospheric loading of ammonium nitrogen, nitrate plus nitrate nitrogen, and phosphate phosphorus.

Concentrations of ammonium nitrogen and nitrate plus nitrate nitrogen in precipitation were set to mean annual values for 2007 through 2014 reported for a precipitation chemistry monitoring site in the town of Alfred in Allegheny County, New York (Table 7). The Alfred monitoring site is part of the National Atmospheric Deposition Program (NADP) Network National Trends Network (station ID NY01; latitude 42.2276 longitude -77.8016). Mean annual ammonium nitrogen and nitrate nitrogen concentrations for the Alfred site were acquired from the NADP website.

Table 7. Mean annual concentrations of ammonium nitrogen (NH4-N) and nitrate nitrogen (NO3-N) measured in precipitation at the Alfred monitoring site.

Year	NH4-N (mg/L)	NO3-N (mg/L)
2007	0.204	0.885
2008	0.224	0.878
2009	0.186	0.748
2010	0.201	0.732
2011	0.244	0.881
2012	0.234	0.857
2013	0.255	0.874
2014	0.253	0.814

The concentration of phosphate phosphorus in precipitation was estimated from an aerial loading rate reported in USGS (2005), based on precipitation chemistry samples collected at Mendon Ponds County Part in Monroe County, New York during the years 2000 through 2002. The average atmospheric aerial loading rate of phosphate phosphorus over this period is 233 pounds per square mile. This value was converted to a phosphate phosphorus concentration of 0.079 milligrams per liter using the Honeoye Lake surface area and precipitation totals.

Sediment Temperature

Bottom sediment temperature was set to the mean annual air temperature from the Dansville Municipal Airport weather station (9.08 degrees Celsius) in the Honeoye Lake CE-QUAL-W2 model. This is the approach recommended in the CE-QUAL-W2 user manual (Cole and Wells 2015).

Initial Model Parameter Values

Initial values of remaining hydrodynamic and water quality parameters were set to default values specified in the CE-QUAL-W2 user manual (Cole and Wells 2015).

Simulation Period

The simulation period for the Honeoye Lake CE-QUAL-W2 is January 1, 2007 through December 31, 2014.

A4 Model Calibration

Model calibration consisted of evaluating model hydrodynamics (water level and flow), water temperatures, and water quality constituent concentrations using in-lake observations from each simulation year and adjusting model parameter values and inputs so that simulated data better matched observed data.

Water Surface Level

Daily observations of 2007 through 2014 water surface elevations were available for the Honeoye Lake outlet (acquired from the Honeoye Lake Watershed Task Force). Calibration of water surface levels was completed by adding a "water balance" inflow as a distributed tributary inflow to Honeoye Lake and adjusting inflow magnitudes based on a comparison of water level predictions from CE-QUAL-W2 to observed water levels. This was an iterative process, where water balance flows were manually adjusted until predicted water levels matched observations.

Error statistics for predicted Honeoye Lake water level were a mean error of -0.01 meters and a mean absolute error of 0.032 meters. Figure 3 illustrates calibrated water surface levels in the Honeoye Lake model.

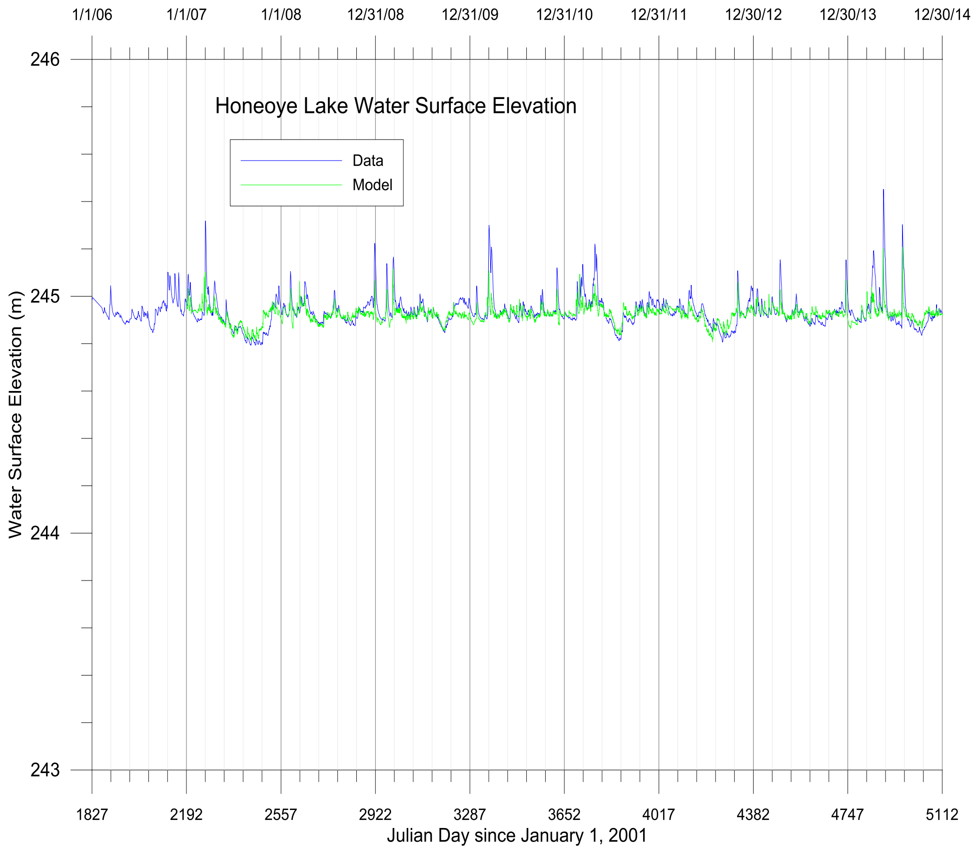


Figure 3. Predicted (green) and observed (blue) Honeoye Lake water surface level.

Temperature and Water Quality Calibration

Sources of observed data for temperature and water quality calibration included in-lake monitoring data for 2007 through 2014 conducted by the Honeoye Lake Watershed Task Force. The Task Force collects water quality sample data from the deepest point in the lake (model segment 15). Samples of temperature, dissolved oxygen, soluble reactive phosphorus, total phosphorus, and chlorophyll-a were available for calibration. Samples of Honeoye Lake nitrogen concentrations were not available for calibration.

Calibration of water quality in the Honeoye Lake CE-QUAL-W2 model focused on adjusting parameters related to zero-order and first-order sediment decay, algal growth rates, and algal nutrient stoichiometry. Calibration was challenging because of uncertainty regarding the accuracy of input data on meteorological conditions and inflow water quantity/quality. Meteorological inputs were based on conditions at a weather station located 8.9 miles from Honeoye Lake (see Section A5) rather than on-site meteorological records. Inflow water volumes and constituent concentrations were derived from a SWAT watershed model (see Section A11) rather than from field monitoring. We strived to match predicted water quality dynamics over the long-term to trends in field monitoring data. We did not undertake a major effort to adjust wind sheltering, meteorological records, or other inputs to further reduce differences between model predictions and monitoring data. This provides a model that is not over-fit to observed data and is better-suited for simulating water quality management strategies.

Zero-order sediment oxygen demand (SOD) was calibrated to a value of 0.5 grams O_2 per square meter per day. Zero-order SOD represents the oxygen demand exerted by legacy organic matter deposited to the lake bottom prior to the simulation period. Typical values for SOD for eutrophic systems range from 1.0 to 5.0 grams O_2 per square meter per day (Cole and Wells 2015). Hypolimnetic phosphorus concentrations were sensitive to the zero-order sediment release rate of phosphorous, calibrated to a value of 0.01. Since the zero-order sediment release rate of phosphorous is specified as a fraction of SOD, the calibrated value of 0.01 equates to an anaerobic phosphorus release rate of 5 milligrams P per square meter per day. This is in line with the anaerobic phosphorus release rate used in a previous study of internal nutrient loading in Honeoye Lake (6 milligrams P per square meter per day; Princeton Hydro 2007).

The first-order sediment compartment was used to model oxic decay of organic matter deposited to the lake bottom during the simulation period. The first-order sediment compartment is not a true sediment diagenesis compartment as it does not keep track of organic nutrient delivery to the sediments, their decay, and subsequent release back into the water column during hypoxic/anoxic conditions. However, it does keep track of organic matter delivery to the sediments via particulate organic matter and dead algal cells, and the subsequent water column oxygen demand that is exerted. Calibration of first-order sediment compartment parameters focused on the first-order sediment decay rate (calibrated to 0.06 per day) and the sediment burial rate (calibrated to 0.025 per day). The growth of algae in Honeoye Lake was sensitive to values of algal stoichiometric fractions for nitrogen (the ratio between nitrogen in algal biomass and total algal biomass) and phosphorus (the ratio between phosphorus in algal biomass and total algal biomass). The stoichiometric fraction for phosphorus was calibrated to 0.015 for algae group 1 and 0.01 for algae group 2. The stoichiometric fraction for nitrogen fractions was calibrated to 0.08 for both algae groups. Calibrated values indicated that Honeoye Lake is a system in which algae growth is phosphorus limited (discussed further in Section A5).

Table 8 lists performance statistics for the calibrated Honeoye Lake CE-QUAL-W2 model. Plots of observed versus predicted surface concentrations of phosphorus and chlorophyll-a are provided in Figure 4 and Figure 5. General guidelines for acceptable performance of CE-QUAL-W2 models include mean absolute errors (MAE) of less than 1 degree Celsius for temperature and less than 1.0 mg/l for dissolved oxygen. For the Honeoye Lake model, the temperature MAE (0.76) is below the guideline and the dissolved oxygen MAE (1.34) is slightly above the guideline. A calibration guideline for chlorophyll-a is MAE less than 0.2 times the range of observed concentrations. For Honeoye Lake, the chlorophyll-a MAE is approximately 0.14 times the range of observations (within the guideline).

Table 8. Honeoye Lake water quality error statistics.

Constituent	# of Profiles	# of Samples	Mean Error	Mean Absolute Error	Root Mean Square Error
Temperature, C	84	756	-0.17	0.76	0.91
Dissolved Oxygen, mg/l	84	755	-0.5	1.34	1.69
Soluble Reactive Phosphorus, mg/l	62	142	0.029	0.036	0.047
Total Phosphorus, mg/l	62	142	0.02	0.037	0.045
Chlorophyll a, µg/l	61	61	4.13	26.7	26.7

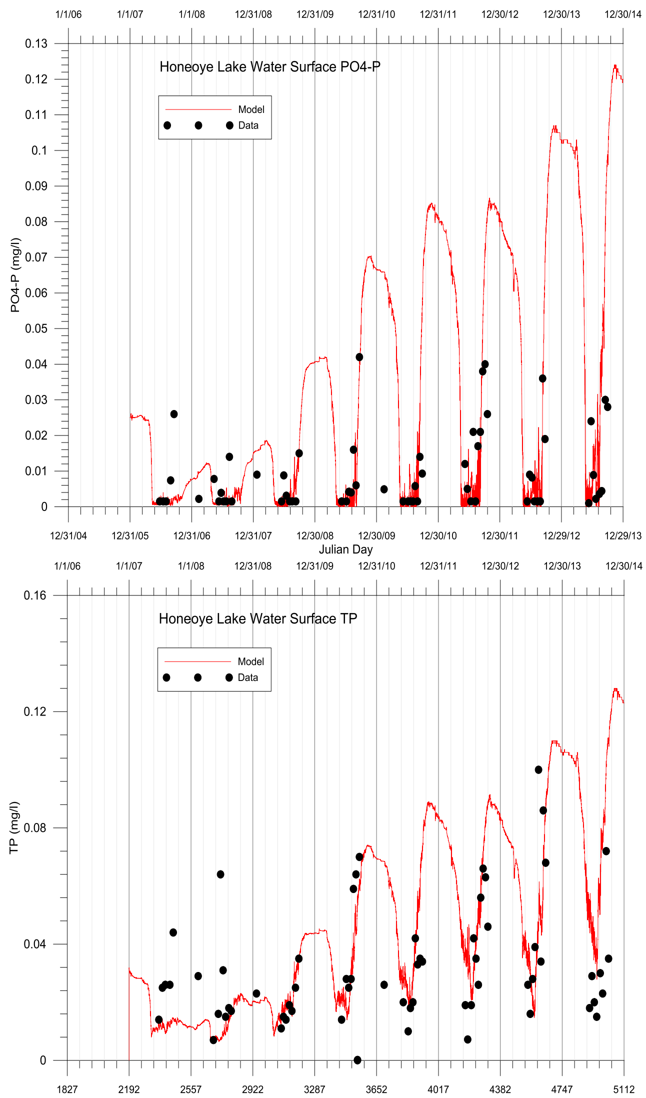


Figure 4. Predicted (red line) and observed (black points) concentrations of phosphate phosphorus (PO4-P; top) and total phosphorus (TP; bottom) at the surface of Honeoye Lake at its deepest point.

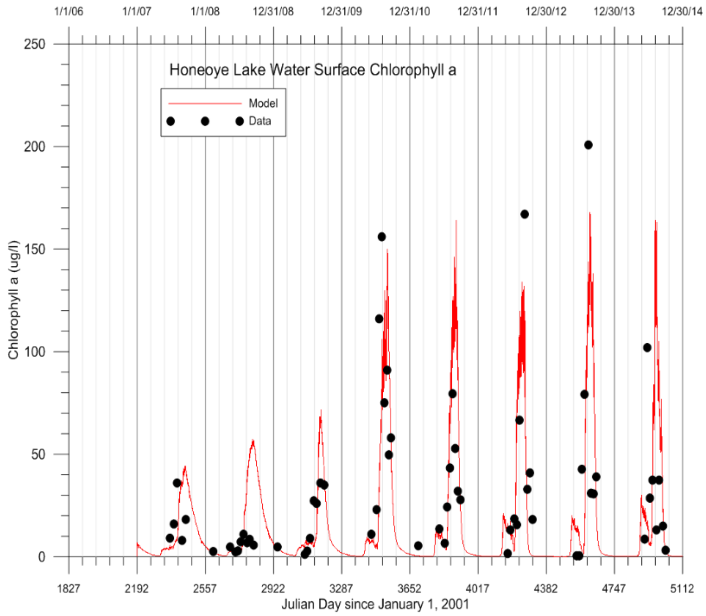
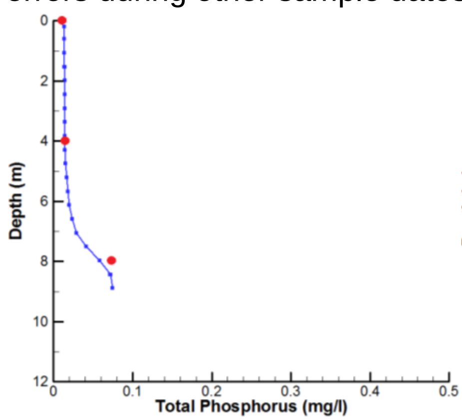


Figure 5. Predicted (red line) and observed (black points) concentrations of chlorophyll-a at the surface of Honeoye Lake at its deepest point.

Figure 6 illustrates predicted and observed total phosphorus concentrations at the deepest point of Honeoye Lake at two different times during the simulation period. These plots demonstrate our calibration approach and implications on model performance statistics. The 6/6/09 plot shows a typical total phosphorus profile during the summer months (concentrations at depth greater than surface concentrations) and model predictions accurately capture vertical variation. In the 6/6/12 plot, samples from 0 and 8 meters have similar phosphorus concentrations but the model predicts strong vertical gradient. We attribute the error in 6/6/12 predictions to meteorological and inflow input data. Further adjustment to achieve better fit to 6/6/12 observations would result in greater errors during other sample dates that follow more typical patterns in the sample data.



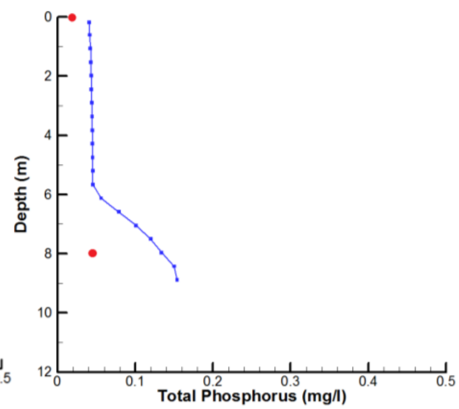


Figure 6. Predicted (blue line) & observed (red point) TP concentrations at the deepest point of Honeoye Lake on 6/16/09 (left) and 6/6/12 (right).

Table 9 lists sampled and modeled mean growing season (June through September) surface chlorophyll-a concentrations in Honeoye Lake from 2007 through 2014. One of the intended applications of the Honeoye Lake CE-QUAL-W2 model is to assess mean epilimnion growing season chlorophyll-a concentrations under alternative nutrient loading scenarios. The ability of the model to recreate observed patterns in mean epilimnion growing season chlorophyll-a concentrations is therefore of interest for evaluating model performance.

Modeled growing season chlorophyll-a concentrations average 37.5 micrograms per liter while sampled concentrations average 32.5 micrograms per liter, a difference of 5.0 micrograms per liter or 15% of the sampled mean. Sampled and modeled mean concentrations are very similar (within 10%) in 2007, 2009, and 2013. Other years, such as 2008, have very large differences, with modeled concentrations generally higher than sample means. The frequency of sampling should be considered when evaluating modeled versus sampled concentrations. Most years include 5 to 8 chlorophyll-a samples, which may not be adequate for characterizing the growing season mean in years with high chlorophyll-a variability.

Table 9. Sampled and modeled mean growing season (June through September) chlorophyll-a concentrations in Honeoye Lake. Samples are from the surface of Honeoye Lake at its deepest point. Modeled concentrations are for the upper two model layers at the deepest point.

Year	**Sampled Chlorophyll-a (µg/l)**	**Modeled Chlorophyll-a (µg/L)**	**Sample Notes**
2007	17.5	18.6	Sample size = 5
2008	5.7	25.9	Sample size =7
2009	19.6	17.9	Sample size =7
2010	75.7	51.4	Sample size =7
2011	35.0	48.5	Sample size =8
2012	23.0	45.4	Sample size =5
2013	53.1	54.0	Sample size =8
2014	30.7	38.6	Sample size =8
Average	32.5	37.5	-

Calibrated Parameter Values

Calibrated parameter values for the Honeoye Lake CE-QUAL-W2 model are displayed in Table 10. Also displayed are typical parameter ranges from the CE-QUAL-W2 user manual (Cole and Wells 2015).

Table 10. Calibrated parameter values for the Honeoye Lake CE-QUAL-W2 model. Typical values ranges reported in Cole and Wells (2015).

Parameter	Description	Units	Typical Values	Calibrated Value
WSC	Wind sheltering coefficient	-	0.8-1.2	1.1-1.2
BETA	Fraction of incident solar radiation absorbed at the water surface	-	0.45	0.45
EXH20	Extinction for water	/m	0.25	0.25
EXA	Extinction due to algae	$m^3/m/g$	0.1-0.2	0.2
AG, group 1	Maximum growth rate	/day	1 – 2.5	1.5
AS, group 1	Settling rate	/day	0-1	0.1
ASAT, group 1	Saturation intensity at maximum photosynthetic rate	W/m^2	10-150	90
AT1, group 1	Lower temperature for algal growth	ºC	4-10	8
AT2, group 1	Lower temperature for maximum algal growth	ºC	6-20	12
AT3, group 1	Upper temperature for maximum algal growth	ºC	15-25	20
AT4, group 1	Upper temperature for algal growth	ºC	20-30	28
ALGP, group 1	Stoichiometric equivalent between organic matter and phosphorus		0.003-0.014	0.015
ALGN, group 1	Stoichiometric equivalent between organic matter and nitrogen		0.04-0.11	0.08
AHSP, group 1	Half-saturation constant for phosphorous	g/m	0.002 to 0.1	0.002
AHSN, group 1	Half-saturation constant for nitrogen	g/m^3	0.005-0.2	0.014
ACHLA, group 1	Ratio between algal biomass and chlorophyll a in terms of mg algae/μg chl a	mg algae/μg chl a	0.01 to 0.4	0.09
AG, group 2	Maximum growth rate	/day	1 – 2.5	2.3
AS, group 2	Settling rate	/day	0-1	0.11
ASAT, group 2	Saturation intensity at maximum photosynthetic rate	W/m^2	10-100	150
AT1, group 2	Lower temperature for algal growth	ºC	4-10	20
AT2, group 2	Lower temperature for maximum algal growth	ºC	6-20	25
AT3, group 2	Upper temperature for maximum algal growth	ºC	15-25	28
AT4, group 2	Upper temperature for algal growth	ºC	20-30	35
ALGP, group 2	Stoichiometric equivalent between organic matter and phosphorus		0.003-0.014	0.01
ALGN, group 2	Stoichiometric equivalent between organic matter and nitrogen		0.04-0.11	0.08
AHSP, group 2	Half-saturation constant for phosphorous	g/m	0.002 to 0.1	0.0025
AHSN, group 2	Half-saturation constant for ammonia	g/m^3	0.005-0.2	0.014

Parameter	Description	Units	Typical Values	Calibrated Value
ACHLA, group 2	Ratio between algal biomass and chlorophyll a in terms of mg algae/µg chl a	mg algae/µg chl a	0.01 to 0.4	0.02
EG	Epiphyton growth rate	/day	1 – 2.5	1.5
EHS	Biomass limitation factor	$g\text{-}m^{-2}$		40.0
ESAT	Saturation intensity at maximum photosynthetic rate	W/m^2	10-100	150
EP	Epiphyton stoichiometric equivalent between organic matter and phosphorus		0.003-0.014	0.01
EN	Epiphyton stoichiometric equivalent between organic matter and nitrogen		0.04-0.11	0.08
ZG	Maximum zooplankton growth rate	/day		0.42
LDOMDK	Labile DOM decay rate	/day	0.04-0.12	0.1
RDOMDK	Maximum refractory DOM decay rate	/day	0.001	0.001
LPOMDK	Labile Detritus decay rate	/day	0.001 to 0.1	0.08
POMS	Detritus settling rate	m/day	0.35-1.5	1.0
SEDK	Sediment decay rate	/day	0.06	0.06
SEDBR	Sediment burial rate	/day	0.01	0.025
PO4R	Sediment release rate of phosphorus, fraction of SOD		0.0005 to 0.02	0.01
NH4DK	Ammonia decay rate (nitrification rate)	/day	0.001 to 0.12	0.12
NH4R	Sediment release rate of ammonium, fraction of SOD		0.001 to 0.015	0.005
NO3DK	Nitrate decay rate (denitrification rate)	/day	0.05-0.15	0.15
O2AG	Oxygen stoichiometric equivalent for algal growth		1.4	1.6, group 1 1.6, group 2
SOD	Zero-order sediment oxygen demand for each segment	$g\ O2\ m^{-2}\ day^{-1}$	0.1 to 3	0.5

A5 Discussion of Model Results

Water Residence Time

Water residence time can be tracked in CE-QUAL-W2 as a “dummy” generic water quality constituent. Figure 7 displays the predicted water residence time in Honeoye Lake throughout the simulation period. Water residence time reaches a maximum of 590 days (1.6 years) during the simulation period. This shows that lake conditions in any given year are in part influenced by conditions during the preceding 1 to 2 years. Furthermore, model predictions during the first two years of the simulation period (2007 & 2008) are highly dependent on assumptions related to initial conditions.

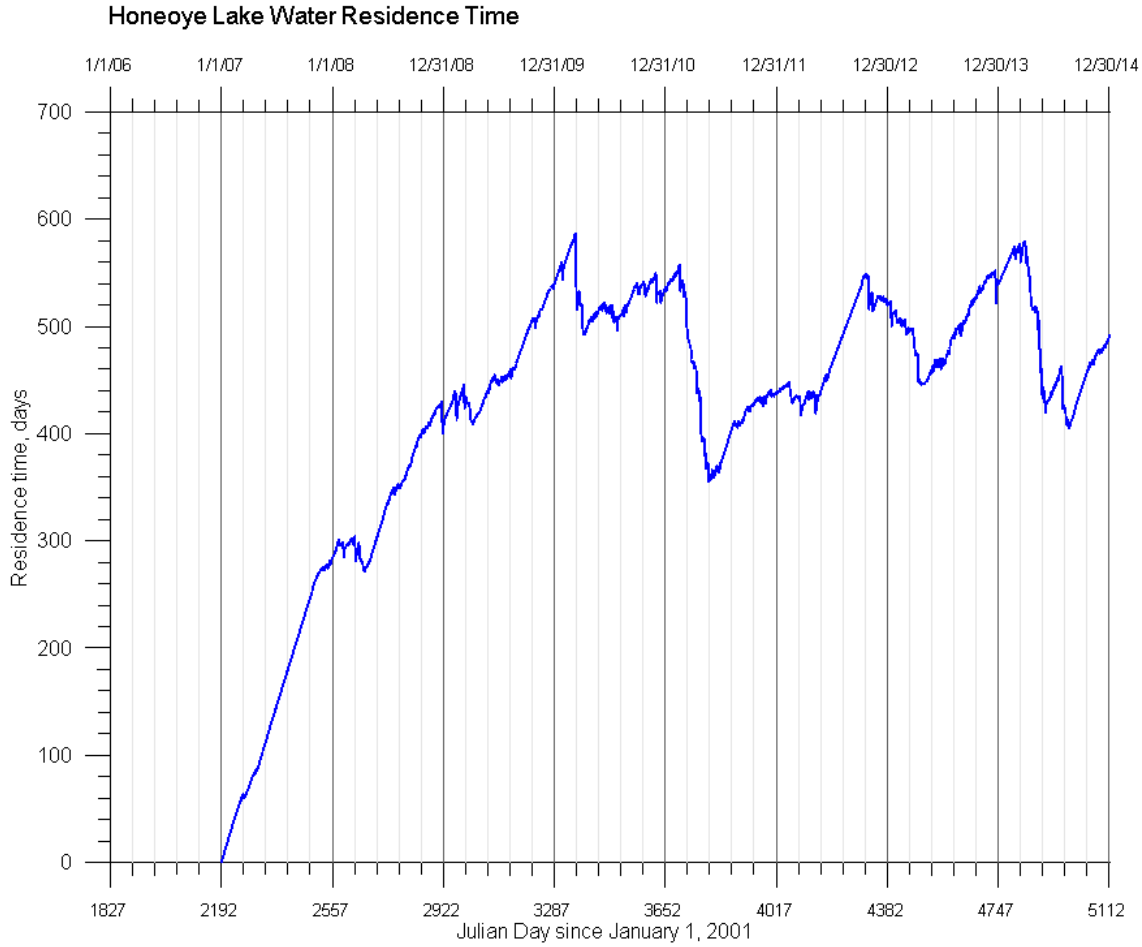


Figure 7. Water residence time in Honeoye Lake.

Thermal Stratification and Turnover

The degree of thermal stratification in a lake is dependent on surface heat transfer processes such as incoming short-wave solar radiation, long-wave atmospheric radiation, back radiation, evaporation, and conduction. Wind energy primarily determines the depth of the thermocline.

The thermal structure of Honeoye Lake directly impacts water quality. Strong thermal stratification results in a large anoxic volume at depth over an extended time period. Such conditions support anoxic release of nutrients from bottom sediments into the water column. Large algal blooms can occur if nutrient rich bottom waters mix with upper layers during the growing season.

Model predicted surface and bottom temperatures at the deepest point of Honeoye Lake are shown in Figure 8. Results show a weakly stratified dimictic to polymictic lake. Stratification develops in the spring by approximately May 1st. Early season winds can easily break down the early stratification and keep the lake well-mixed throughout the growing season because of its shallow depth. This pattern is evident in 2007 through 2009. If stratification can strengthen throughout May and June without a mixing event, then the lake can continue to be stratified until turnover, which typically occurs by September 1st.

Winter stratification also occurs in the Honeoye Lake model, with surface temperatures less than bottom temperatures because of the density-temperature relationship for water. Ice cover was predicted during each winter between 2007 through 2014 with maximum ice thicknesses ranging from 0.1 to 0.4 meters thick.

Model predicted temperature profiles in

Figure 9 show the typical progression and decrease of stratification, as well as inverse winter stratification, for 2010.

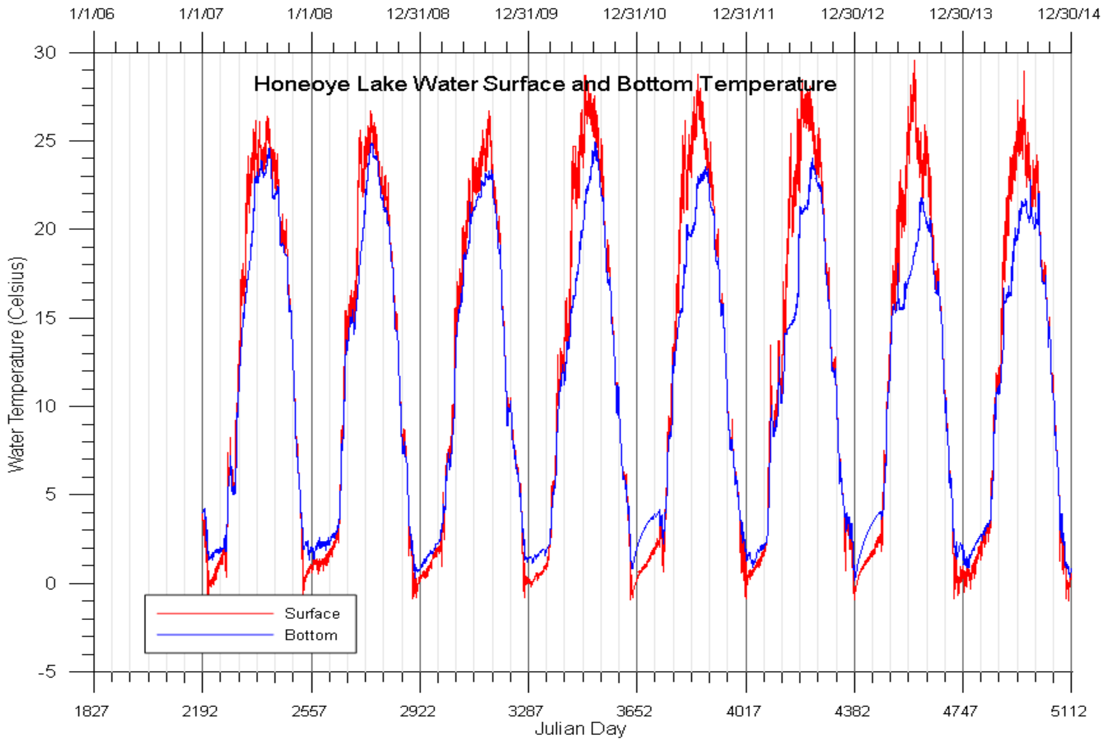


Figure 8. Predicted surface and bottom water temperature in Honeoye Lake.

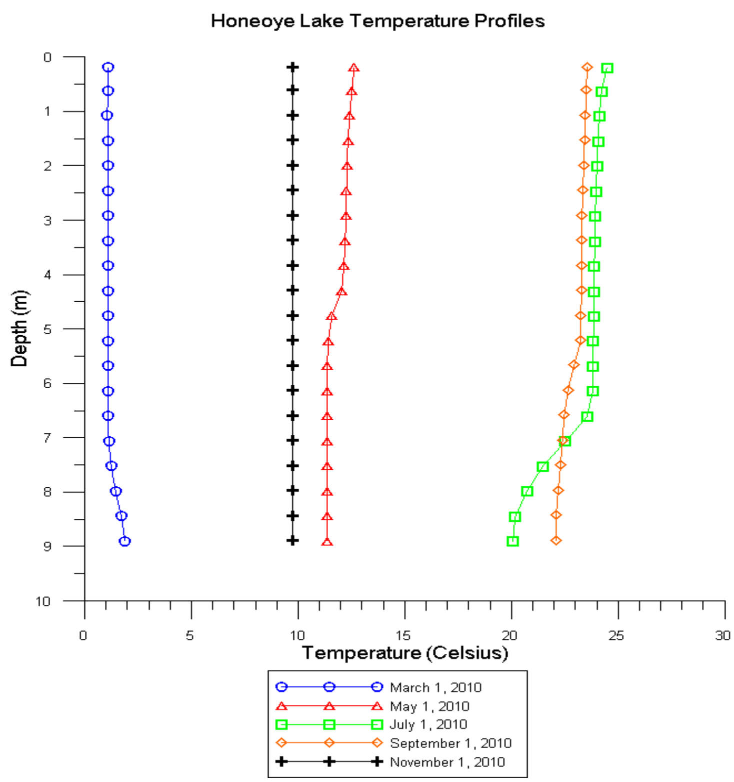
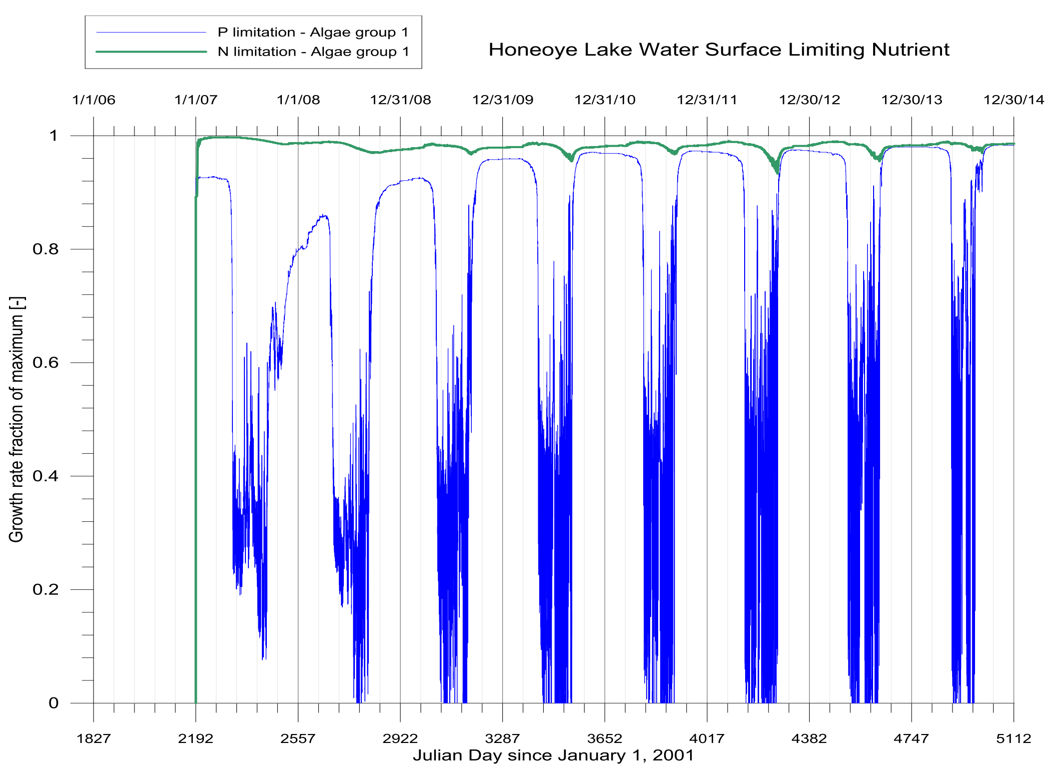


Figure 9. Water temperature profiles for 2010 at deepest point in Honeoye Lake

Nutrient Limitation for Algal Growth

Algal growth in the Honeoye Lake CE-QUAL-W2 model is in part a function of growth rate multipliers for nutrients. Rate multipliers vary over time between 0 (complete growth limitation) and 1 (no growth limitation) based on water column nutrient concentrations. Separate rate multipliers are computed in the model for nitrogen and phosphorus. The nutrient with the lowest magnitude multiplier at any point is the limiting nutrient for algal growth at that time.

Growth rate multipliers can be used to explore nutrient limitation for algal growth in Honeoye Lake. Algal growth rate multipliers for phosphorus and nitrogen are displayed in Figure 10. Throughout most of the simulation period, the rate multiplier for phosphorus is much lower than the rate multiplier for nitrogen, indicating that phosphorus is predominantly the limiting nutrient for algal growth in Honeoye Lake. The exception is toward the end of the growing season in 2012 through 2014, when high phosphorus availability results in similar rate multipliers for nitrogen and phosphorus.



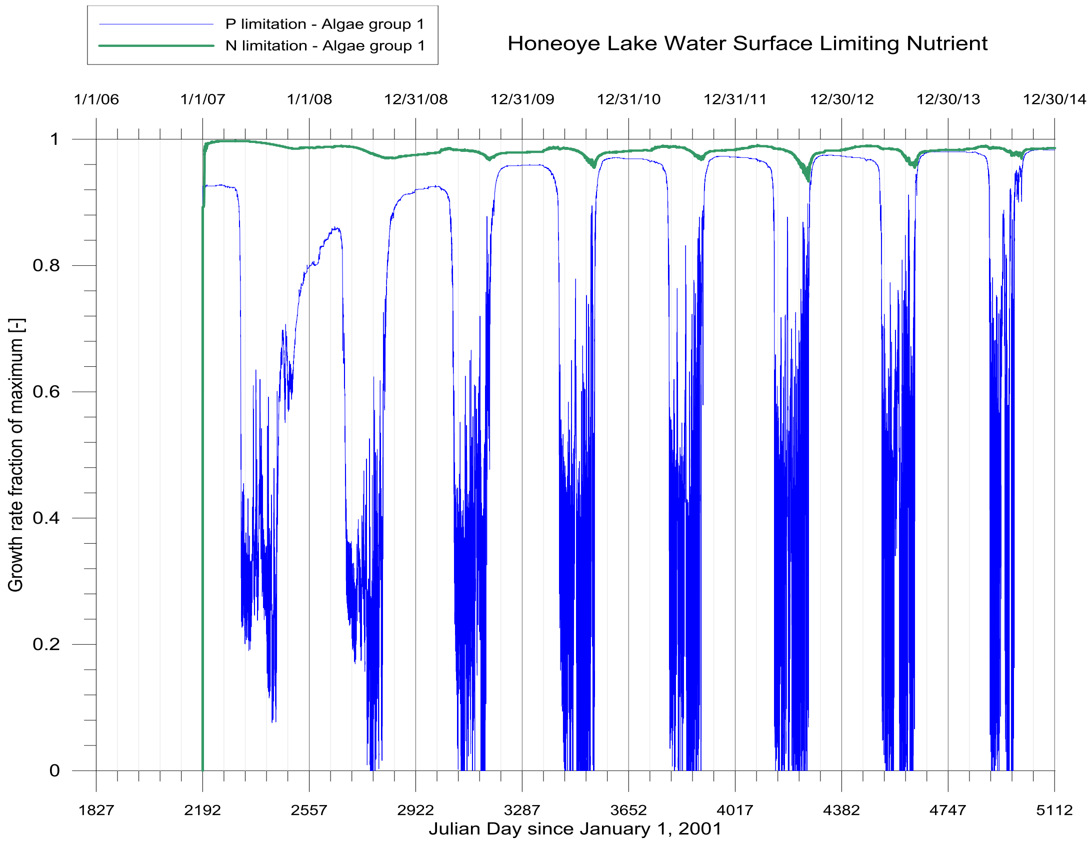


Figure 10. Growth rate multiplier for nitrogen (green) and phosphorus (blue) for algae group 1 (top) and algae group 2 (bottom) in the Honeoye Lake CE-QUAL-W2 model.

Nutrient Mass Balance & Fluxes

An understanding of the relative magnitude of nutrient inputs, outputs, and internal transformations within a waterbody is useful for evaluating water quality improvement strategies. This section uses CE-QUAL-W2 model output to present the cumulative mass of nitrogen and phosphorus that enters, exits, and is stored in Honeoye Lake throughout the simulation period.

Phosphorus and nitrogen mass balance plots for Honeoye Lake are displayed in Figure 11 and Figure 12, respectively. These plots include the following curves:

- Branch Inflow – The cumulative mass of nitrogen/phosphorus entering Honeoye Lake from the watershed in branch inflow;
- Distributed Tributary – The cumulative mass of nitrogen/phosphorus entering Honeoye Lake from the watershed in distributed tributary inflow;
- Precipitation – The cumulative mass of nitrogen/phosphorus entering Honeoye Lake from direct precipitation onto the lake surface;
- Sediment Release – The cumulative mass of nitrogen/phosphorus released into the water column of Honeoye Lake from zero-order anoxic sediment decay and first-order oxic sediment decay;
- Outflow – The cumulative mass of nitrogen/phosphorus output from Honeoye Lake from the lake outlet;

- Sediment Settling – The cumulative mass of nitrogen/phosphorus that settles out of the water column of Honeoye Lake into the first-order sediment compartment;
- Water Column – The instantaneous mass of nitrogen/phosphorus stored in the water column of Honeoye Lake;
- Aquatic Plants – The instantaneous mass of nitrogen/phosphorus stored in the aquatic plant community of Honeoye Lake.

The largest input of phosphorus to Honeoye Lake is bottom sediment release followed by branch inflow, distributed tributary inflow, and precipitation. The largest output of phosphorus is settling to bottom sediment followed by lake outflow. Note that although bottom sediment release represents a large phosphorus input term, the ultimate source of this phosphorus is the Honeoye Lake watershed. Furthermore, bottom sediment is also a large sink for water column phosphorus, and phosphorus is continually cycled between the water column and sediment. At the end of the simulation, the cumulative mass of phosphorus released from bottom sediment is slightly less than the mass that settles out of the water column, indicating that there is a net deposition of phosphorus to bottom sediments during the simulation period. The nitrogen mass balance plot demonstrates similar patterns.

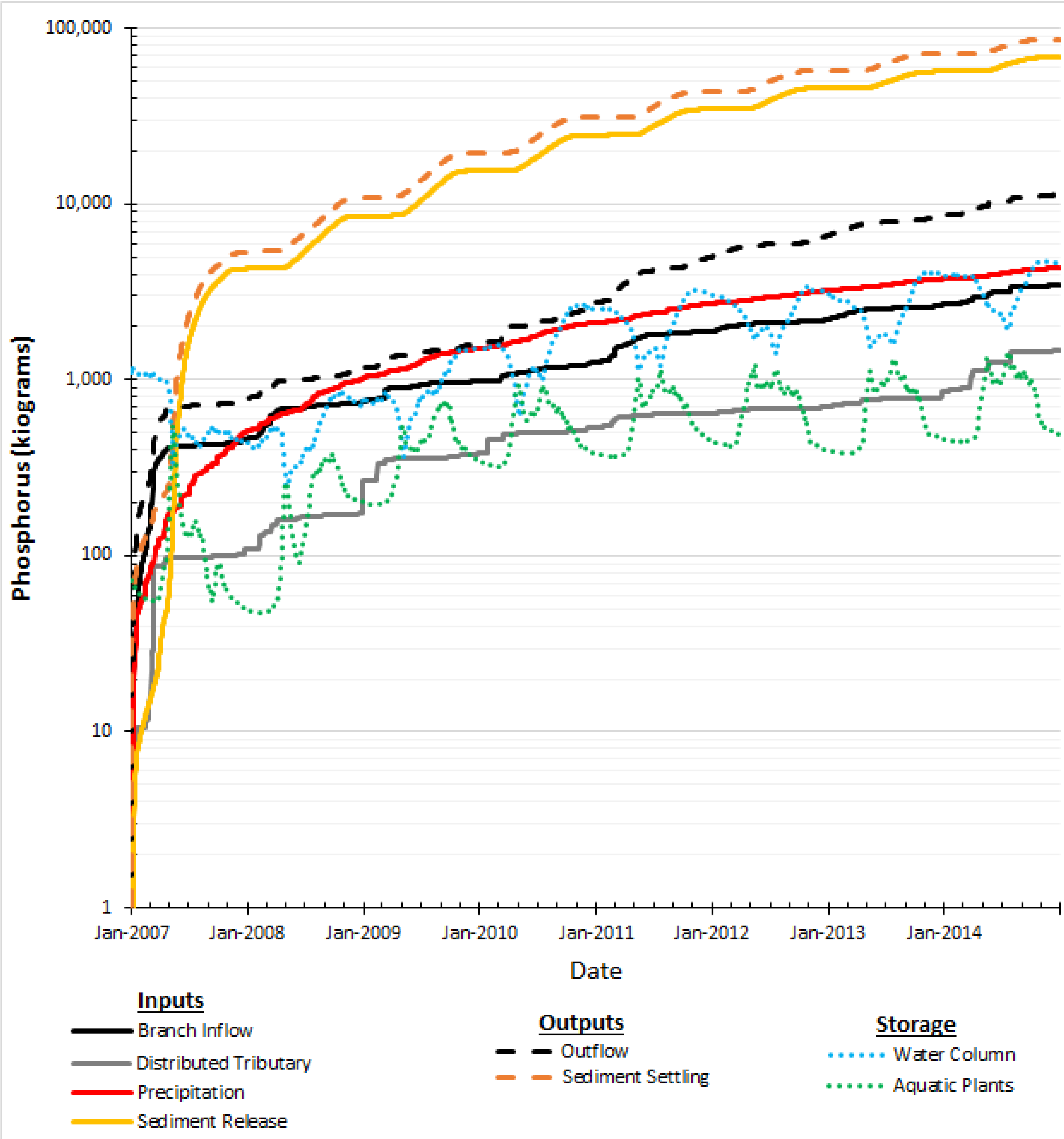


Figure 11. Phosphorus mass balance plot for Honeoye Lake. Masses are cumulative for inputs and outputs and instantaneous for storage terms.

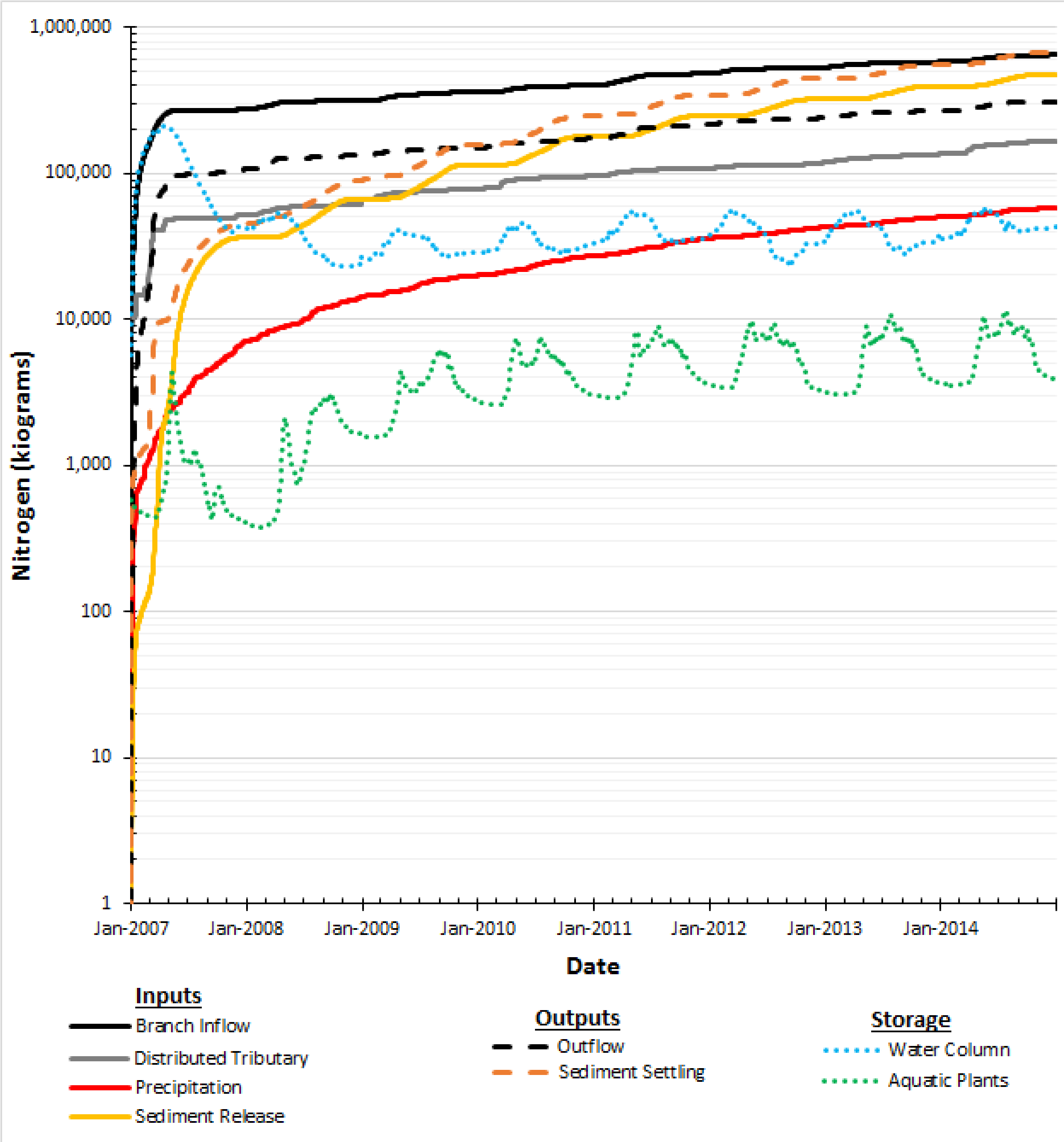


Figure 12. Nitrogen mass balance plot for Honeoye Lake. Masses are cumulative for inputs and outputs and instantaneous for storage terms.

A6 Conclusion

A CE-QUAL-W2 model of Honeoye Lake was setup and calibrated to support development of a phosphorus TMDL for the lake. While the model is adequate for use in water quality planning, several areas for improvement were noted during model setup and calibration that could be addressed in a later modeling study. These include:

- Meteorological forcing data are from the Dansville Municipal Airport station, located 8.9 miles from Honeoye Lake. On-site meteorological data from each lake would provide more representative model inputs. Spot measurements of wind speed and air temperature on each lake, for example, could be collected and used to adjust records from the Dansville Municipal Airport station.

- Measured wind speed at the Dansville Municipal Airport station included a large number of zero values. This may reflect an error in weather station records.

- SWAT model estimates of inflow rates and water quality constituent concentrations could be refined using measurements of flow and water quality from each lake watershed. Inflows could also be refined spatially to represent multiple tributary inputs from different subwatersheds.

- The model computational grids were developed without any layers above the average water surface elevation of the lake. A refined model grid could incorporate Digital Elevation Models (DEMs) of the surrounding landscape to include areas above the average water surface elevation.

- Mussels were not explicitly represented in the Honeoye Lake CE-QUAL-W2 model. Their effect on water quality could be important as they facilitate recycling of nutrients between bottom sediments and the water column.

- The Honeoye Lake CE-QUAL-W2 model does not use the detailed sediment diagenesis submodel available in the latest release of CE-QUAL-W2. The sediment diagenesis submodel is useful for evaluating alternative nutrient loading reduction strategies since the model predicts sediment responses to reduced nutrient loads. In the zero-order sediment decay function used in the current Honeoye Lake model, nutrient releases occur independently of external nutrient loading and load reduction scenarios must assume a fixed reduction rate from zero-order sediment decay.

A7 References

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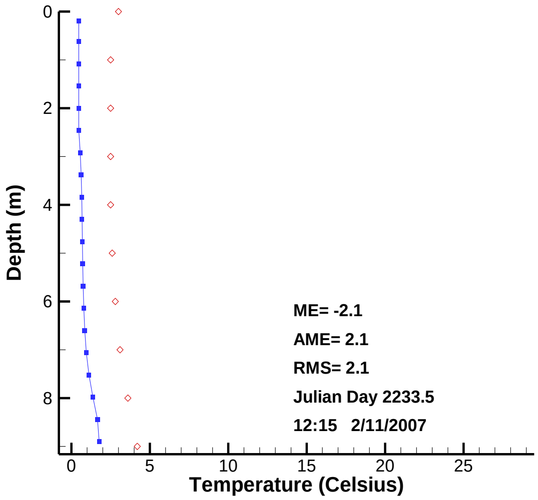
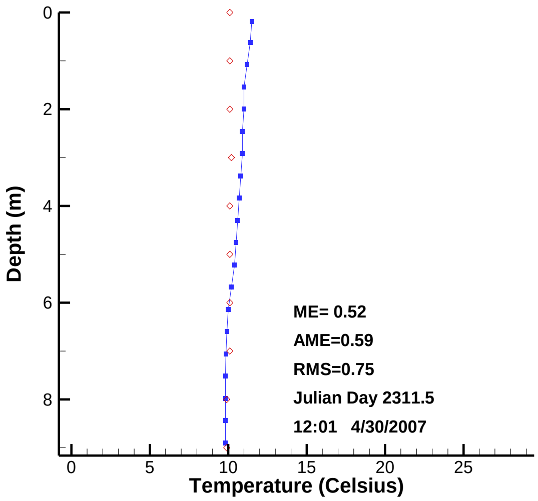
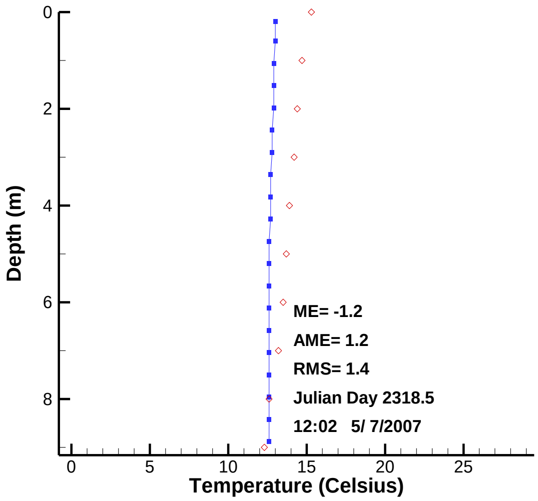
APPENDIX B: HONEOYE LAKE CE-QUAL-W2 MODEL TEMPERATURE & WATER QUALITY PROFILE PLOTS

B1 Water Temperature Profile Plots






Depth (m)
Temperature (Celsius)
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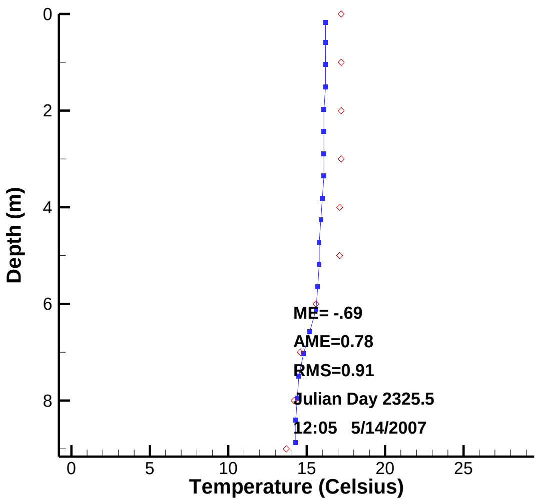
AME= 1.2
RMS= 1.4
Julian Day 2318.5
12:02 5/ 7/2007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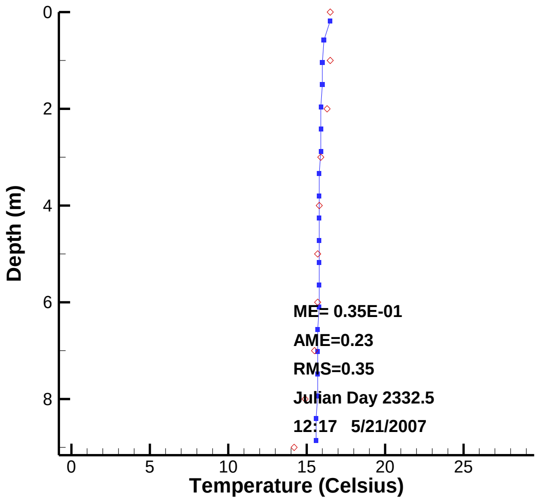
12:05 5/14/2007



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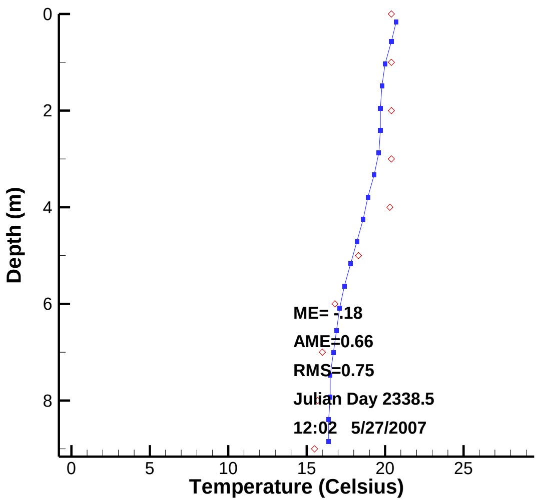
Depth (m)
Temperature (Celsius)



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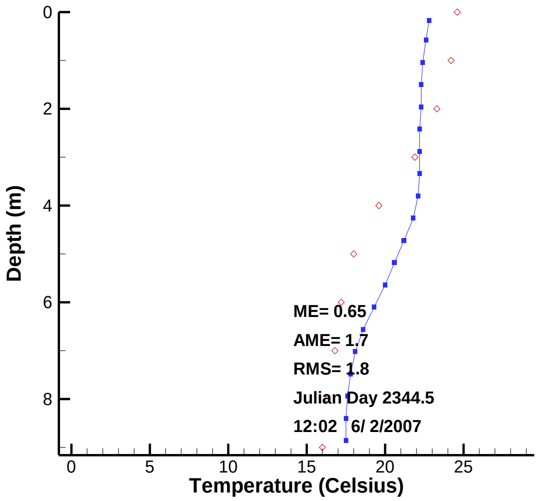
Depth (m)
Temperature (Celsius)


Depth (m)
Temperature (Celsius)
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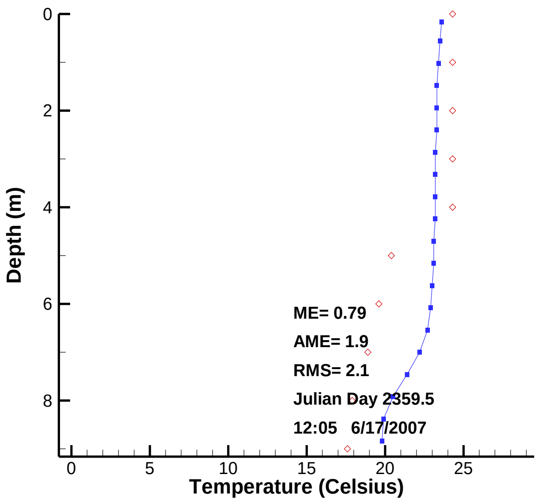
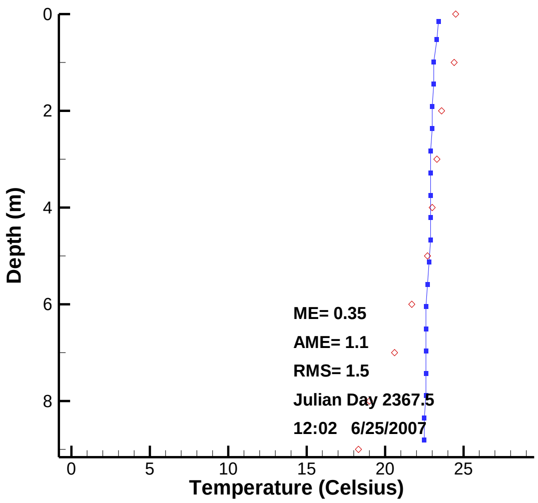
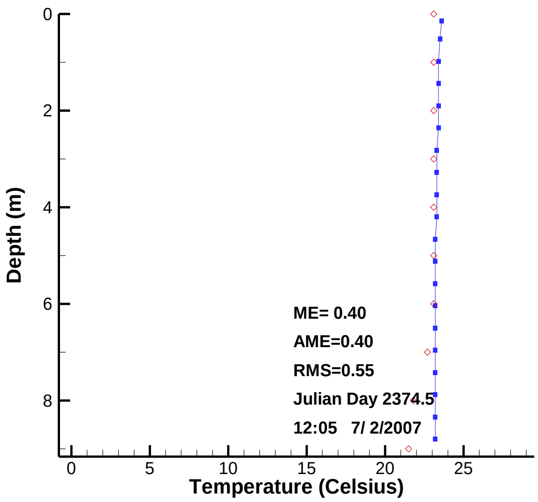
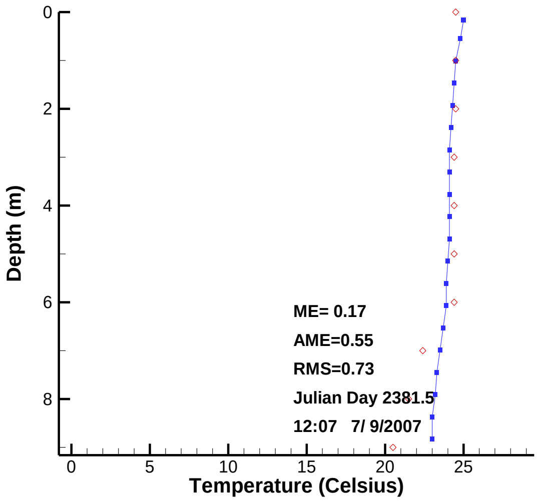
AME= 1.7
RMS= 1.8
Julian Day 2344.5
12:02 6/ 2/2007

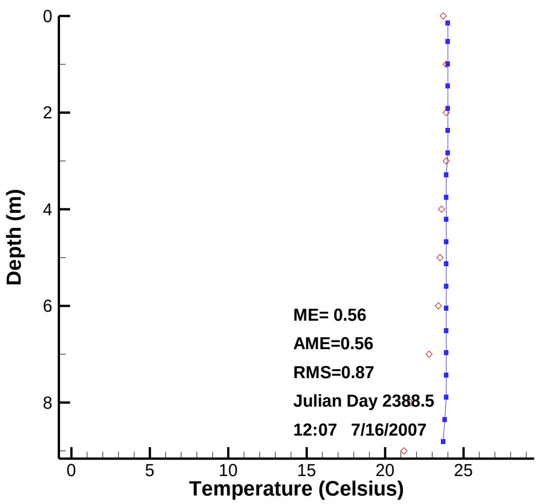

Depth (m)
Temperature (Celsius)
ME= 0.79
AME= 1.9
RMS= 2.1
Julian Day 2359.5
12:05 6/17/2007


Depth (m)
Temperature (Celsius)
ME= 0.35
AME= 1.1
RMS= 1.5
Julian Day 2367.5
12:02 6/25/2007

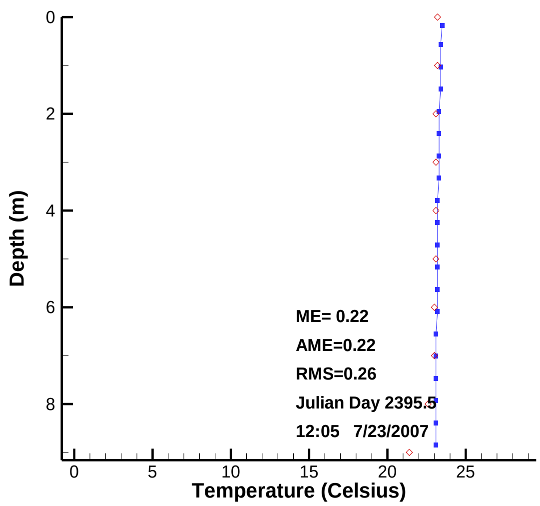

Depth (m)
Temperature (Celsius)
ME= 0.40
AME=0.40
RMS=0.55
Julian Day 2374.5
12:05 7/ 2/2007



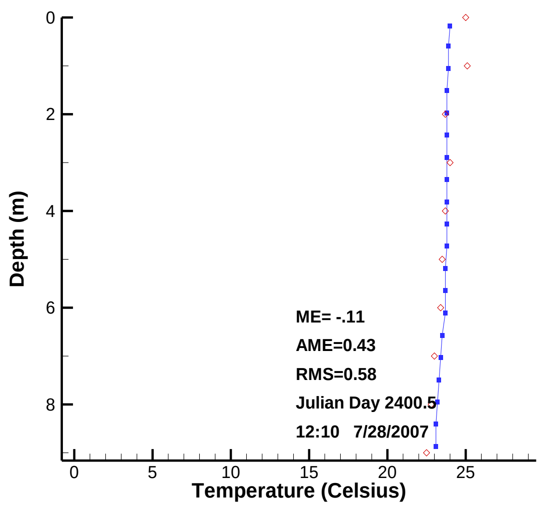
Depth (m)
0
2
4
6
8
ME= 0.17
AME=0.55
RMS=0.73
Julian Day 2381.5
12:07 7/ 9/2007
0
5
10
15
20
25
Temperature (Celsius)



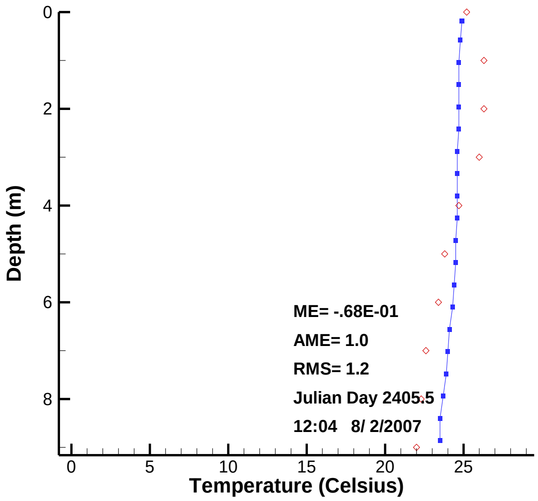
Depth (m)
0
2
4
6
8
ME= 0.56
AME=0.56
RMS=0.87
Julian Day 2388.5
12:07 7/16/2007
0
5
10
15
20
25
Temperature (Celsius)

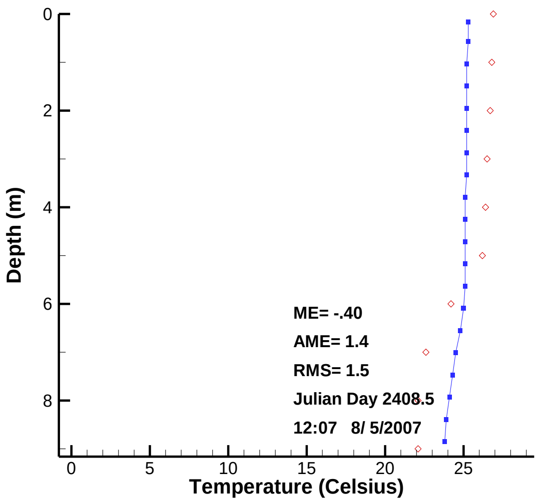


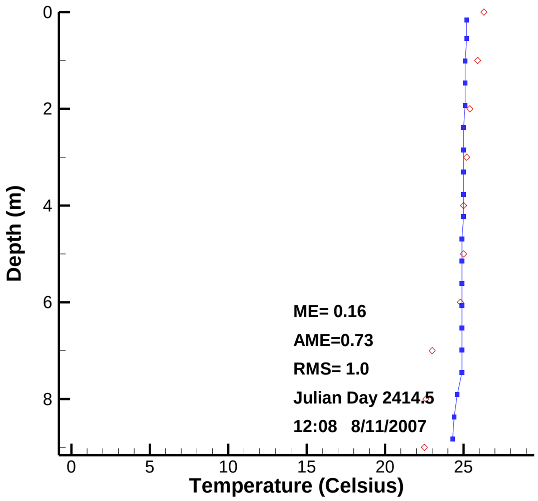
ME= 0.22
AME=0.22
RMS=0.26
Julian Day 2395.5
12:05 7/23/2007
Depth (m)
Temperature (Celsius)

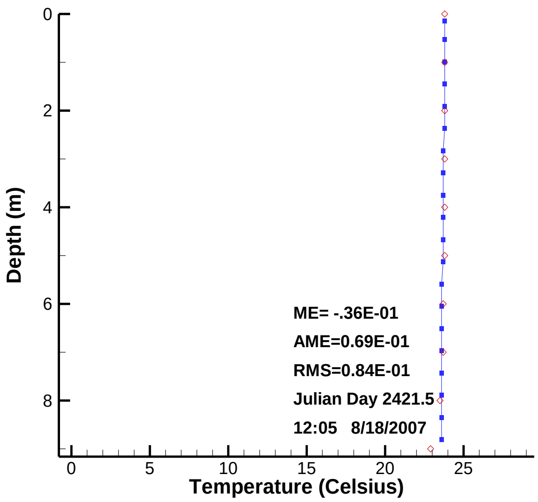


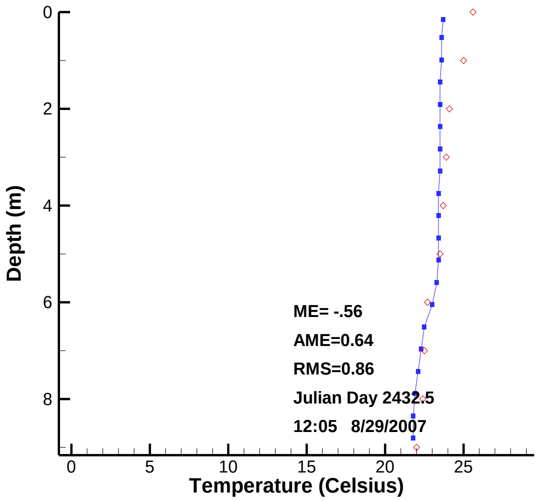
ME= -.11
AME=0.43
RMS=0.58
Julian Day 2400.5
12:10 7/28/2007
Depth (m)
Temperature (Celsius)

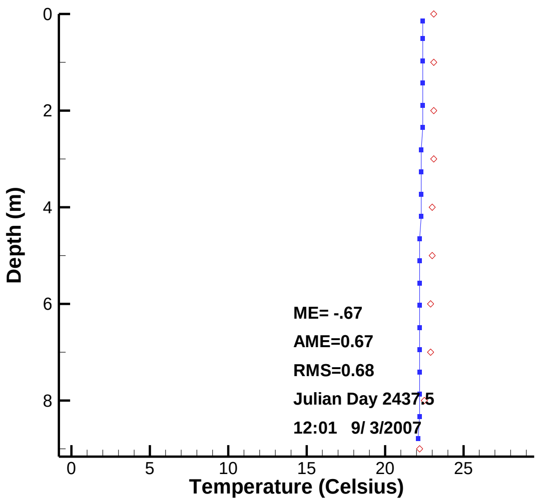

Depth (m)
ME= -.68E-01
AME= 1.0
RMS= 1.2
Julian Day 2405.5
12:04 8/ 2/2007
Temperature (Celsius)

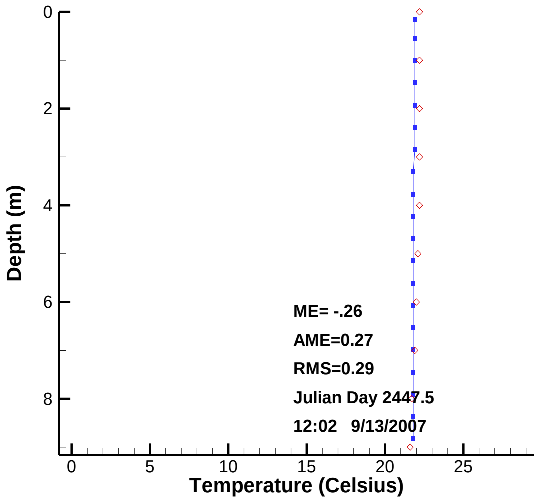

Depth (m)
ME= -.40
AME= 1.4
RMS= 1.5
Julian Day 2408.5
12:07 8/ 5/2007
Temperature (Celsius)


ME= 0.16
AME=0.73
RMS= 1.0
Julian Day 2414.5
12:08 8/11/2007
Depth (m)
Temperature (Celsius)
0
2
4
6
8
0
5
10
15
20
25

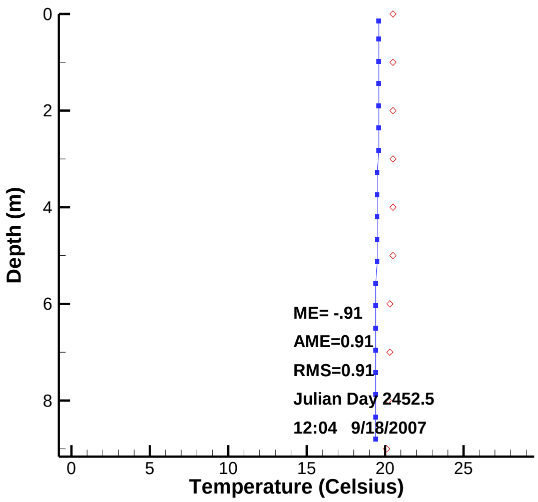

ME= -.36E-01
AME=0.69E-01
RMS=0.84E-01
Julian Day 2421.5
12:05 8/18/2007
Depth (m)
Temperature (Celsius)
0
2
4
6
8
0
5
10
15
20
25


Depth (m)
Temperature (Celsius)
ME= -.56
AME=0.64
RMS=0.86
Julian Day 2432.5
12:05 8/29/2007

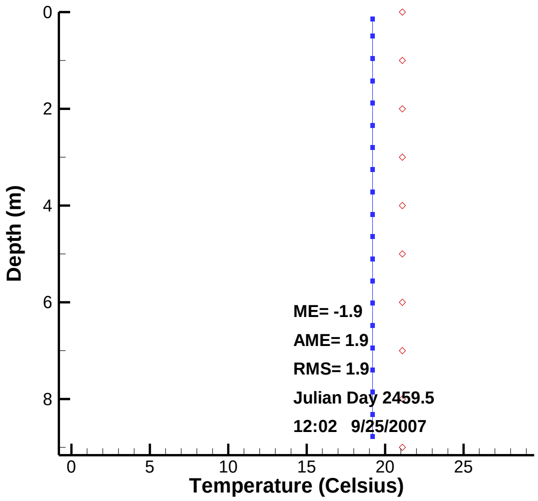

Depth (m)
Temperature (Celsius)
ME= -.67
AME=0.67
RMS=0.68
Julian Day 2437.5
12:01 9/ 3/2007

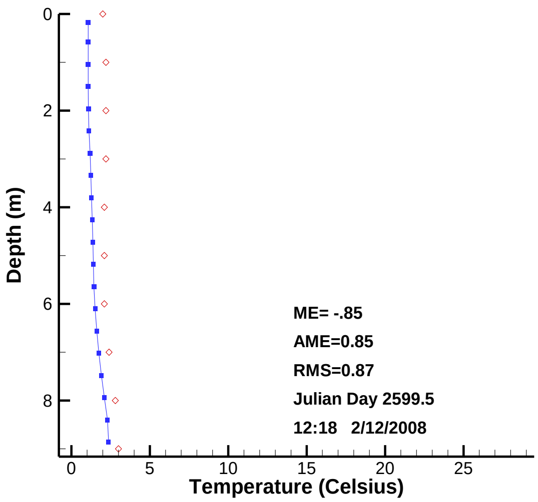


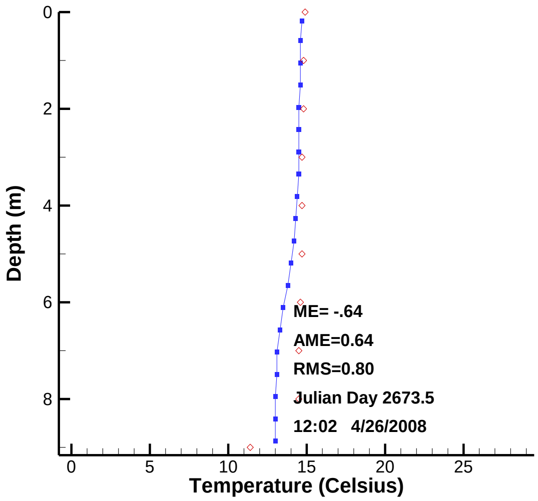
ME= -.26
AME=0.27
RMS=0.29
Julian Day 2447.5
12:02 9/13/2007
Depth (m)
Temperature (Celsius)

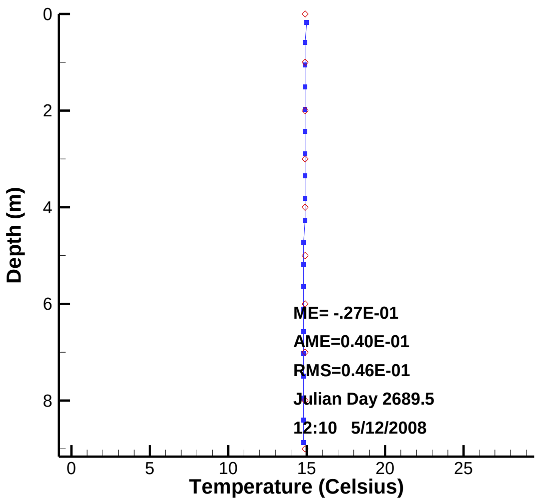


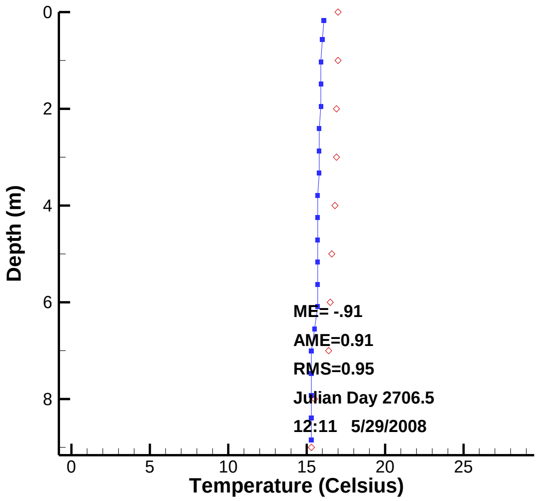
ME= -.91
AME=0.91
RMS=0.91
Julian Day 2452.5
12:04 9/18/2007
Depth (m)
Temperature (Celsius)

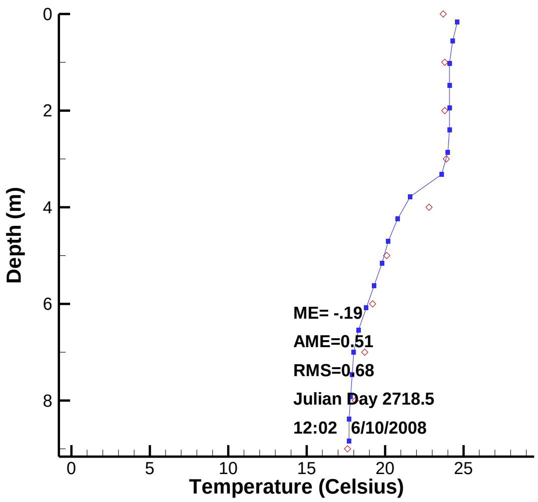

ME= -1.9
AME= 1.9
RMS= 1.9
Julian Day 2459.5
12:02 9/25/2007
Depth (m)
Temperature (Celsius)

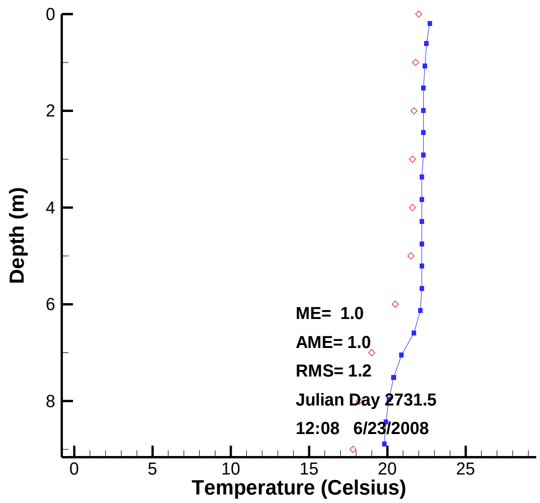

ME= -.85
AME=0.85
RMS=0.87
Julian Day 2599.5
12:18 2/12/2008
Depth (m)
Temperature (Celsius)


ME= -.64
AME=0.64
RMS=0.80
Julian Day 2673.5
12:02 4/26/2008
Depth (m)
Temperature (Celsius)
0
2
4
6
8
0
5
10
15
20
25

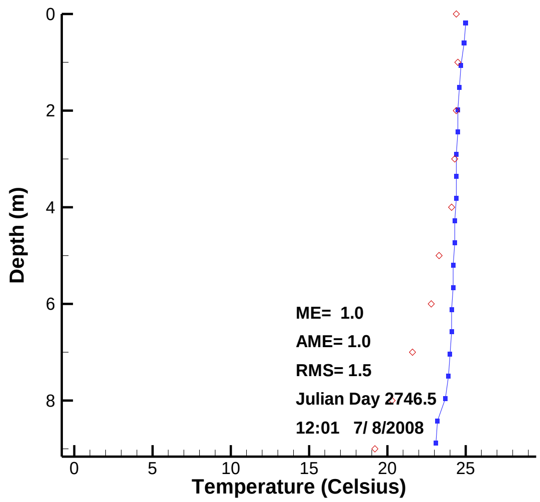

ME= -.27E-01
AME=0.40E-01
RMS=0.46E-01
Julian Day 2689.5
12:10 5/12/2008
Depth (m)
Temperature (Celsius)
0
2
4
6
8
0
5
10
15
20
25


ME= -.91
AME=0.91
RMS=0.95
Julian Day 2706.5
12:11 5/29/2008
Depth (m)
Temperature (Celsius)
0
2
4
6
8
0
5
10
15
20
25

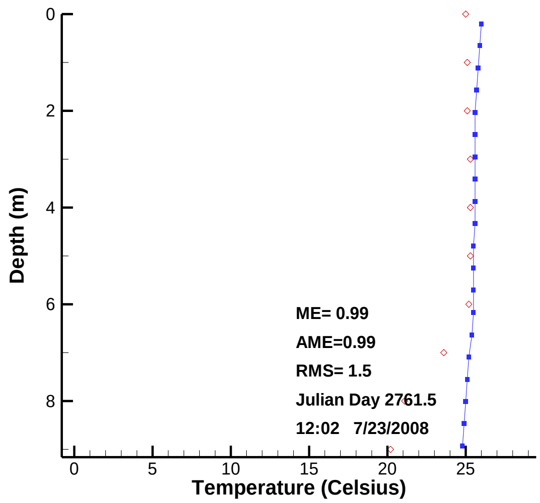

ME= -.19
AME=0.51
RMS=0.68
Julian Day 2718.5
12:02 6/10/2008
Depth (m)
Temperature (Celsius)
0
2
4
6
8
0
5
10
15
20
25



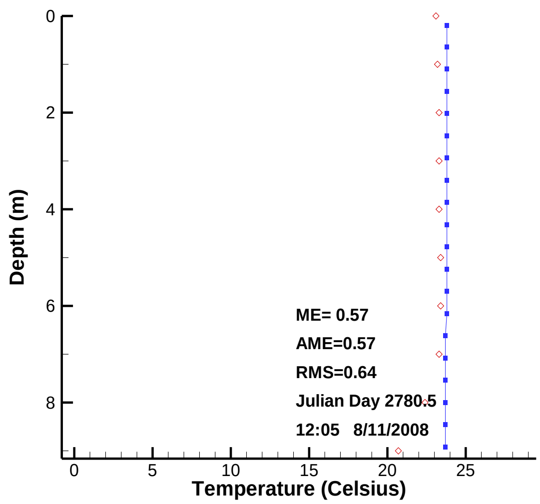
Depth (m)
0
2
4
6
8
ME= 1.0
AME= 1.0
RMS= 1.2
Julian Day 2731.5
12:08 6/23/2008
0
5
10
15
20
25
Temperature (Celsius)



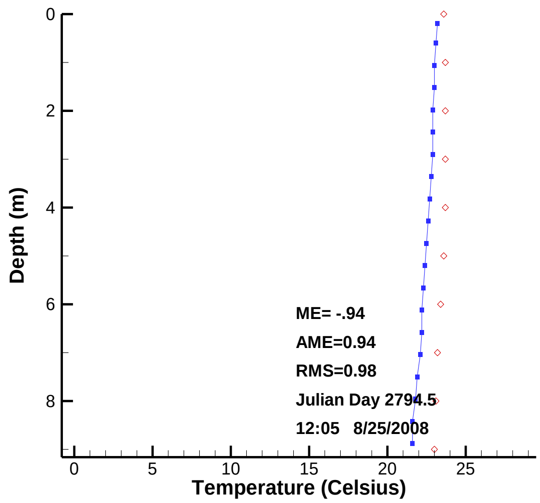
Depth (m)
0
2
4
6
8
ME= 1.0
AME= 1.0
RMS= 1.5
Julian Day 2746.5
12:01 7/ 8/2008
0
5
10
15
20
25
Temperature (Celsius)

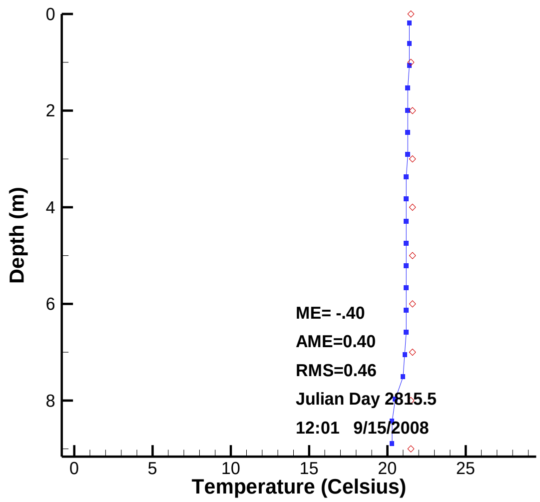


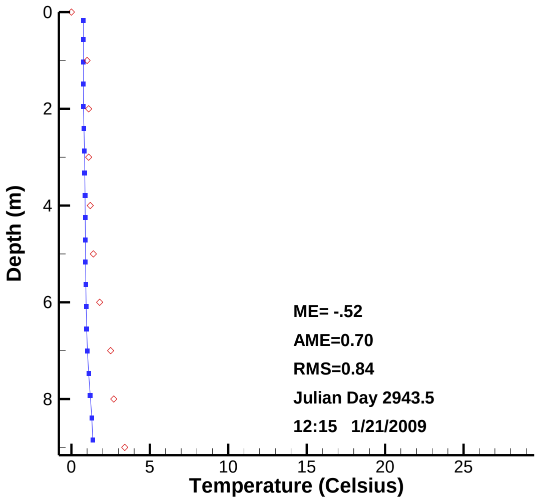
Depth (m)
0
2
4
6
8
ME= 0.99
AME=0.99
RMS= 1.5
Julian Day 2761.5
12:02 7/23/2008
0
5
10
15
20
25
Temperature (Celsius)

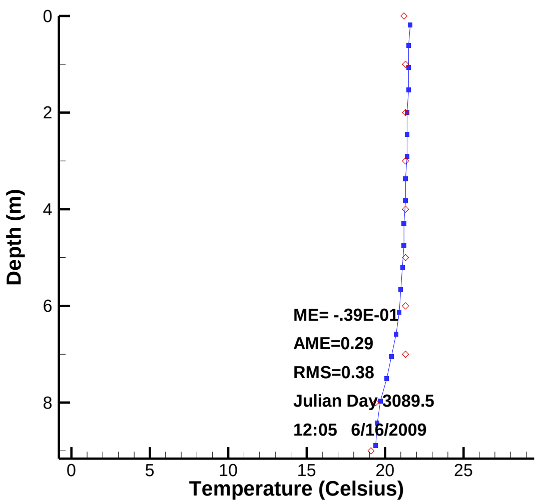


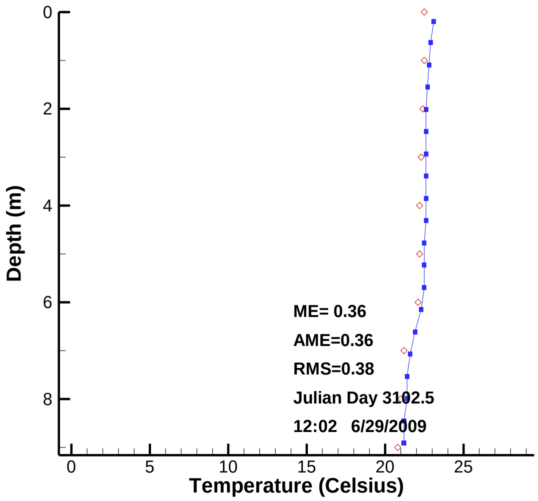
Depth (m)
0
2
4
6
8
ME= 0.57
AME=0.57
RMS=0.64
Julian Day 2780.5
12:05 8/11/2008
0
5
10
15
20
25
Temperature (Celsius)


Depth (m)
Temperature (Celsius)
ME= -.94
AME=0.94
RMS=0.98
Julian Day 2794.5
12:05 8/25/2008

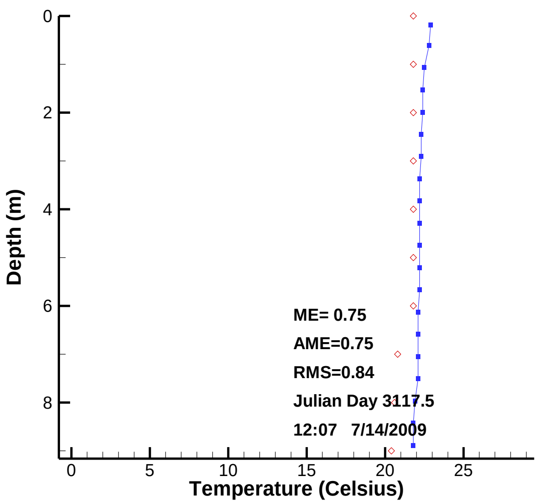

Depth (m)
Temperature (Celsius)
ME= -.40
AME=0.40
RMS=0.46
Julian Day 2815.5
12:01 9/15/2008


0
2
4
6
8
Depth (m)
ME= -.52
AME=0.70
RMS=0.84
Julian Day 2943.5
12:15 1/21/2009
0
5
10
15
20
25
Temperature (Celsius)

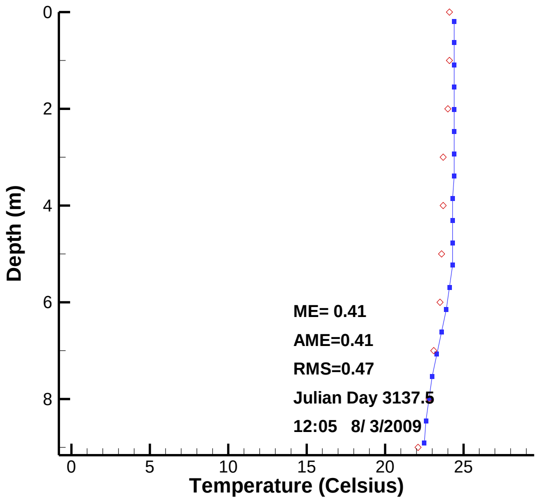

0
2
4
6
8
Depth (m)
ME= -.39E-01
AME=0.29
RMS=0.38
Julian Day 3089.5
12:05 6/16/2009
0
5
10
15
20
25
Temperature (Celsius)

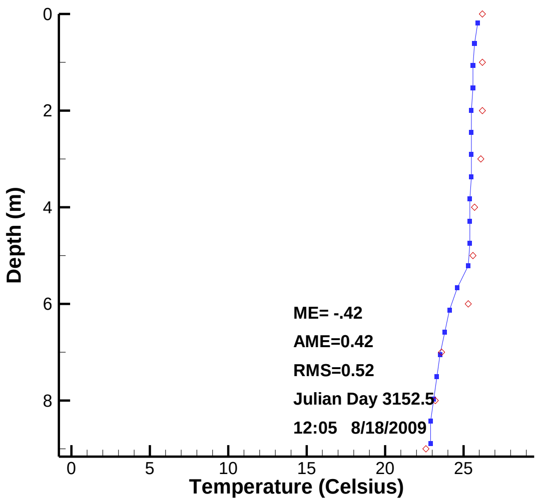


ME= 0.36
AME=0.36
RMS=0.38
Julian Day 3102.5
12:02 6/29/2009
Depth (m)
Temperature (Celsius)

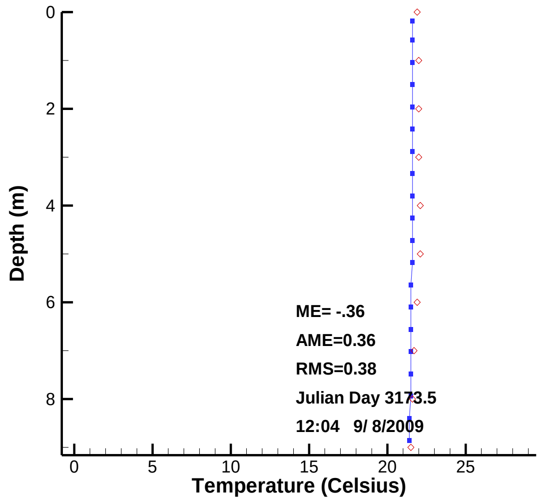


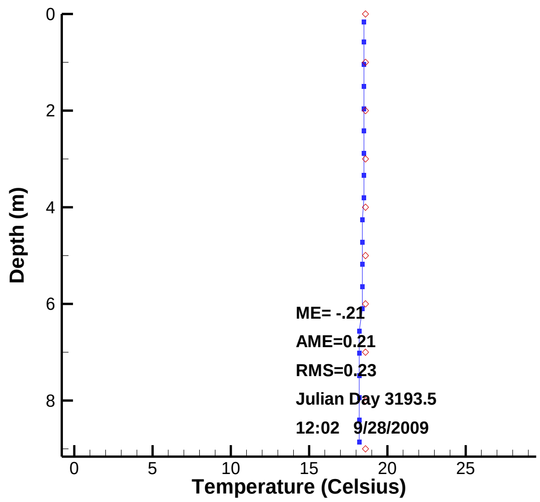
ME= 0.75
AME=0.75
RMS=0.84
Julian Day 3117.5
12:07 7/14/2009
Depth (m)
Temperature (Celsius)

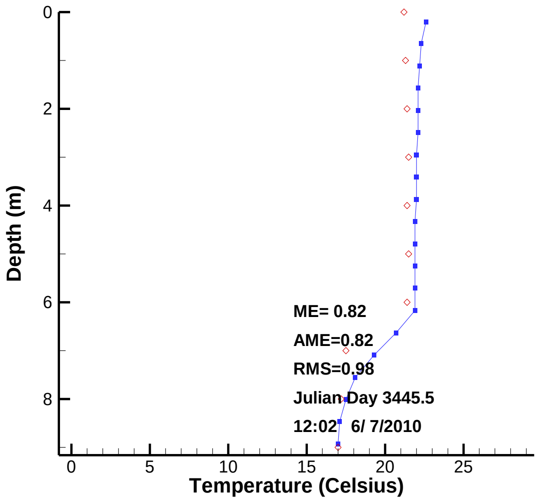

0
2
4
6
8
Depth (m)
ME= 0.41
AME=0.41
RMS=0.47
Julian Day 3137.5
12:05 8/ 3/2009
0
5
10
15
20
25
Temperature (Celsius)


0
2
4
6
8
Depth (m)
ME= -.42
AME=0.42
RMS=0.52
Julian Day 3152.5
12:05 8/18/2009
0
5
10
15
20
25
Temperature (Celsius)

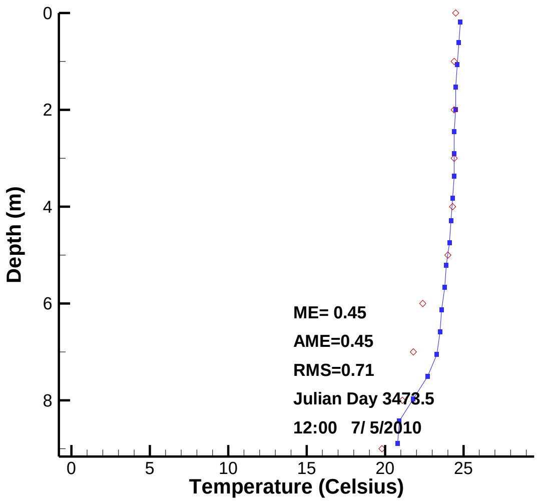
13


0
2
4
6
8
Depth (m)
ME= -.36
AME=0.36
RMS=0.38
Julian Day 3173.5
12:04 9/ 8/2009
0
5
10
15
20
25
Temperature (Celsius)

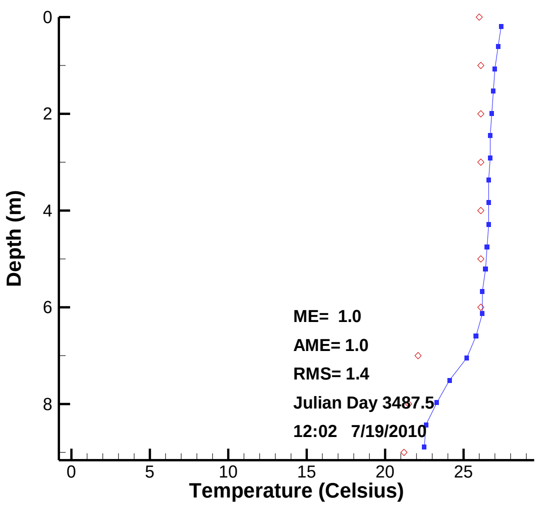

0
2
4
6
8
Depth (m)
ME= -.21
AME=0.21
RMS=0.23
Julian Day 3193.5
12:02 9/28/2009
0
5
10
15
20
25
Temperature (Celsius)

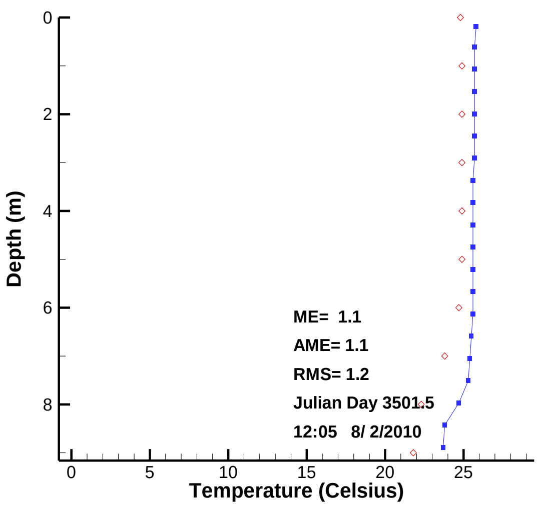


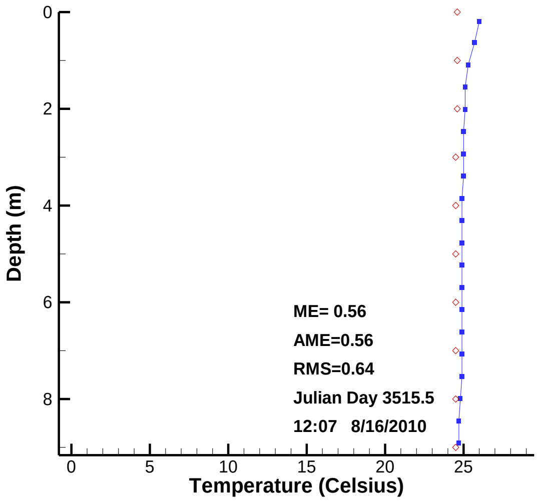
0
2
4
6
8
Depth (m)
ME= 0.82
AME=0.82
RMS=0.98
Julian Day 3445.5
12:02 6/ 7/2010
0
5
10
15
20
25
Temperature (Celsius)



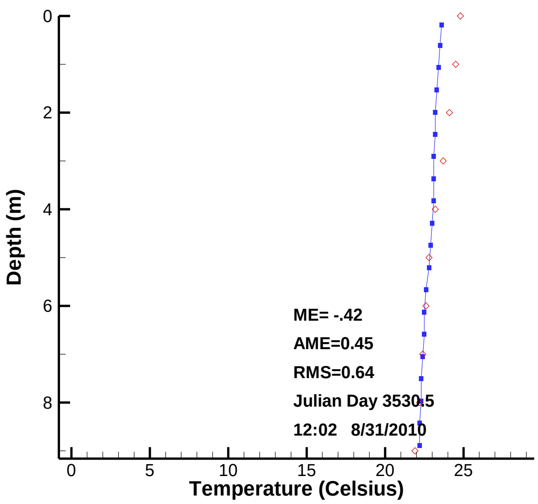
0
2
4
6
8
Depth (m)
ME= 0.45
AME=0.45
RMS=0.71
Julian Day 3478.5
12:00 7/ 5/2010
0
5
10
15
20
25
Temperature (Celsius)


Depth (m)
Temperature (Celsius)
ME= 1.0
AME= 1.0
RMS= 1.4
Julian Day 3487.5
12:02 7/19/2010

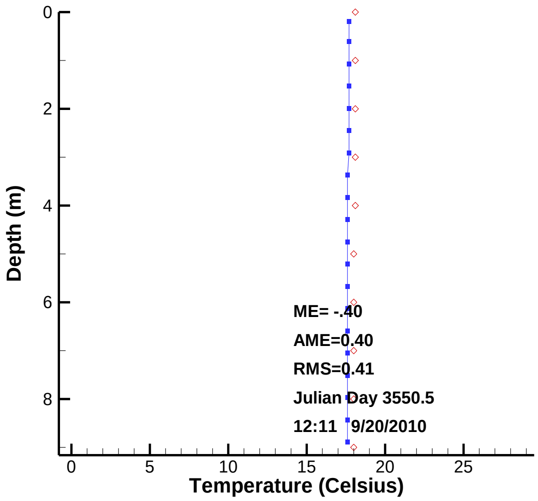

Depth (m)
Temperature (Celsius)
ME= 1.1
AME= 1.1
RMS= 1.2
Julian Day 3501.5
12:05 8/ 2/2010

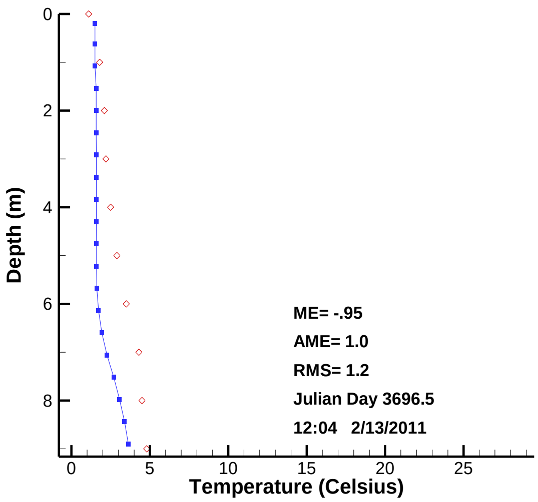


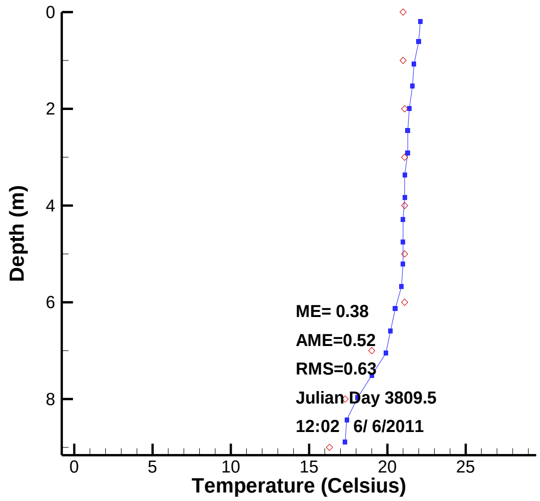
0
2
4
6
8
Depth (m)
ME= 0.56
AME=0.56
RMS=0.64
Julian Day 3515.5
12:07 8/16/2010
0
5
10
15
20
25
Temperature (Celsius)

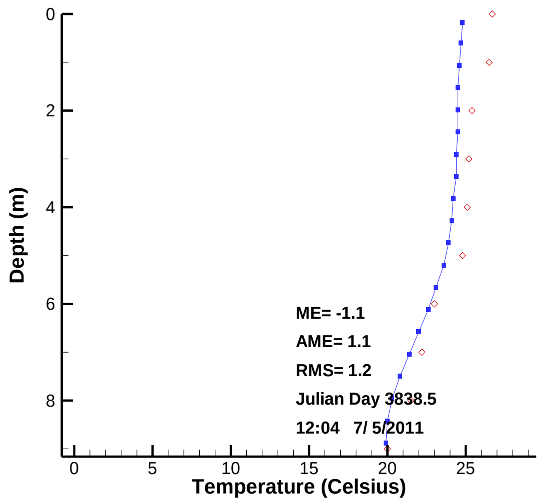


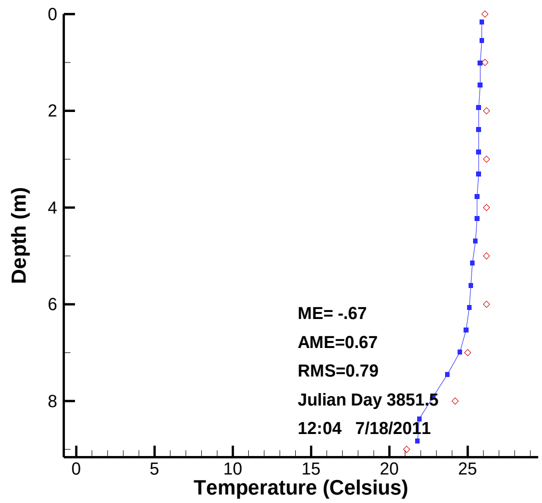
0
2
4
6
8
Depth (m)
ME= -.42
AME=0.45
RMS=0.64
Julian Day 3530.5
12:02 8/31/2010
0
5
10
15
20
25
Temperature (Celsius)

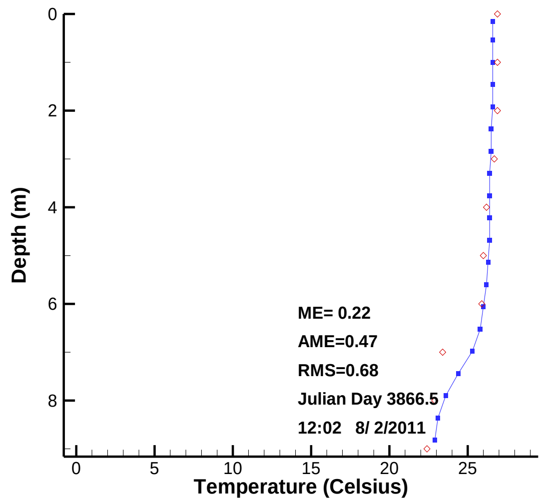

ME= -.40
AME=0.40
RMS=0.41
Julian Day 3550.5
12:11 9/20/2010
Depth (m)
Temperature (Celsius)
0
2
4
6
8
0
5
10
15
20
25

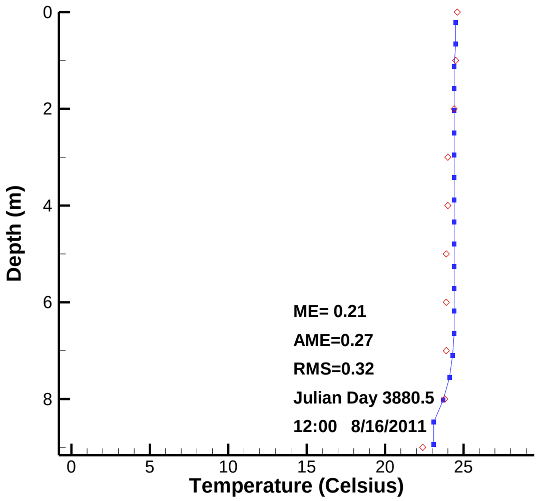

ME= -.95
AME= 1.0
RMS= 1.2
Julian Day 3696.5
12:04 2/13/2011
Depth (m)
Temperature (Celsius)
0
2
4
6
8
0
5
10
15
20
25


Depth (m)
Temperature (Celsius)
ME= 0.38
AME=0.52
RMS=0.63
Julian Day 3809.5
12:02 6/ 6/2011

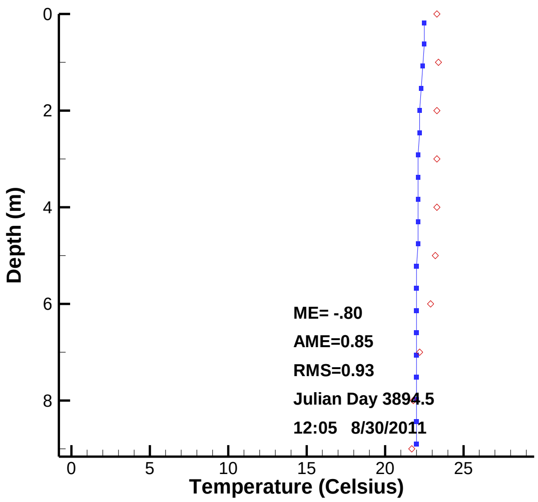

Depth (m)
Temperature (Celsius)
ME= -1.1
AME= 1.1
RMS= 1.2
Julian Day 3838.5
12:04 7/ 5/2011


ME= -.67
AME=0.67
RMS=0.79
Julian Day 3851.5
12:04 7/18/2011
Depth (m)
Temperature (Celsius)

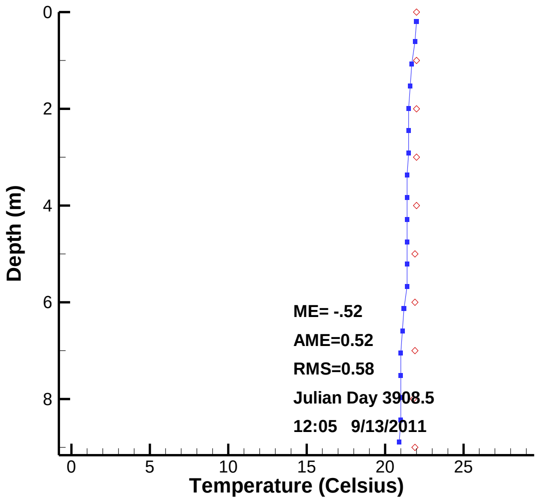

ME= 0.22
AME=0.47
RMS=0.68
Julian Day 3866.5
12:02 8/ 2/2011
Depth (m)
Temperature (Celsius)



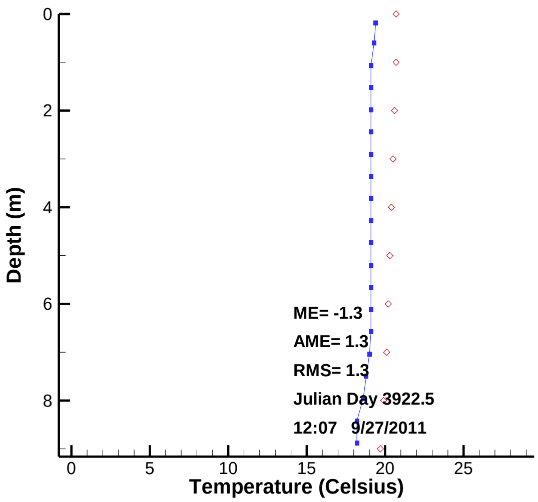
Depth (m)
0
2
4
6
8
ME= 0.21
AME=0.27
RMS=0.32
Julian Day 3880.5
12:00 8/16/2011
0
5
10
15
20
25
Temperature (Celsius)



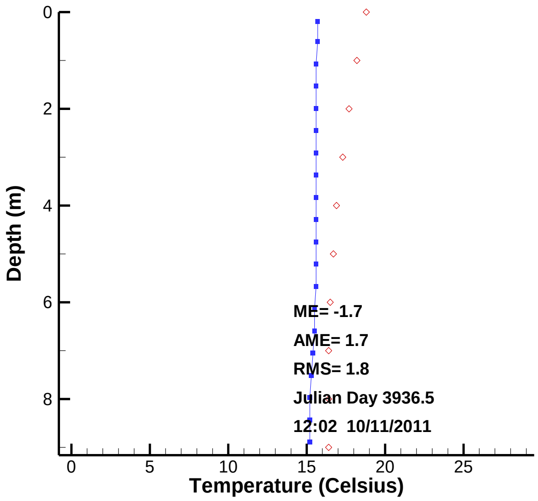
Depth (m)
0
2
4
6
8
ME= -.80
AME=0.85
RMS=0.93
Julian Day 3894.5
12:05 8/30/2011
0
5
10
15
20
25
Temperature (Celsius)



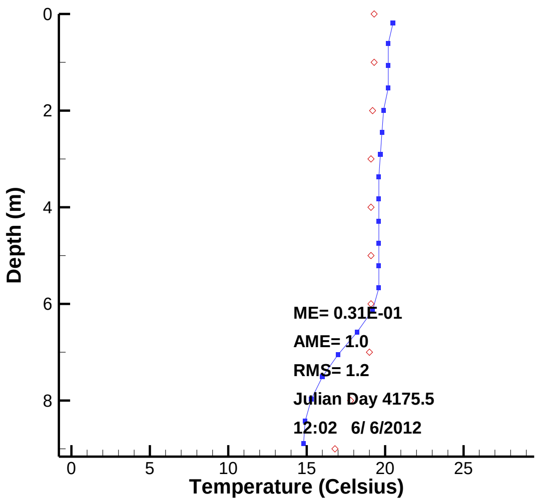
0
2
4
6
8
Depth (m)
ME= -.52
AME=0.52
RMS=0.58
Julian Day 3908.5
12:05 9/13/2011
0
5
10
15
20
25
Temperature (Celsius)



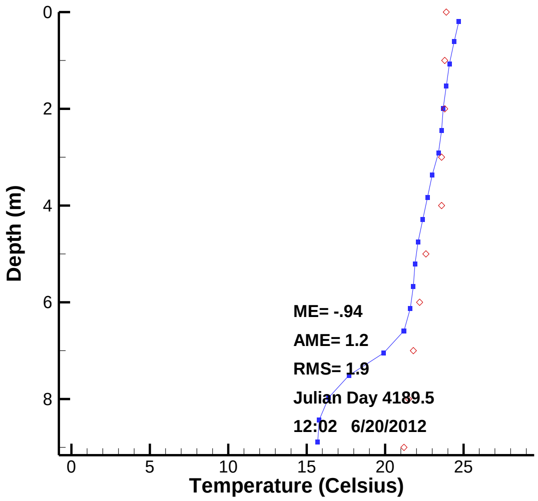
0
2
4
6
8
Depth (m)
ME= -1.3
AME= 1.3
RMS= 1.3
Julian Day 3922.5
12:07 9/27/2011
0
5
10
15
20
25
Temperature (Celsius)



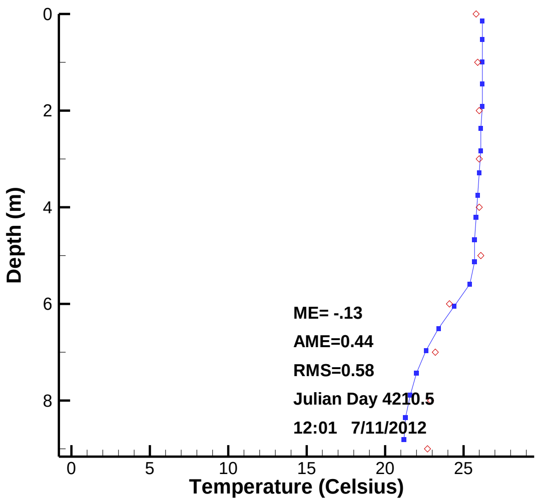
Depth (m)
Temperature (Celsius)
ME= -1.7
AME= 1.7
RMS= 1.8
Julian Day 3936.5
12:02 10/11/2011



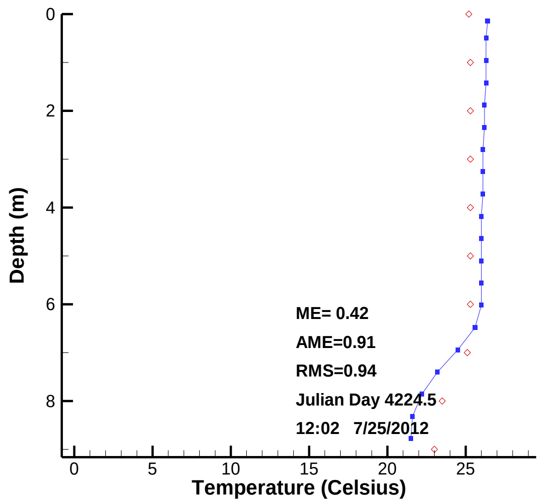
Depth (m)
Temperature (Celsius)
ME= 0.31E-01
AME= 1.0
RMS= 1.2
Julian Day 4175.5
12:02 6/ 6/2012

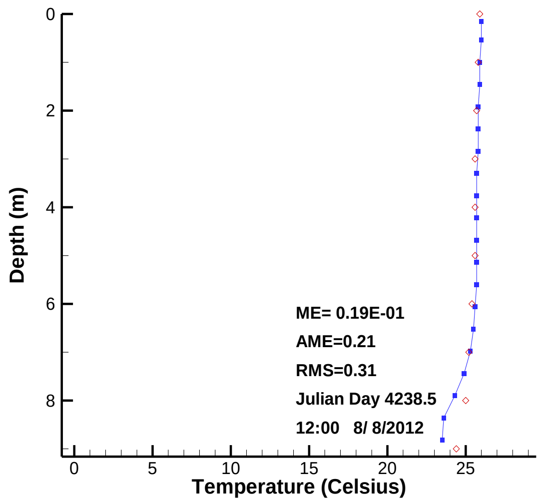


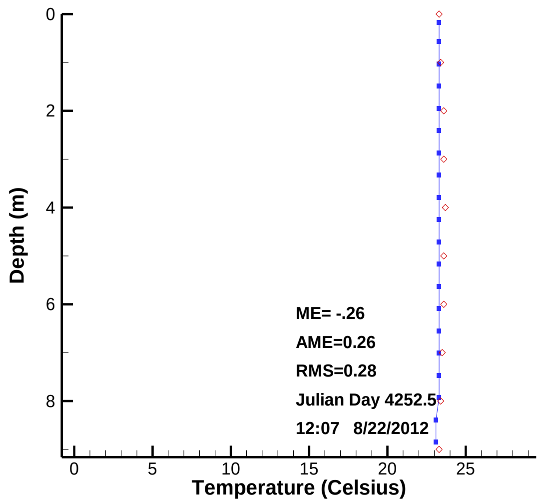
0
2
4
6
8
Depth (m)
ME= -.94
AME= 1.2
RMS= 1.9
Julian Day 4189.5
12:02 6/20/2012
0
5
10
15
20
25
Temperature (Celsius)

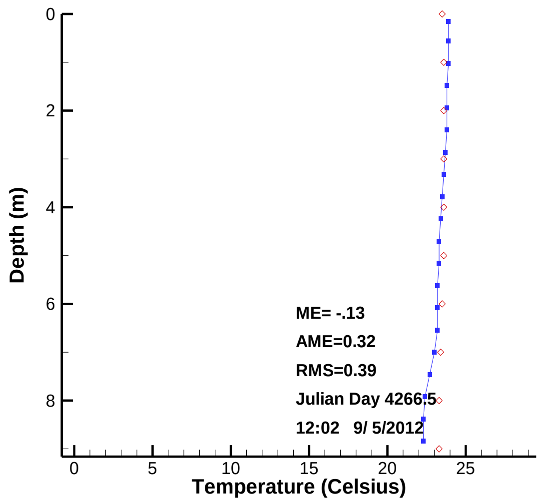


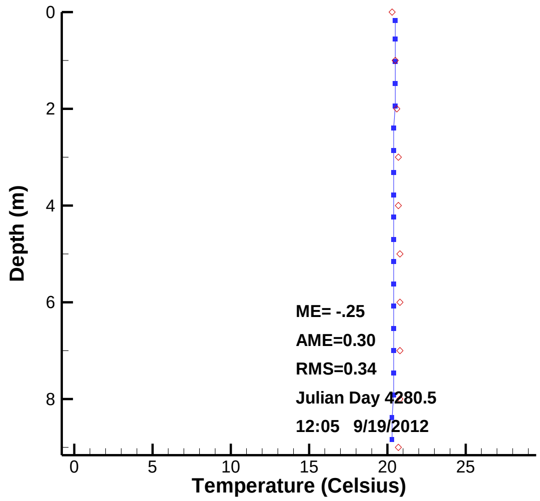
0
2
4
6
8
Depth (m)
ME= -.13
AME=0.44
RMS=0.58
Julian Day 4210.5
12:01 7/11/2012
0
5
10
15
20
25
Temperature (Celsius)


Depth (m)
Temperature (Celsius)
ME= 0.42
AME=0.91
RMS=0.94
Julian Day 4224.5
12:02 7/25/2012

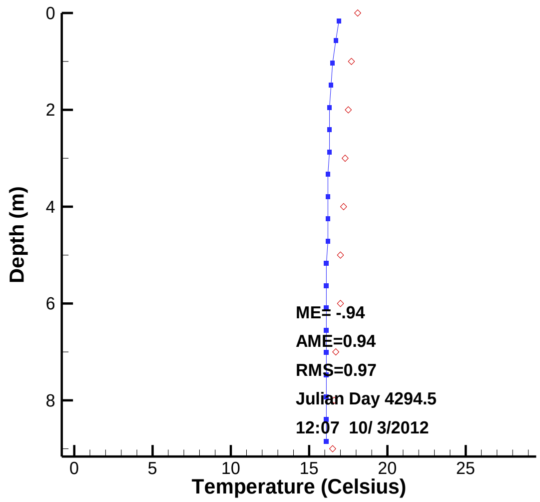

Depth (m)
Temperature (Celsius)
ME= 0.19E-01
AME=0.21
RMS=0.31
Julian Day 4238.5
12:00 8/ 8/2012


Depth (m)
ME= -.26
AME=0.26
RMS=0.28
Julian Day 4252.5
12:07 8/22/2012
Temperature (Celsius)

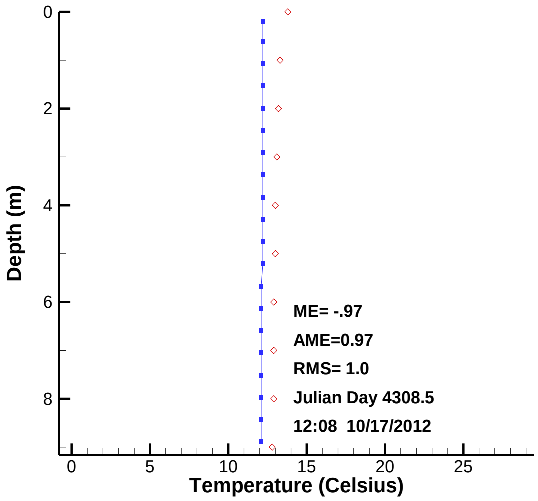

Depth (m)
ME= -.13
AME=0.32
RMS=0.39
Julian Day 4266.5
12:02 9/ 5/2012
Temperature (Celsius)

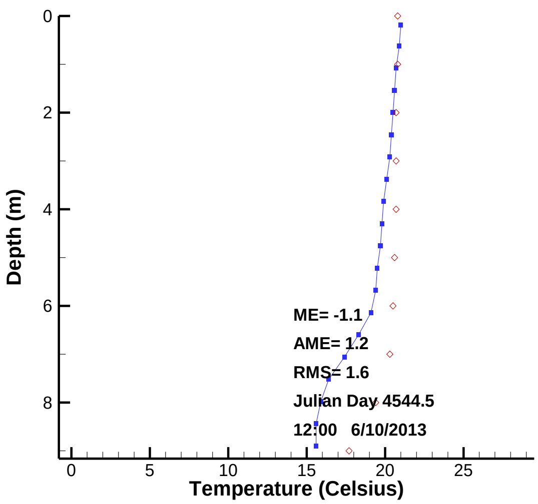


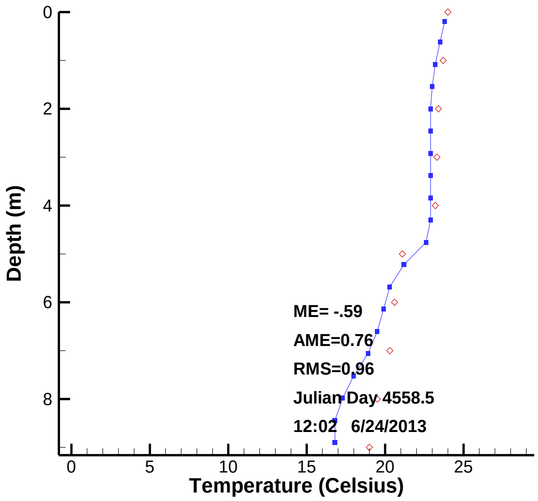
Depth (m)
ME= -.25
AME=0.30
RMS=0.34
Julian Day 4280.5
12:05 9/19/2012
Temperature (Celsius)



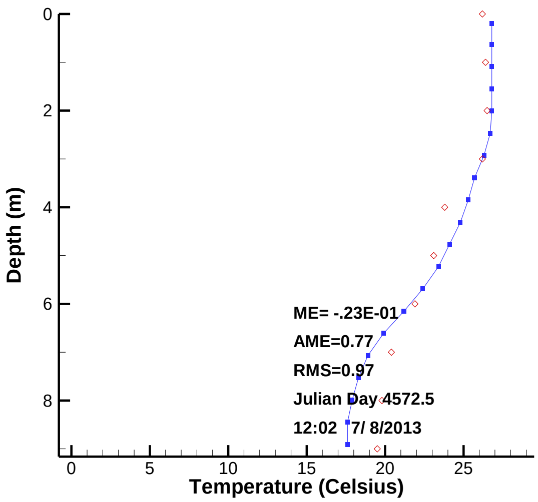
Depth (m)
ME= -.94
AME=0.94
RMS=0.97
Julian Day 4294.5
12:07 10/ 3/2012
Temperature (Celsius)


Depth (m)
Temperature (Celsius)
ME= -.97
AME=0.97
RMS= 1.0
Julian Day 4308.5
12:08 10/17/2012

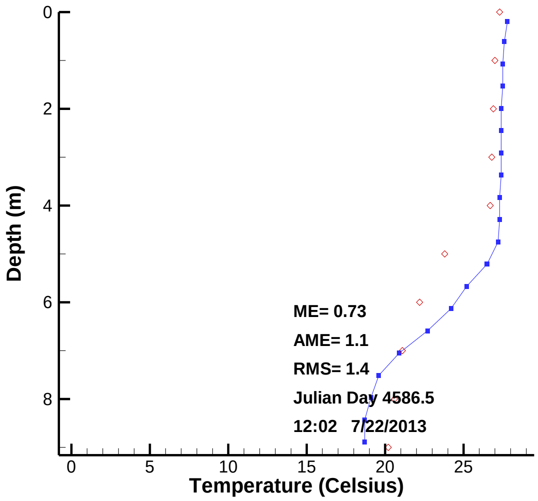

Depth (m)
Temperature (Celsius)
ME= -1.1
AME= 1.2
RMS= 1.6
Julian Day 4544.5
12:00 6/10/2013

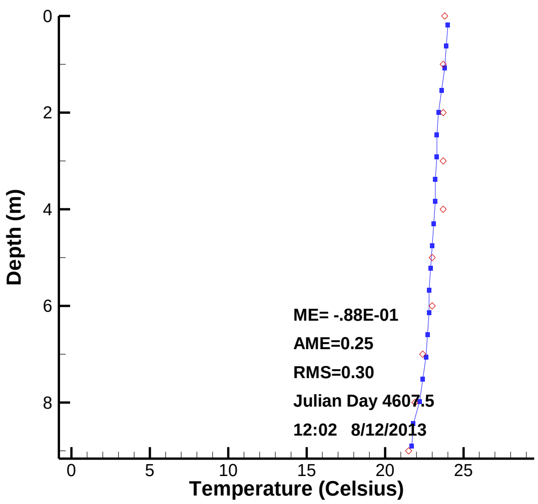


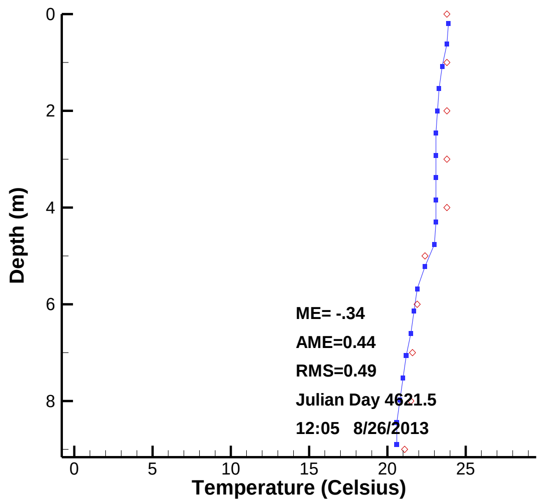
0
2
4
6
8
Depth (m)
ME= -.59
AME=0.76
RMS=0.96
Julian Day 4558.5
12:02 6/24/2013
0
5
10
15
20
25
Temperature (Celsius)



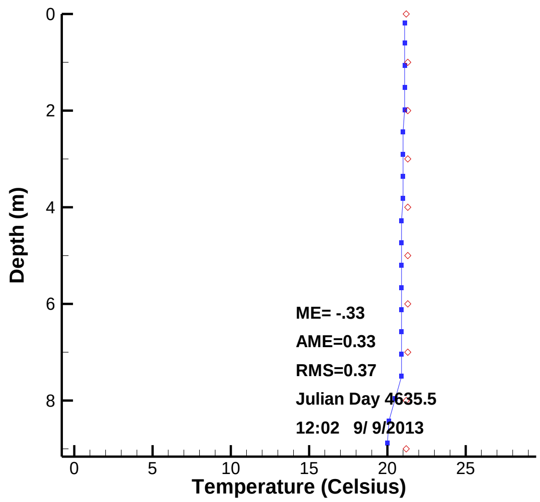
0
2
4
6
8
Depth (m)
ME= -.23E-01
AME=0.77
RMS=0.97
Julian Day 4572.5
12:02 7/ 8/2013
0
5
10
15
20
25
Temperature (Celsius)


ME= 0.73
AME= 1.1
RMS= 1.4
Julian Day 4586.5
12:02 7/22/2013
Depth (m)
Temperature (Celsius)

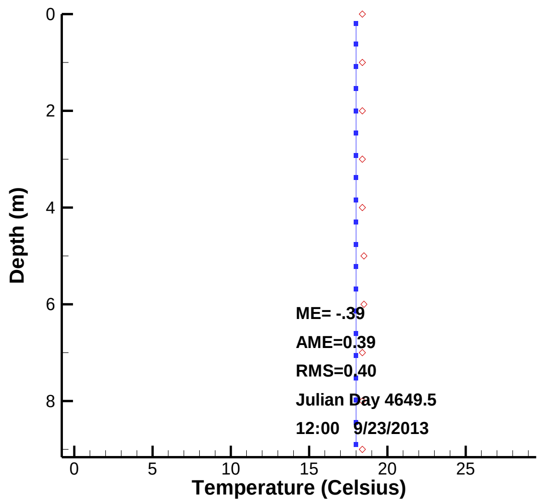

ME= -.88E-01
AME=0.25
RMS=0.30
Julian Day 4607.5
12:02 8/12/2013
Depth (m)
Temperature (Celsius)

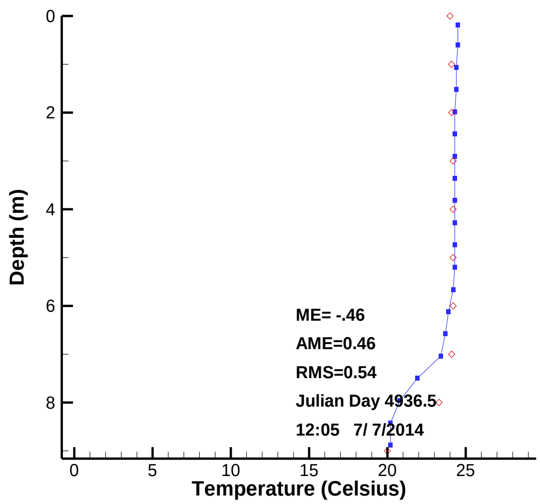


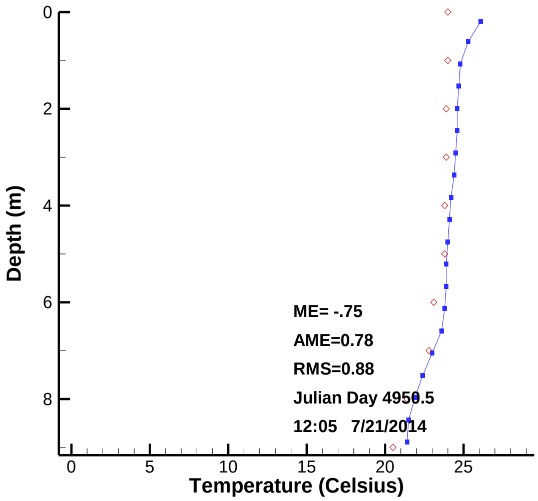
Depth (m)
0
2
4
6
8
ME= -.34
AME=0.44
RMS=0.49
Julian Day 4621.5
12:05 8/26/2013
0
5
10
15
20
25
Temperature (Celsius)



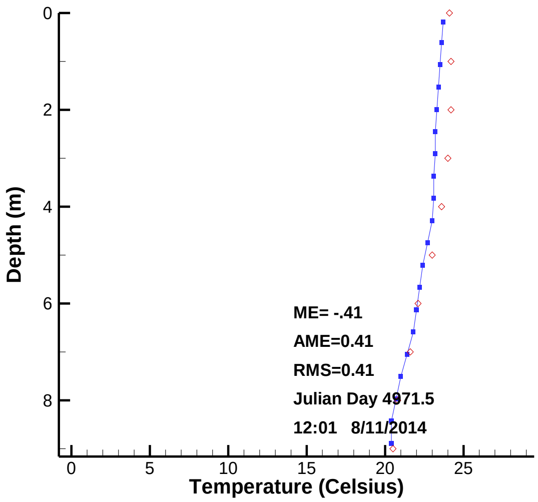
Depth (m)
0
2
4
6
8
ME= -.33
AME=0.33
RMS=0.37
Julian Day 4635.5
12:02 9/ 9/2013
0
5
10
15
20
25
Temperature (Celsius)


Depth (m)
0
2
4
6
8
0
5
10
15
20
25
Temperature (Celsius)
ME= -.39
AME=0.39
RMS=0.40
Julian Day 4649.5
12:00 9/23/2013

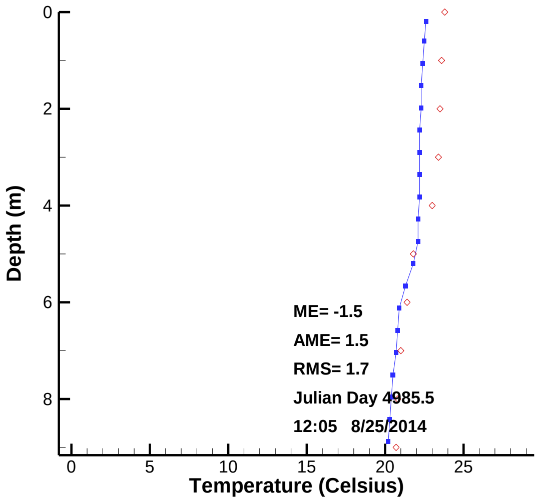

Depth (m)
0
2
4
6
8
0
5
10
15
20
25
Temperature (Celsius)
ME= -.46
AME=0.46
RMS=0.54
Julian Day 4936.5
12:05 7/ 7/2014



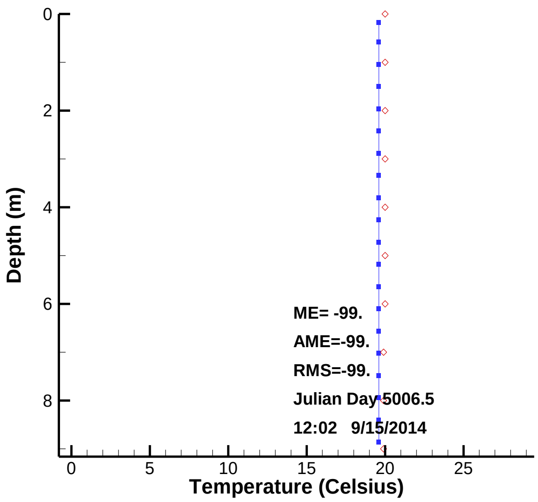
0
2
4
6
8
Depth (m)
0
5
10
15
20
25
Temperature (Celsius)
ME= -.75
AME=0.78
RMS=0.88
Julian Day 4950.5
12:05 7/21/2014



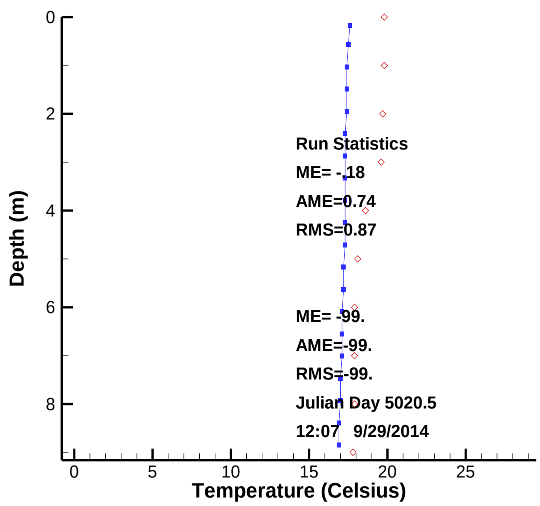
0
2
4
6
8
Depth (m)
0
5
10
15
20
25
Temperature (Celsius)
ME= -.41
AME=0.41
RMS=0.41
Julian Day 4971.5
12:01 8/11/2014



Depth (m)
Temperature (Celsius)
ME= -1.5
AME= 1.5
RMS= 1.7
Julian Day 4985.5
12:05 8/25/2014

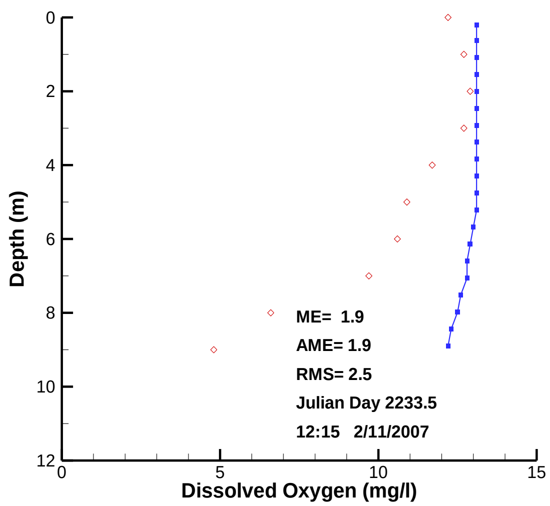


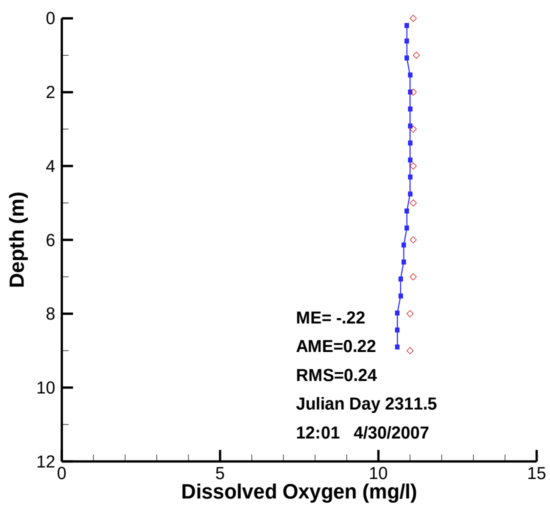
Depth (m)
Temperature (Celsius)
ME= -99.
AME=-99.
RMS=-99.
Julian Day 5006.5
12:02 9/15/2014

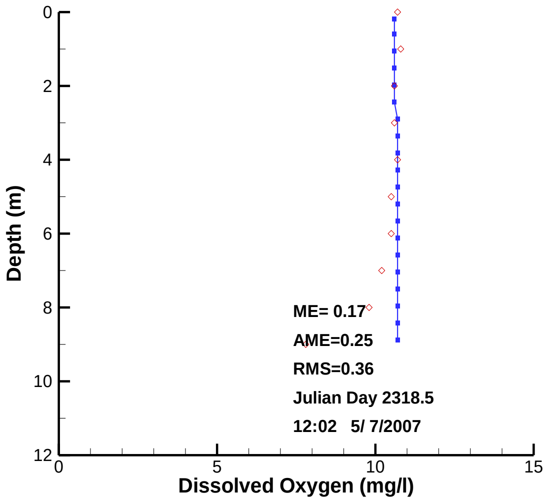


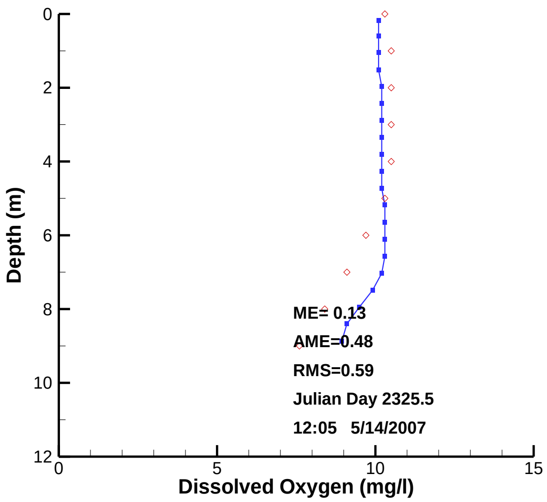
Run Statistics
ME= -.18
AME=0.74
RMS=0.87
ME= -99.
AME=-99.
RMS=-99.
Julian Day 5020.5
12:07 9/29/2014
Depth (m)
Temperature (Celsius)
0
2
4
6
8
0
5
10
15
20
25

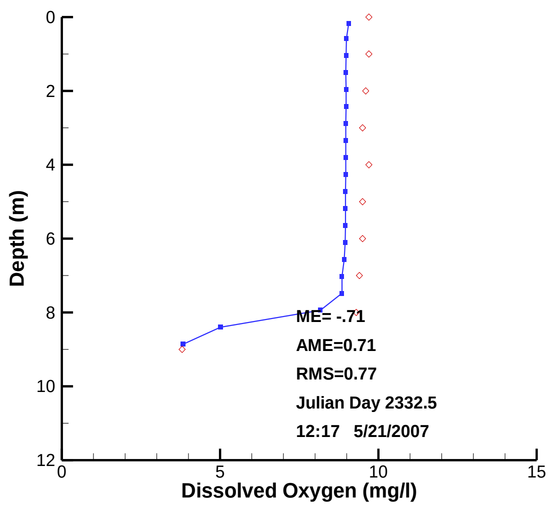
B2 Dissolved Oxygen Profile Plots

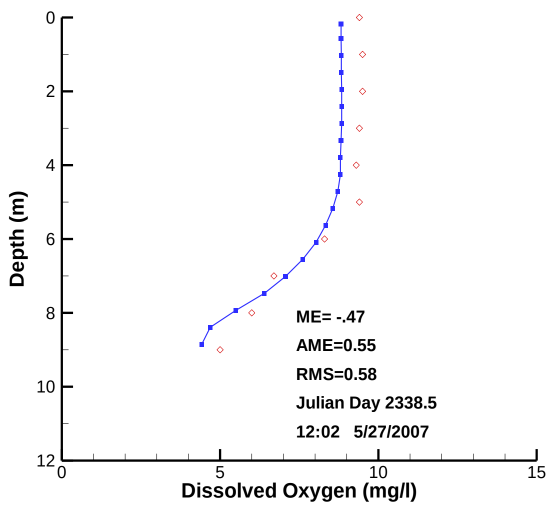


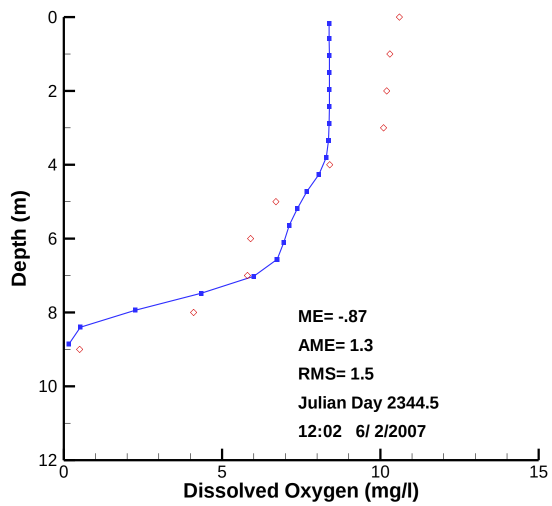


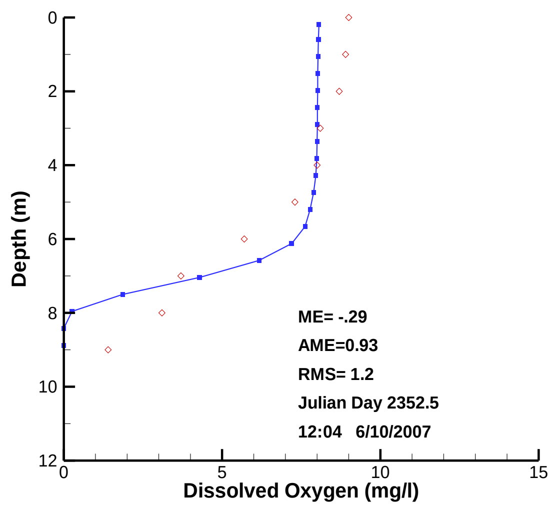

ME= 0.17
AME=0.25
RMS=0.36
Julian Day 2318.5
12:02 5/ 7/2007
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15

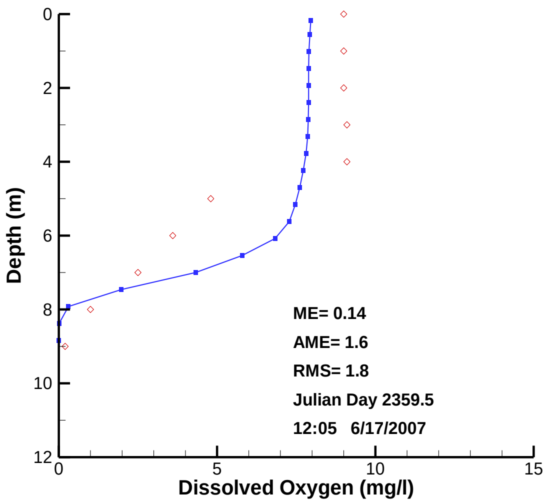

ME= 0.13
AME=0.48
RMS=0.59
Julian Day 2325.5
12:05 5/14/2007
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15

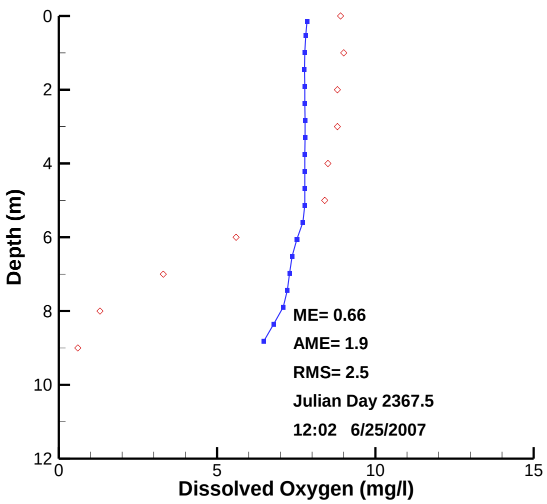

Depth (m)
Dissolved Oxygen (mg/l)
ME= -.71
AME=0.71
RMS=0.77
Julian Day 2332.5
12:17 5/21/2007

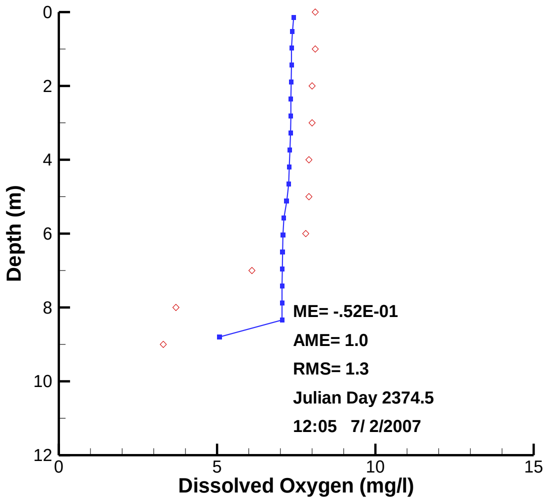

Depth (m)
Dissolved Oxygen (mg/l)
ME= -.47
AME=0.55
RMS=0.58
Julian Day 2338.5
12:02 5/27/2007

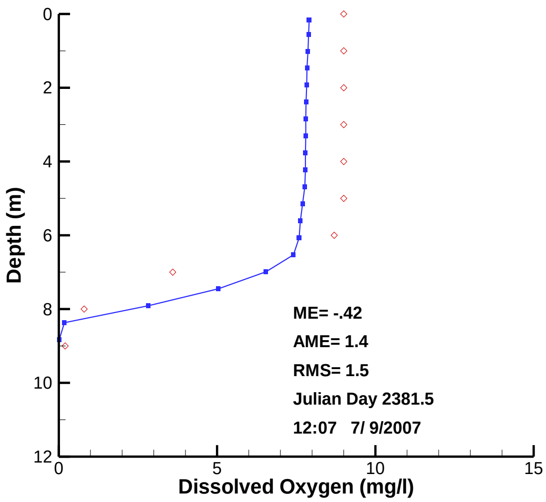

ME= -.87
AME= 1.3
RMS= 1.5
Julian Day 2344.5
12:02 6/ 2/2007
Depth (m)
Dissolved Oxygen (mg/l)

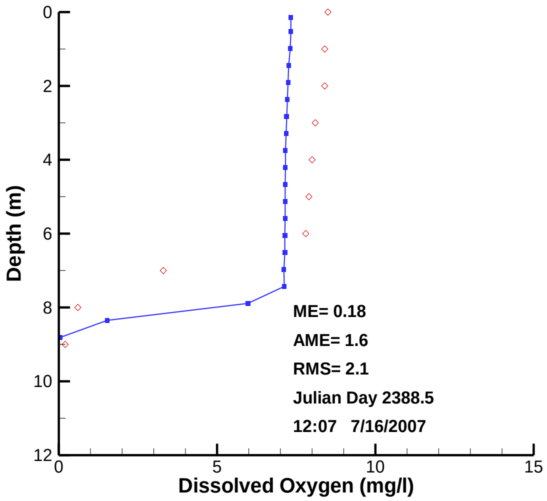

ME= -.29
AME=0.93
RMS= 1.2
Julian Day 2352.5
12:04 6/10/2007
Depth (m)
Dissolved Oxygen (mg/l)


Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.14
AME= 1.6
RMS= 1.8
Julian Day 2359.5
12:05 6/17/2007

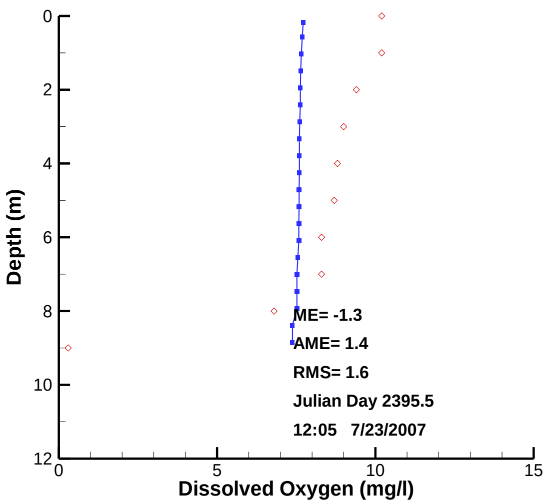

Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.66
AME= 1.9
RMS= 2.5
Julian Day 2367.5
12:02 6/25/2007


Depth (m)
Dissolved Oxygen (mg/l)
ME= -.52E-01
AME= 1.0
RMS= 1.3
Julian Day 2374.5
12:05 7/ 2/2007

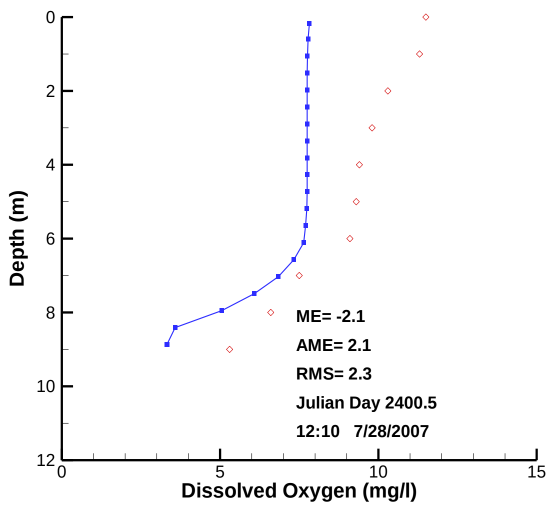

Depth (m)
Dissolved Oxygen (mg/l)
ME= -.42
AME= 1.4
RMS= 1.5
Julian Day 2381.5
12:07 7/ 9/2007

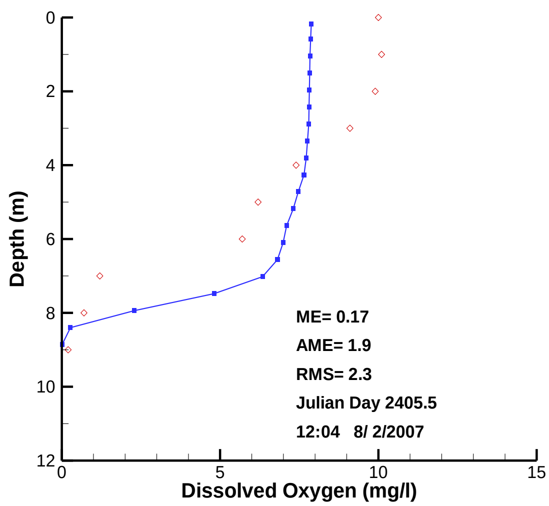


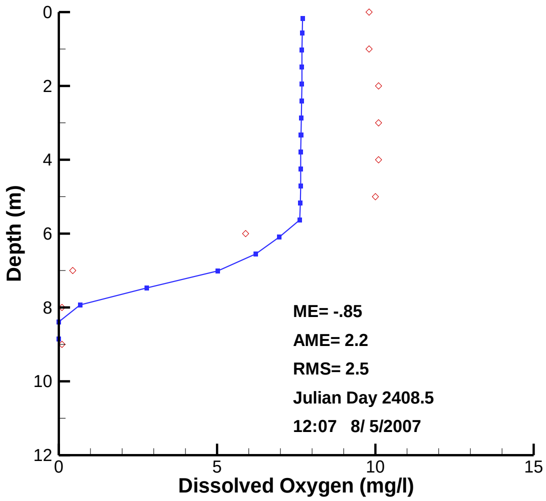
0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= 0.18
AME= 1.6
RMS= 2.1
Julian Day 2388.5
12:07 7/16/2007



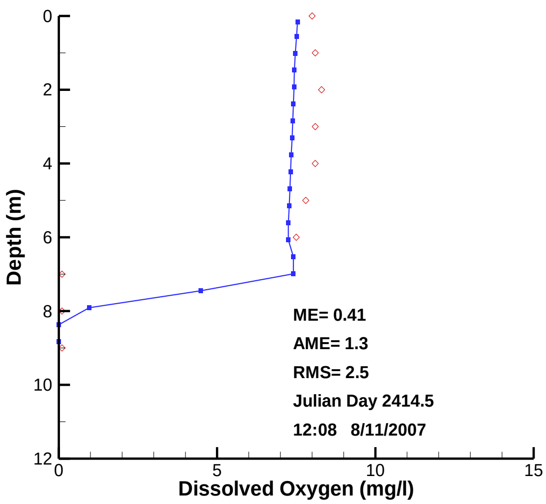
0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -1.3
AME= 1.4
RMS= 1.6
Julian Day 2395.5
12:05 7/23/2007


0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -2.1
AME= 2.1
RMS= 2.3
Julian Day 2400.5
12:10 7/28/2007

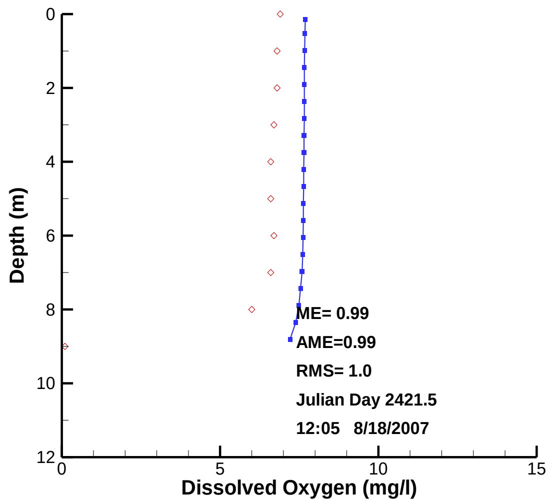

0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= 0.17
AME= 1.9
RMS= 2.3
Julian Day 2405.5
12:04 8/ 2/2007



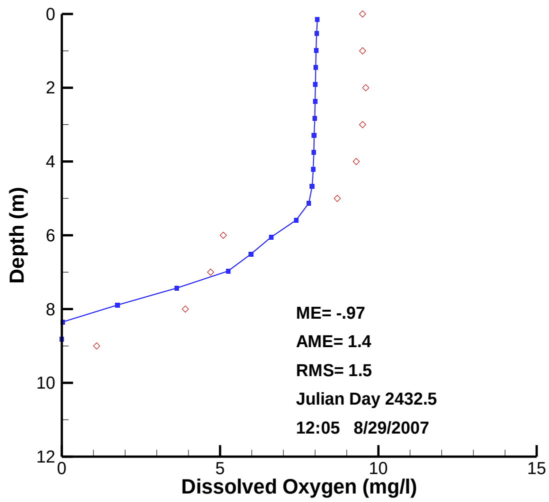
Depth (m)
Dissolved Oxygen (mg/l)
ME= -.85
AME= 2.2
RMS= 2.5
Julian Day 2408.5
12:07 8/ 5/2007



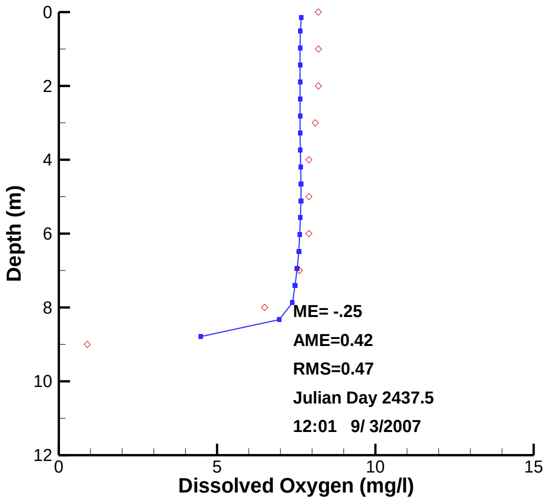
Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.41
AME= 1.3
RMS= 2.5
Julian Day 2414.5
12:08 8/11/2007

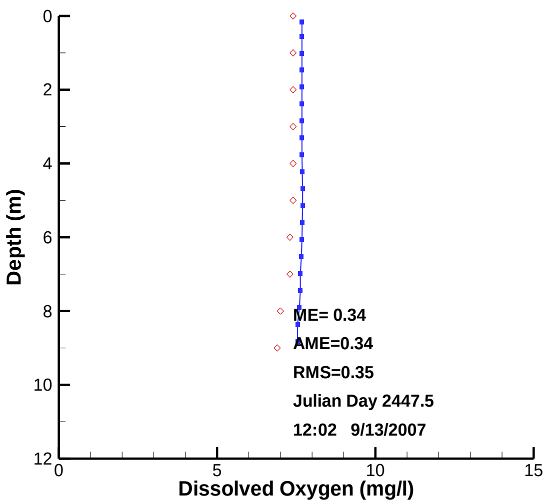


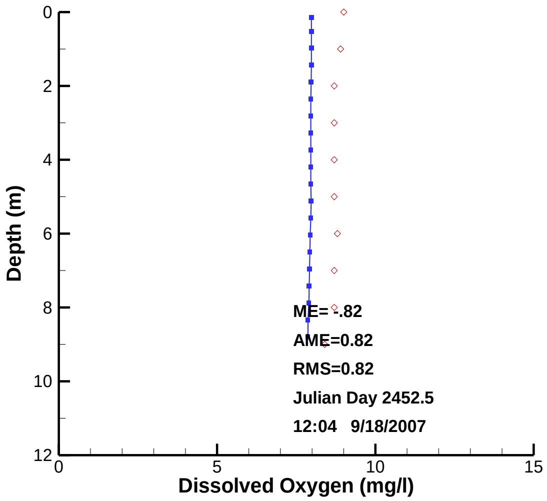
Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.99
AME=0.99
RMS= 1.0
Julian Day 2421.5
12:05 8/18/2007

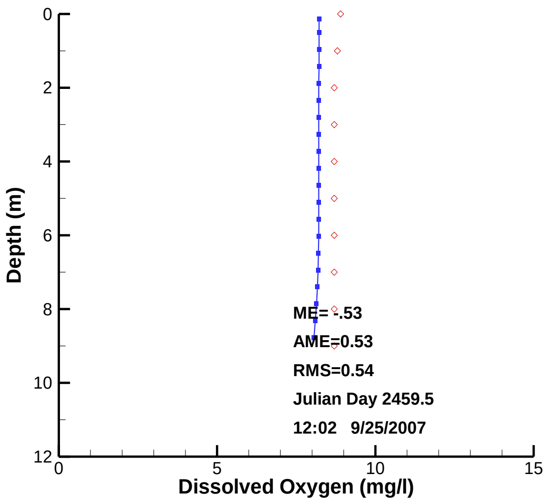


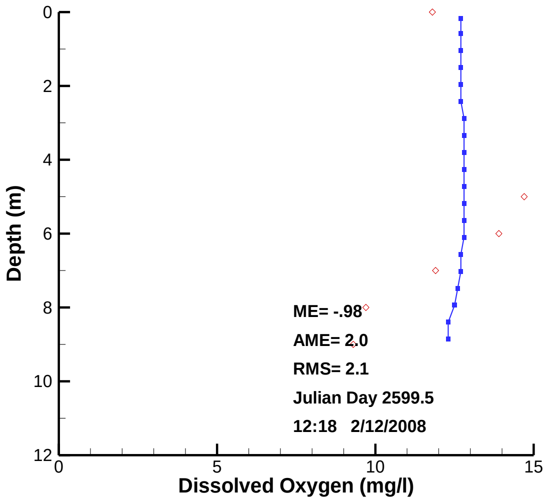
Depth (m)
Dissolved Oxygen (mg/l)
ME= -.97
AME= 1.4
RMS= 1.5
Julian Day 2432.5
12:05 8/29/2007

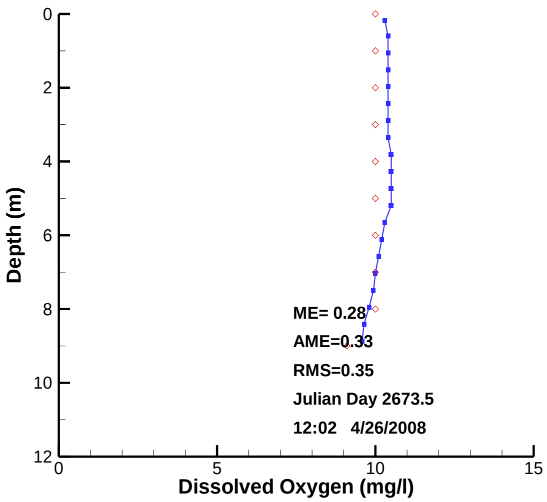

Depth (m)
Dissolved Oxygen (mg/l)
ME= -.25
AME=0.42
RMS=0.47
Julian Day 2437.5
12:01 9/ 3/2007

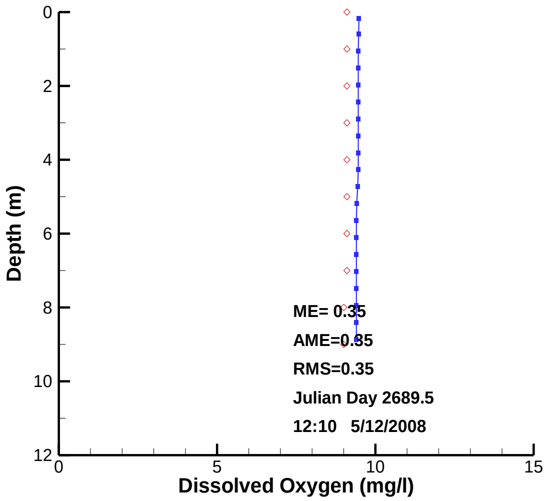

Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.34
AME=0.34
RMS=0.35
Julian Day 2447.5
12:02 9/13/2007


ME=-.82
AME=0.82
RMS=0.82
Julian Day 2452.5
12:04 9/18/2007
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15

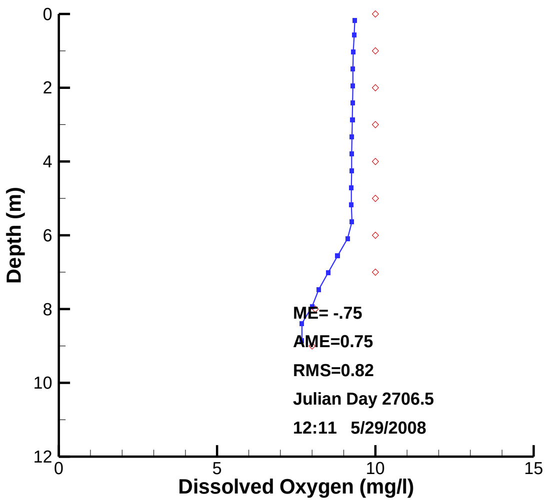

ME=-.53
AME=0.53
RMS=0.54
Julian Day 2459.5
12:02 9/25/2007
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15


ME= -.98
AME= 2.0
RMS= 2.1
Julian Day 2599.5
12:18 2/12/2008
Depth (m)
Dissolved Oxygen (mg/l)

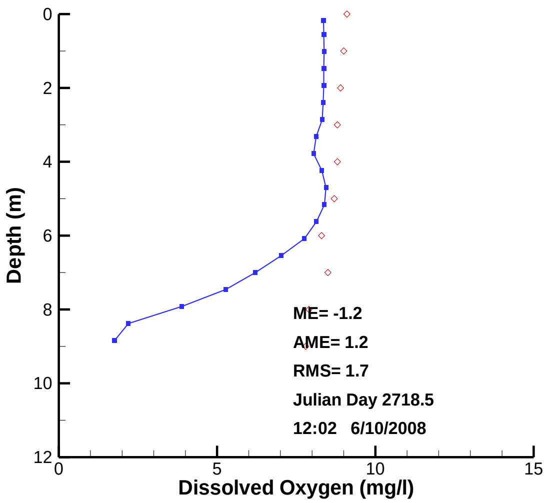

ME= 0.28
AME=0.33
RMS=0.35
Julian Day 2673.5
12:02 4/26/2008
Depth (m)
Dissolved Oxygen (mg/l)

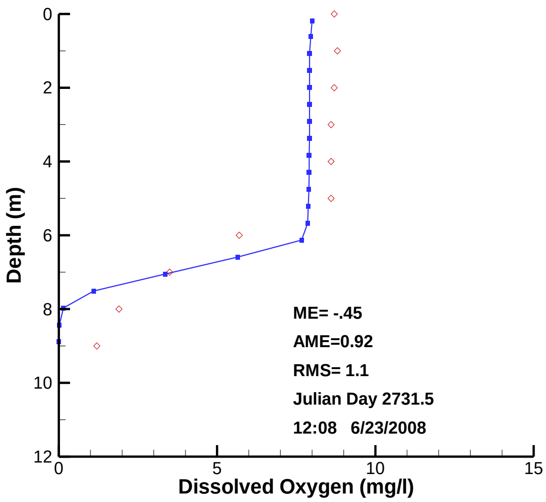


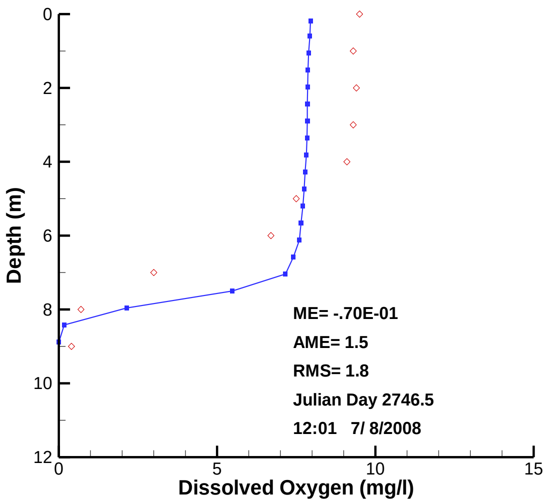
Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.35
AME=0.35
RMS=0.35
Julian Day 2689.5
12:10 5/12/2008

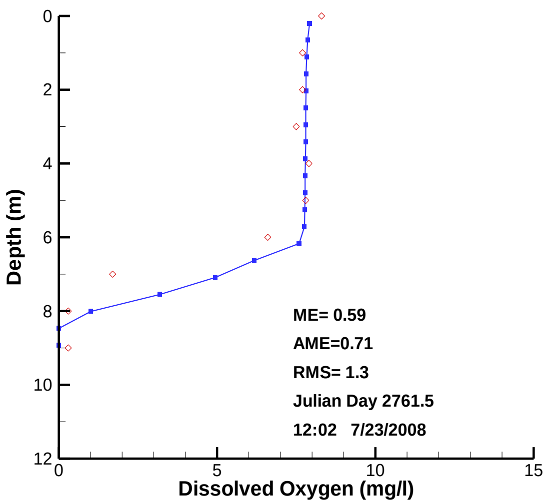


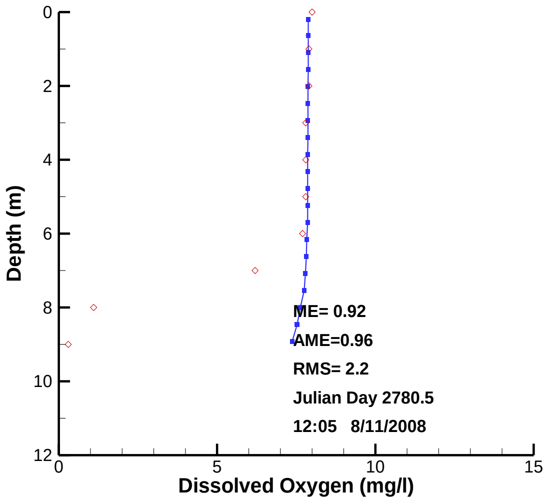
Depth (m)
Dissolved Oxygen (mg/l)
ME= -.75
AME=0.75
RMS=0.82
Julian Day 2706.5
12:11 5/29/2008


Depth (m)
Dissolved Oxygen (mg/l)
ME= -1.2
AME= 1.2
RMS= 1.7
Julian Day 2718.5
12:02 6/10/2008

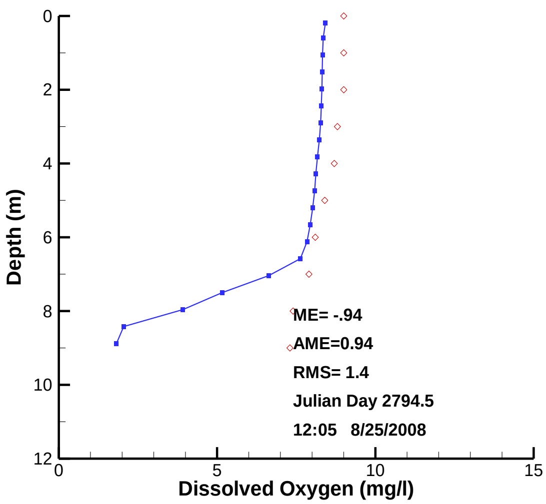

Depth (m)
Dissolved Oxygen (mg/l)
ME= -.45
AME=0.92
RMS= 1.1
Julian Day 2731.5
12:08 6/23/2008


ME= -.70E-01
AME= 1.5
RMS= 1.8
Julian Day 2746.5
12:01 7/ 8/2008
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15

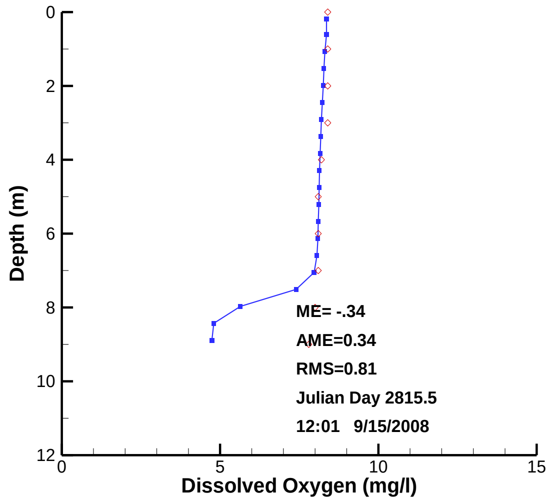

ME= 0.59
AME=0.71
RMS= 1.3
Julian Day 2761.5
12:02 7/23/2008
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15



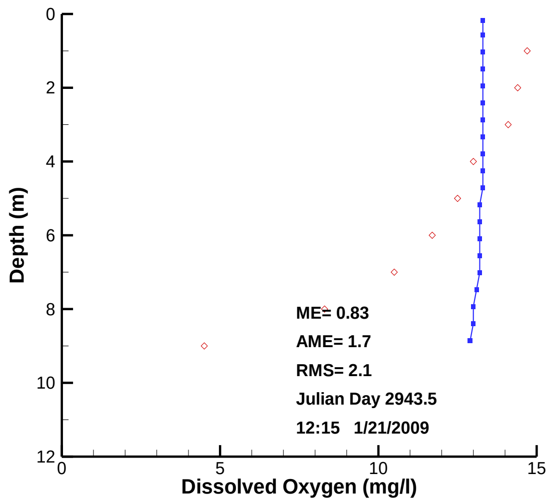
Depth (m)
0
2
4
6
8
10
12
0
5
10
15
Dissolved Oxygen (mg/l)
ME= 0.92
AME=0.96
RMS= 2.2
Julian Day 2780.5
12:05 8/11/2008



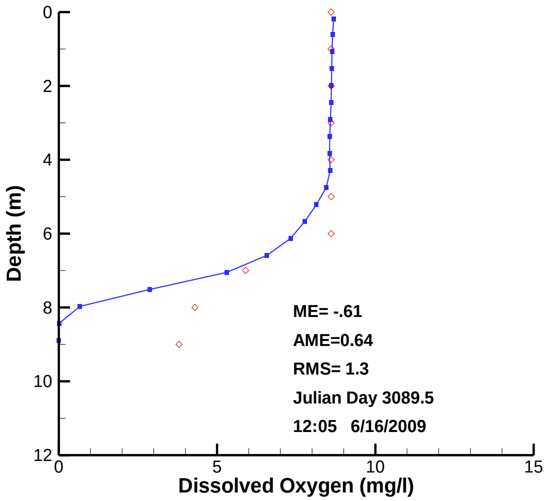
Depth (m)
0
2
4
6
8
10
12
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -.94
AME=0.94
RMS= 1.4
Julian Day 2794.5
12:05 8/25/2008



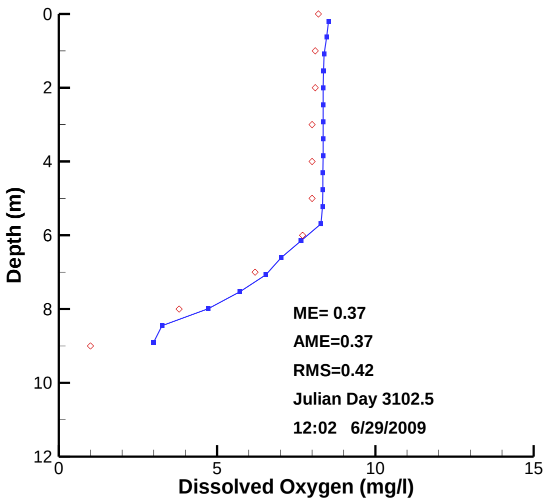
0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -.34
AME=0.34
RMS=0.81
Julian Day 2815.5
12:01 9/15/2008



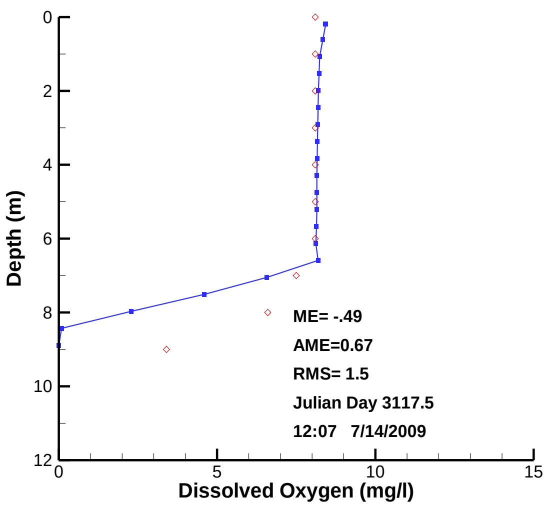
0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= 0.83
AME= 1.7
RMS= 2.1
Julian Day 2943.5
12:15 1/21/2009



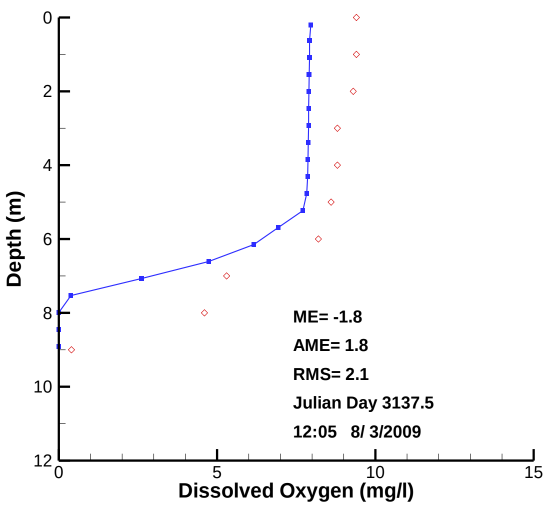
Depth (m)
0
2
4
6
8
10
12
ME= -.61
AME=0.64
RMS= 1.3
Julian Day 3089.5
12:05 6/16/2009
0
5
10
15
Dissolved Oxygen (mg/l)



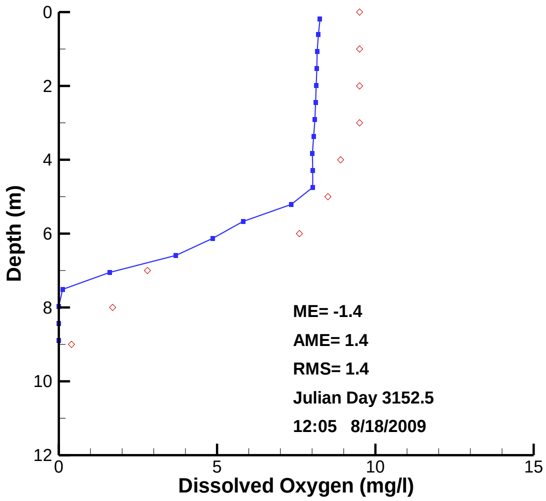
Depth (m)
0
2
4
6
8
10
12
ME= 0.37
AME=0.37
RMS=0.42
Julian Day 3102.5
12:02 6/29/2009
0
5
10
15
Dissolved Oxygen (mg/l)



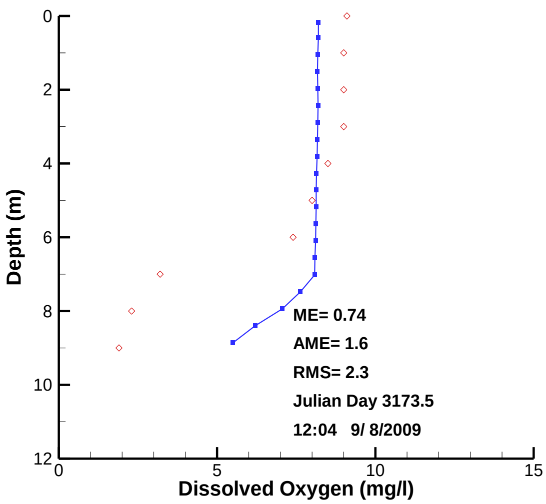
0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -.49
AME=0.67
RMS= 1.5
Julian Day 3117.5
12:07 7/14/2009



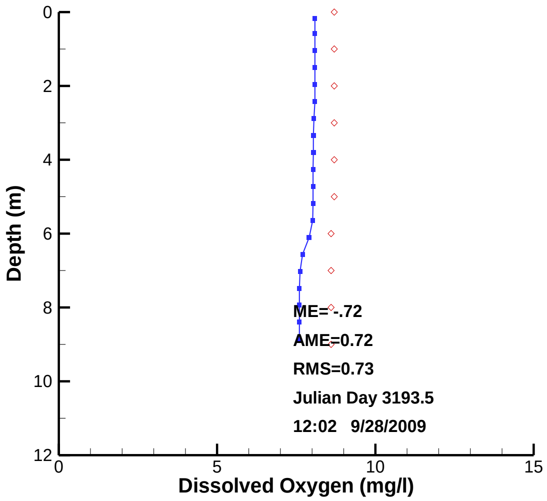
0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -1.8
AME= 1.8
RMS= 2.1
Julian Day 3137.5
12:05 8/ 3/2009

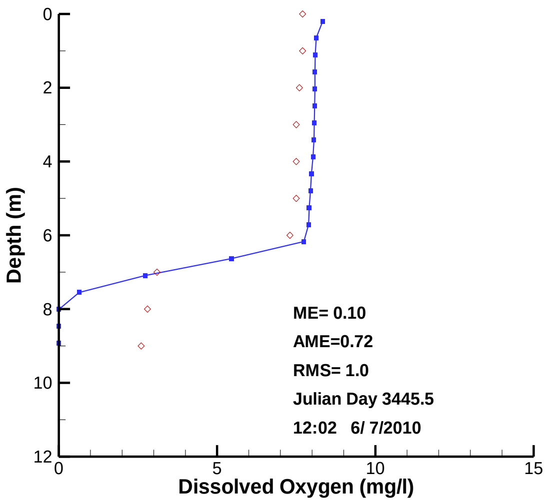


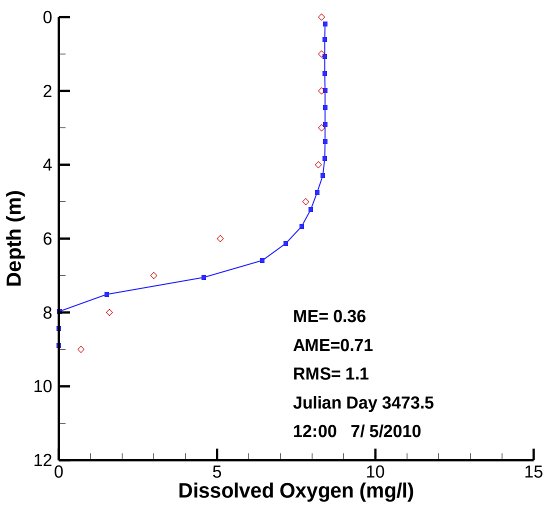
0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -1.4
AME= 1.4
RMS= 1.4
Julian Day 3152.5
12:05 8/18/2009

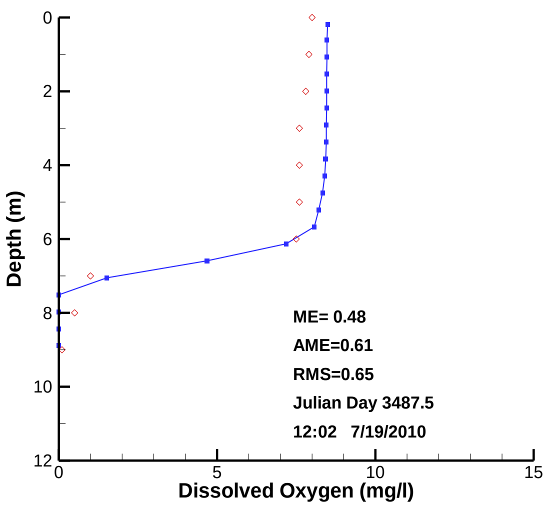


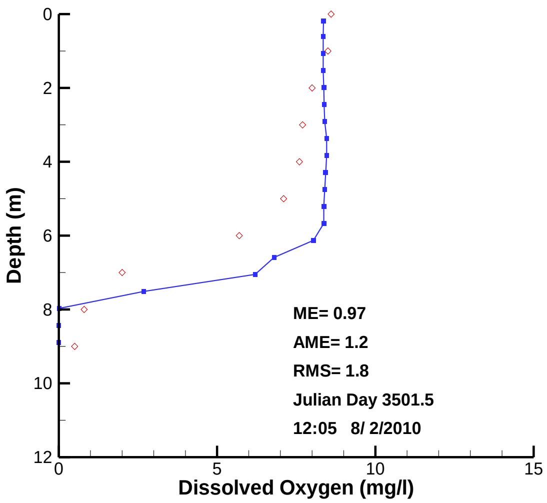
0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= 0.74
AME= 1.6
RMS= 2.3
Julian Day 3173.5
12:04 9/ 8/2009

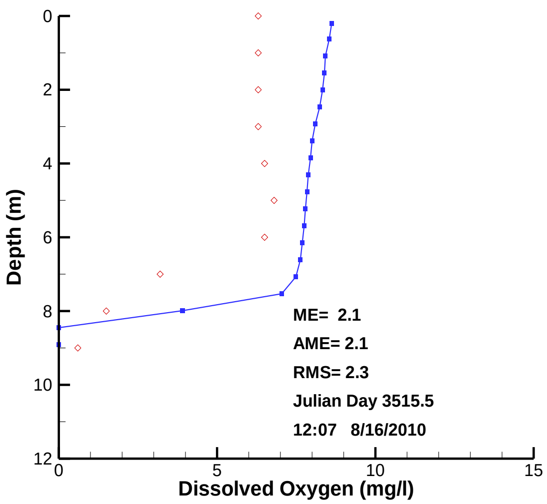

ME= -.72
AME=0.72
RMS=0.73
Julian Day 3193.5
12:02 9/28/2009
Depth (m)
Dissolved Oxygen (mg/l)

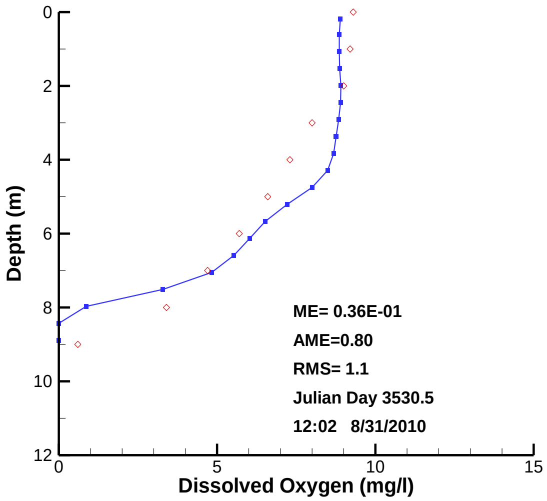

ME= 0.10
AME=0.72
RMS= 1.0
Julian Day 3445.5
12:02 6/ 7/2010
Depth (m)
Dissolved Oxygen (mg/l)

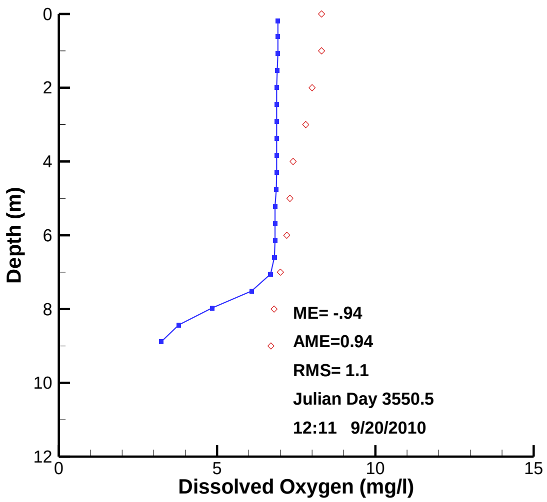

Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.36
AME=0.71
RMS= 1.1
Julian Day 3473.5
12:00 7/ 5/2010
0
2
4
6
8
10
12
0
5
10
15

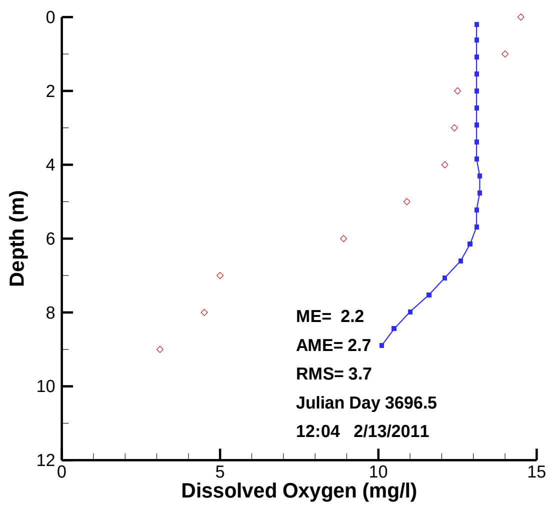

Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.48
AME=0.61
RMS=0.65
Julian Day 3487.5
12:02 7/19/2010
0
2
4
6
8
10
12
0
5
10
15

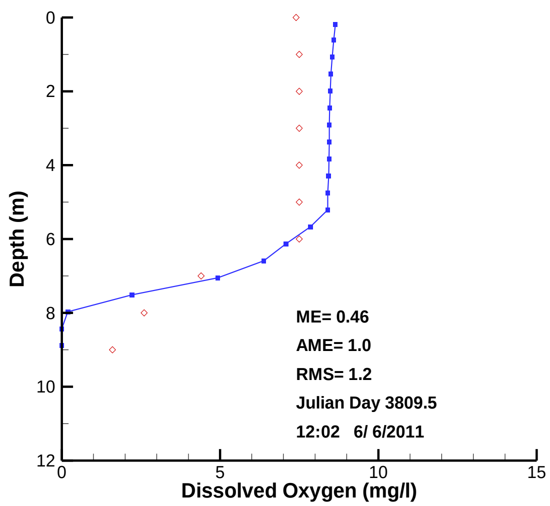

ME= 0.97
AME= 1.2
RMS= 1.8
Julian Day 3501.5
12:05 8/ 2/2010
Depth (m)
Dissolved Oxygen (mg/l)

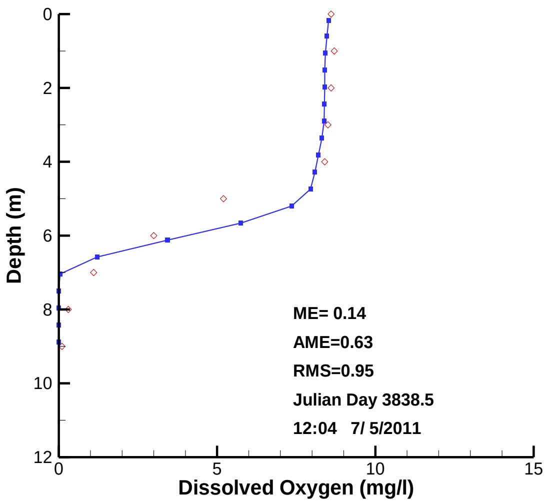

ME= 2.1
AME= 2.1
RMS= 2.3
Julian Day 3515.5
12:07 8/16/2010
Depth (m)
Dissolved Oxygen (mg/l)

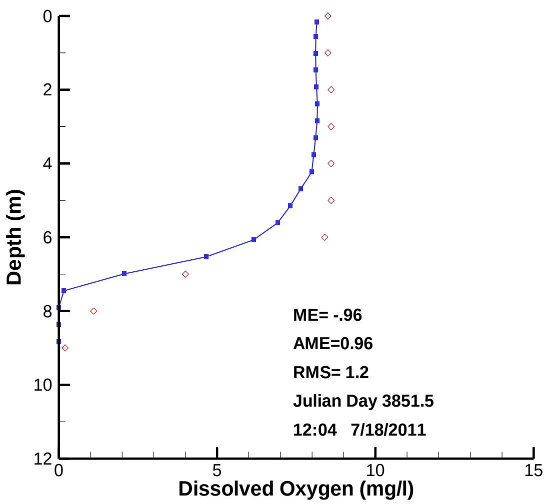

Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.36E-01
AME=0.80
RMS= 1.1
Julian Day 3530.5
12:02 8/31/2010

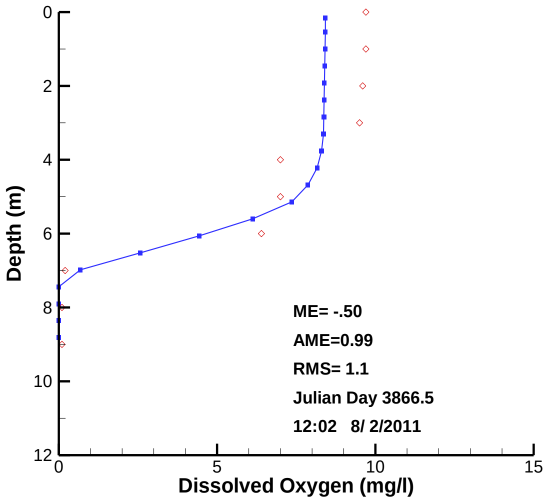

Depth (m)
Dissolved Oxygen (mg/l)
ME= -.94
AME=0.94
RMS= 1.1
Julian Day 3550.5
12:11 9/20/2010

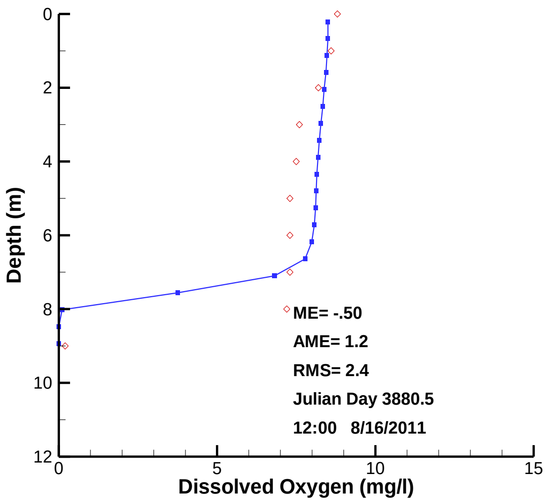

Depth (m)
Dissolved Oxygen (mg/l)
ME= 2.2
AME= 2.7
RMS= 3.7
Julian Day 3696.5
12:04 2/13/2011

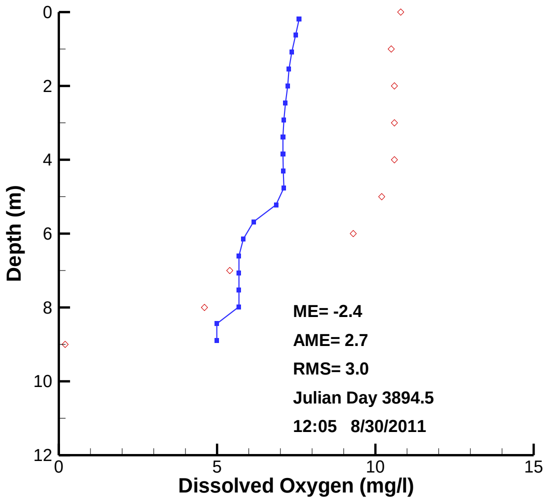

Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.46
AME= 1.0
RMS= 1.2
Julian Day 3809.5
12:02 6/ 6/2011

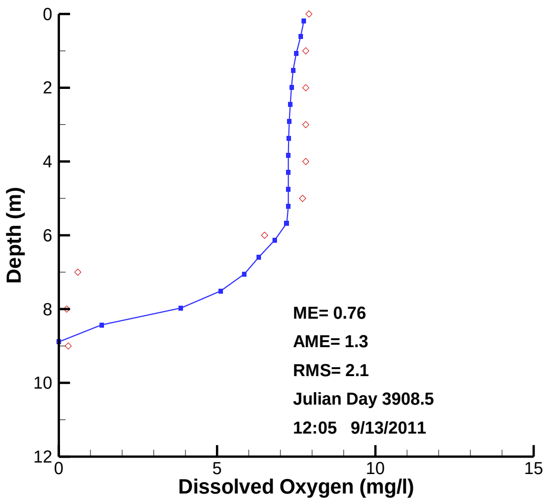

Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15
ME= 0.14
AME=0.63
RMS=0.95
Julian Day 3838.5
12:04 7/ 5/2011

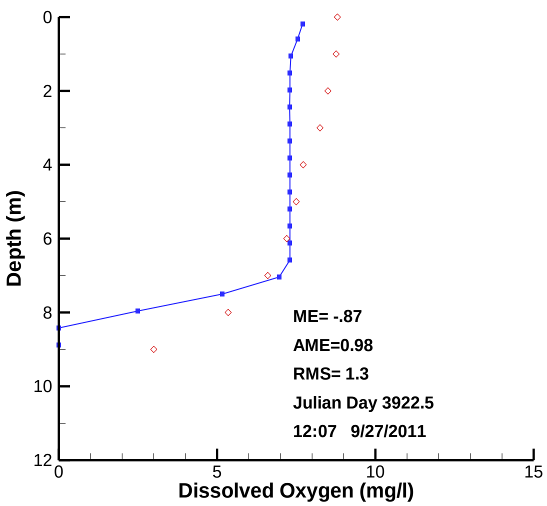

Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15
ME= -.96
AME=0.96
RMS= 1.2
Julian Day 3851.5
12:04 7/18/2011

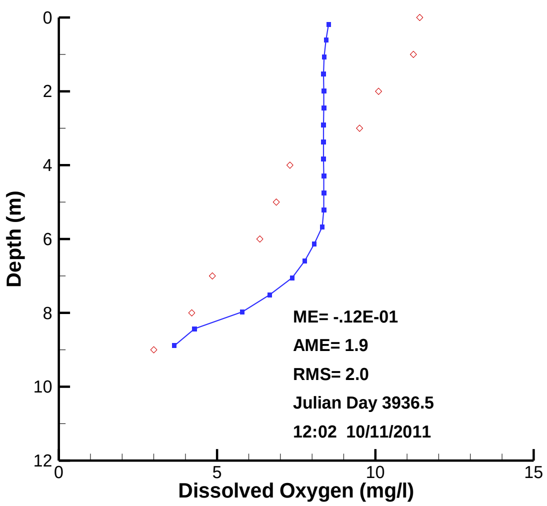

ME= -.50
AME=0.99
RMS= 1.1
Julian Day 3866.5
12:02 8/ 2/2011
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15

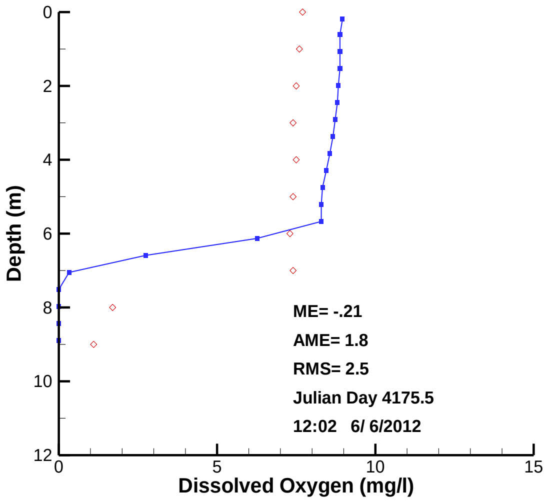

ME= -.50
AME= 1.2
RMS= 2.4
Julian Day 3880.5
12:00 8/16/2011
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15


ME= -2.4
AME= 2.7
RMS= 3.0
Julian Day 3894.5
12:05 8/30/2011
Depth (m)
Dissolved Oxygen (mg/l)

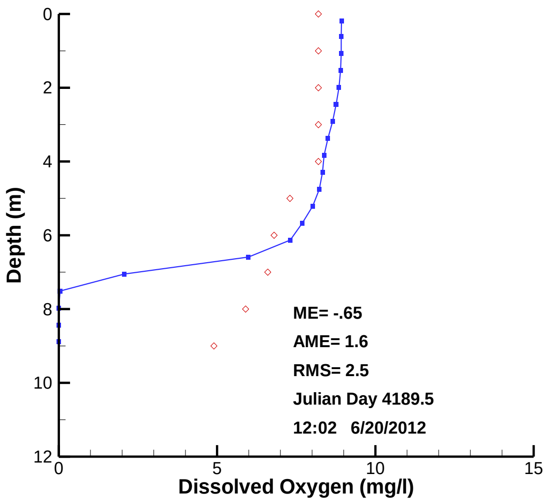

ME= 0.76
AME= 1.3
RMS= 2.1
Julian Day 3908.5
12:05 9/13/2011
Depth (m)
Dissolved Oxygen (mg/l)


Depth (m)
Dissolved Oxygen (mg/l)
ME= -.87
AME=0.98
RMS= 1.3
Julian Day 3922.5
12:07 9/27/2011

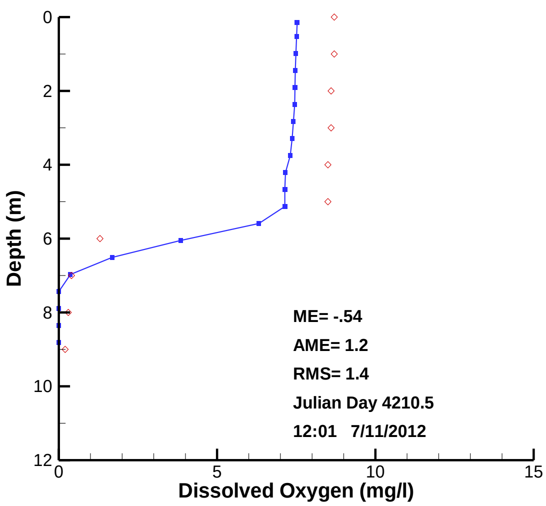

Depth (m)
Dissolved Oxygen (mg/l)
ME= -.12E-01
AME= 1.9
RMS= 2.0
Julian Day 3936.5
12:02 10/11/2011



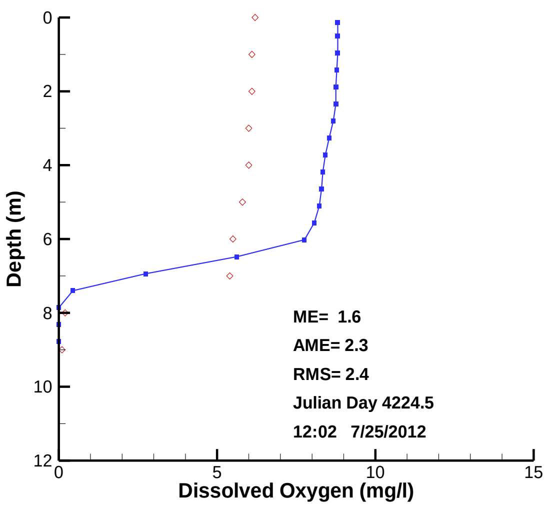
Depth (m)
Dissolved Oxygen (mg/l)
ME= -.21
AME= 1.8
RMS= 2.5
Julian Day 4175.5
12:02 6/ 6/2012



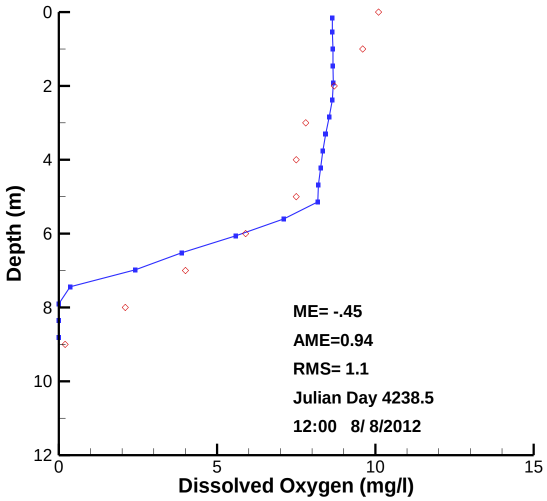
Depth (m)
Dissolved Oxygen (mg/l)
ME= -.65
AME= 1.6
RMS= 2.5
Julian Day 4189.5
12:02 6/20/2012

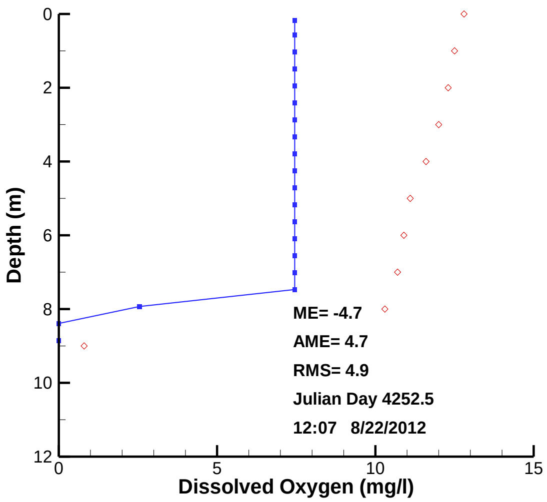


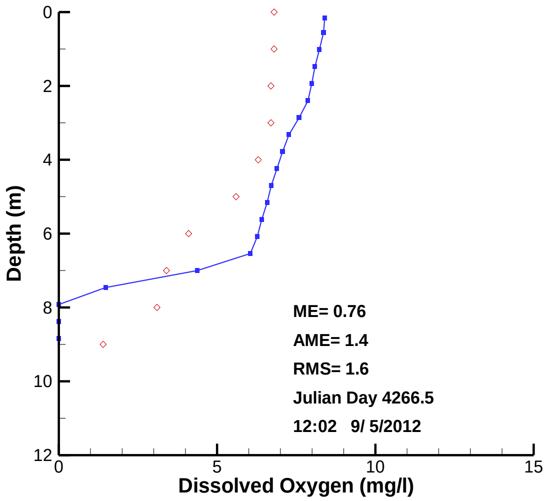
0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -.54
AME= 1.2
RMS= 1.4
Julian Day 4210.5
12:01 7/11/2012

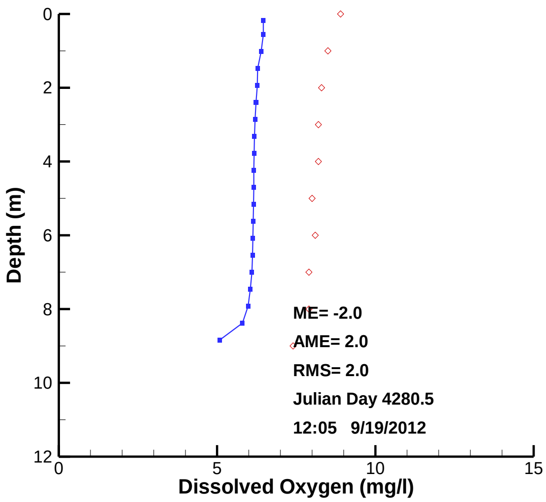


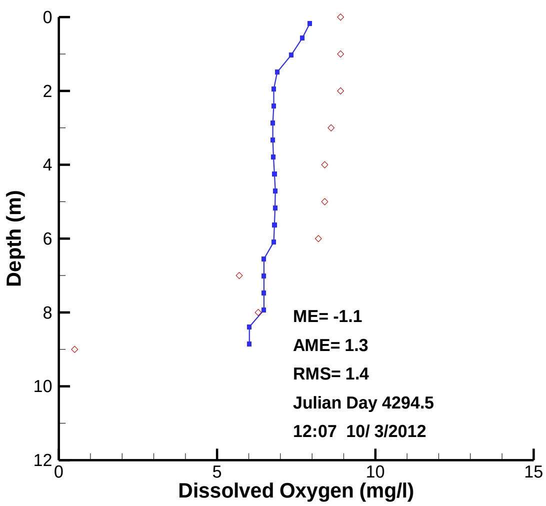
0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= 1.6
AME= 2.3
RMS= 2.4
Julian Day 4224.5
12:02 7/25/2012


ME= -.45
AME=0.94
RMS= 1.1
Julian Day 4238.5
12:00 8/ 8/2012
Depth (m)
Dissolved Oxygen (mg/l)

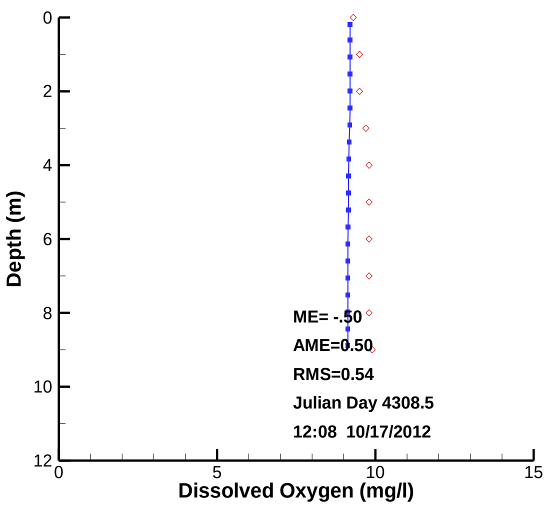

ME= -4.7
AME= 4.7
RMS= 4.9
Julian Day 4252.5
12:07 8/22/2012
Depth (m)
Dissolved Oxygen (mg/l)


ME= 0.76
AME= 1.4
RMS= 1.6
Julian Day 4266.5
12:02 9/ 5/2012
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15

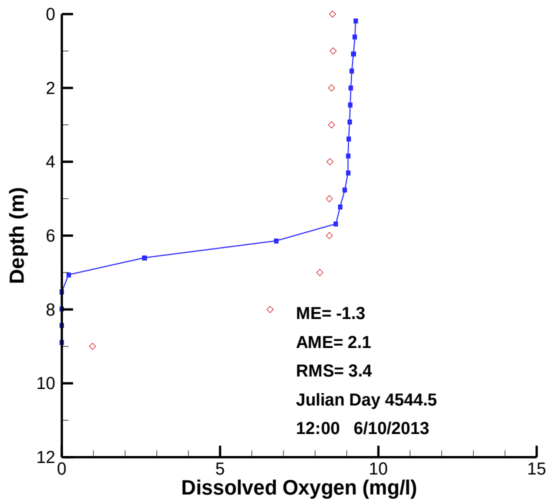

ME= -2.0
AME= 2.0
RMS= 2.0
Julian Day 4280.5
12:05 9/19/2012
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15



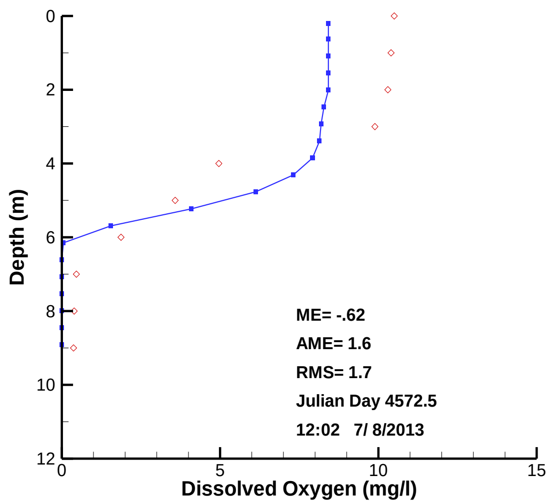
ME= -1.1
AME= 1.3
RMS= 1.4
Julian Day 4294.5
12:07 10/ 3/2012
Depth (m)
Dissolved Oxygen (mg/l)



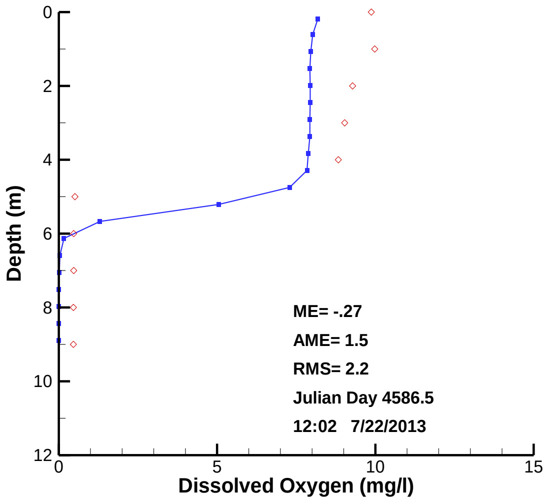
ME= -.50
AME=0.50
RMS=0.54
Julian Day 4308.5
12:08 10/17/2012
Depth (m)
Dissolved Oxygen (mg/l)



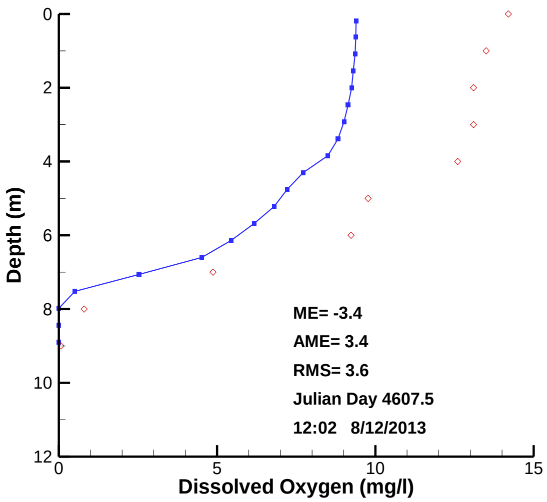
Depth (m)
0
2
4
6
8
10
12
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -1.3
AME= 2.1
RMS= 3.4
Julian Day 4544.5
12:00 6/10/2013



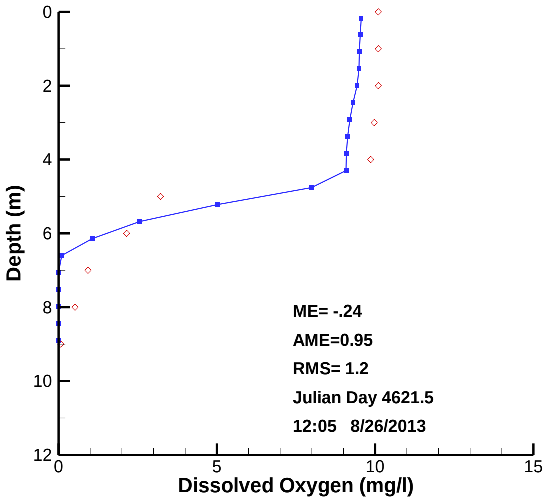
Depth (m)
0
2
4
6
8
10
12
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -.62
AME= 1.6
RMS= 1.7
Julian Day 4572.5
12:02 7/ 8/2013



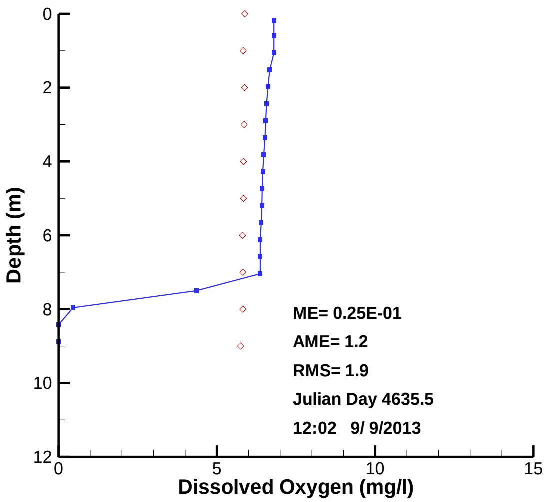
Depth (m)
Dissolved Oxygen (mg/l)
ME= -.27
AME= 1.5
RMS= 2.2
Julian Day 4586.5
12:02 7/22/2013



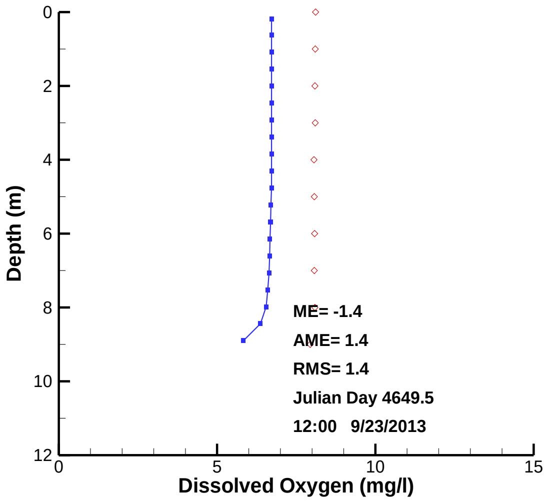
Depth (m)
Dissolved Oxygen (mg/l)
ME= -3.4
AME= 3.4
RMS= 3.6
Julian Day 4607.5
12:02 8/12/2013



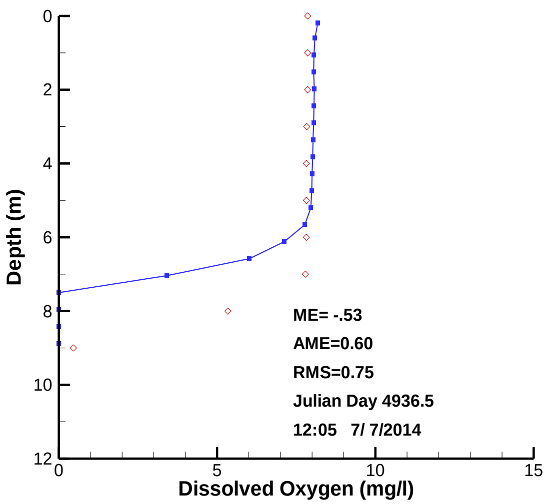
0
2
4
6
8
10
12
0
5
10
15
Depth (m)
Dissolved Oxygen (mg/l)
ME= -.24
AME=0.95
RMS= 1.2
Julian Day 4621.5
12:05 8/26/2013



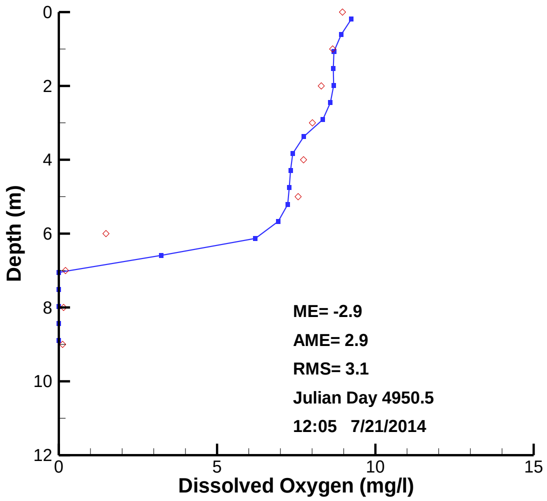
0
2
4
6
8
10
12
0
5
10
15
Depth (m)
Dissolved Oxygen (mg/l)
ME= 0.25E-01
AME= 1.2
RMS= 1.9
Julian Day 4635.5
12:02 9/ 9/2013

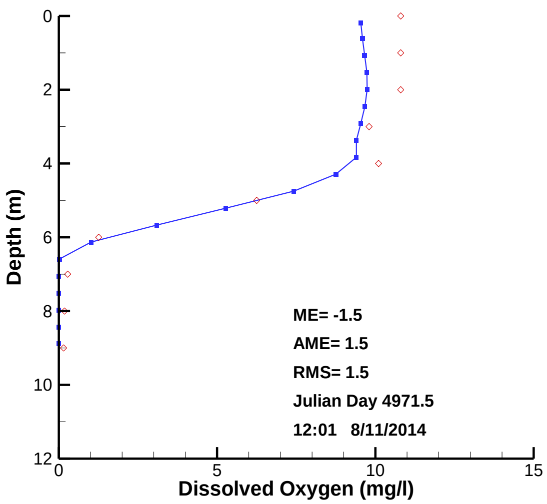


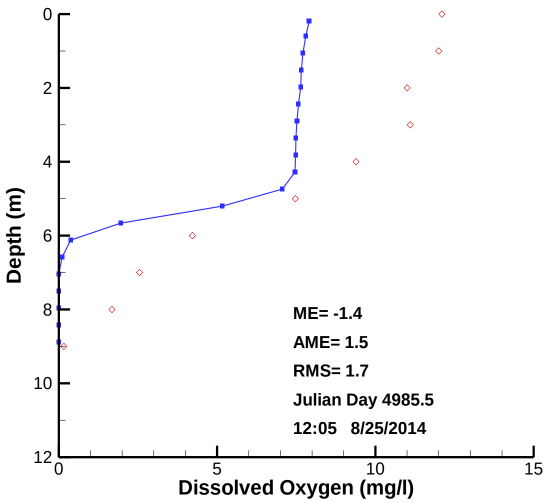
Depth (m)
Dissolved Oxygen (mg/l)
ME= -1.4
AME= 1.4
RMS= 1.4
Julian Day 4649.5
12:00 9/23/2013

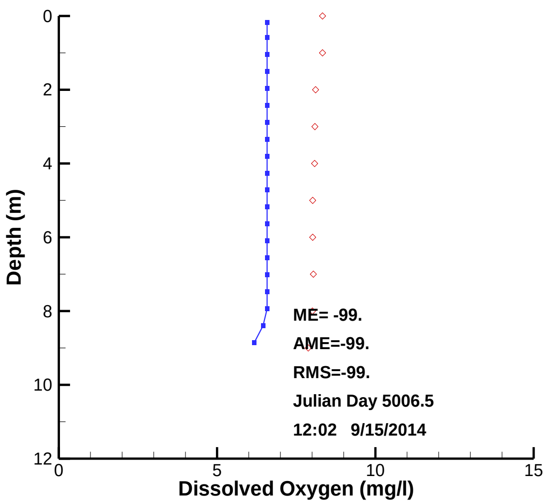


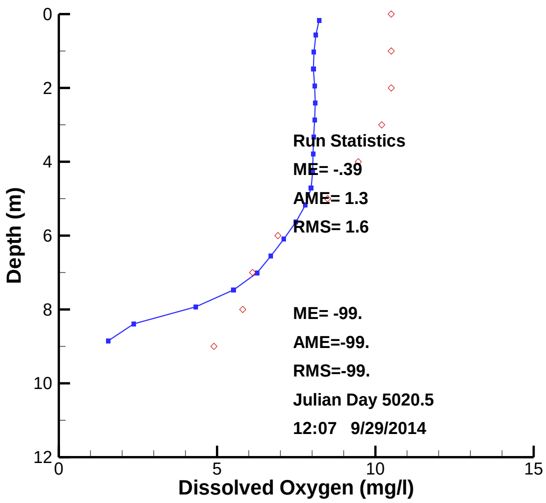
Depth (m)
Dissolved Oxygen (mg/l)
ME= -.53
AME=0.60
RMS=0.75
Julian Day 4936.5
12:05 7/ 7/2014


0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -2.9
AME= 2.9
RMS= 3.1
Julian Day 4950.5
12:05 7/21/2014


0
2
4
6
8
10
12
Depth (m)
0
5
10
15
Dissolved Oxygen (mg/l)
ME= -1.5
AME= 1.5
RMS= 1.5
Julian Day 4971.5
12:01 8/11/2014

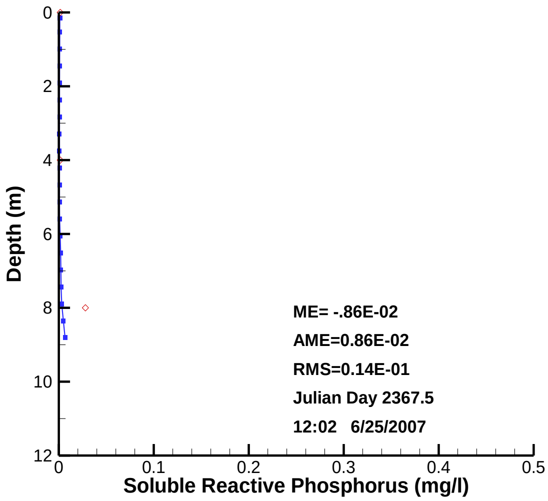

Depth (m)
Dissolved Oxygen (mg/l)
ME= -1.4
AME= 1.5
RMS= 1.7
Julian Day 4985.5
12:05 8/25/2014

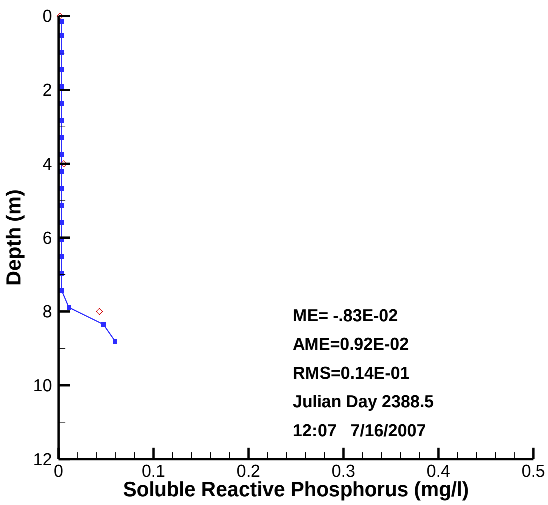

Depth (m)
Dissolved Oxygen (mg/l)
ME= -99.
AME=-99.
RMS=-99.
Julian Day 5006.5
12:02 9/15/2014

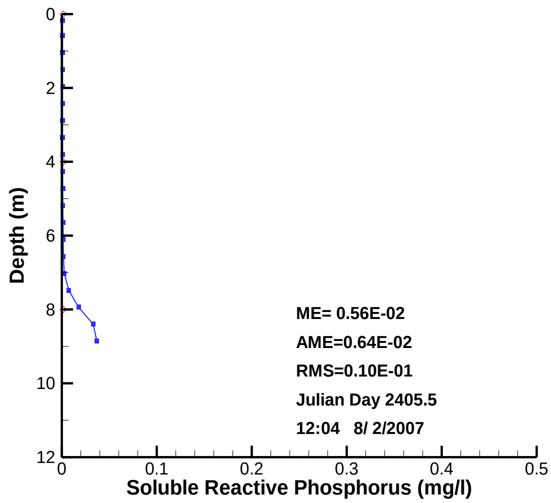


Run Statistics
ME= -.39
AME= 1.3
RMS= 1.6
ME= -99.
AME=-99.
RMS=-99.
Julian Day 5020.5
12:07 9/29/2014
Depth (m)
Dissolved Oxygen (mg/l)
0
2
4
6
8
10
12
0
5
10
15

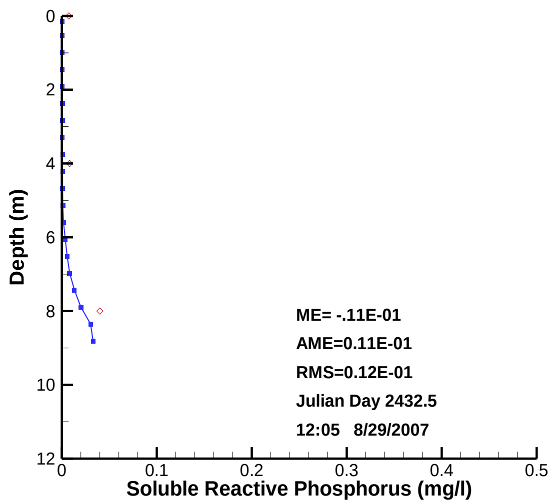
B3 Soluble Reactive Phosphorus Profile Plots



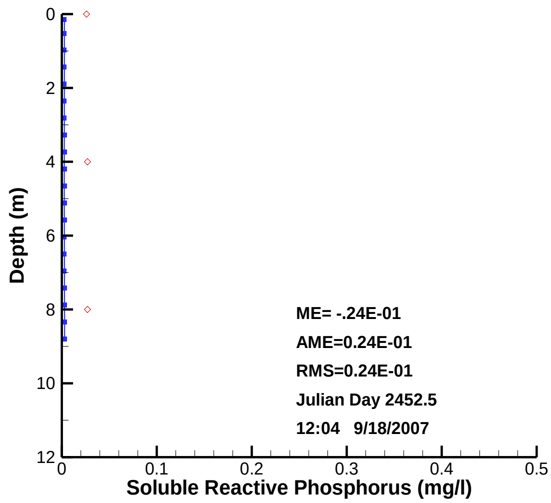




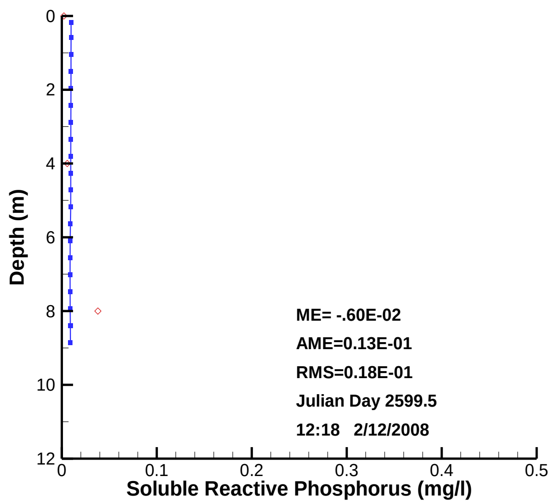
0
2
4
6
8
10
12
Depth (m)
ME= 0.56E-02
AME=0.64E-02
RMS=0.10E-01
Julian Day 2405.5
12:04 8/ 2/2007
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)



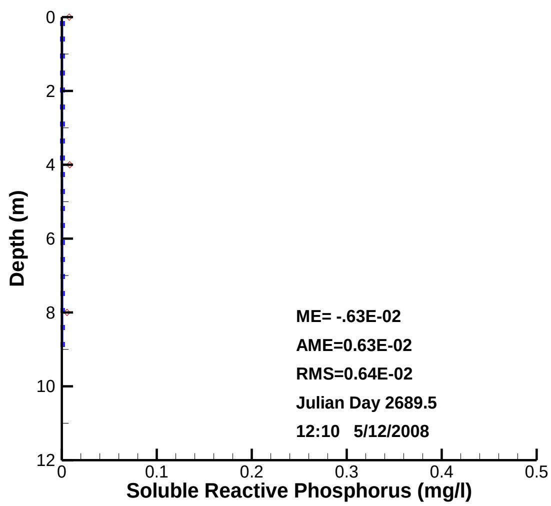
0
2
4
6
8
10
12
Depth (m)
ME= -.11E-01
AME=0.11E-01
RMS=0.12E-01
Julian Day 2432.5
12:05 8/29/2007
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

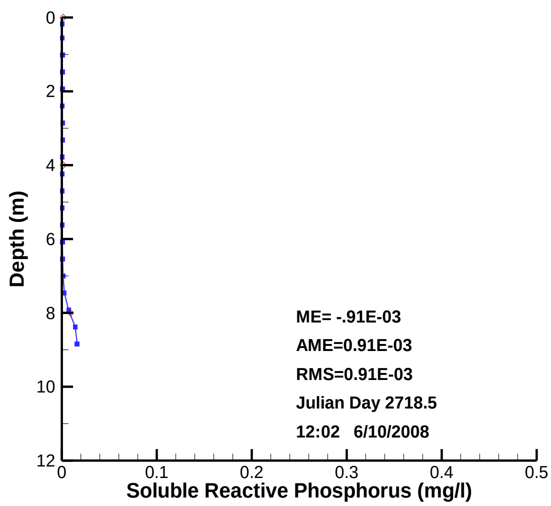


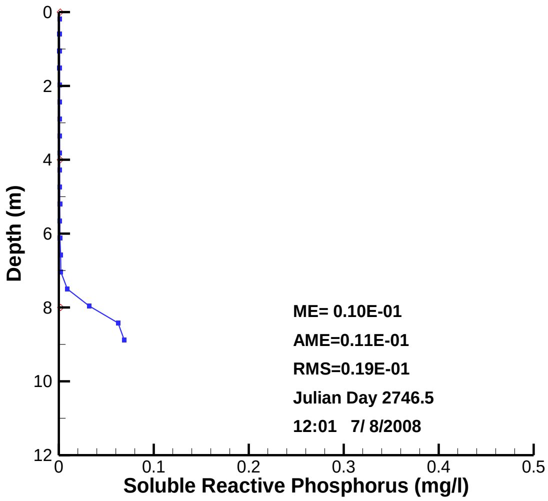
Depth (m)
0
2
4
6
8
10
12
ME= -.24E-01
AME=0.24E-01
RMS=0.24E-01
Julian Day 2452.5
12:04 9/18/2007
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

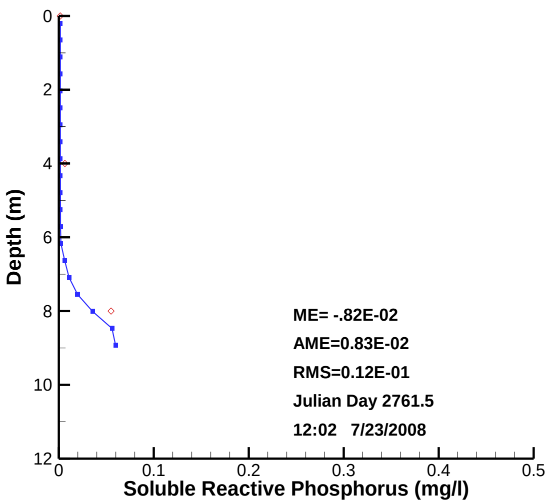


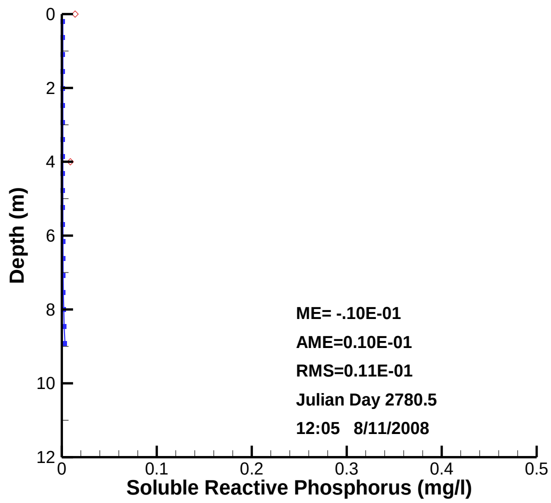
Depth (m)
0
2
4
6
8
10
12
ME= -.60E-02
AME=0.13E-01
RMS=0.18E-01
Julian Day 2599.5
12:18 2/12/2008
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

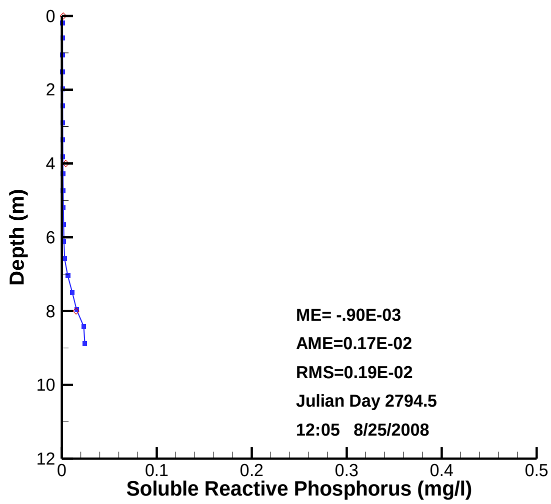

0
2
4
6
8
10
12
Depth (m)
ME= -.63E-02
AME=0.63E-02
RMS=0.64E-02
Julian Day 2689.5
12:10 5/12/2008
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

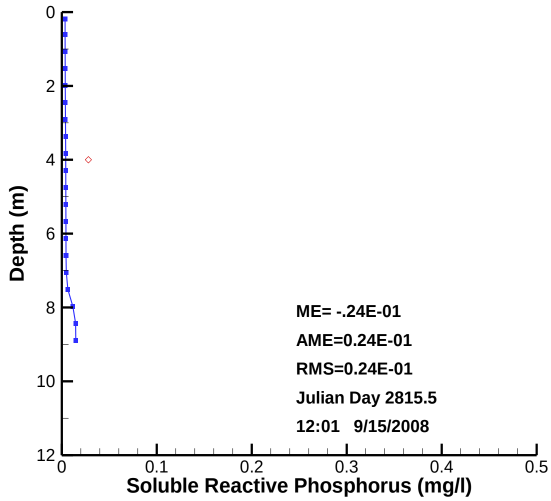

0
2
4
6
8
10
12
Depth (m)
ME= -.91E-03
AME=0.91E-03
RMS=0.91E-03
Julian Day 2718.5
12:02 6/10/2008
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)


Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.10E-01
AME=0.11E-01
RMS=0.19E-01
Julian Day 2746.5
12:01 7/ 8/2008

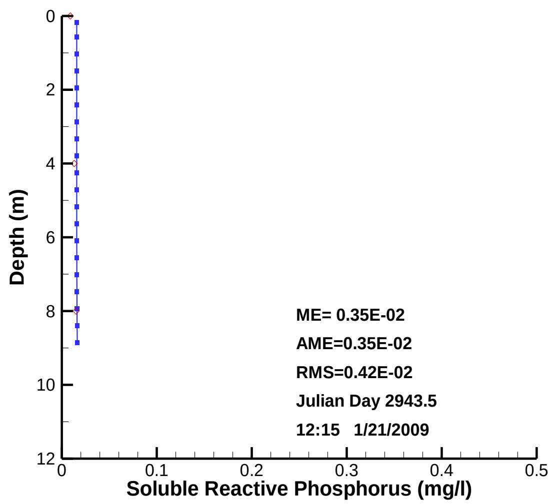

Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= -.82E-02
AME=0.83E-02
RMS=0.12E-01
Julian Day 2761.5
12:02 7/23/2008


ME= -.10E-01
AME=0.10E-01
RMS=0.11E-01
Julian Day 2780.5
12:05 8/11/2008
Depth (m)
Soluble Reactive Phosphorus (mg/l)

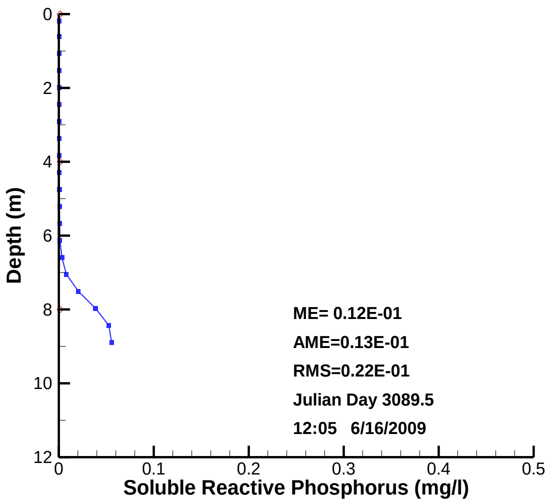

ME= -.90E-03
AME=0.17E-02
RMS=0.19E-02
Julian Day 2794.5
12:05 8/25/2008
Depth (m)
Soluble Reactive Phosphorus (mg/l)



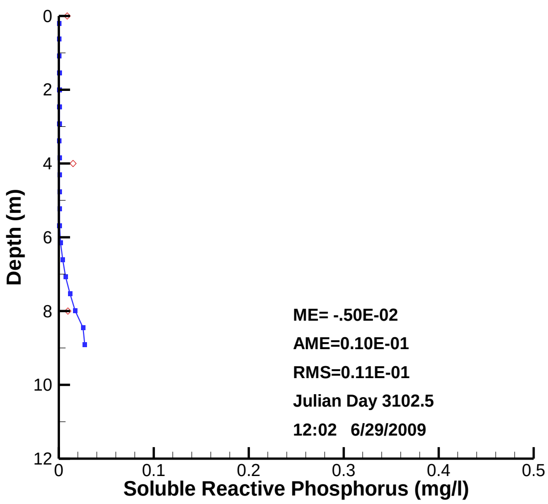
Depth (m)
ME= -.24E-01
AME=0.24E-01
RMS=0.24E-01
Julian Day 2815.5
12:01 9/15/2008
Soluble Reactive Phosphorus (mg/l)



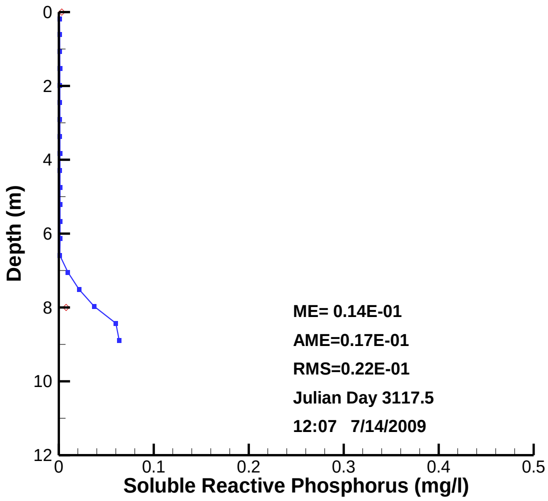
Depth (m)
ME= 0.35E-02
AME=0.35E-02
RMS=0.42E-02
Julian Day 2943.5
12:15 1/21/2009
Soluble Reactive Phosphorus (mg/l)

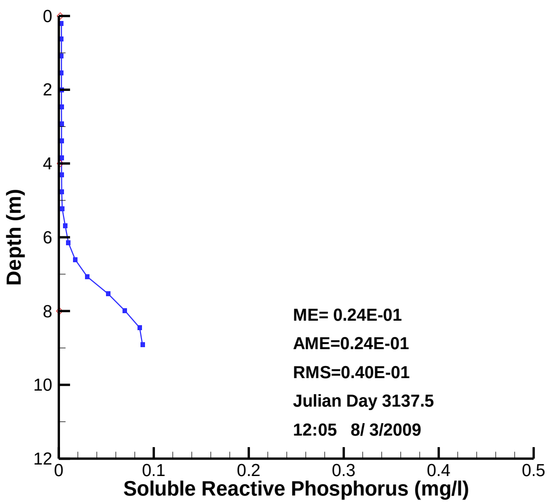


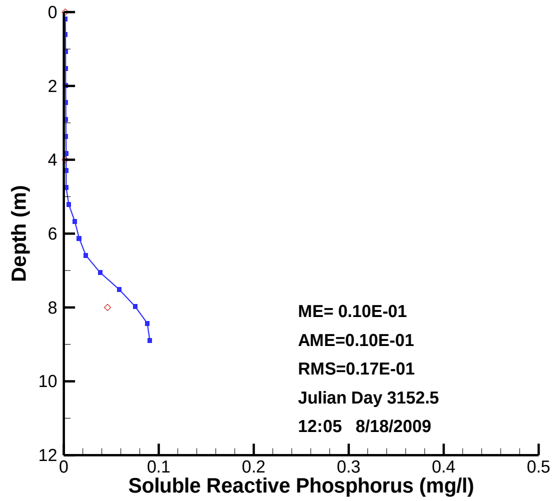
Depth (m)
0
2
4
6
8
10
12
ME= 0.12E-01
AME=0.13E-01
RMS=0.22E-01
Julian Day 3089.5
12:05 6/16/2009
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

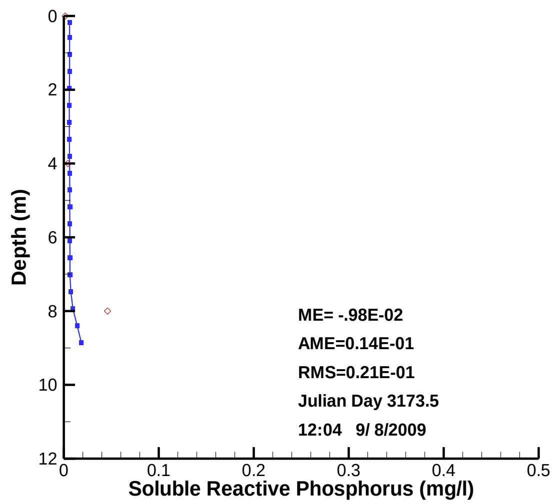


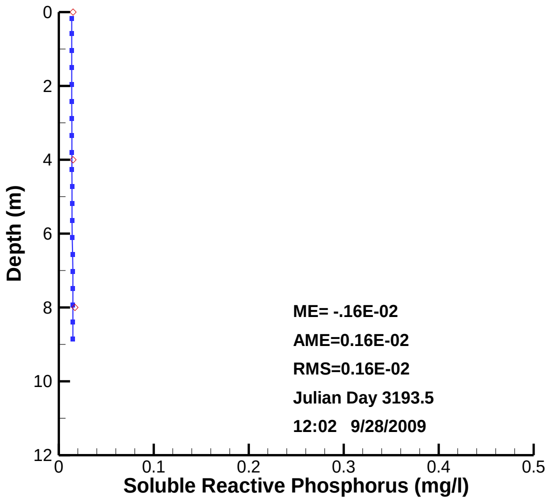
Depth (m)
0
2
4
6
8
10
12
ME= -.50E-02
AME=0.10E-01
RMS=0.11E-01
Julian Day 3102.5
12:02 6/29/2009
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

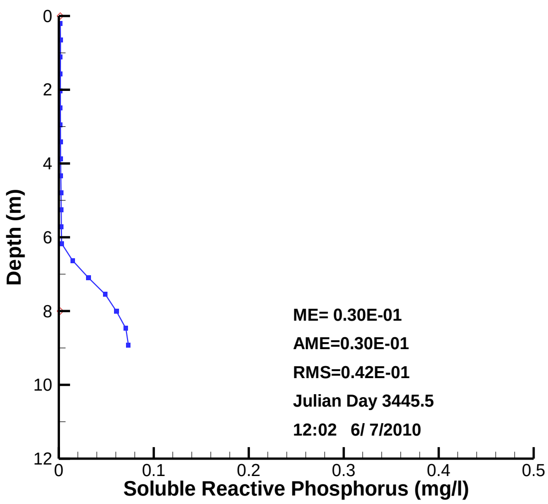

ME= 0.14E-01
AME=0.17E-01
RMS=0.22E-01
Julian Day 3117.5
12:07 7/14/2009
Depth (m)
Soluble Reactive Phosphorus (mg/l)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5

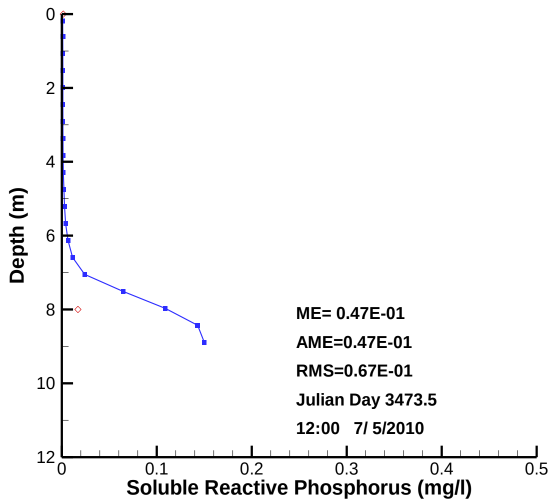

ME= 0.24E-01
AME=0.24E-01
RMS=0.40E-01
Julian Day 3137.5
12:05 8/ 3/2009
Depth (m)
Soluble Reactive Phosphorus (mg/l)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5

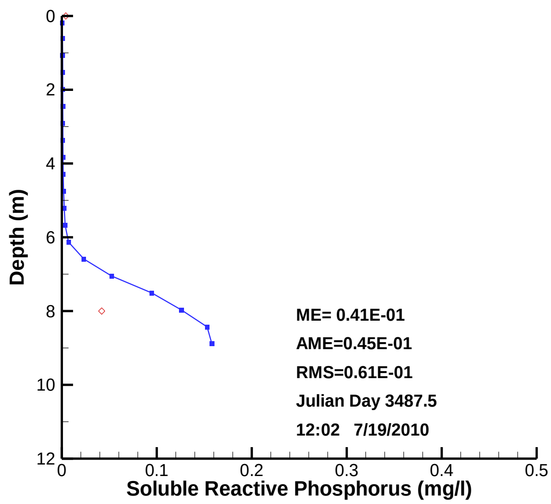

ME= 0.10E-01
AME=0.10E-01
RMS=0.17E-01
Julian Day 3152.5
12:05 8/18/2009
Depth (m)
Soluble Reactive Phosphorus (mg/l)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5

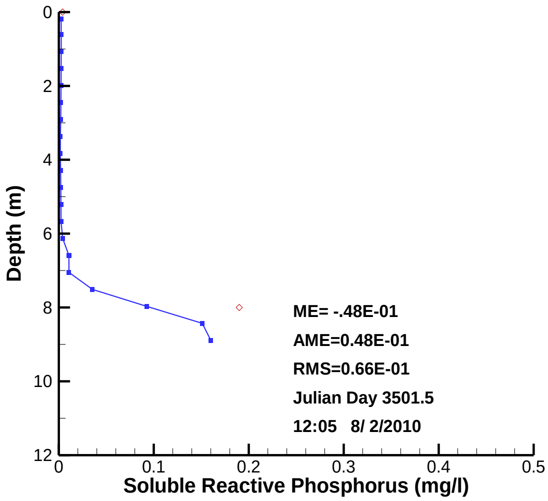

ME= -.98E-02
AME=0.14E-01
RMS=0.21E-01
Julian Day 3173.5
12:04 9/ 8/2009
Depth (m)
Soluble Reactive Phosphorus (mg/l)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5


Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= -.16E-02
AME=0.16E-02
RMS=0.16E-02
Julian Day 3193.5
12:02 9/28/2009

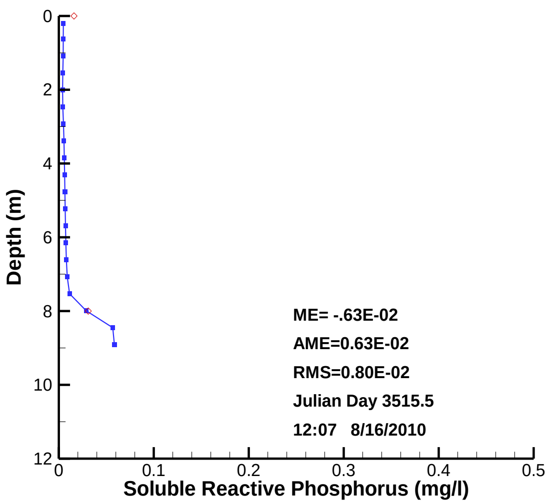

Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.30E-01
AME=0.30E-01
RMS=0.42E-01
Julian Day 3445.5
12:02 6/ 7/2010


Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)
ME= 0.47E-01
AME=0.47E-01
RMS=0.67E-01
Julian Day 3473.5
12:00 7/ 5/2010

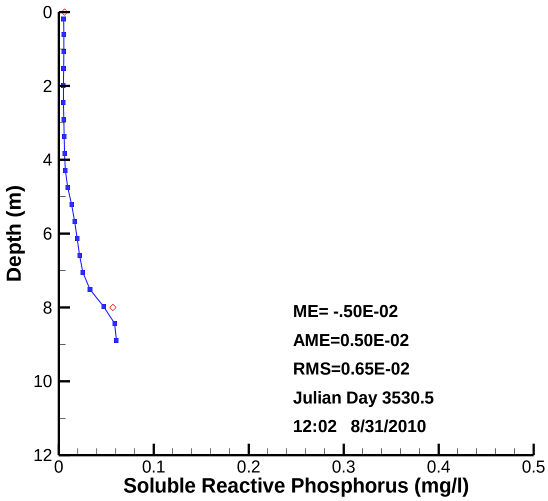

Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)
ME= 0.41E-01
AME=0.45E-01
RMS=0.61E-01
Julian Day 3487.5
12:02 7/19/2010



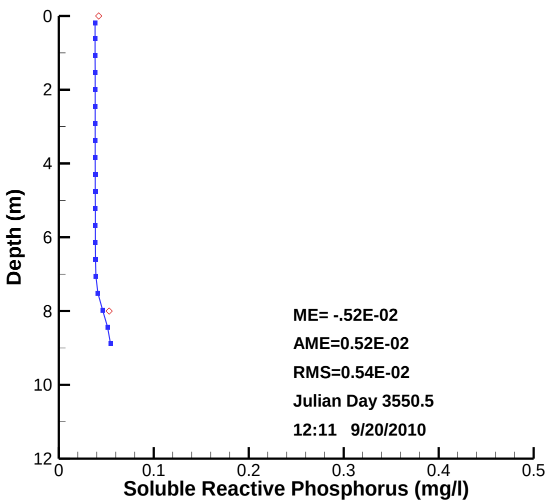
0
2
4
6
8
10
12
Depth (m)
ME= -.48E-01
AME=0.48E-01
RMS=0.66E-01
Julian Day 3501.5
12:05 8/ 2/2010
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)



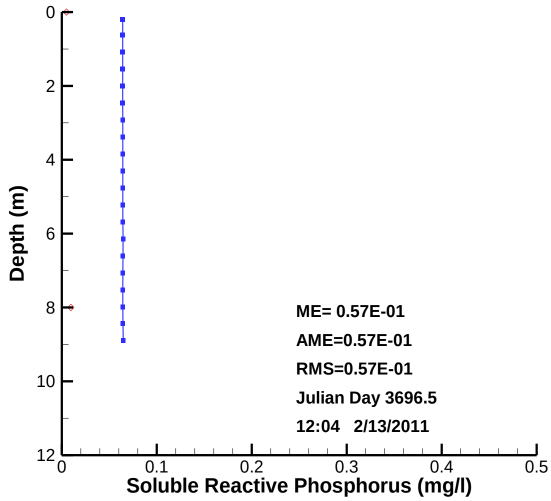
0
2
4
6
8
10
12
Depth (m)
ME= -.63E-02
AME=0.63E-02
RMS=0.80E-02
Julian Day 3515.5
12:07 8/16/2010
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

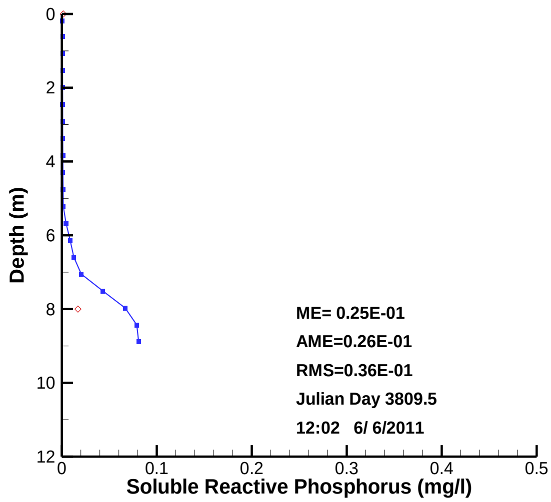


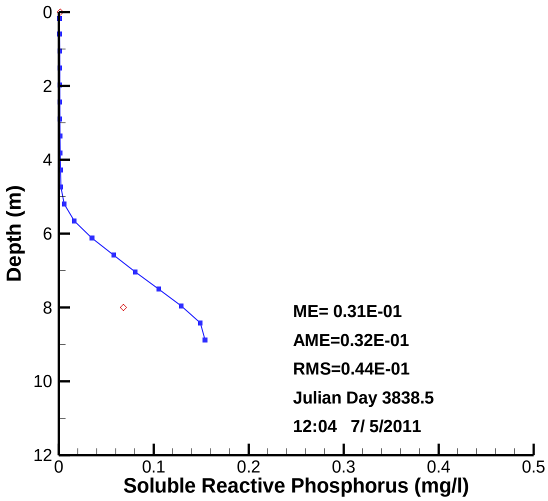
0
2
4
6
8
10
12
Depth (m)
ME= -.50E-02
AME=0.50E-02
RMS=0.65E-02
Julian Day 3530.5
12:02 8/31/2010
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

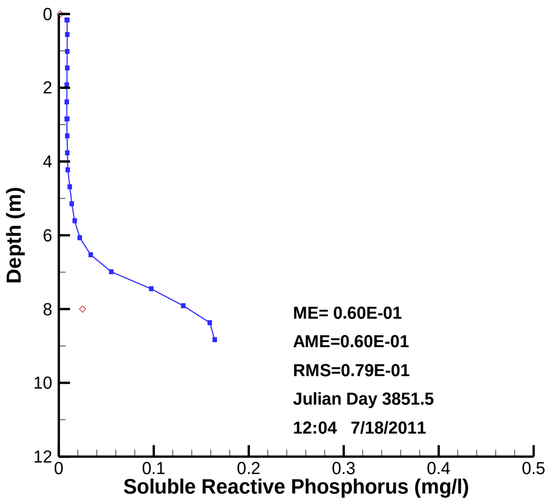


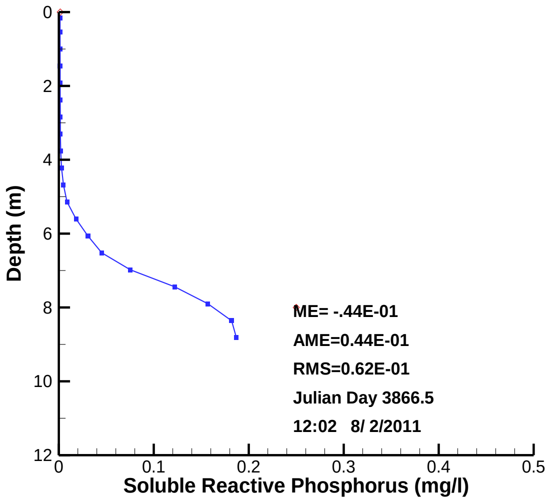
0
2
4
6
8
10
12
Depth (m)
ME= -.52E-02
AME=0.52E-02
RMS=0.54E-02
Julian Day 3550.5
12:11 9/20/2010
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)


Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.57E-01
AME=0.57E-01
RMS=0.57E-01
Julian Day 3696.5
12:04 2/13/2011

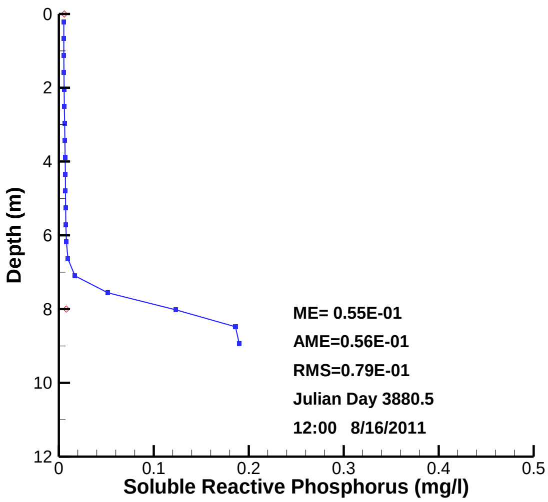

Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.25E-01
AME=0.26E-01
RMS=0.36E-01
Julian Day 3809.5
12:02 6/ 6/2011


Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.31E-01
AME=0.32E-01
RMS=0.44E-01
Julian Day 3838.5
12:04 7/ 5/2011

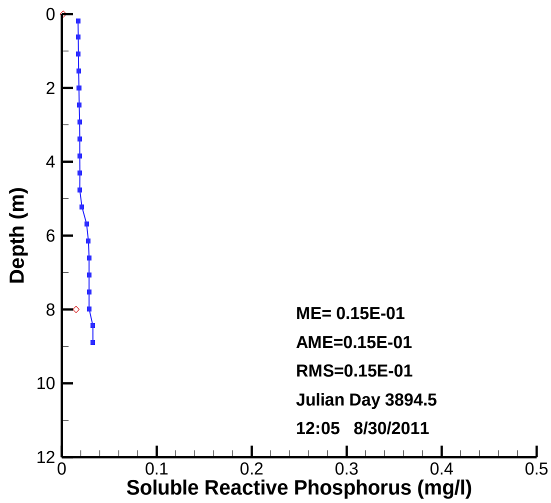

Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.60E-01
AME=0.60E-01
RMS=0.79E-01
Julian Day 3851.5
12:04 7/18/2011

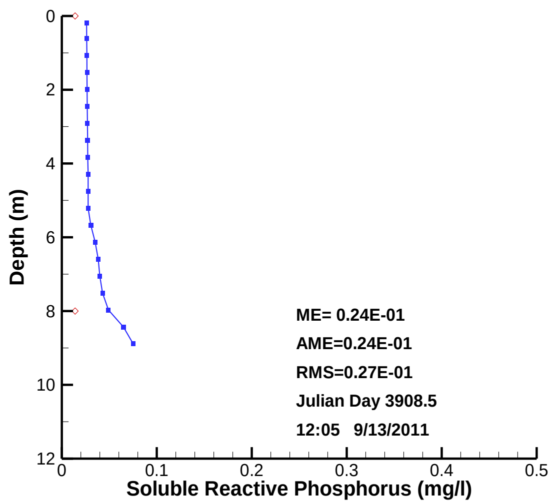


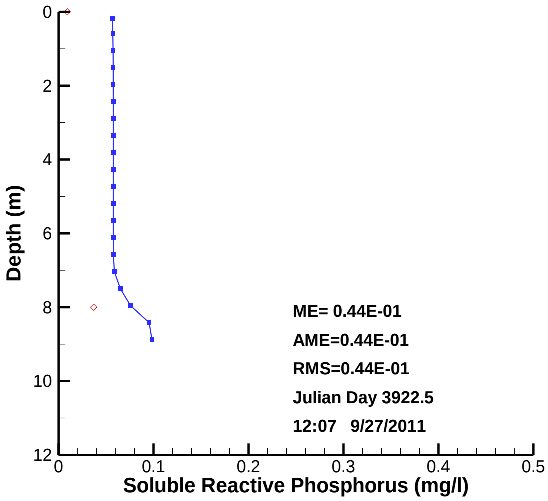
Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= -.44E-01
AME=0.44E-01
RMS=0.62E-01
Julian Day 3866.5
12:02 8/ 2/2011



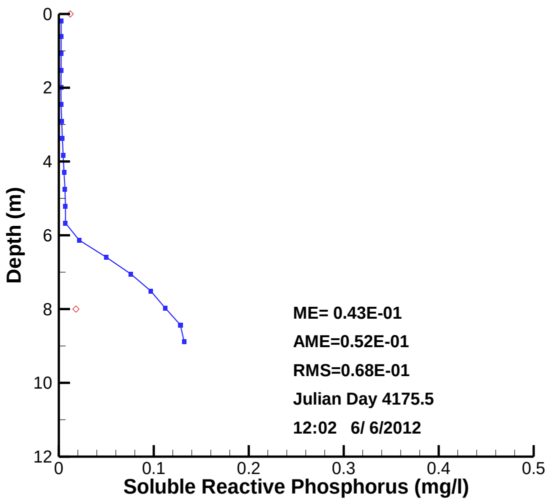
Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.55E-01
AME=0.56E-01
RMS=0.79E-01
Julian Day 3880.5
12:00 8/16/2011


Depth (m)
0
2
4
6
8
10
12
ME= 0.15E-01
AME=0.15E-01
RMS=0.15E-01
Julian Day 3894.5
12:05 8/30/2011
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

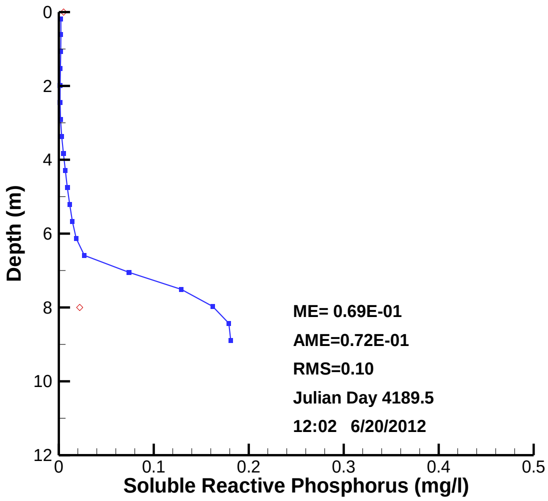

Depth (m)
0
2
4
6
8
10
12
ME= 0.24E-01
AME=0.24E-01
RMS=0.27E-01
Julian Day 3908.5
12:05 9/13/2011
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

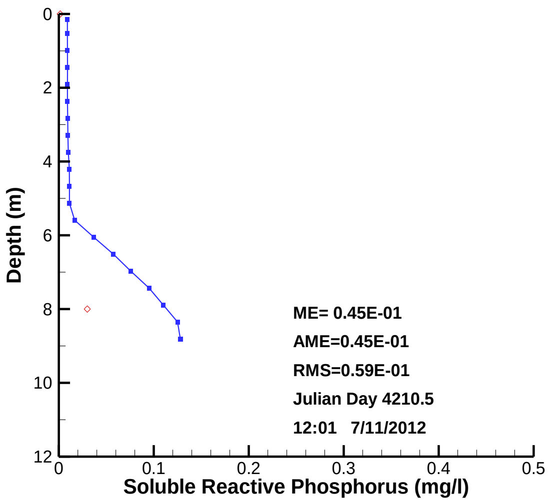


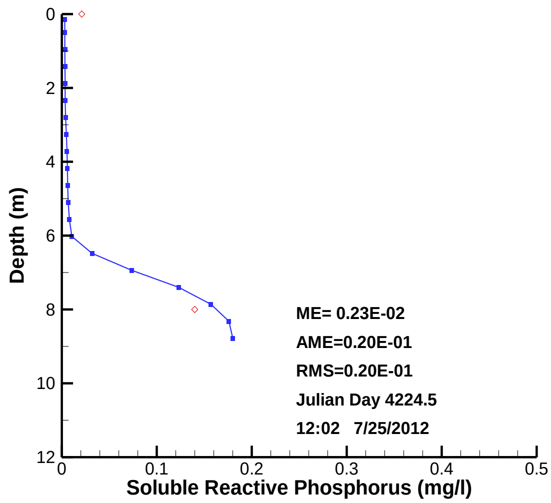
ME= 0.44E-01
AME=0.44E-01
RMS=0.44E-01
Julian Day 3922.5
12:07 9/27/2011
Depth (m)
Soluble Reactive Phosphorus (mg/l)

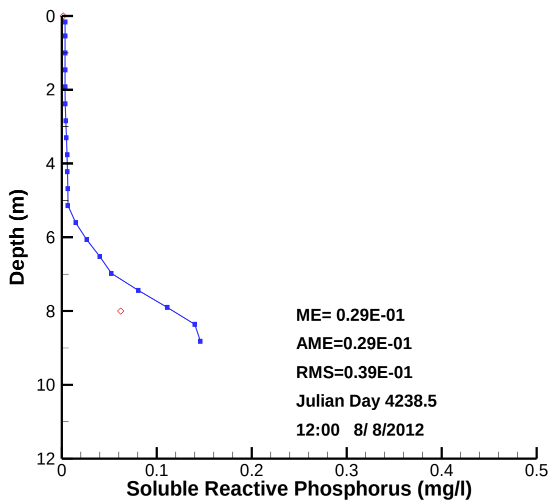


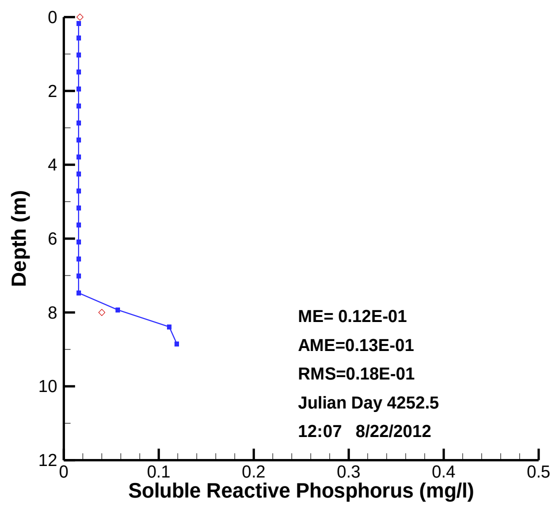
ME= 0.43E-01
AME=0.52E-01
RMS=0.68E-01
Julian Day 4175.5
12:02 6/ 6/2012
Depth (m)
Soluble Reactive Phosphorus (mg/l)


Depth (m)
0
2
4
6
8
10
12
ME= 0.69E-01
AME=0.72E-01
RMS=0.10
Julian Day 4189.5
12:02 6/20/2012
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

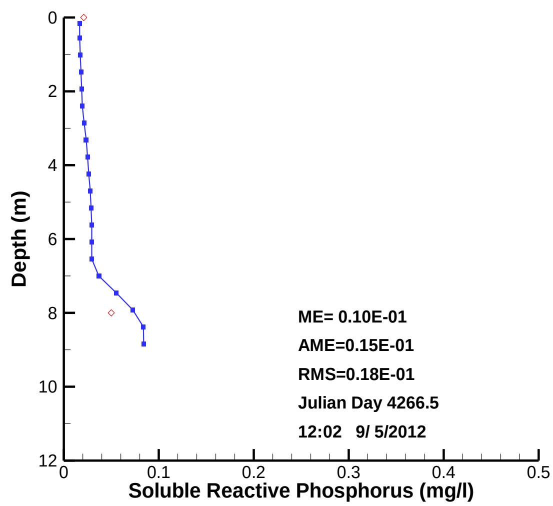

Depth (m)
0
2
4
6
8
10
12
ME= 0.45E-01
AME=0.45E-01
RMS=0.59E-01
Julian Day 4210.5
12:01 7/11/2012
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)


Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.23E-02
AME=0.20E-01
RMS=0.20E-01
Julian Day 4224.5
12:02 7/25/2012

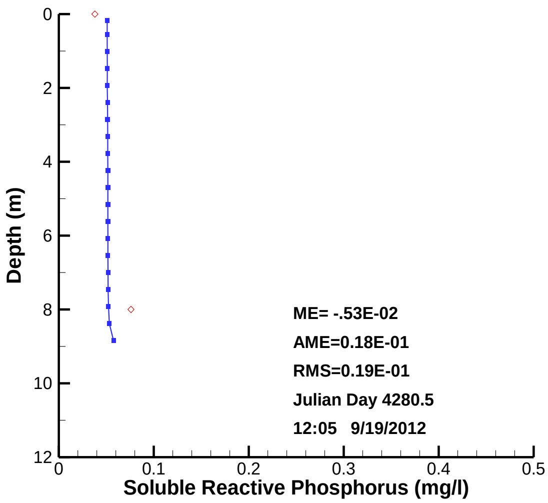

Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.29E-01
AME=0.29E-01
RMS=0.39E-01
Julian Day 4238.5
12:00 8/ 8/2012

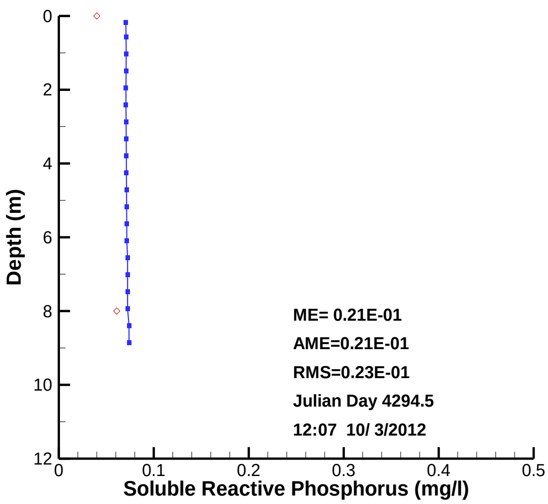


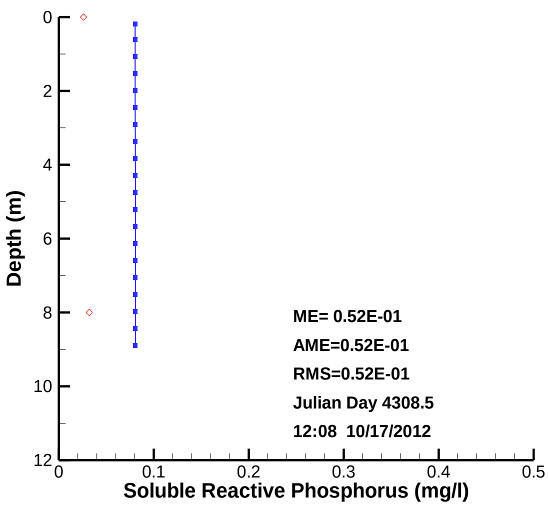
Depth (m)
ME= 0.12E-01
AME=0.13E-01
RMS=0.18E-01
Julian Day 4252.5
12:07 8/22/2012
Soluble Reactive Phosphorus (mg/l)



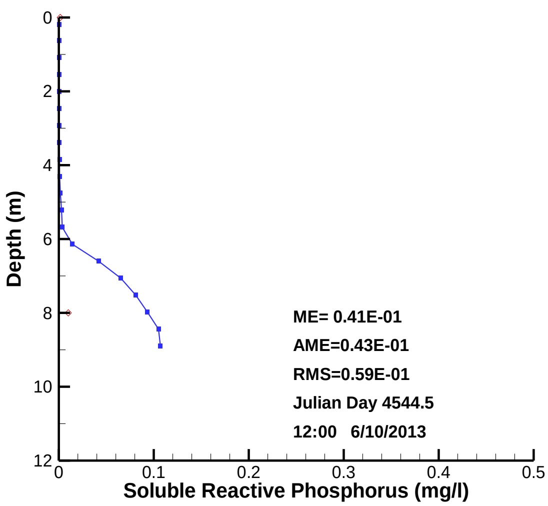
Depth (m)
ME= 0.10E-01
AME=0.15E-01
RMS=0.18E-01
Julian Day 4266.5
12:02 9/ 5/2012
Soluble Reactive Phosphorus (mg/l)


0
2
4
6
8
10
12
Depth (m)
ME= -.53E-02
AME=0.18E-01
RMS=0.19E-01
Julian Day 4280.5
12:05 9/19/2012
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

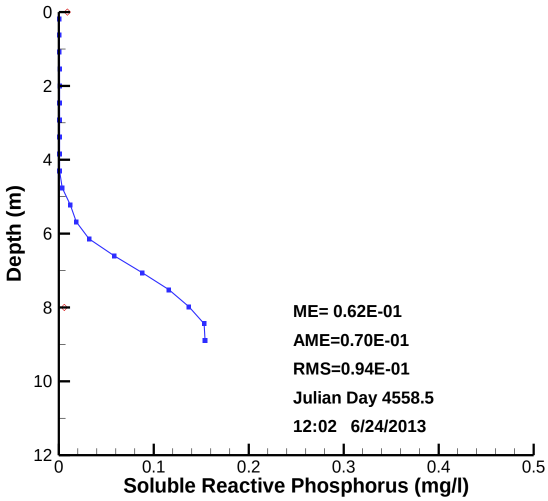

0
2
4
6
8
10
12
Depth (m)
ME= 0.21E-01
AME=0.21E-01
RMS=0.23E-01
Julian Day 4294.5
12:07 10/ 3/2012
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

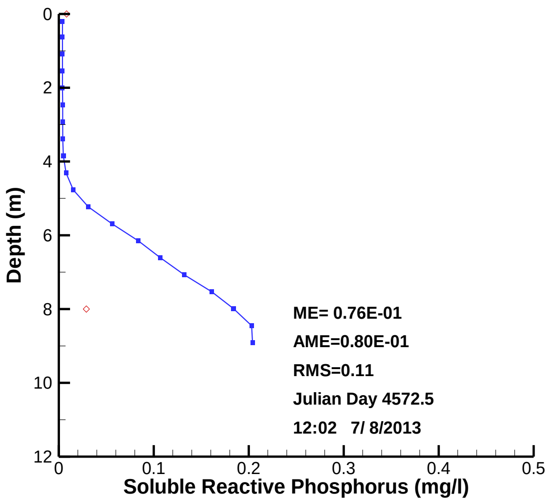


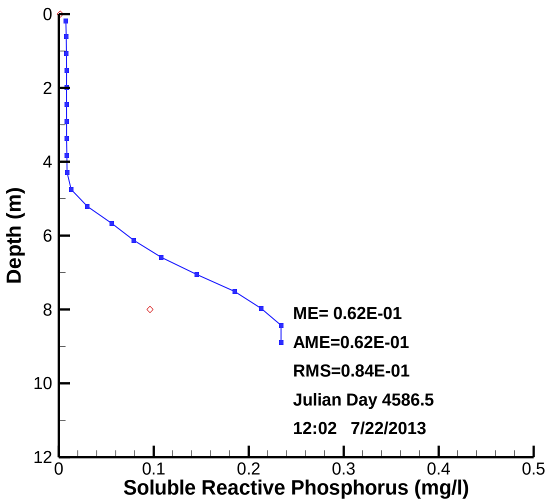
0
2
4
6
8
10
12
Depth (m)
ME= 0.52E-01
AME=0.52E-01
RMS=0.52E-01
Julian Day 4308.5
12:08 10/17/2012
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)



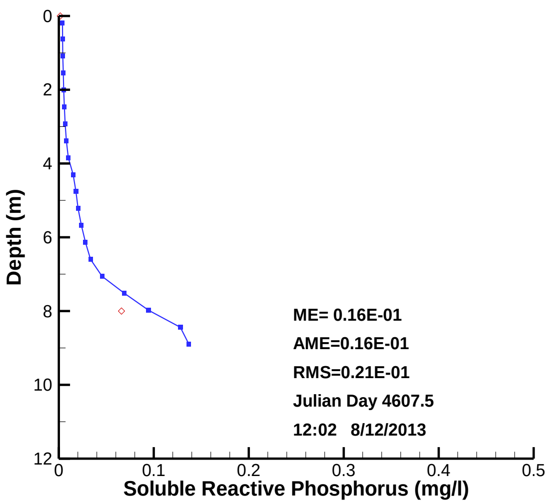
0
2
4
6
8
10
12
Depth (m)
ME= 0.41E-01
AME=0.43E-01
RMS=0.59E-01
Julian Day 4544.5
12:00 6/10/2013
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)


Depth (m)
ME= 0.62E-01
AME=0.70E-01
RMS=0.94E-01
Julian Day 4558.5
12:02 6/24/2013
Soluble Reactive Phosphorus (mg/l)

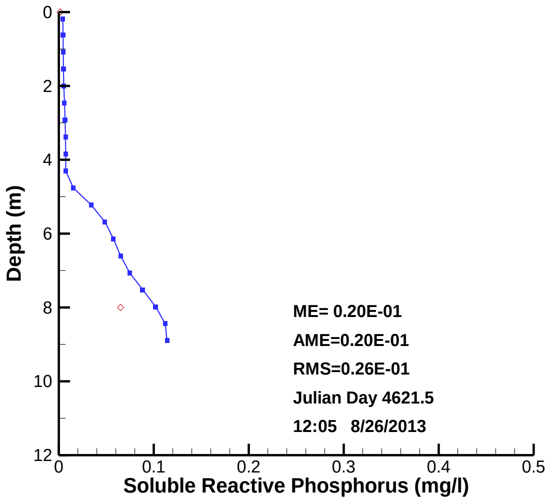

Depth (m)
ME= 0.76E-01
AME=0.80E-01
RMS=0.11
Julian Day 4572.5
12:02 7/ 8/2013
Soluble Reactive Phosphorus (mg/l)

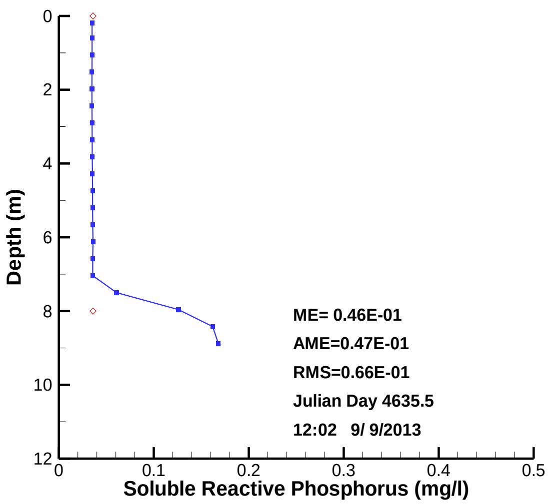


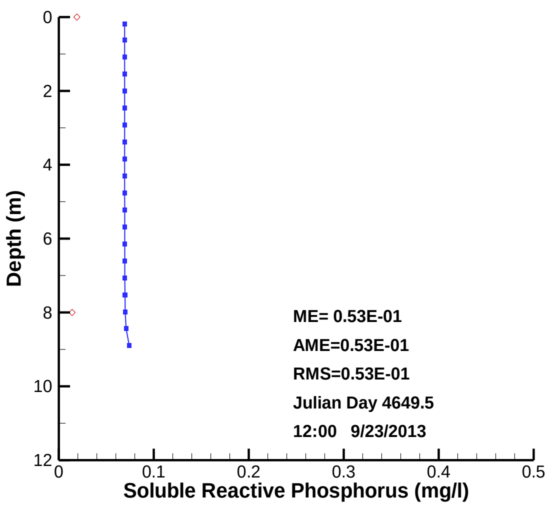
Depth (m)
0
2
4
6
8
10
12
ME= 0.62E-01
AME=0.62E-01
RMS=0.84E-01
Julian Day 4586.5
12:02 7/22/2013
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

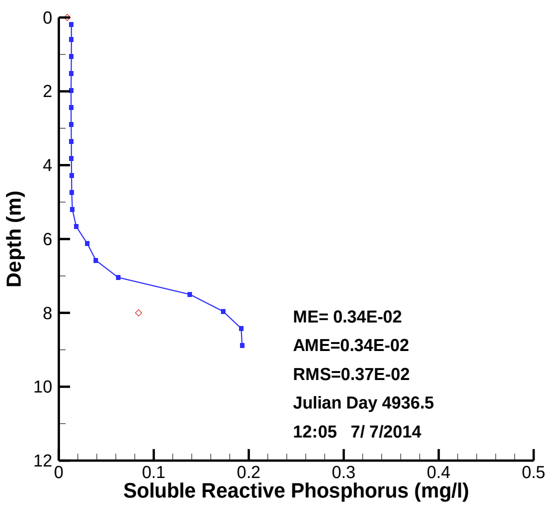


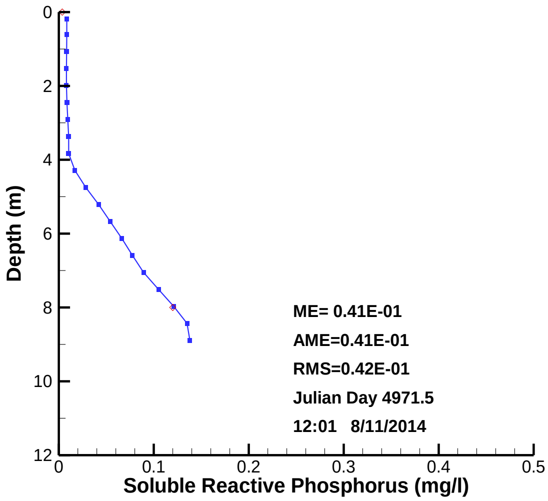
Depth (m)
0
2
4
6
8
10
12
ME= 0.16E-01
AME=0.16E-01
RMS=0.21E-01
Julian Day 4607.5
12:02 8/12/2013
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

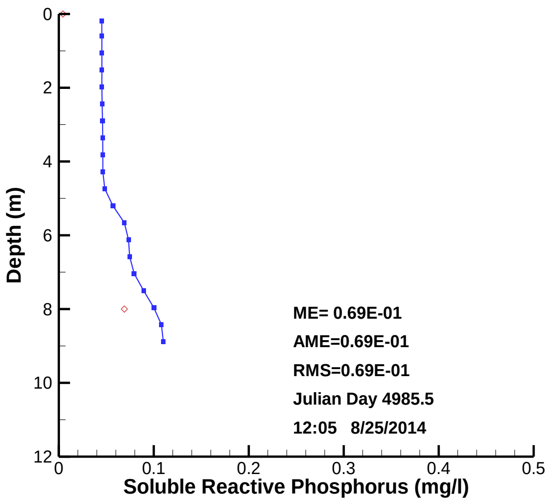

Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)
ME= 0.20E-01
AME=0.20E-01
RMS=0.26E-01
Julian Day 4621.5
12:05 8/26/2013

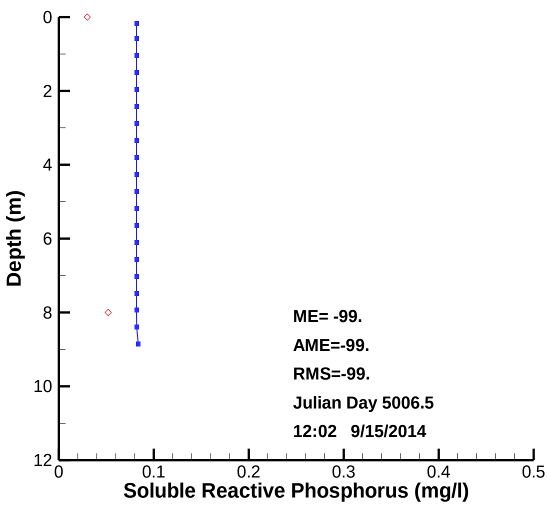

Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)
ME= 0.46E-01
AME=0.47E-01
RMS=0.66E-01
Julian Day 4635.5
12:02 9/ 9/2013


Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.53E-01
AME=0.53E-01
RMS=0.53E-01
Julian Day 4649.5
12:00 9/23/2013

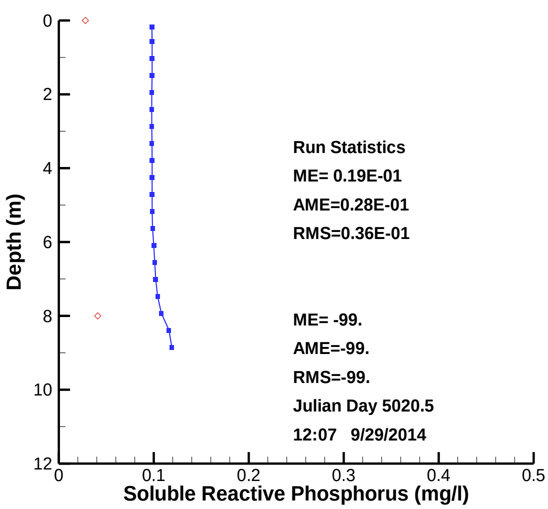

Depth (m)
Soluble Reactive Phosphorus (mg/l)
ME= 0.34E-02
AME=0.34E-02
RMS=0.37E-02
Julian Day 4936.5
12:05 7/ 7/2014


Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)
ME= 0.41E-01
AME=0.41E-01
RMS=0.42E-01
Julian Day 4971.5
12:01 8/11/2014


Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)
ME= 0.69E-01
AME=0.69E-01
RMS=0.69E-01
Julian Day 4985.5
12:05 8/25/2014

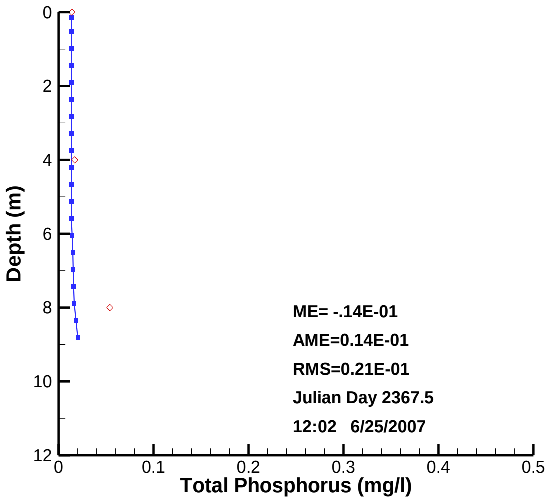


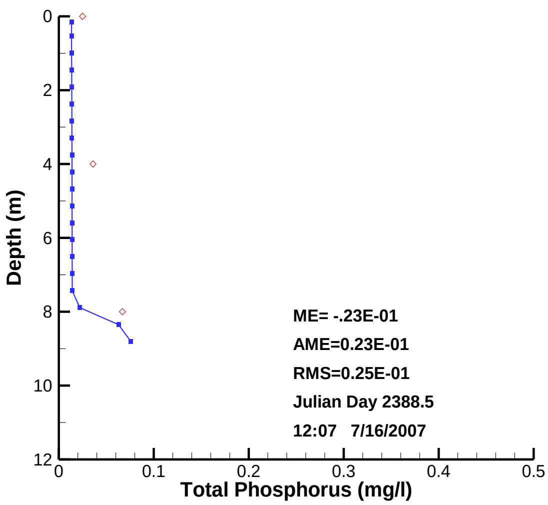
Depth (m)
0
2
4
6
8
10
12
ME= -99.
AME=-99.
RMS=-99.
Julian Day 5006.5
12:02 9/15/2014
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

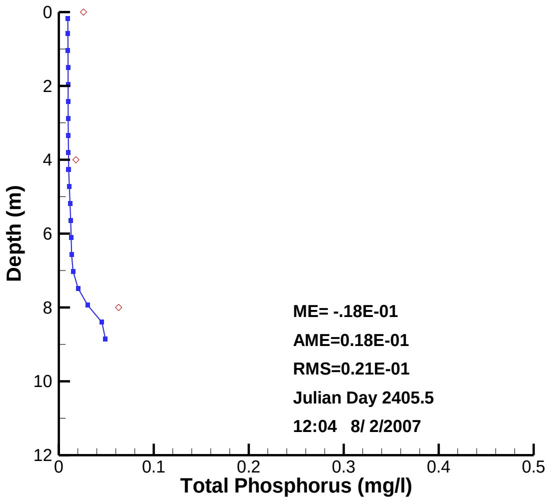


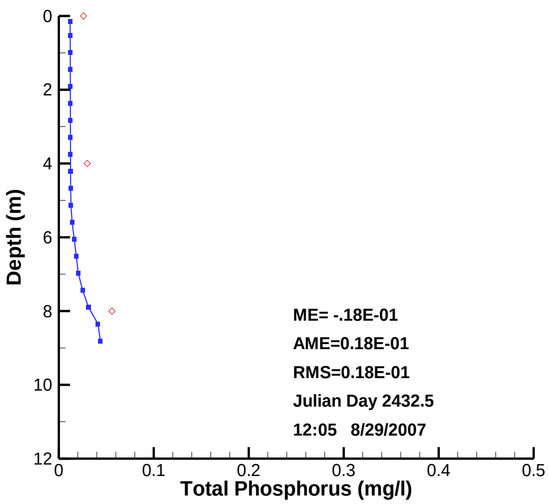
Depth (m)
0
2
4
6
8
10
12
Run Statistics
ME= 0.19E-01
AME=0.28E-01
RMS=0.36E-01
ME= -99.
AME=-99.
RMS=-99.
Julian Day 5020.5
12:07 9/29/2014
0
0.1
0.2
0.3
0.4
0.5
Soluble Reactive Phosphorus (mg/l)

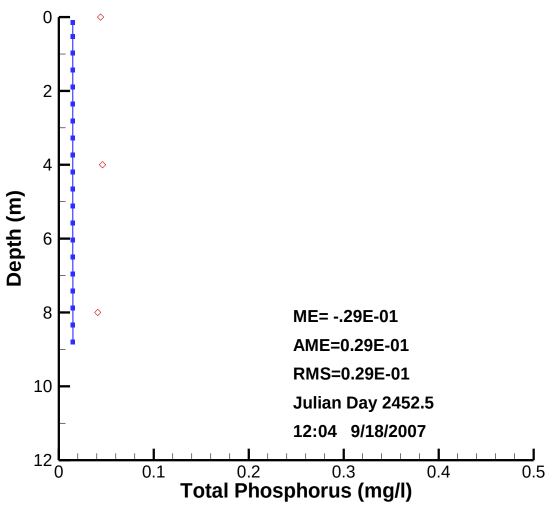
B4 Total Phosphorus Profile Plots

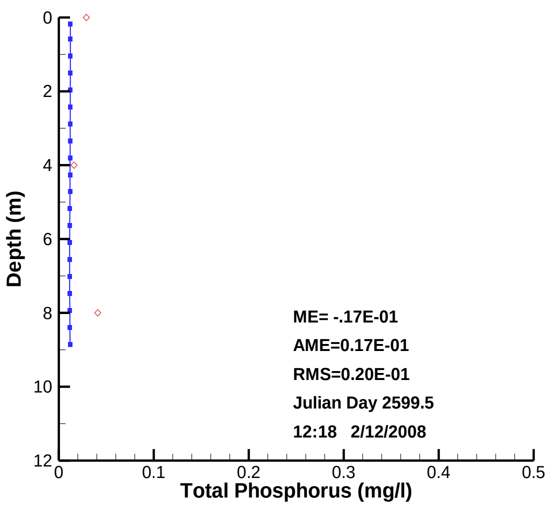


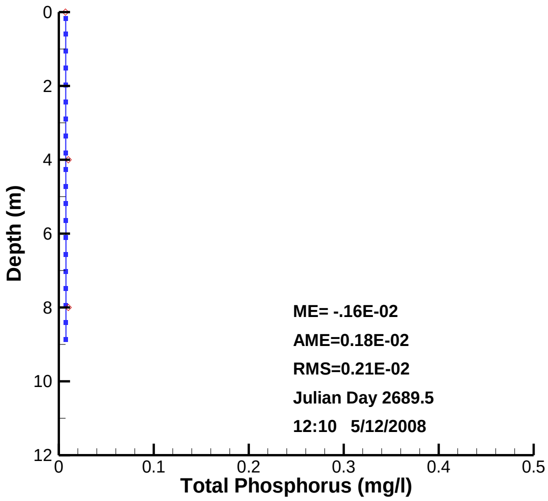



Depth (m)
Total Phosphorus (mg/l)
ME= -.18E-01
AME=0.18E-01
RMS=0.21E-01
Julian Day 2405.5
12:04 8/ 2/2007

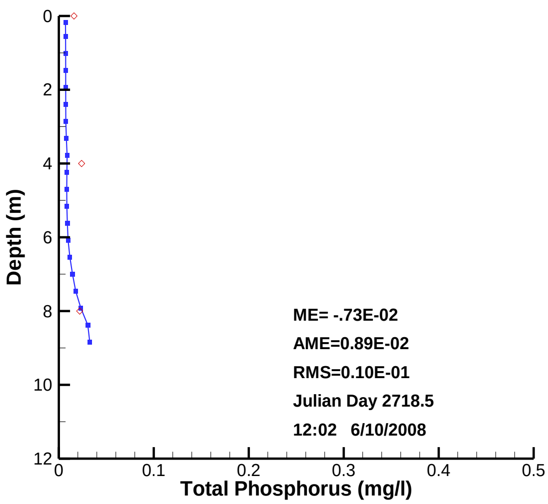

Depth (m)
Total Phosphorus (mg/l)
ME= -.18E-01
AME=0.18E-01
RMS=0.18E-01
Julian Day 2432.5
12:05 8/29/2007


Depth (m)
Total Phosphorus (mg/l)
ME= -.29E-01
AME=0.29E-01
RMS=0.29E-01
Julian Day 2452.5
12:04 9/18/2007

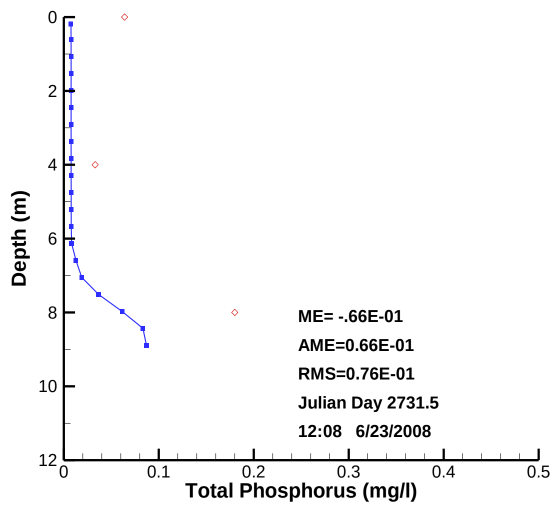

Depth (m)
Total Phosphorus (mg/l)
ME= -.17E-01
AME=0.17E-01
RMS=0.20E-01
Julian Day 2599.5
12:18 2/12/2008



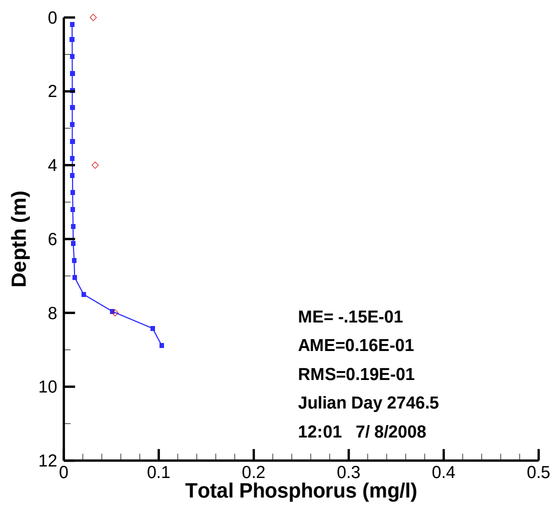
Depth (m)
0
2
4
6
8
10
12
ME= -.16E-02
AME=0.18E-02
RMS=0.21E-02
Julian Day 2689.5
12:10 5/12/2008
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)



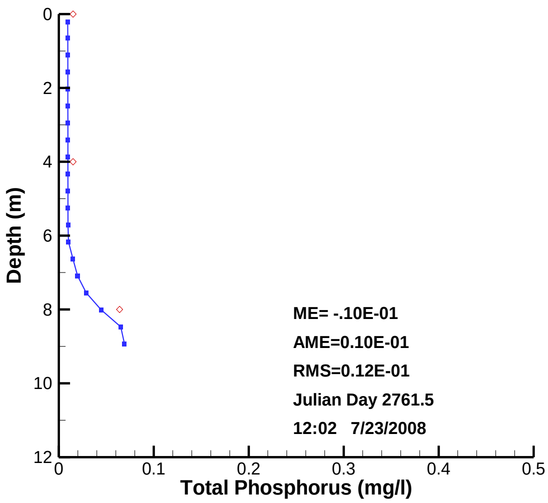
Depth (m)
0
2
4
6
8
10
12
ME= -.73E-02
AME=0.89E-02
RMS=0.10E-01
Julian Day 2718.5
12:02 6/10/2008
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)



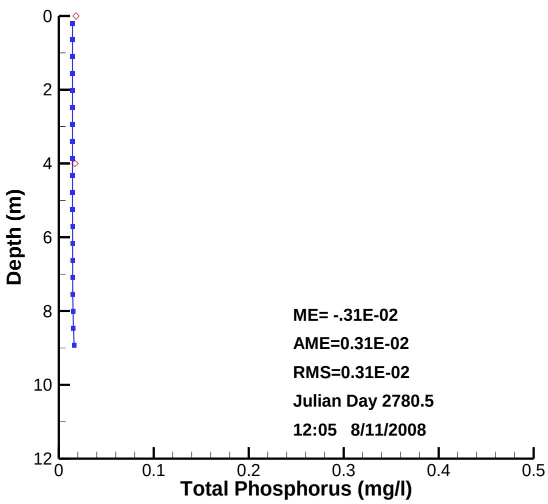
0
2
4
6
8
10
12
Depth (m)
ME= -.66E-01
AME=0.66E-01
RMS=0.76E-01
Julian Day 2731.5
12:08 6/23/2008
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)



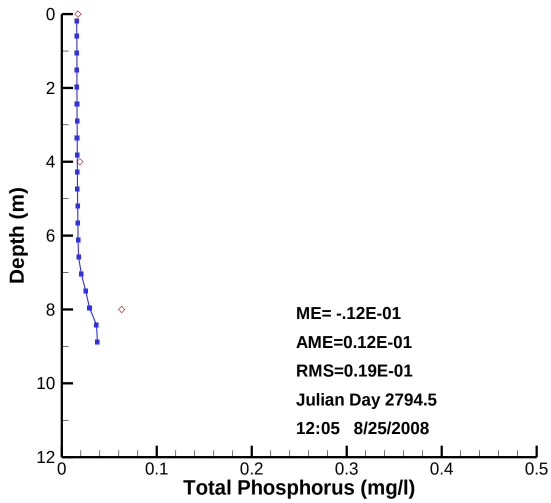
0
2
4
6
8
10
12
Depth (m)
ME= -.15E-01
AME=0.16E-01
RMS=0.19E-01
Julian Day 2746.5
12:01 7/ 8/2008
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)

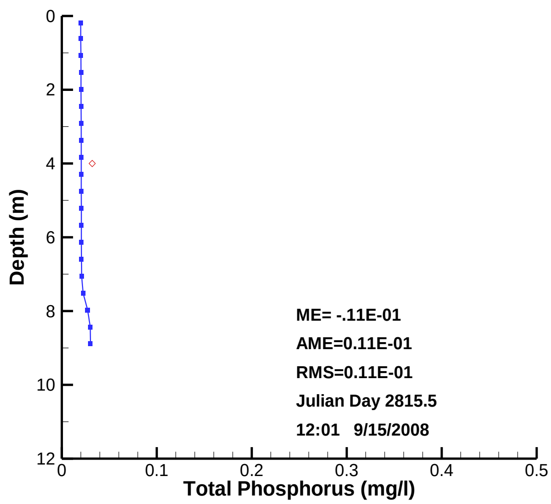


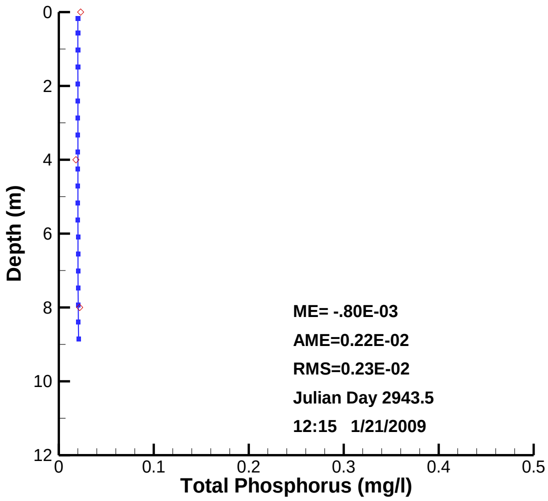
Depth (m)
0
2
4
6
8
10
12
ME= -.10E-01
AME=0.10E-01
RMS=0.12E-01
Julian Day 2761.5
12:02 7/23/2008
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)



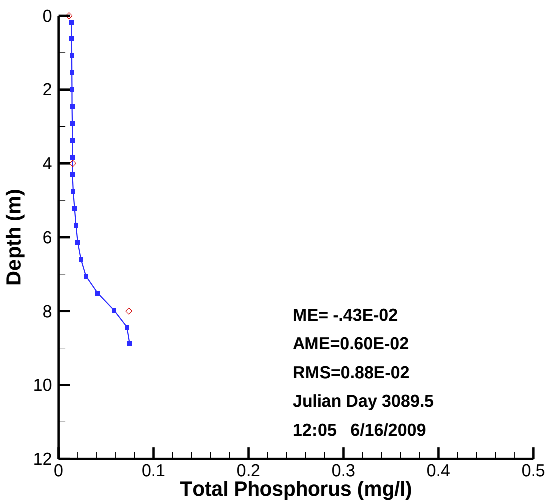
Depth (m)
0
2
4
6
8
10
12
ME= -.31E-02
AME=0.31E-02
RMS=0.31E-02
Julian Day 2780.5
12:05 8/11/2008
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)


Depth (m)
Total Phosphorus (mg/l)
ME= -.12E-01
AME=0.12E-01
RMS=0.19E-01
Julian Day 2794.5
12:05 8/25/2008

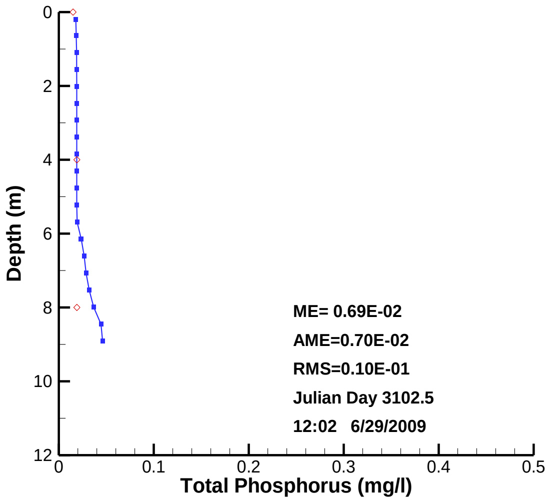

Depth (m)
Total Phosphorus (mg/l)
ME= -.11E-01
AME=0.11E-01
RMS=0.11E-01
Julian Day 2815.5
12:01 9/15/2008

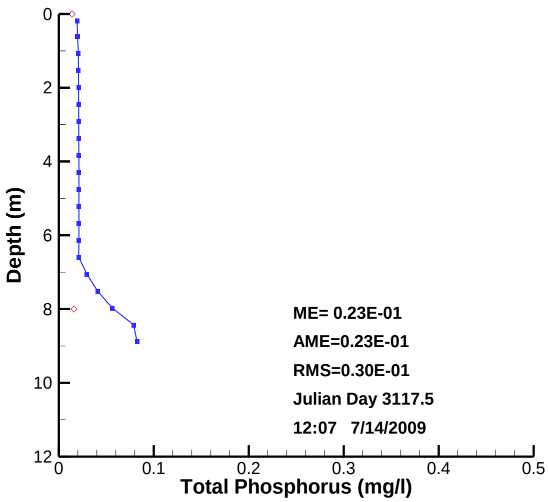


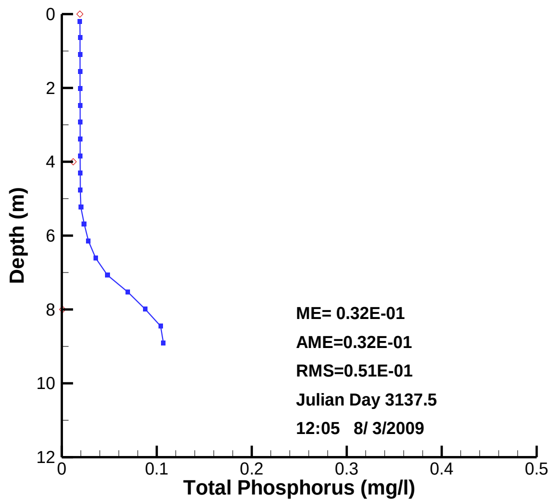
ME= -.80E-03
AME=0.22E-02
RMS=0.23E-02
Julian Day 2943.5
12:15 1/21/2009
Depth (m)
Total Phosphorus (mg/l)

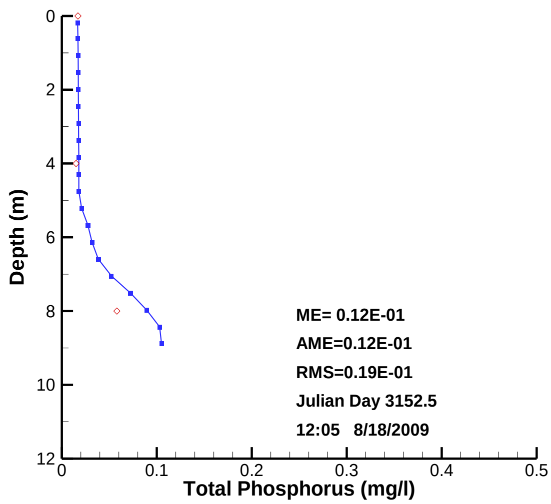


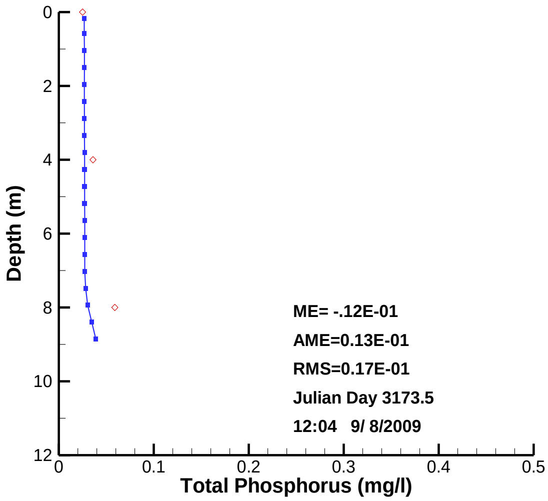
ME= -.43E-02
AME=0.60E-02
RMS=0.88E-02
Julian Day 3089.5
12:05 6/16/2009
Depth (m)
Total Phosphorus (mg/l)

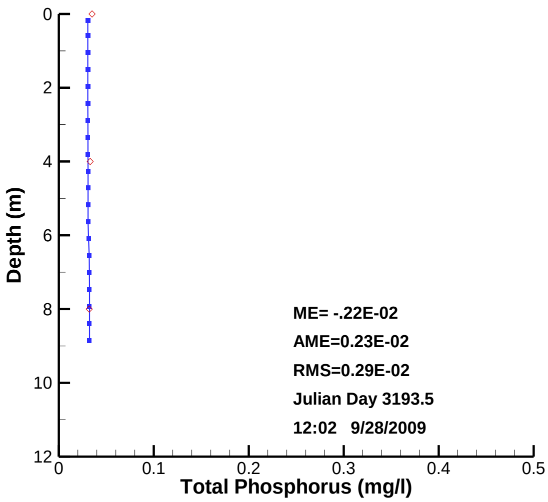

Depth (m)
Total Phosphorus (mg/l)
ME= 0.69E-02
AME=0.70E-02
RMS=0.10E-01
Julian Day 3102.5
12:02 6/29/2009

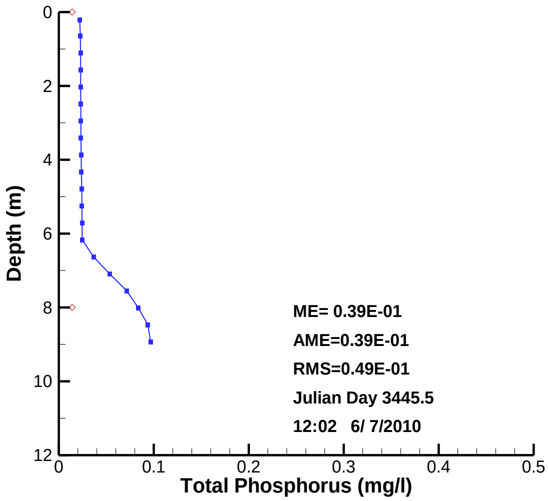

Depth (m)
Total Phosphorus (mg/l)
ME= 0.23E-01
AME=0.23E-01
RMS=0.30E-01
Julian Day 3117.5
12:07 7/14/2009


Depth (m)
0
2
4
6
8
10
12
ME= 0.32E-01
AME=0.32E-01
RMS=0.51E-01
Julian Day 3137.5
12:05 8/ 3/2009
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)

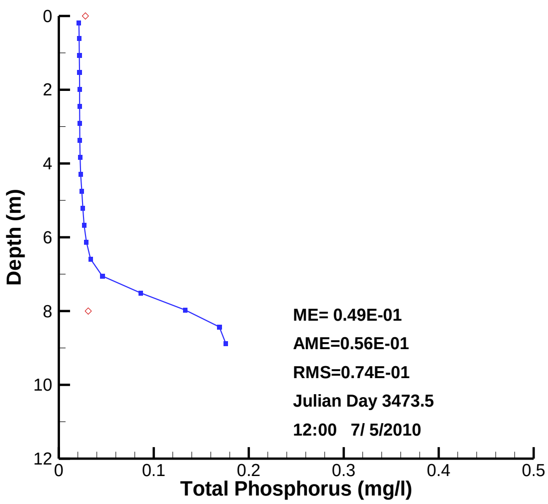

Depth (m)
0
2
4
6
8
10
12
ME= 0.12E-01
AME=0.12E-01
RMS=0.19E-01
Julian Day 3152.5
12:05 8/18/2009
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)


Depth (m)
Total Phosphorus (mg/l)
ME= -.12E-01
AME=0.13E-01
RMS=0.17E-01
Julian Day 3173.5
12:04 9/ 8/2009

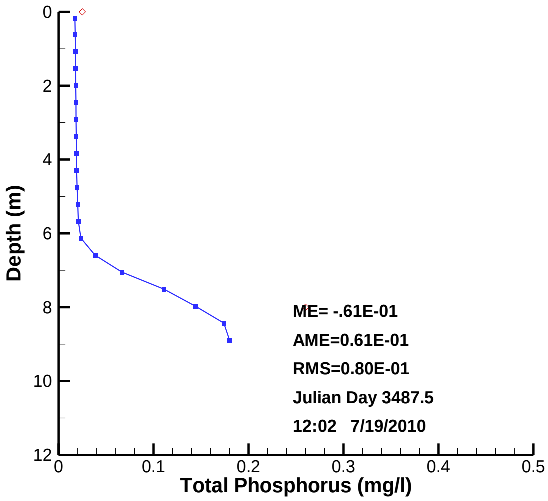

Depth (m)
Total Phosphorus (mg/l)
ME= -.22E-02
AME=0.23E-02
RMS=0.29E-02
Julian Day 3193.5
12:02 9/28/2009



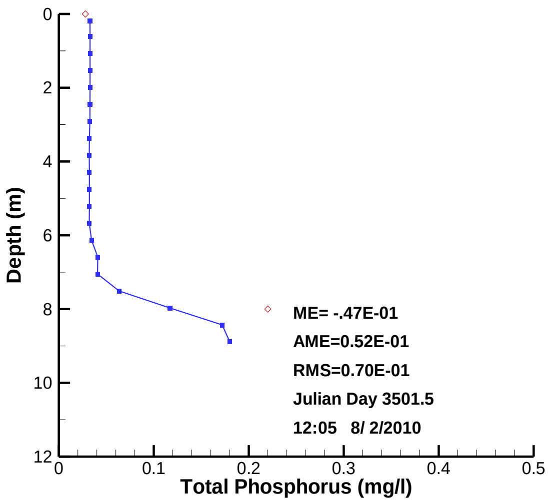
Depth (m)
Total Phosphorus (mg/l)
ME= 0.39E-01
AME=0.39E-01
RMS=0.49E-01
Julian Day 3445.5
12:02 6/ 7/2010



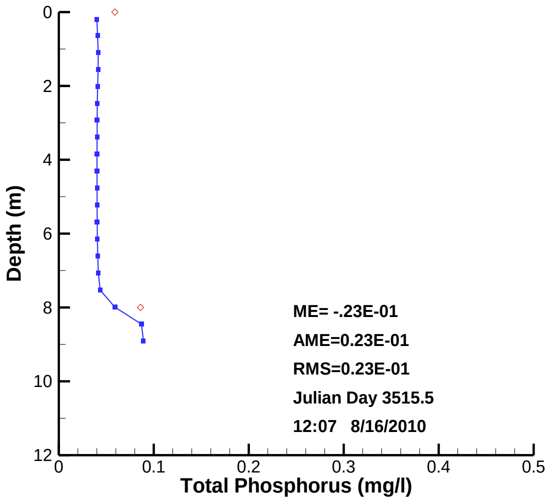
Depth (m)
Total Phosphorus (mg/l)
ME= 0.49E-01
AME=0.56E-01
RMS=0.74E-01
Julian Day 3473.5
12:00 7/ 5/2010



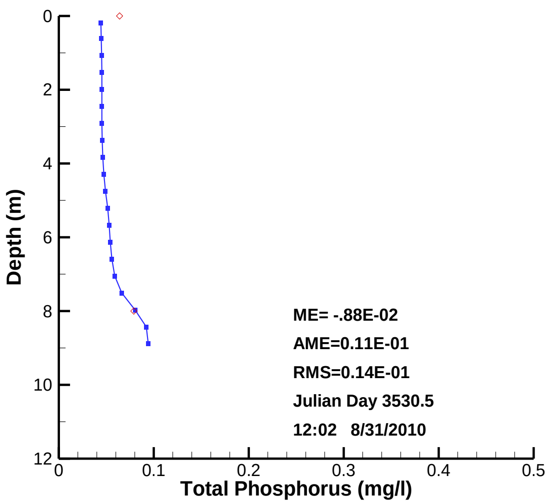
0
2
4
6
8
10
12
Depth (m)
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)
ME= -.61E-01
AME=0.61E-01
RMS=0.80E-01
Julian Day 3487.5
12:02 7/19/2010



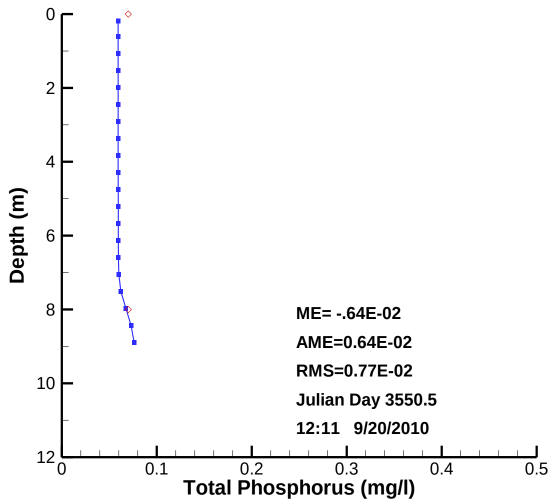
0
2
4
6
8
10
12
Depth (m)
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)
ME= -.47E-01
AME=0.52E-01
RMS=0.70E-01
Julian Day 3501.5
12:05 8/ 2/2010

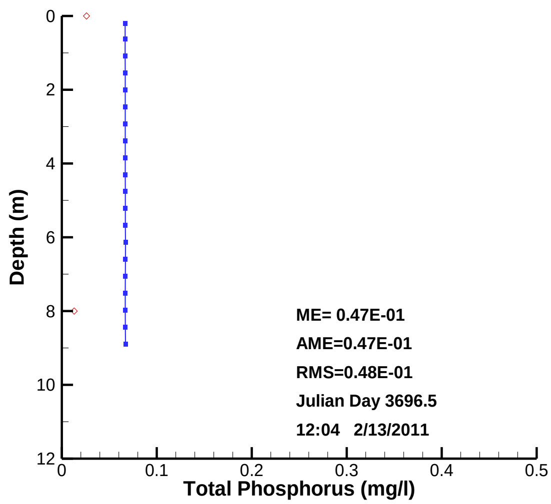


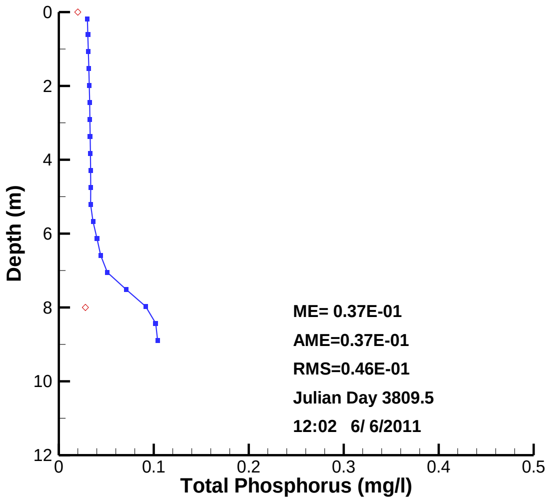
Depth (m)
0
2
4
6
8
10
12
ME= -.23E-01
AME=0.23E-01
RMS=0.23E-01
Julian Day 3515.5
12:07 8/16/2010
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)

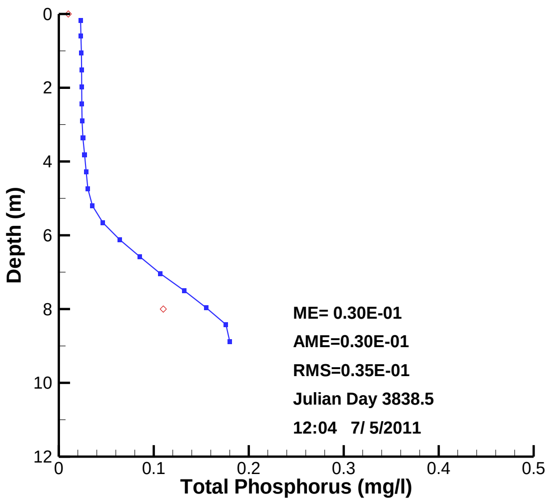


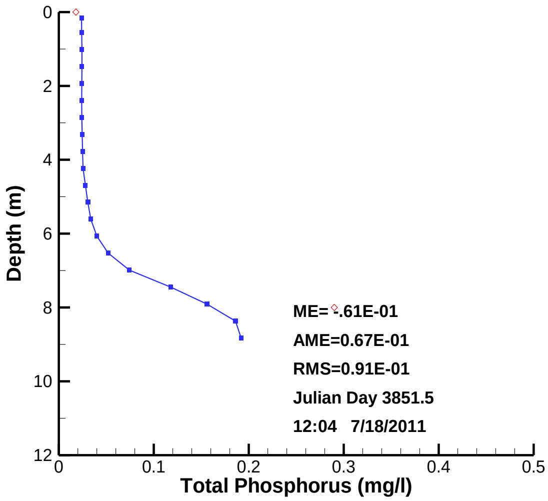
Depth (m)
0
2
4
6
8
10
12
ME= -.88E-02
AME=0.11E-01
RMS=0.14E-01
Julian Day 3530.5
12:02 8/31/2010
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)

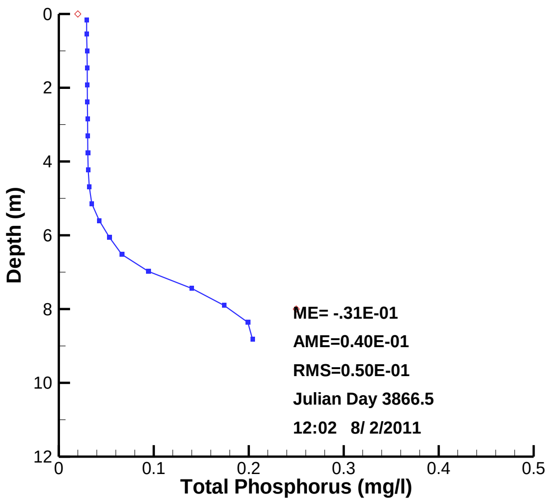

0
2
4
6
8
10
12
Depth (m)
ME= -.64E-02
AME=0.64E-02
RMS=0.77E-02
Julian Day 3550.5
12:11 9/20/2010
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)

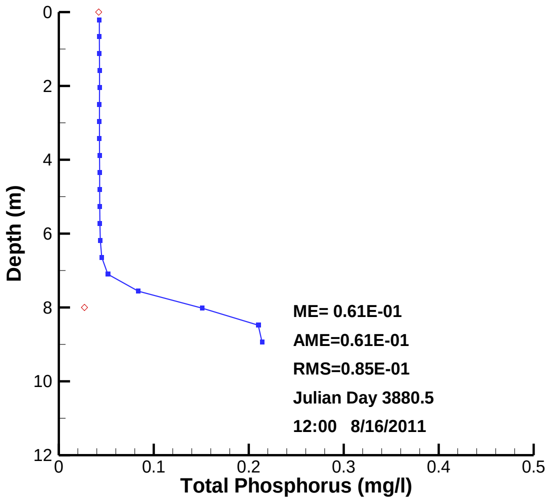

0
2
4
6
8
10
12
Depth (m)
ME= 0.47E-01
AME=0.47E-01
RMS=0.48E-01
Julian Day 3696.5
12:04 2/13/2011
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)


ME= 0.37E-01
AME=0.37E-01
RMS=0.46E-01
Julian Day 3809.5
12:02 6/ 6/2011
Depth (m)
Total Phosphorus (mg/l)

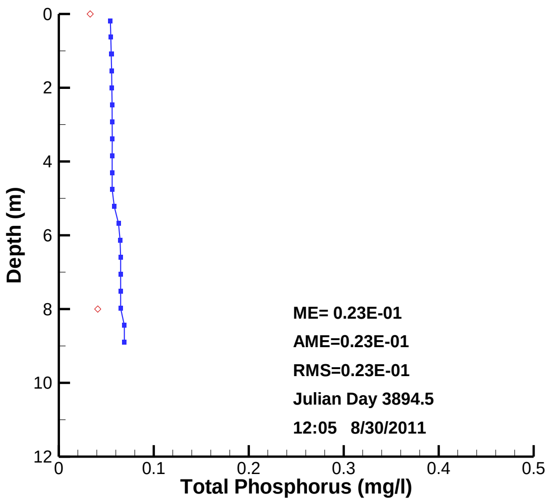

ME= 0.30E-01
AME=0.30E-01
RMS=0.35E-01
Julian Day 3838.5
12:04 7/ 5/2011
Depth (m)
Total Phosphorus (mg/l)


Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)
ME= -.61E-01
AME=0.67E-01
RMS=0.91E-01
Julian Day 3851.5
12:04 7/18/2011

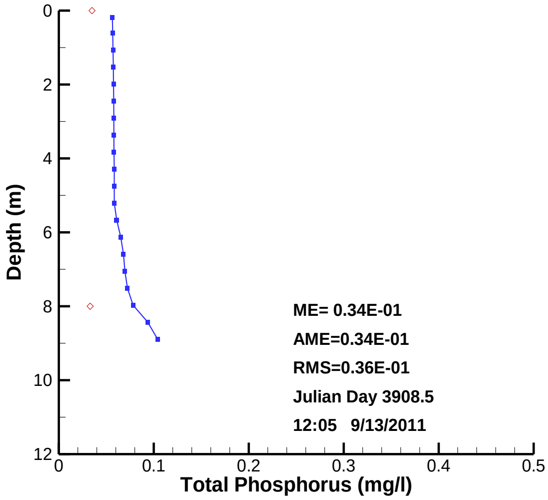

Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)
ME= -.31E-01
AME=0.40E-01
RMS=0.50E-01
Julian Day 3866.5
12:02 8/ 2/2011



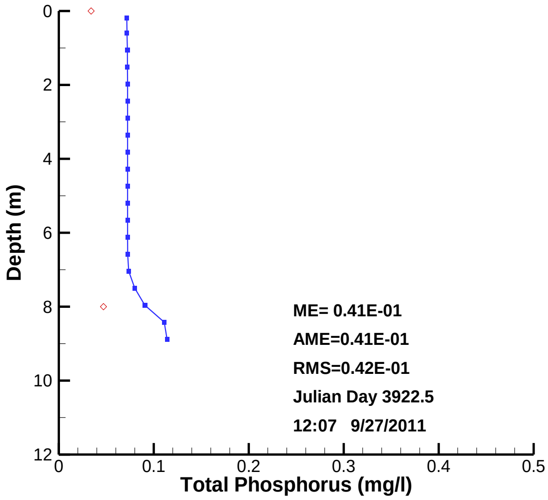
Depth (m)
Total Phosphorus (mg/l)
ME= 0.61E-01
AME=0.61E-01
RMS=0.85E-01
Julian Day 3880.5
12:00 8/16/2011



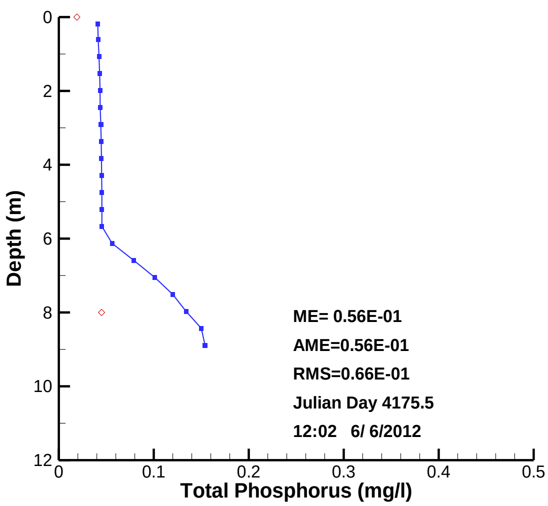
Depth (m)
Total Phosphorus (mg/l)
ME= 0.23E-01
AME=0.23E-01
RMS=0.23E-01
Julian Day 3894.5
12:05 8/30/2011



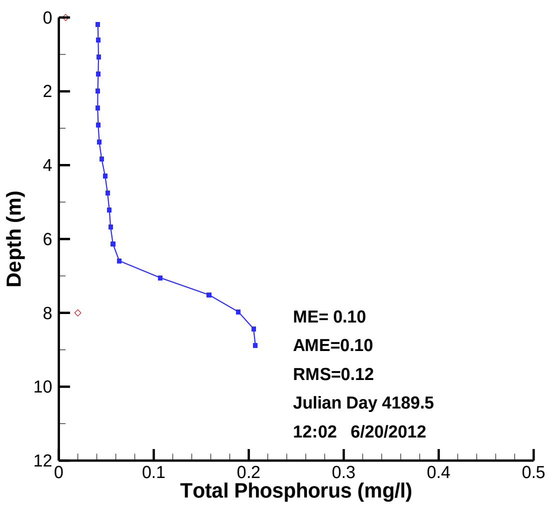
Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)
ME= 0.34E-01
AME=0.34E-01
RMS=0.36E-01
Julian Day 3908.5
12:05 9/13/2011



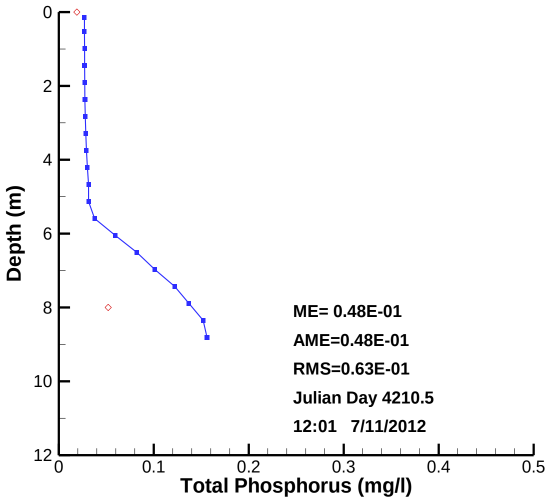
Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)
ME= 0.41E-01
AME=0.41E-01
RMS=0.42E-01
Julian Day 3922.5
12:07 9/27/2011

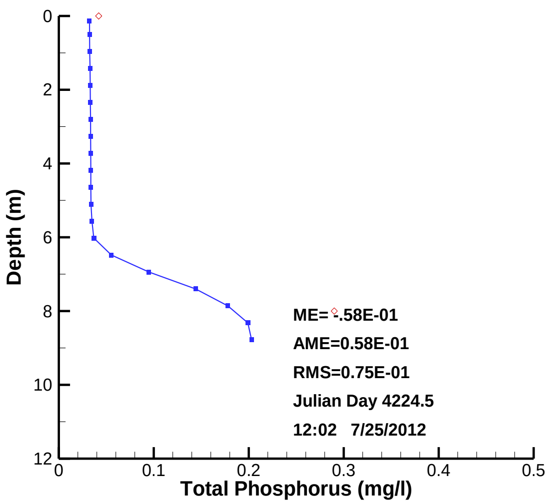


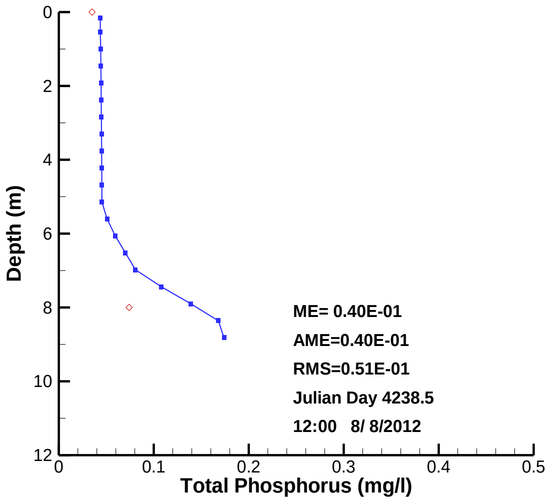
0
2
4
6
8
10
12
Depth (m)
ME= 0.56E-01
AME=0.56E-01
RMS=0.66E-01
Julian Day 4175.5
12:02 6/ 6/2012
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)

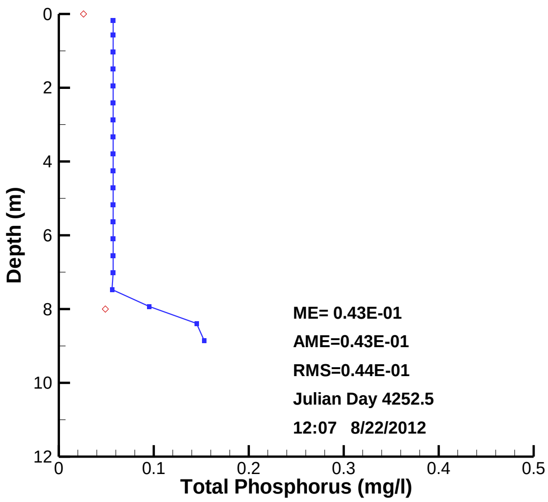


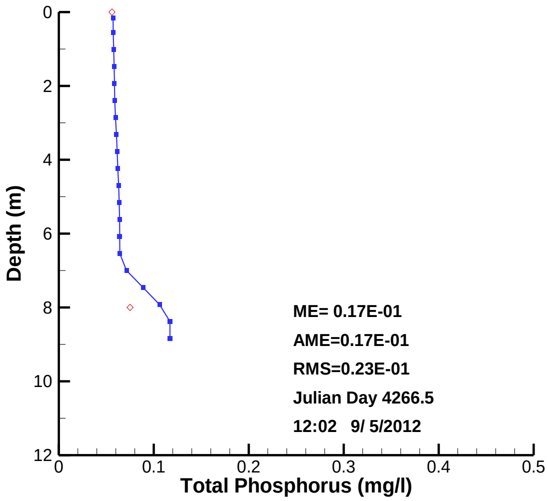
0
2
4
6
8
10
12
Depth (m)
ME= 0.10
AME=0.10
RMS=0.12
Julian Day 4189.5
12:02 6/20/2012
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)


Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)
ME= 0.48E-01
AME=0.48E-01
RMS=0.63E-01
Julian Day 4210.5
12:01 7/11/2012

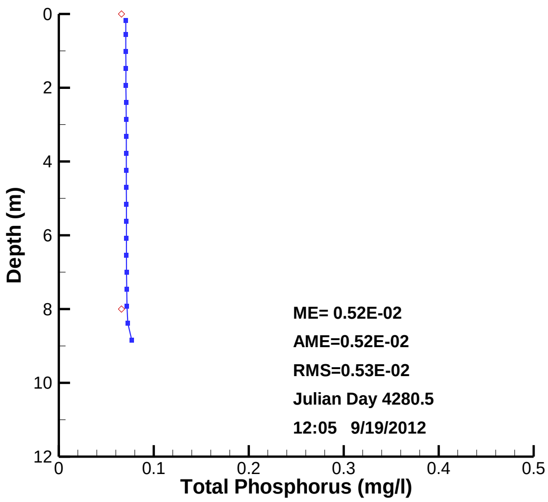

Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)
ME= -.58E-01
AME=0.58E-01
RMS=0.75E-01
Julian Day 4224.5
12:02 7/25/2012


Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)
ME= 0.40E-01
AME=0.40E-01
RMS=0.51E-01
Julian Day 4238.5
12:00 8/ 8/2012

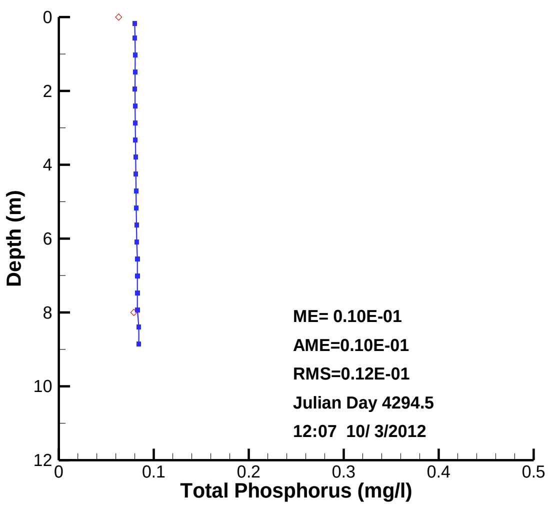

Depth (m)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)
ME= 0.43E-01
AME=0.43E-01
RMS=0.44E-01
Julian Day 4252.5
12:07 8/22/2012

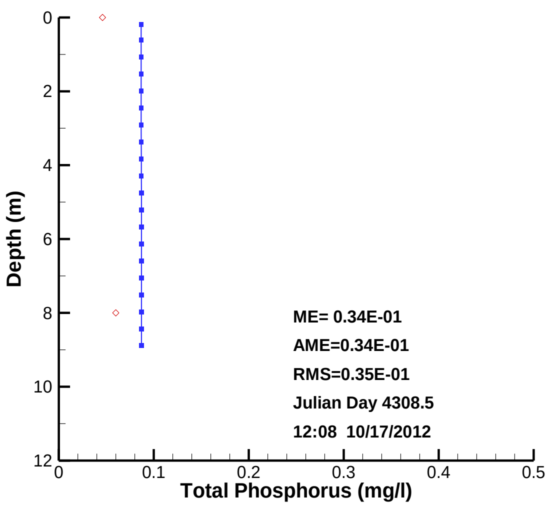


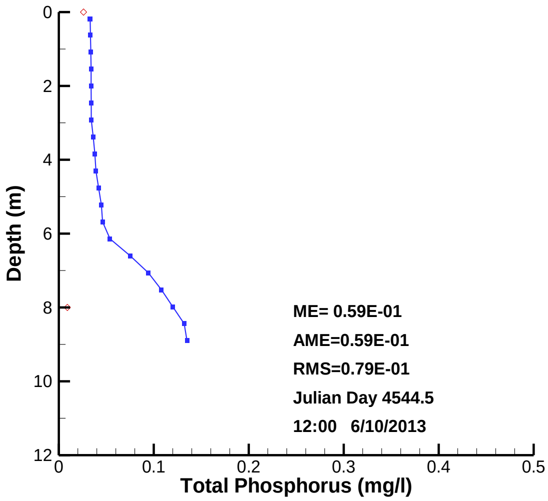
Depth (m)
Total Phosphorus (mg/l)
ME= 0.17E-01
AME=0.17E-01
RMS=0.23E-01
Julian Day 4266.5
12:02 9/ 5/2012

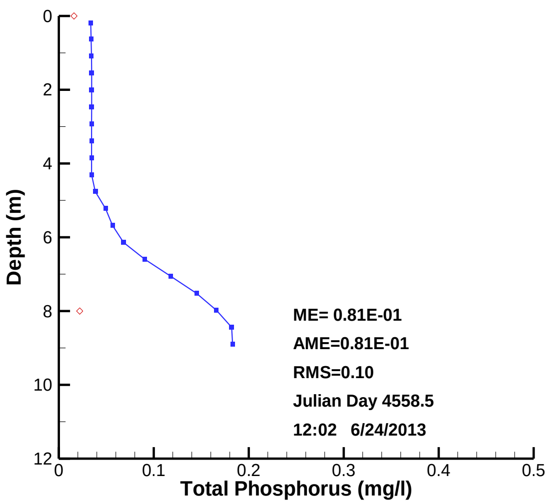


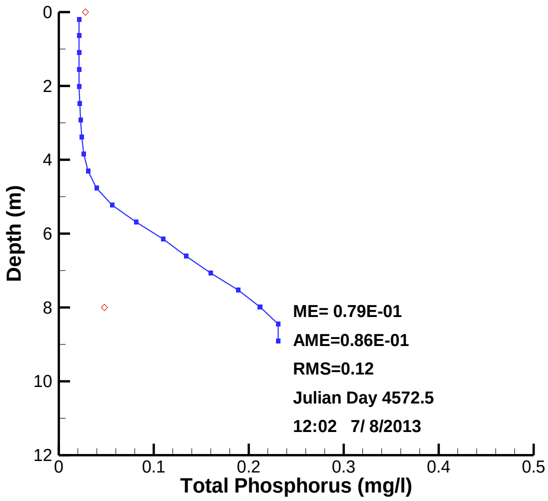
Depth (m)
Total Phosphorus (mg/l)
ME= 0.52E-02
AME=0.52E-02
RMS=0.53E-02
Julian Day 4280.5
12:05 9/19/2012


0
2
4
6
8
10
12
Depth (m)
ME= 0.10E-01
AME=0.10E-01
RMS=0.12E-01
Julian Day 4294.5
12:07 10/ 3/2012
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)

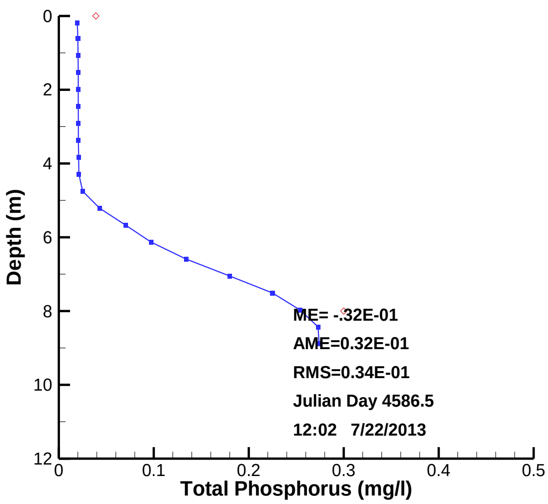

0
2
4
6
8
10
12
Depth (m)
ME= 0.34E-01
AME=0.34E-01
RMS=0.35E-01
Julian Day 4308.5
12:08 10/17/2012
0
0.1
0.2
0.3
0.4
0.5
Total Phosphorus (mg/l)


ME= 0.59E-01
AME=0.59E-01
RMS=0.79E-01
Julian Day 4544.5
12:00 6/10/2013
Depth (m)
Total Phosphorus (mg/l)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5

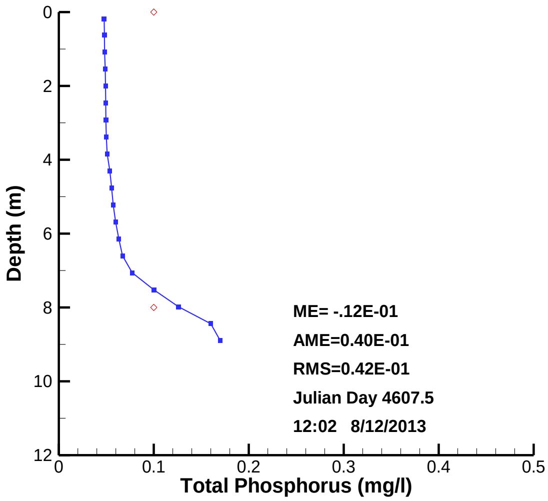

ME= 0.81E-01
AME=0.81E-01
RMS=0.10
Julian Day 4558.5
12:02 6/24/2013
Depth (m)
Total Phosphorus (mg/l)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5



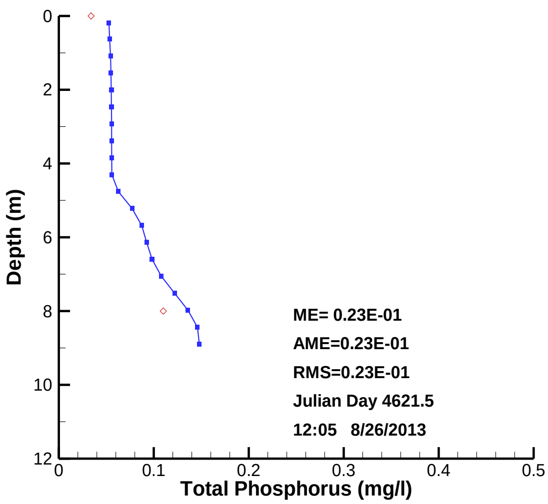
Depth (m)
Total Phosphorus (mg/l)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
ME= 0.79E-01
AME=0.86E-01
RMS=0.12
Julian Day 4572.5
12:02 7/ 8/2013



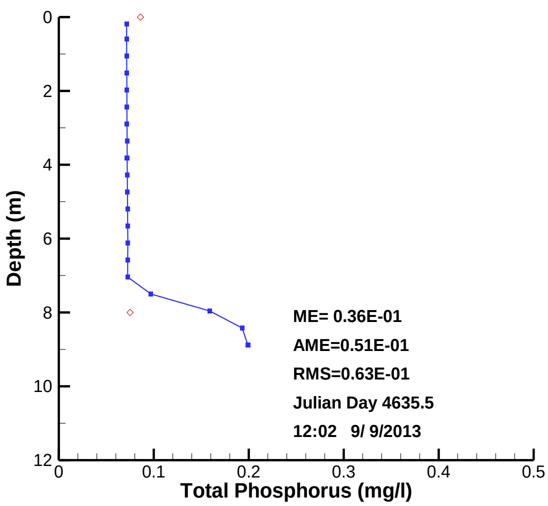
Depth (m)
Total Phosphorus (mg/l)
0
2
4
6
8
10
12
0
0.1
0.2
0.3
0.4
0.5
ME= -.32E-01
AME=0.32E-01
RMS=0.34E-01
Julian Day 4586.5
12:02 7/22/2013

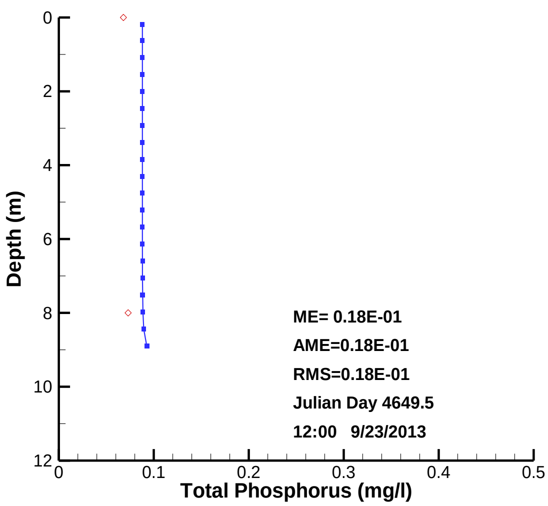


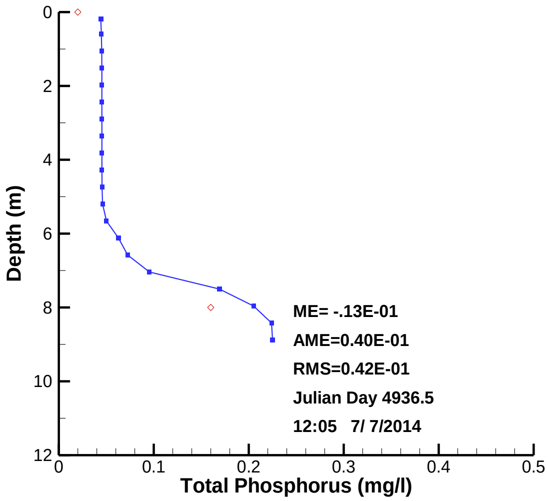
Depth (m)
Total Phosphorus (mg/l)
ME= -.12E-01
AME=0.40E-01
RMS=0.42E-01
Julian Day 4607.5
12:02 8/12/2013



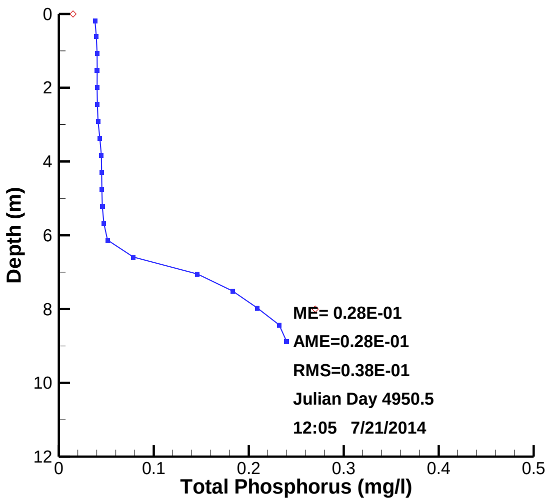
Depth (m)
Total Phosphorus (mg/l)
ME= 0.23E-01
AME=0.23E-01
RMS=0.23E-01
Julian Day 4621.5
12:05 8/26/2013


ME= 0.36E-01
AME=0.51E-01
RMS=0.63E-01
Julian Day 4635.5
12:02 9/ 9/2013
Depth (m)
Total Phosphorus (mg/l)

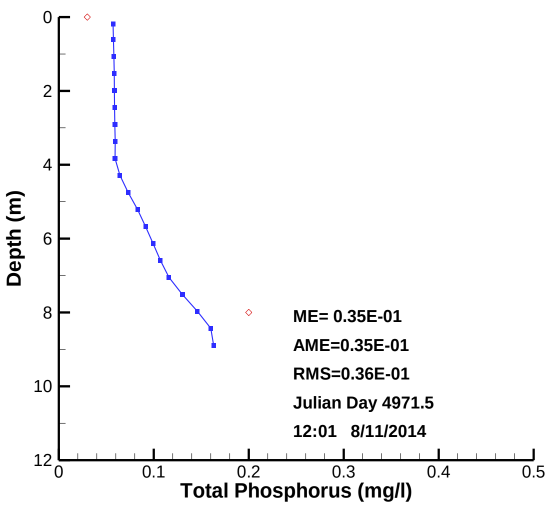

ME= 0.18E-01
AME=0.18E-01
RMS=0.18E-01
Julian Day 4649.5
12:00 9/23/2013
Depth (m)
Total Phosphorus (mg/l)



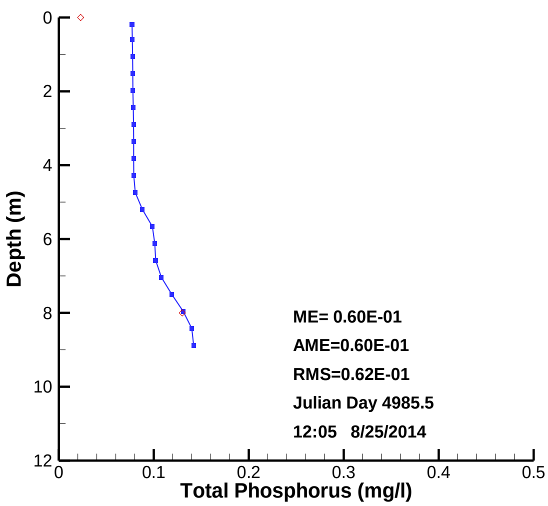
ME= -.13E-01
AME=0.40E-01
RMS=0.42E-01
Julian Day 4936.5
12:05 7/ 7/2014
Depth (m)
Total Phosphorus (mg/l)



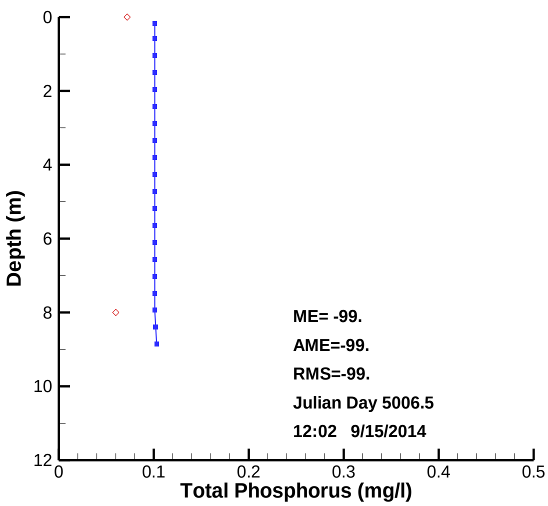
ME= 0.28E-01
AME=0.28E-01
RMS=0.38E-01
Julian Day 4950.5
12:05 7/21/2014
Depth (m)
Total Phosphorus (mg/l)

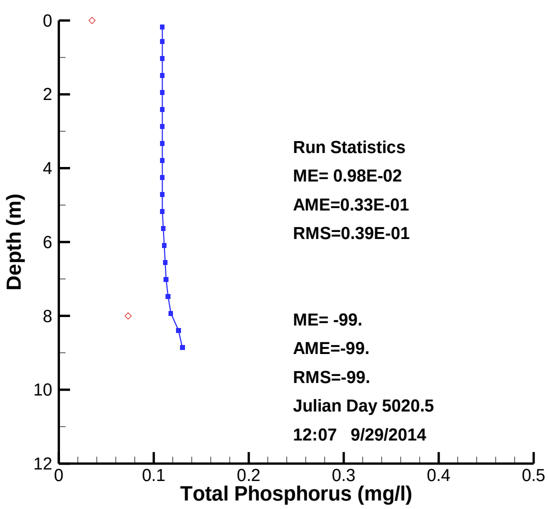


Depth (m)
Total Phosphorus (mg/l)
ME= 0.35E-01
AME=0.35E-01
RMS=0.36E-01
Julian Day 4971.5
12:01 8/11/2014

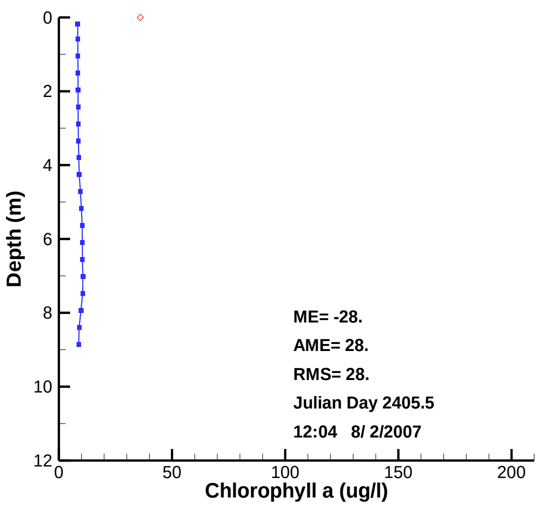


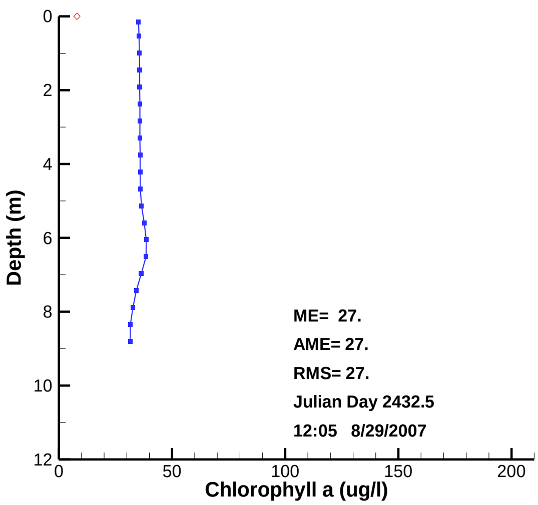
Depth (m)
Total Phosphorus (mg/l)
ME= 0.60E-01
AME=0.60E-01
RMS=0.62E-01
Julian Day 4985.5
12:05 8/25/2014

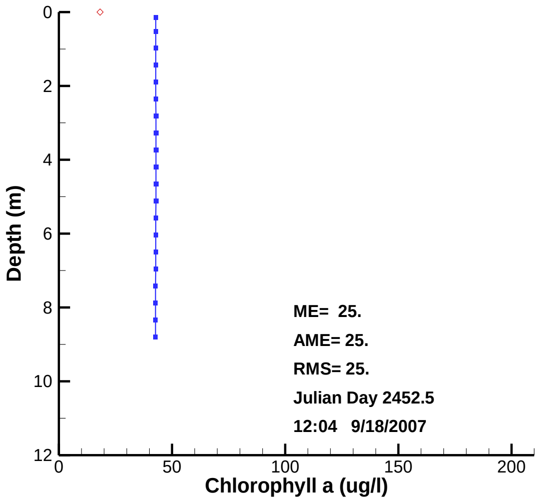

ME= -99.
AME=-99.
RMS=-99.
Julian Day 5006.5
12:02 9/15/2014
Depth (m)
Total Phosphorus (mg/l)

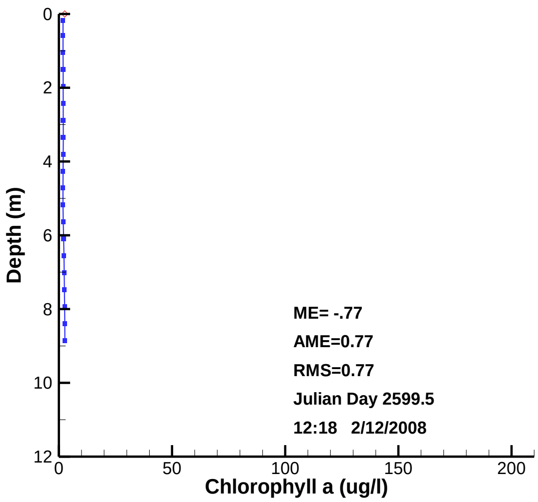

Run Statistics
ME= 0.98E-02
AME=0.33E-01
RMS=0.39E-01
ME= -99.
AME=-99.
RMS=-99.
Julian Day 5020.5
12:07 9/29/2014
Depth (m)
Total Phosphorus (mg/l)

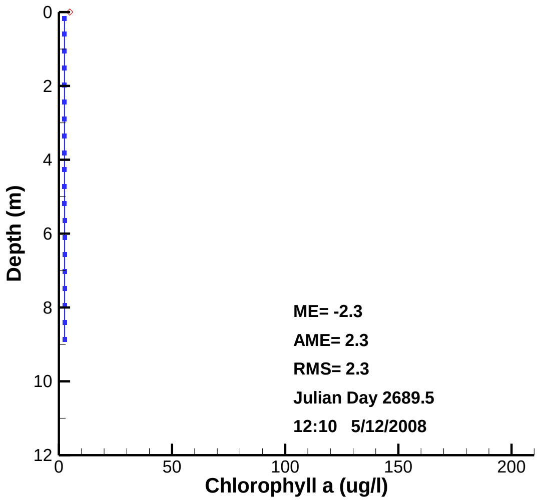
B5 Chlorophyll-a Profile Plots

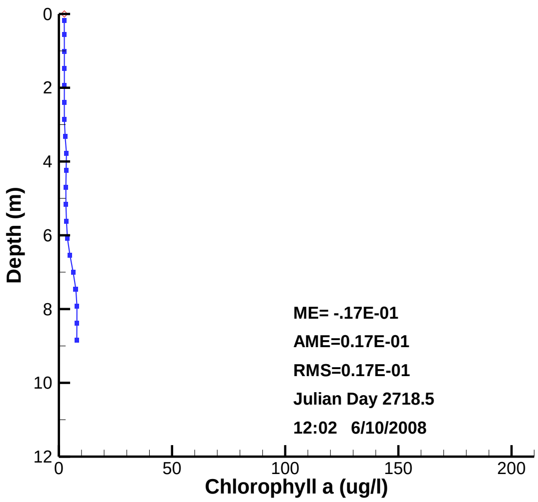


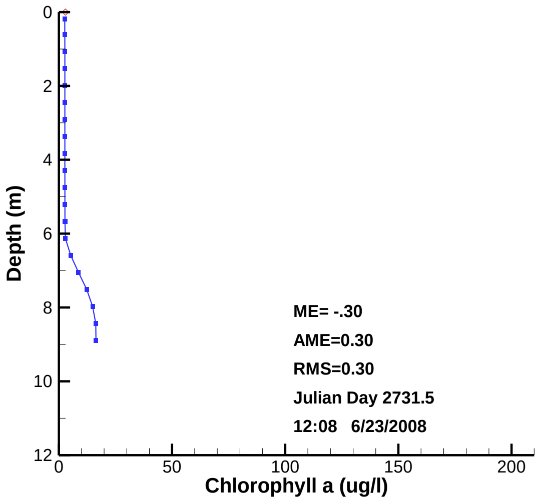


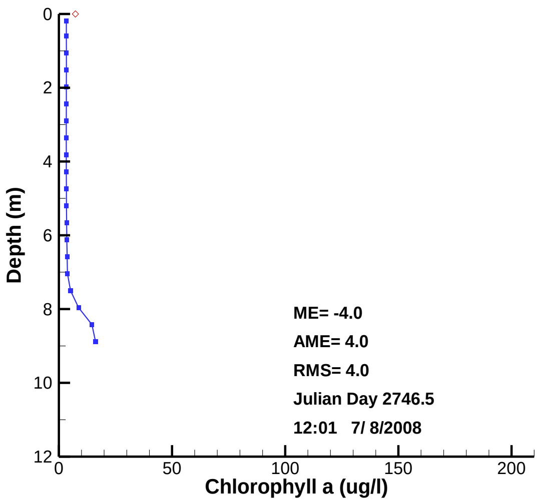

Depth (m)
Chlorophyll a (ug/l)
ME= 25.
AME= 25.
RMS= 25.
Julian Day 2452.5
12:04 9/18/2007

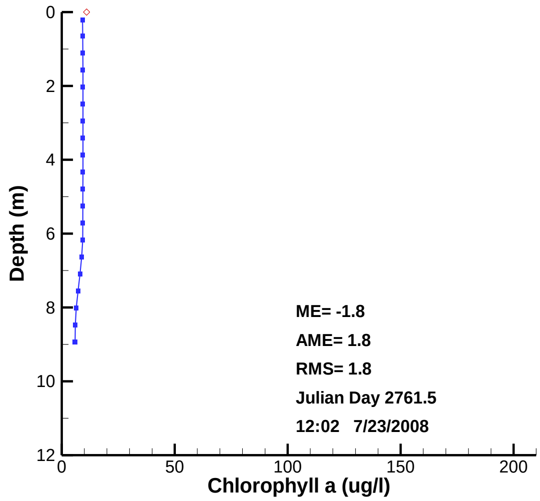

Depth (m)
Chlorophyll a (ug/l)
ME= -.77
AME=0.77
RMS=0.77
Julian Day 2599.5
12:18 2/12/2008

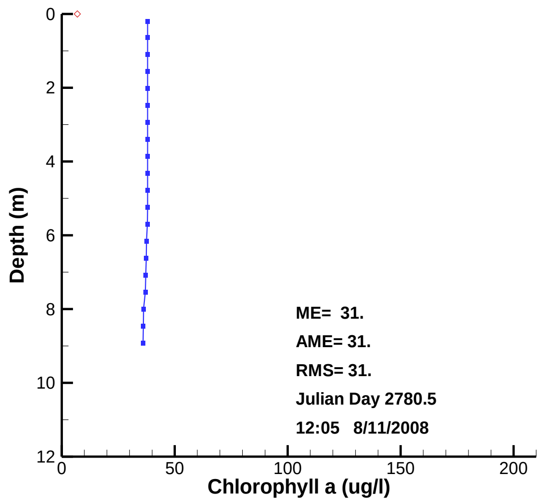

Depth (m)
0
2
4
6
8
10
12
ME= -2.3
AME= 2.3
RMS= 2.3
Julian Day 2689.5
12:10 5/12/2008
0
50
100
150
200
Chlorophyll a (ug/l)

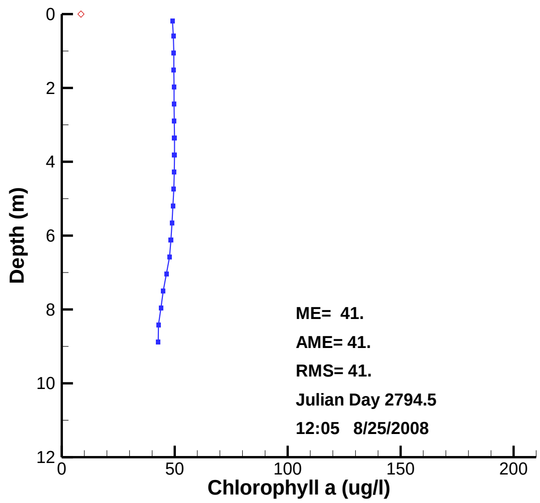

Depth (m)
0
2
4
6
8
10
12
ME= -.17E-01
AME=0.17E-01
RMS=0.17E-01
Julian Day 2718.5
12:02 6/10/2008
0
50
100
150
200
Chlorophyll a (ug/l)

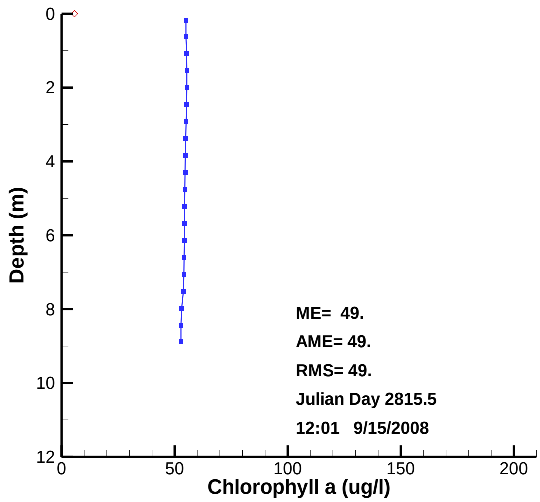

Depth (m)
Chlorophyll a (ug/l)
ME= -.30
AME=0.30
RMS=0.30
Julian Day 2731.5
12:08 6/23/2008

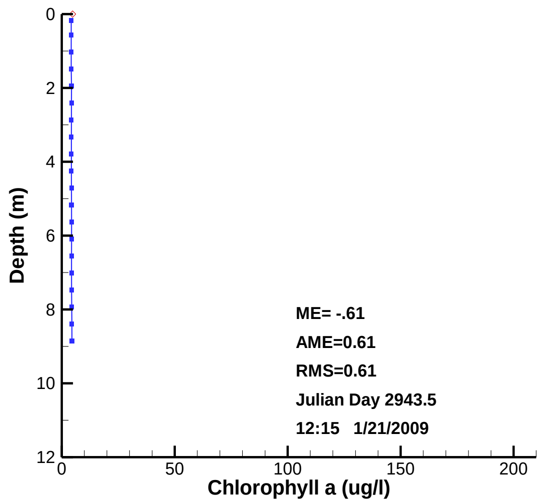

Depth (m)
Chlorophyll a (ug/l)
ME= -4.0
AME= 4.0
RMS= 4.0
Julian Day 2746.5
12:01 7/ 8/2008

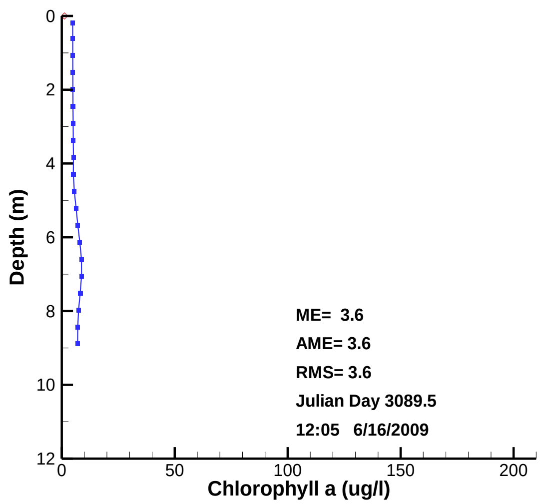

0
2
4
6
8
10
12
Depth (m)
ME= -1.8
AME= 1.8
RMS= 1.8
Julian Day 2761.5
12:02 7/23/2008
0
50
100
150
200
Chlorophyll a (ug/l)

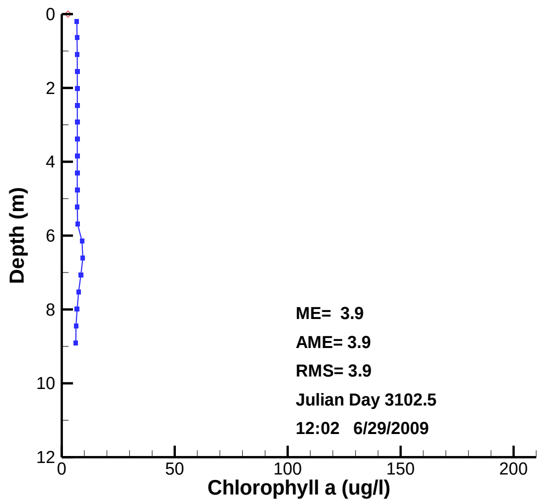

0
2
4
6
8
10
12
Depth (m)
ME= 31.
AME= 31.
RMS= 31.
Julian Day 2780.5
12:05 8/11/2008
0
50
100
150
200
Chlorophyll a (ug/l)


Depth (m)
Chlorophyll a (ug/l)
ME= 41.
AME= 41.
RMS= 41.
Julian Day 2794.5
12:05 8/25/2008

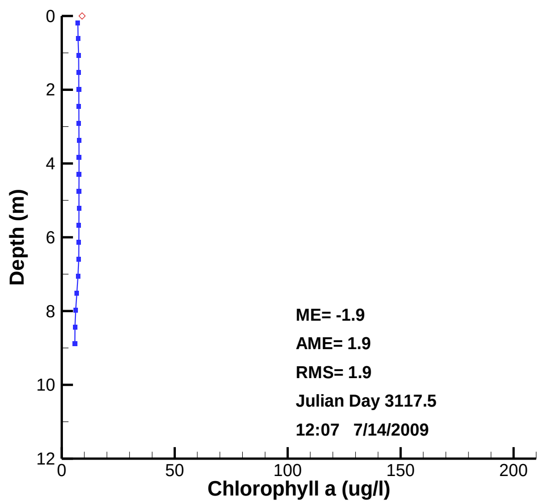

Depth (m)
Chlorophyll a (ug/l)
ME= 49.
AME= 49.
RMS= 49.
Julian Day 2815.5
12:01 9/15/2008


Depth (m)
Chlorophyll a (ug/l)
ME= -.61
AME=0.61
RMS=0.61
Julian Day 2943.5
12:15 1/21/2009

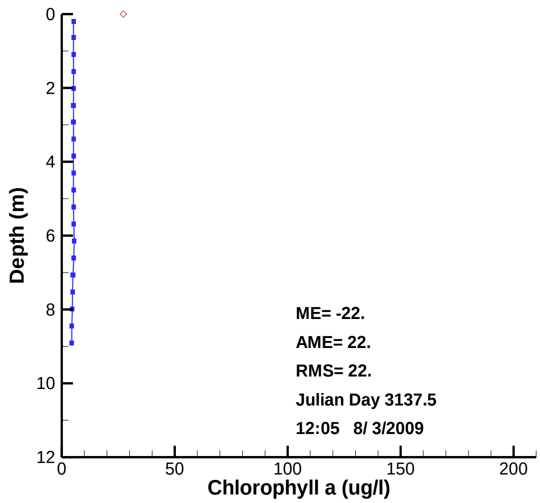

Depth (m)
Chlorophyll a (ug/l)
ME= 3.6
AME= 3.6
RMS= 3.6
Julian Day 3089.5
12:05 6/16/2009

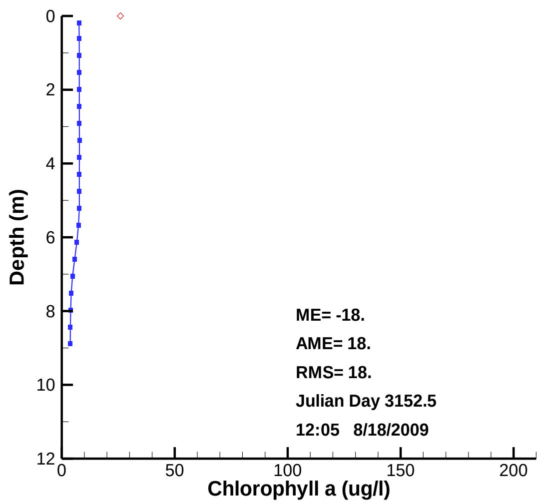


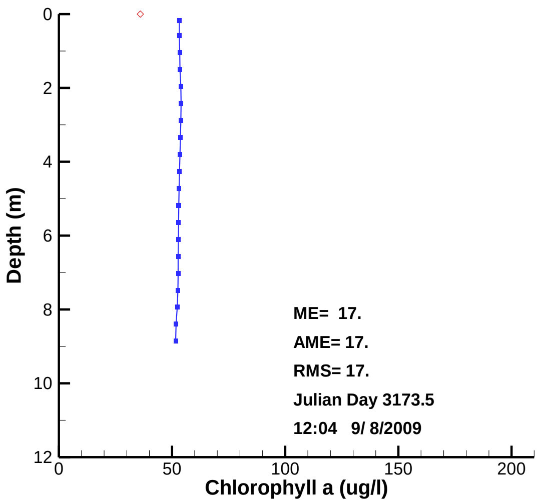
0
2
4
6
8
10
12
Depth (m)
ME= 3.9
AME= 3.9
RMS= 3.9
Julian Day 3102.5
12:02 6/29/2009
0
50
100
150
200
Chlorophyll a (ug/l)

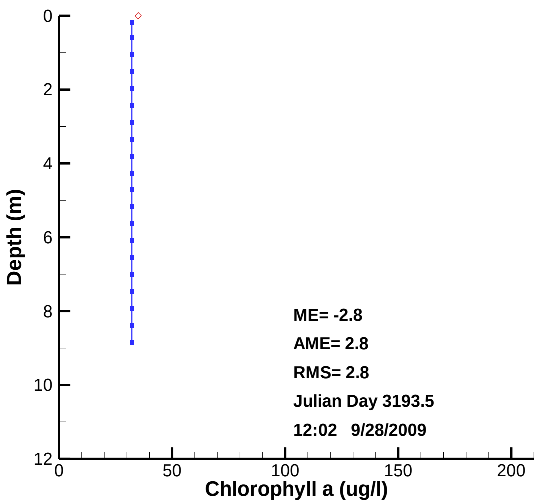


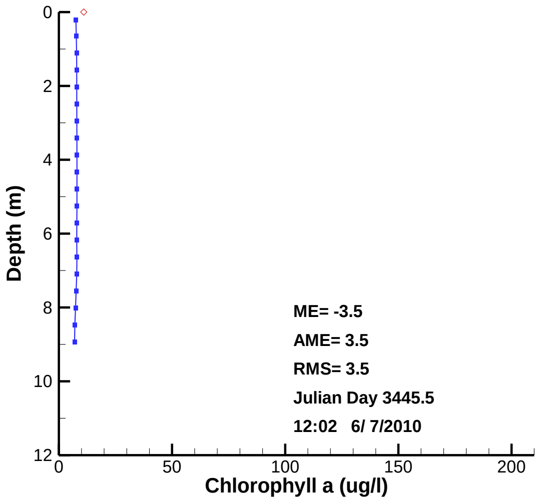
0
2
4
6
8
10
12
Depth (m)
ME= -1.9
AME= 1.9
RMS= 1.9
Julian Day 3117.5
12:07 7/14/2009
0
50
100
150
200
Chlorophyll a (ug/l)

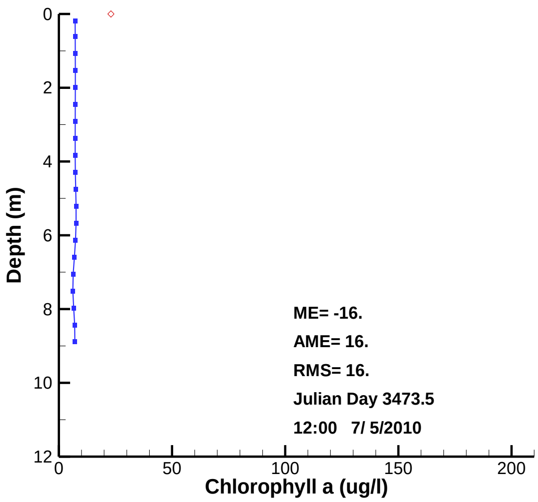

ME= -22.
AME= 22.
RMS= 22.
Julian Day 3137.5
12:05 8/ 3/2009
Depth (m)
Chlorophyll a (ug/l)

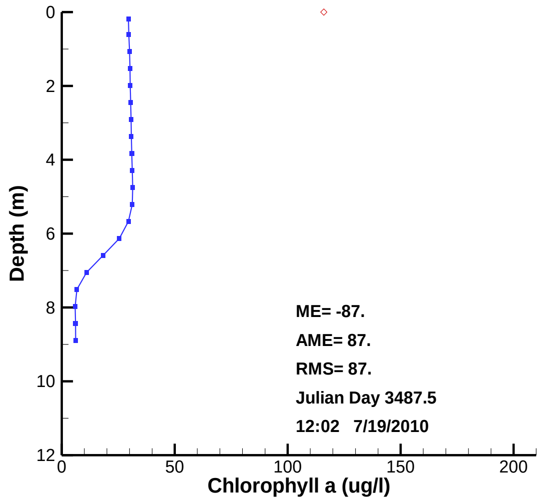

ME= -18.
AME= 18.
RMS= 18.
Julian Day 3152.5
12:05 8/18/2009
Depth (m)
Chlorophyll a (ug/l)


Depth (m)
Chlorophyll a (ug/l)
ME= 17.
AME= 17.
RMS= 17.
Julian Day 3173.5
12:04 9/ 8/2009

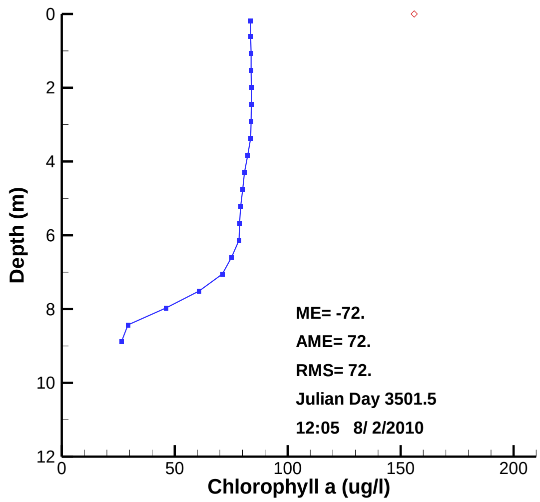

Depth (m)
Chlorophyll a (ug/l)
ME= -2.8
AME= 2.8
RMS= 2.8
Julian Day 3193.5
12:02 9/28/2009


ME= -3.5
AME= 3.5
RMS= 3.5
Julian Day 3445.5
12:02 6/ 7/2010
Depth (m)
Chlorophyll a (ug/l)

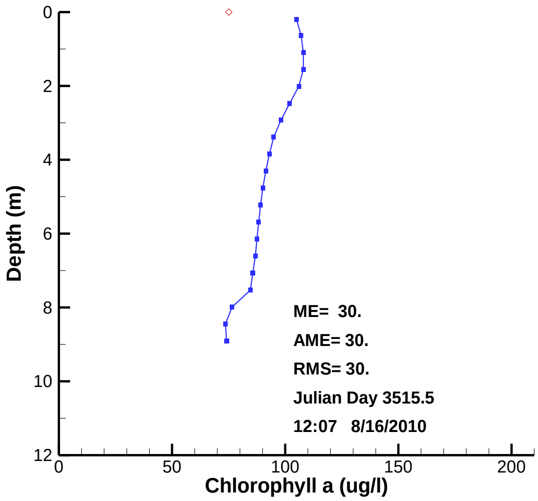

ME= -16.
AME= 16.
RMS= 16.
Julian Day 3473.5
12:00 7/ 5/2010
Depth (m)
Chlorophyll a (ug/l)



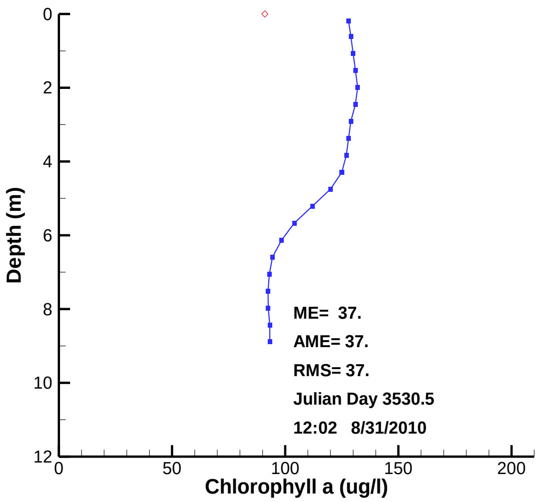
ME= -87.
AME= 87.
RMS= 87.
Julian Day 3487.5
12:02 7/19/2010
Depth (m)
Chlorophyll a (ug/l)
0
2
4
6
8
10
12
0
50
100
150
200



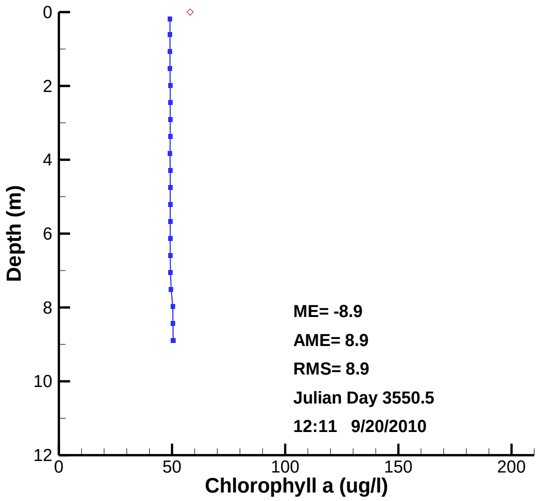
ME= -72.
AME= 72.
RMS= 72.
Julian Day 3501.5
12:05 8/ 2/2010
Depth (m)
Chlorophyll a (ug/l)
0
2
4
6
8
10
12
0
50
100
150
200

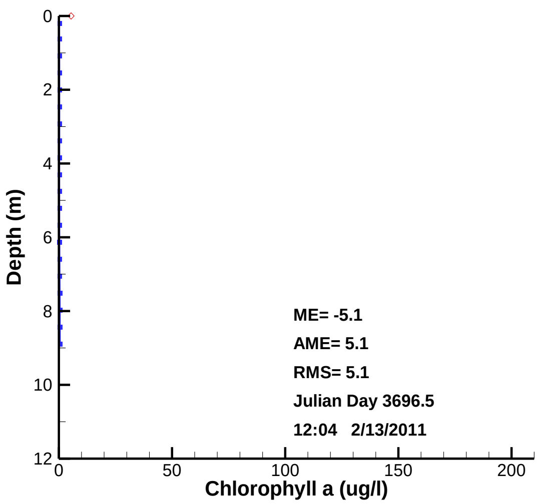


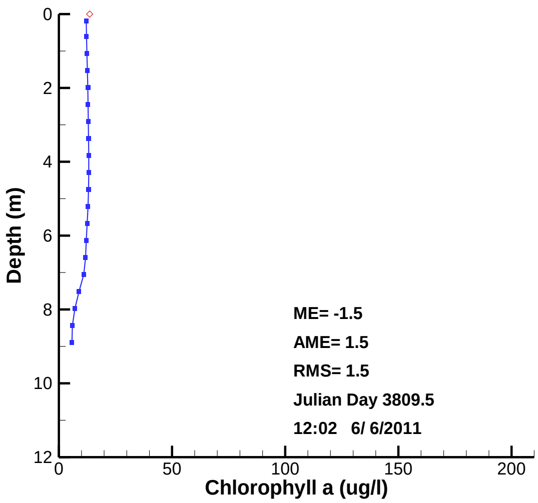
Depth (m)
Chlorophyll a (ug/l)
ME= 30.
AME= 30.
RMS= 30.
Julian Day 3515.5
12:07 8/16/2010

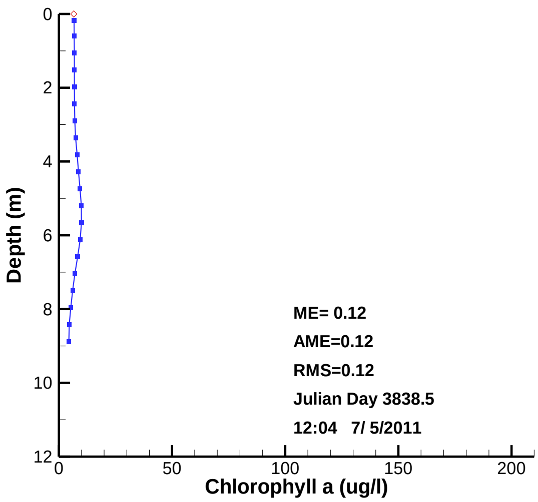


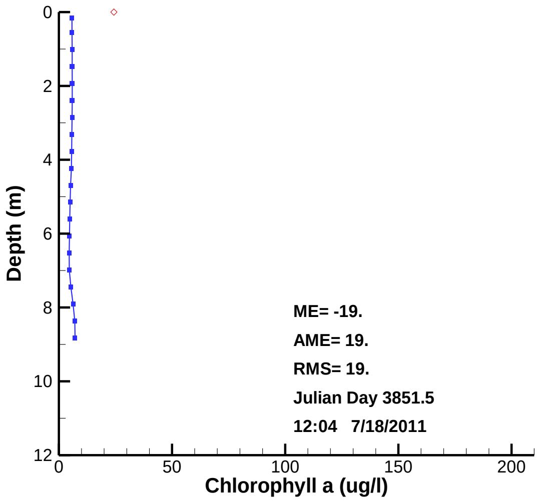
Depth (m)
Chlorophyll a (ug/l)
ME= 37.
AME= 37.
RMS= 37.
Julian Day 3530.5
12:02 8/31/2010


Depth (m)
Chlorophyll a (ug/l)
ME= -8.9
AME= 8.9
RMS= 8.9
Julian Day 3550.5
12:11 9/20/2010


Depth (m)
Chlorophyll a (ug/l)
ME= -5.1
AME= 5.1
RMS= 5.1
Julian Day 3696.5
12:04 2/13/2011


Depth (m)
ME= -1.5
AME= 1.5
RMS= 1.5
Julian Day 3809.5
12:02 6/ 6/2011
Chlorophyll a (ug/l)


Depth (m)
ME= 0.12
AME=0.12
RMS=0.12
Julian Day 3838.5
12:04 7/ 5/2011
Chlorophyll a (ug/l)


0
2
4
6
8
10
12
Depth (m)
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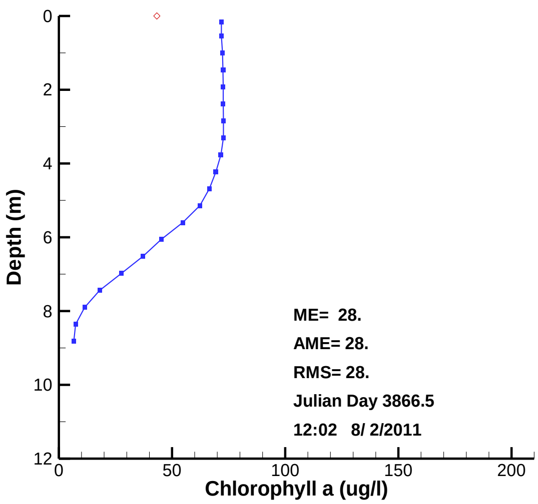
150
200
Chlorophyll a (ug/l)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4
6
8
10
12
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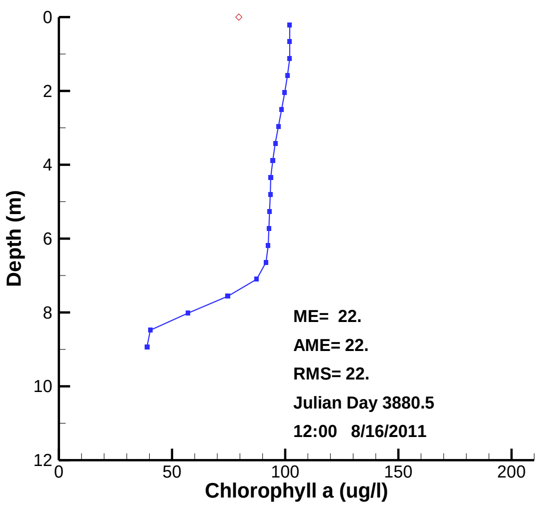
50
100
150
200
Chlorophyll a (ug/l)



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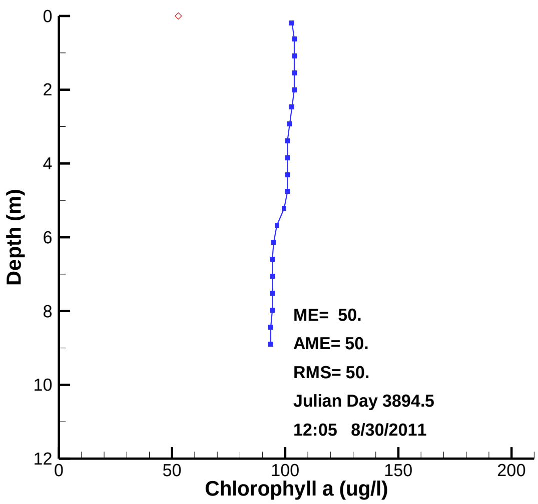

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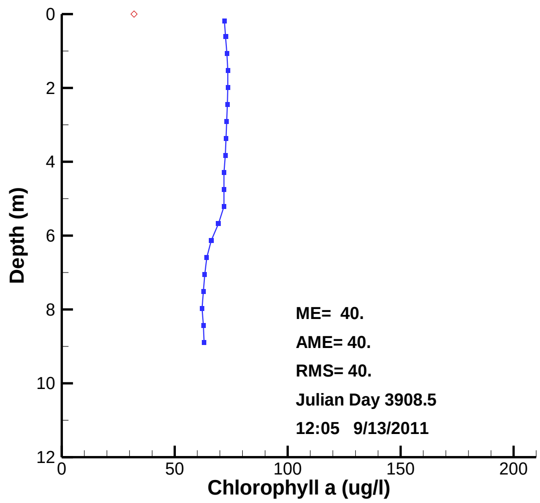

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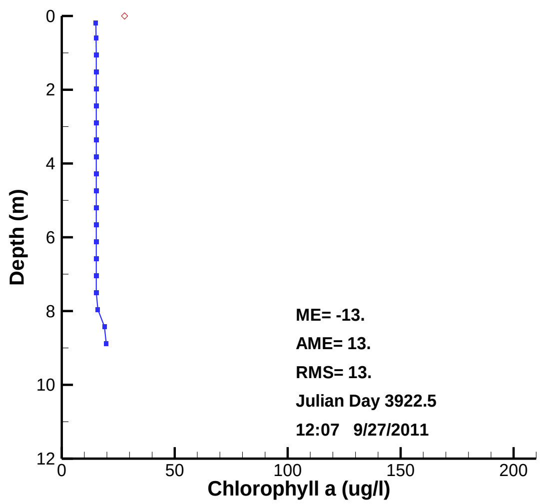
Chlorophyll a (ug/l)



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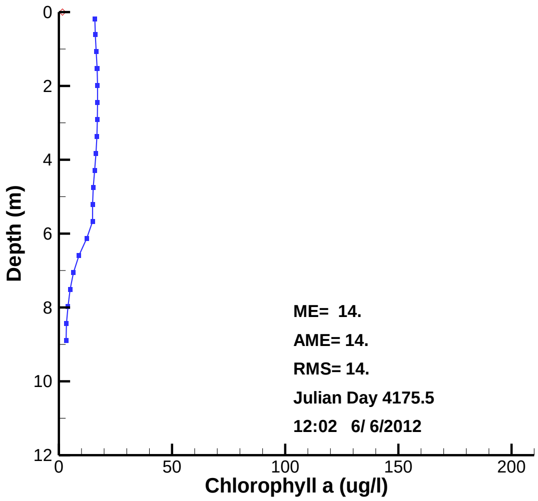
Chlorophyll a (ug/l)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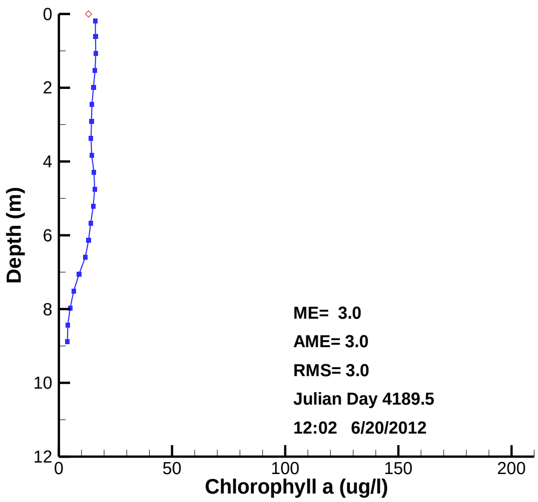
12:02 6/ 6/2012


Depth (m)
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2
4
6
8
10
12
0
50
100
150
200
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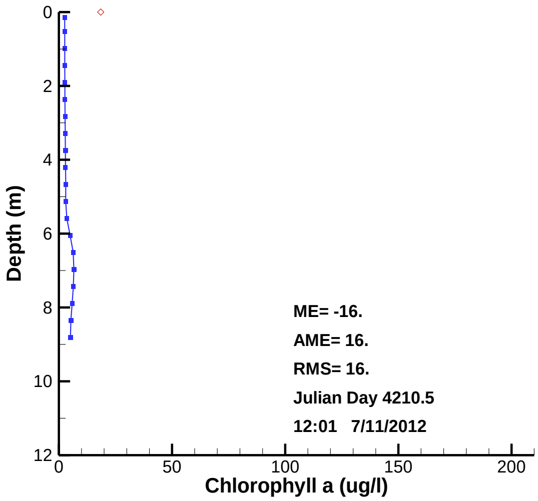
12:02 6/20/2012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Chlorophyll a (ug/l)
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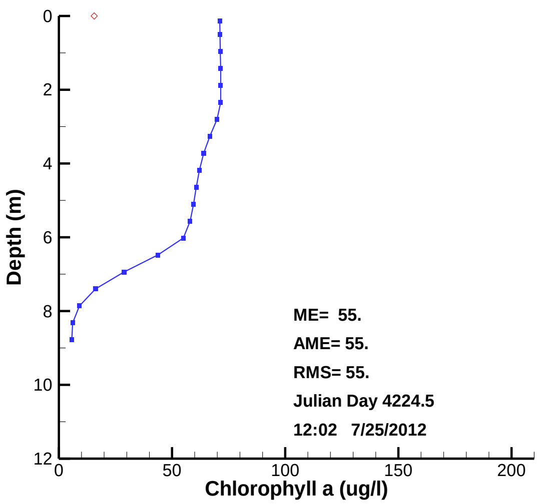
4
6
8
10
12
0
50
100
150
200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RMS= 55.
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12:02 7/25/2012
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Chlorophyll a (ug/l)
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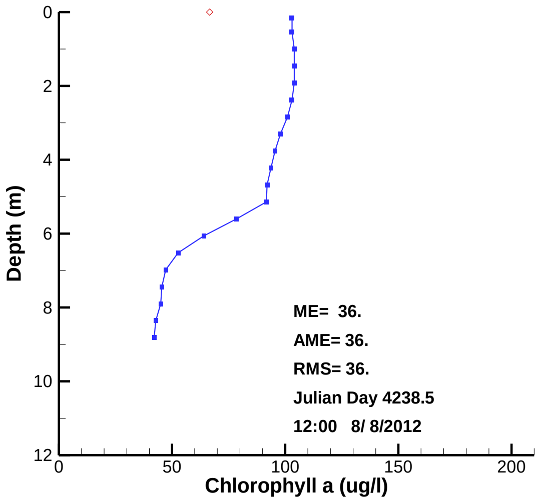
4
6
8
10
12
0
50
100
150
200



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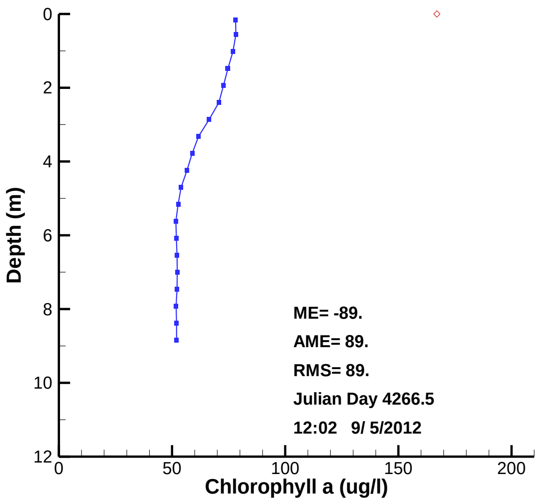

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Chlorophyll a (ug/l)
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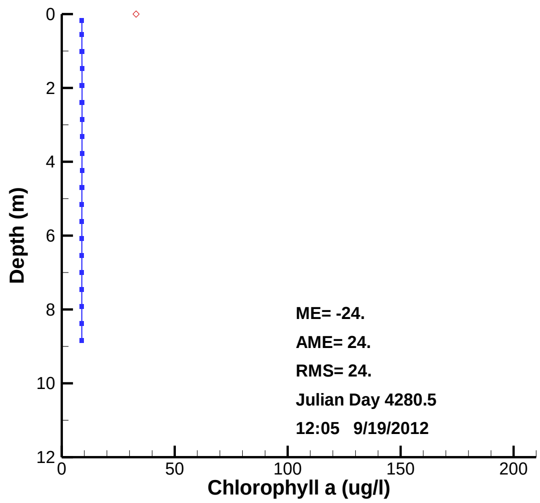
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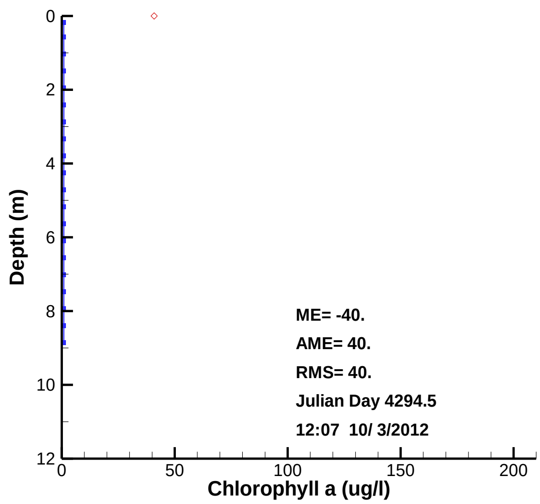
12:05 9/19/2012
Depth (m)
Chlorophyll a (ug/l)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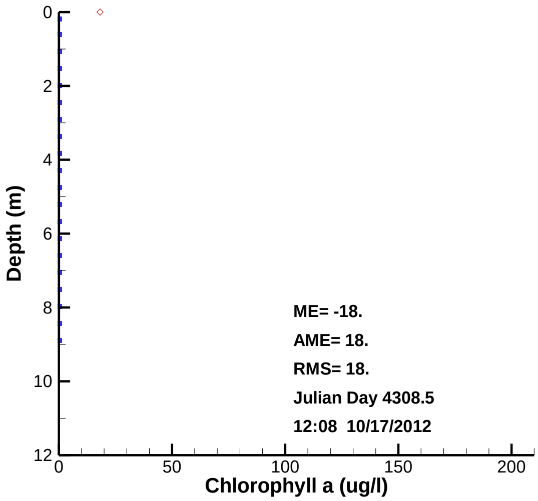
12:07 10/ 3/2012
Depth (m)
Chlorophyll a (ug/l)


0
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4
6
8
10
12
Depth (m)
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12:08 10/17/2012
0
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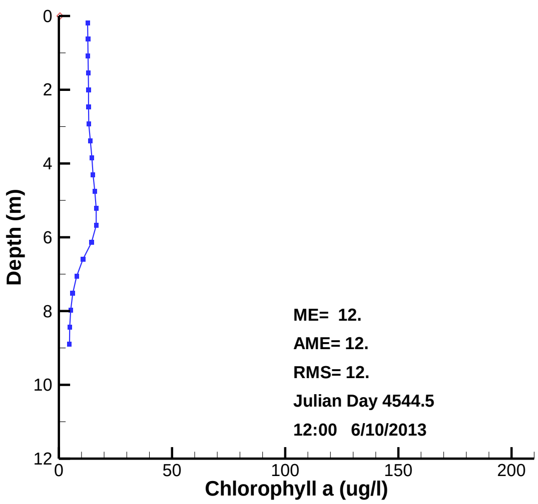
100
150
200
Chlorophyll a (ug/l)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8
10
12
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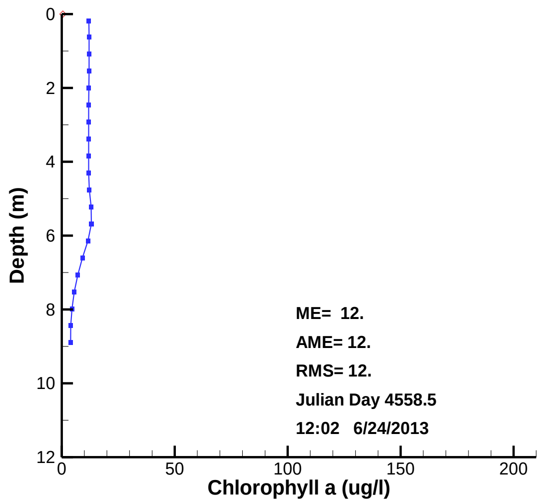
12:00 6/10/2013
0
50
100
150
200
Chlorophyll a (ug/l)



Depth (m)
Chlorophyll a (ug/l)
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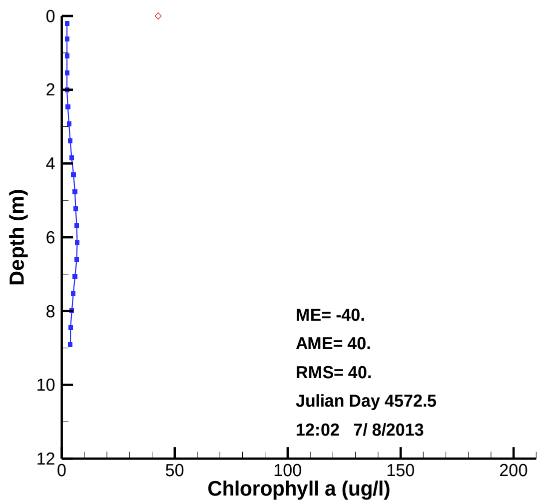
RMS= 12.
Julian Day 4558.5
12:02 6/24/2013



Depth (m)
Chlorophyll a (ug/l)
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RMS= 40.
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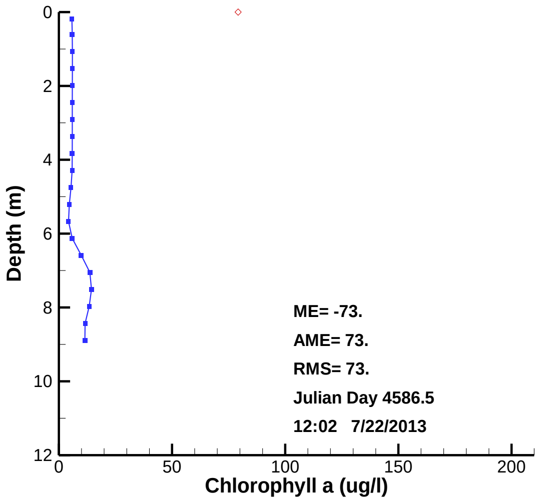
12:02 7/ 8/2013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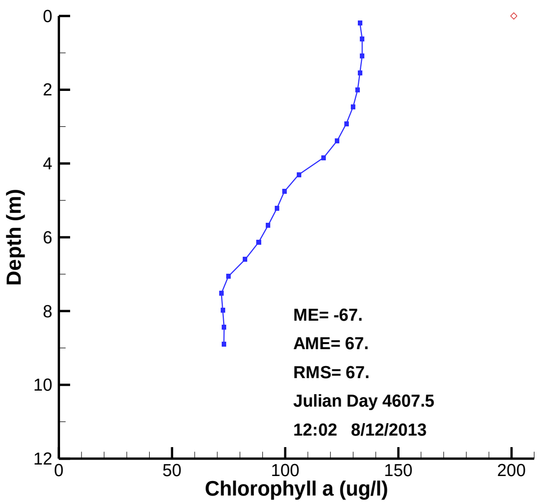
12:02 7/22/2013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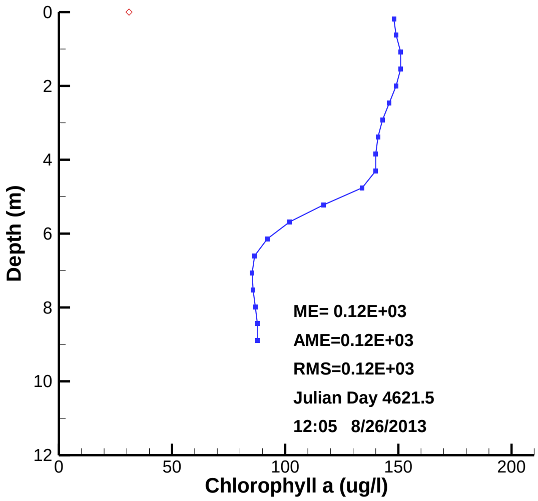
12:02 8/12/2013



Depth (m)
0
2
4
6
8
10
12
0
50
100
150
200
Chlorophyll a (ug/l)
ME= 0.12E+03
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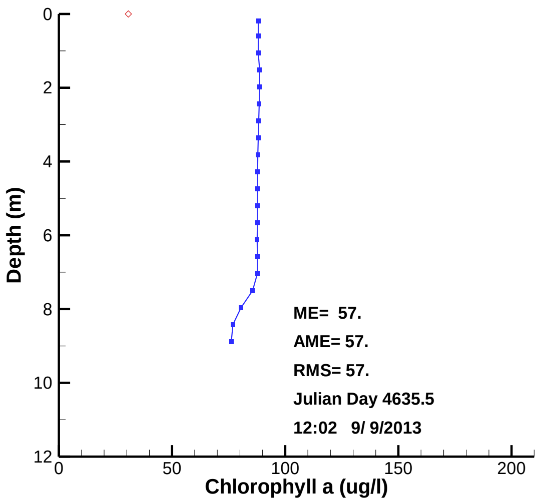
RMS=0.12E+03
Julian Day 4621.5
12:05 8/26/2013



Depth (m)
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4
6
8
10
12
0
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100
150
200
Chlorophyll a (ug/l)
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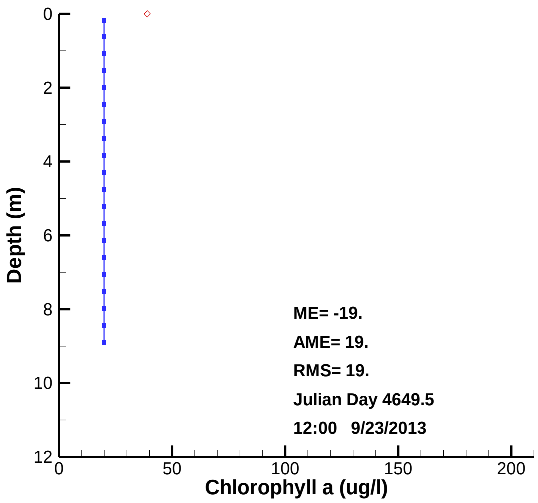
12:02 9/ 9/2013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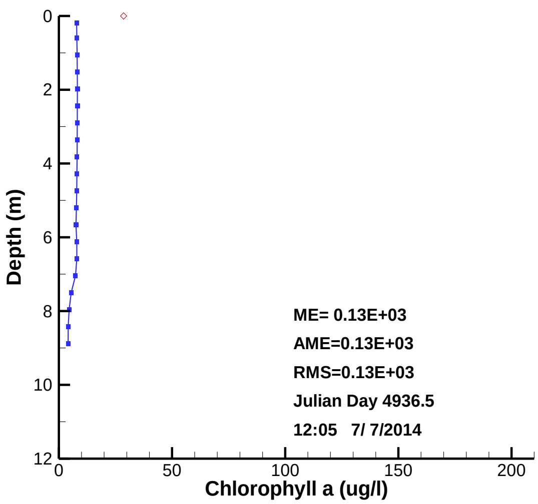
12:00 9/23/2013
Depth (m)
Chlorophyll a (ug/l)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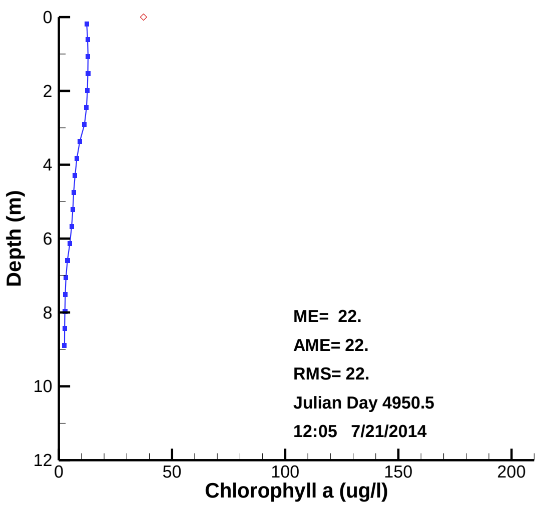
Chlorophyll a (ug/l)


0
2
4
6
8
10
12
Depth (m)
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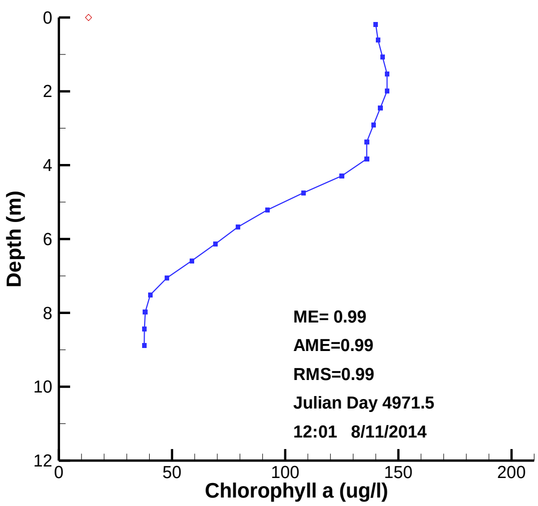
12:05   7/21/2014
0
50
100
150
200
Chlorophyll a (ug/l)


0
2
4
6
8
10
12
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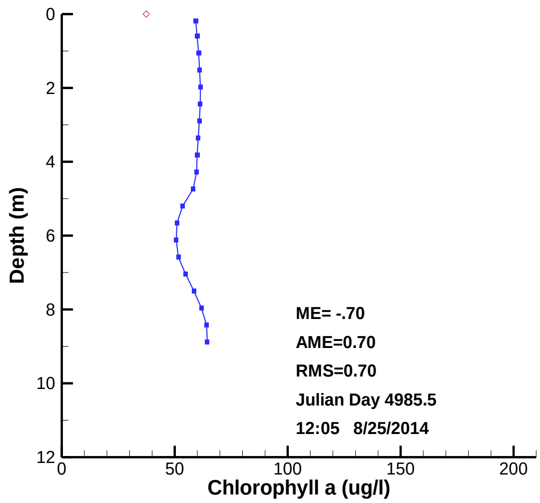
12:01   8/11/2014
0
50
100
150
200
Chlorophyll a (ug/l)



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12:05 8/25/2014
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Chlorophyll a (ug/l)
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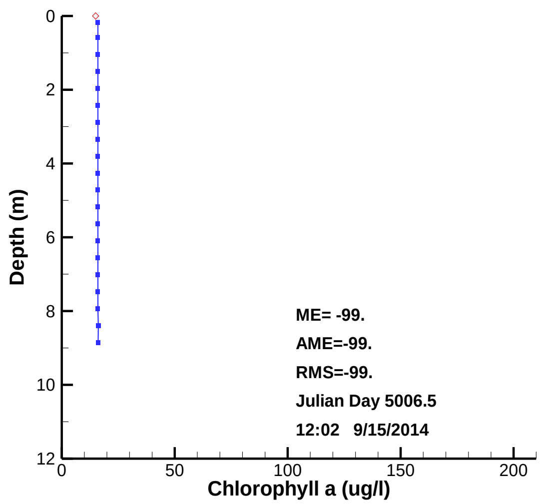
4
6
8
10
12
0
50
100
150
200



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Chlorophyll a (ug/l)
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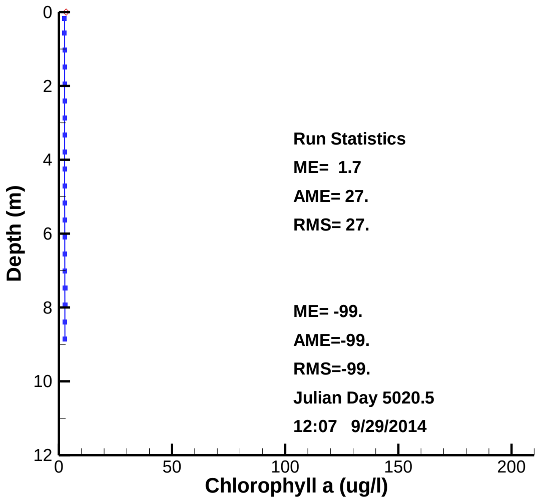
2
4
6
8
10
12
0
50
100
150
200



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4
6
8
10
12
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RMS= 27.
ME= -99.
AME=-99.
RMS=-99.
Julian Day 5020.5
12:07 9/29/2014
0
50
100
150
200
Chlorophyll a (ug/l)

APPENDIX C: NUMERIC ENDPOINT DEVELOPMENT FOR POTABLE WATER USE

The development of a TMDL requires a scientifically defensible numeric endpoint which will ensure that the best uses of the water body are met. For TMDL development in this watershed, a link between phosphorus concentrations and protection of the best use of the water body as a source of drinking water must be established. New York State's current guidance value for phosphorus is 20 µg/l (DEC 1993) but was derived to protect primary and secondary contact recreational uses from impairment due to aesthetic effects. The current guidance value was not specifically derived to protect the drinking water use of water bodies, such as Honeoye Lake. The link is best made through a site-specific interpretation of New York State's existing narrative ambient water quality standard for phosphorus (6NYCRR 703.2): "none in amounts that will result in growths of algae, weeds and slimes that will impair the waters for their best usages" (DEC 2008), because an appropriate numeric translator for drinking water use has not been adopted.

In 2000, DEC incorporated such a site-specific interpretation of the narrative criterion protective of drinking water use into TMDLs for the New York City Reservoirs (DEC 2000). The USEPA, DEC and the New York City Department of Environmental Protection (NYCDEP) worked toward the development of water supply-based phosphorus criteria for the New York City Reservoir Watershed, as part of the Phase II TMDL process. A weight-of-evidence approach utilized all available NYC reservoir-specific data to develop a relationship between phosphorus and chlorophyll-a (chl-a) levels, and a selected set of water quality variables which have been demonstrated to negatively affect the water quality of the drinking water supplied by the reservoirs in the Watershed. Five water quality variables that are important concerns to water supply and are associated with excessive nutrient loading and reservoir water quality were selected, including THM precursor concentrations for certain reservoirs (Stepczyk 1998) (NYCDEP 1999). Using the weight-of-evidence approach, the EPA-approved TMDL used a site-specific phosphorus guidance value of 15 µg/l as the ambient phosphorus level to protect NYC source water reservoirs used directly for public water supply.

Eutrophication-related water quality impairments adversely affect a broad spectrum of water uses, including water supply and recreation, and also adversely affect aquatic life. Concerns about cultural eutrophication (human induced enhancement of primary productivity) are not unique to New York, and the issue is widely recognized as a significant water quality concern at the national and international levels. These concerns lead the USEPA (USEPA, 1998) to initiate a National Nutrient Strategy in 1998 with the goal of assisting all states in the development of numeric nutrient criteria.

To further the process of developing numeric nutrient criteria protective of potable water use, the DEC, in collaboration with investigators from the New York State Department of Health (NYSDOH), Upstate Freshwater Institute (UFI), State University of New York College of Environmental Science and Forestry (SUNY-ESF), and Morgan State University, conducted a study to investigate the relationship between nutrient-related indices and certain human health related indices. The study was funded by the USEPA as part of that agency's National Nutrient Criteria Strategy (USEPA, 1998). The study involved the monthly collection of paired water column samples from 21 lakes and reservoirs during the growing season (May to October 2004 and/or 2007). The study systems were distributed throughout New York State, and spanned a relatively broad range of trophic conditions ranging from oligotrophic systems (low primary productivity) to eutrophic systems (high primary productivity).

From that study, DEC has developed a process for determining Ambient Water Quality Values for ponded sources of potable waters in New York State, (DEC, 2010) which has undergone EPA and peer-review. The research for that process, as described in a peer-review journal (Callinan 2013), is used as the basis to evaluate the degree to which the TMDL target is adequately protective for the Honeoye Lake TMDL, and to provide a correlation between chl-a and Total Phosphorus (TP). This methodology, using the data available in the NYSDEC monitoring, suggests that using the concentration of chl-a as the metric is preferable to using a TP concentration to determine the acceptable watershed phosphorous loading allocations.

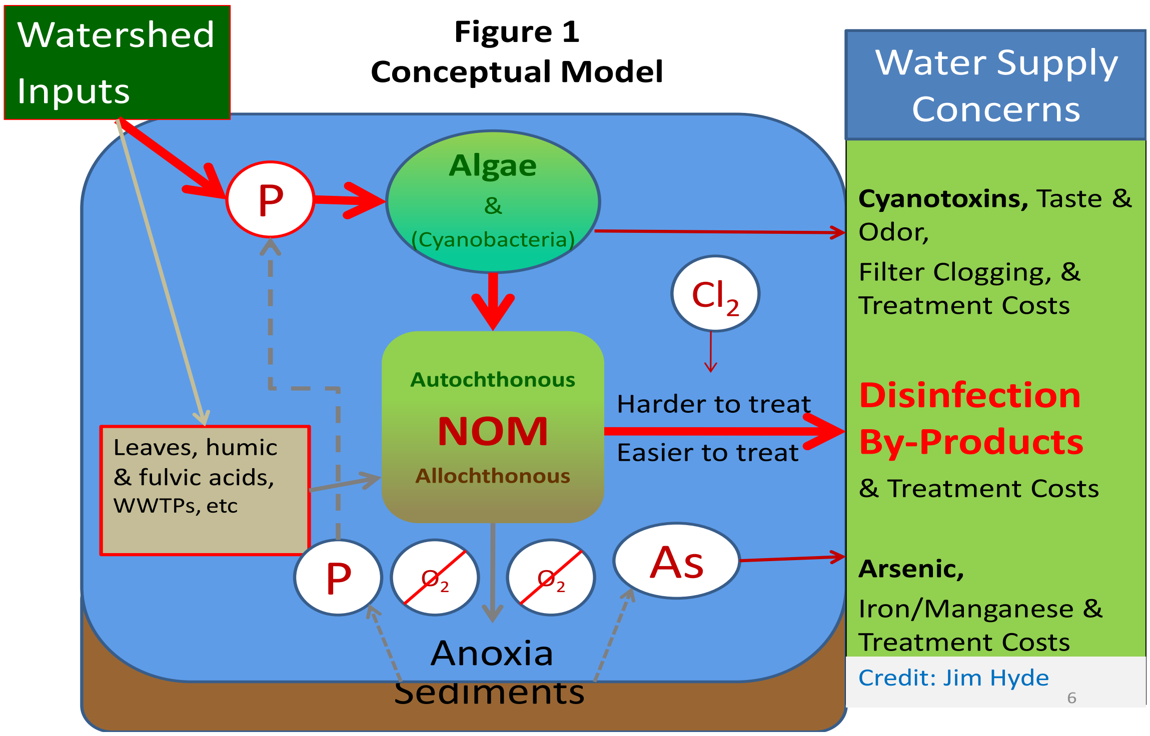
Given the years of available data it was decided to use only the DEC data in assessing target concentration options for consistency, since DEC-based Quality Assurance Project Plan (QAPP) criteria and calculation methods were used to determine the graphical correlation shown later in this Appendix. Using the DEC monitoring data collected, the 4 ug/l chl-a correlated to TP concentrations ranging from 3.3 ug/l to 72 ug/l in varying years (with an average value near 25 ug/l). This wide range, in combination with the fact the chl-a value more closely aligns to the NYS regulatory narrative for potable water best use, suggests that the 4 ug/l chl-a is the appropriate target upon which to base the modeling that determined the desirable watershed loading of Total Phosphorus (TP) for Honeoye Lake.

USEPA recently issued guiding principles "to offer clarity to states about an optional approach for developing a numeric nutrient criterion {Editor's Note: Herein referred to as target concentration} that integrates causal (nitrogen and phosphorus) and response parameters into one water quality standard (WQS). …These guiding principles apply when states wish to rely on response parameters to indicate that a designated use is protected. …A criterion must protect the designated use of the water, and states should clearly identify the use(s) they are seeking to protect. Where a criterion is intended to protect multiple designated uses, states must ensure that it protects the most sensitive one (40 CFR 131.11(a))…. Documentation supporting the criterion should identify all applicable nutrient pathways, addressing all potential direct and indirect effects (e.g., as identified in a conceptual model that outlines the effects of nutrient pollution)" (USEPA 2013).

C.1 Conceptual Model

Nutrient enrichment of lakes and reservoirs used for potable water supply (PWS) can cause adverse effects, ranging from operational problems to increases in health-related risks such as disinfection by-products (DBPs), cyanotoxins, and arsenic.

The linkages between eutrophication and PWS concerns are shown in Figure 1. As illustrated by the red arrows in the figure, the primary route of concern is: (1) nutrient (P) enrichment leads to (2) increases in algae (measured as chl-a), which results in (3) increases in natural organic matter (NOM), which (4) combines with chlorination (Cl_2) to form disinfection by-products.



Additional phosphorus inputs may further accelerate eutrophication, which may lead to oxygen depletion, which may cause reductive release of sediment-bound arsenic and phosphorus, which can provide a positive feedback to further nutrient enrichment, and production of cyanotoxins. Although an increase in arsenic levels and production of cyanotoxins are health concerns for PWS, the DEC study found that formation of DBPs was likely to be the most sensitive endpoint for developing a phosphorus criterion for PWS, and it is the relationship to formation of DBPs that is the focus of the site-specific phosphorus target in this TMDL.

Disinfection By-Products

Disinfection by-products (DBPs) are a group of compounds formed as a result of chemical reactions between natural organic matter (NOM) and certain disinfection agents (e.g., chlorine). The two major classes of DBPs are trihalomethanes (THMs) and haloacetic acids (HAAs). Several of these compounds (e.g., bromodichloromethane, trichloroacetic acid) are carcinogenic (ATSDR 1997, USEPA 2006). There is also some evidence linking DBPs to adverse reproductive effects (USEPA, 2006).

The link between nutrient enrichment and increased production of DBPs occurs because in many temperate freshwater systems, phosphorus acts as the limiting growth factor for primary production. This increase in primary production leads to: (a) an increase in the level of NOM, and (b) a change in the nature of NOM within the system, which heightens the risk for DBP production when the water is subjected to disinfection. The DEC study discussed below was limited to total THMs (TTHMs). The USEPA (2006) defines TTHMS as the sum of four chlorinated compounds: chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

Research on DBPs initially focused on the allochthonous (watershed; e.g., leaves and wastewater) precursor pool; however, subsequent studies also identified the autochthonous (in-lake; e.g., algae) precursor pool as important (Figure 1). There are important distinctions between allochthonous and autochthonous precursors that are relevant to PWS management. For example, autochthonous precursors are both more amenable to mitigation through nutrient management and more difficult to remove through water treatment. Furthermore, autochthonous precursors may produce greater quantities of unregulated DBPs.

C.2 Derivation of Site-specific Ambient Water Quality Values (Criteria)

The approach taken in the DEC study to derive appropriate site-specific ambient water quality values (AWQVs) is based on findings from DEC's Disinfection By-Product/Algal Toxins Project (DBP-AT Project), as well as pertinent material from other independent investigations (both peer reviewed literature and technical reports).

The toxicological basis for the criteria in the DBP-AT Project was based upon previous drinking-water related toxicological findings for disinfection by-products (specifically total trihalomethanes) derived to meet the current maximum contaminant levels (MCLs) as summarized and presented in the Code of Federal Regulations (40 CFR January 4, 2006).

Several assumptions were made in the derivation of nutrient thresholds THMs.

1. The target nutrient thresholds are designed to attain the current maximum contaminant level (MCL) for TTHMs, presently set at 80 µg/l per the USEPA Stage 2 Disinfectants and Disinfection Byproducts Rule (USEPA 2006).

2. The applicable toxicological evidence as presented in the USEPA Stage 2 Rule in support of the current MCL is adequate for the protection of human health. The current MCL for TTHMs is deemed the appropriate target value given that the criteria are directed toward protection of public water supply use which, in all instances for ponded surface waters, involves disinfection.

3. The nutrient thresholds defined for THMs are sufficient to protect for HAAs. Some studies suggest that algae are equally important in the generation of HAAs and TTHMs (Nguyen, et al., 2005), thus, it is assumed that limiting algae production will have comparable effects of both major classes of DBPs.

The DEC's DBP-AT Study involved the collection of paired ambient water samples that were analyzed for Trihalomethane Formation Potential (THMFP) and nutrient-related indices. THMFP is commonly used in research investigations to normalize results for the purpose of system comparisons.

The study developed relationships for each step in the conceptual model. For the first step, the regression relationship between mean chl-a and TP indicates that approximately 78% of the variability in phytoplankton biomass (based on chl-a) is accounted for by changes in TP, which supports the idea that phytoplankton biomass is controlled by phosphorus during the growing season. Study findings also offer several lines of evidence in support of the hypothesis that increased primary productivity (or cultural eutrophication) leads to an increase in the generation of THMFP:

- The relationship between mean Dissolved Organic Carbon (DOC) (a measure of NOM) and chl-a indicates a trend of increasing DOC concentrations with increasing chl-a.
- THMFP levels are substantially influenced by algal biomass. (The importance of the autochthonous precursor pool is supported by observed increases in THMFP concentrations with increases in trophic state, observed correlations between mean concentrations of THMFP and trophic indexes, and observed increases in THMFP concentrations during the growing season in most study systems).
- The relationship between mean THMFP and DOC shows that approximately 80% of the variation in mean THMFP is attributable to mean DOC.

The observed relationships between THMFP and trophic indexes in the DEC's DBP-AT Project provide a sound basis for the derivation of nutrient-related thresholds protective of PWS. These findings are also consistent with a significant body of literature demonstrating a qualitative relationship between nutrient enrichment and the risk of increased THMFP production (Palmstrom, et al 1988, Wardlaw, et al. 1991, Cooke and Kennedy 2001) and showed similar quantitative relationships to research by Arruda and Fromm (1989) and the Colorado Department of Public Health and Environment (2011).

Building upon the relationships discussed above, the next step in the criteria development process is to identify potential AWQVs for the nutrient indices that are protective of potable waters with respect to DBPs. This required associating the measured THMFP to the TTHM drinking water standard. THMFP represents something of a "worst case" scenario in that the analytical protocol is designed to fully exploit the reaction between the available natural organic matter (NOM) and the disinfectant agent. In contrast, water treatment plant (WTP) operators attempt to minimize the generation of TTHMs, and other DBPs, while providing adequate disinfection.

This THMFP to TTHM translation, involved fitting observed THMFP data to a TTHM simulation model, and running the model using representative treatment/distribution system conditions coupled with the TTHM maximum contaminant level (MCL) of 80 µg/l. Using the relationships among chl-a, DOC and THMs established in the DEC's DBP-AT

Project, a threshold of chl-a = 4.0 μg/l was derived, where values apply as growing season (May-October) means within the photic zone of the lake or reservoir.

Target Concentrations (Endpoint)

1. DEC's DBP-AT Project derived threshold for chl-a is 4.0 μg/l as an AWQV to protect Class AA waters, given that these systems are required to meet applicable drinking water standards following only disinfection[1] (without coagulation, sedimentation and/or filtration treatments).
2. For ponded waters it is appropriate to derive distinct target concentrations for different water use classes of ponded surface waters carrying best usage of source of potable water supply, because of the differing level of expected treatment inherent in the specific use classes. Classes AA will be subject to the more stringent target concentrations given that these waters are expected to meet applicable drinking water standards after only disinfection, whereas, ponded water supply source waters carrying water use Classes A will be subject to a somewhat less stringent target concentrations given that they are expected to meet applicable drinking water standards following "conventional" water treatment.[2]
3. Conventional water treatment processes (*coagulation, sedimentation and, filtration)* can reduce levels of DOC in raw source water, however, removal efficiency diminishes as trophic level increases. Thus, the draft fact sheet assumed a somewhat conservative DOC removal efficiency of 10% - note, this is a reduction in DOC, not in phosphorus or chl-a. Thus, using the relationships among chl-a*,* DOC and THMs established in the DEC DBP-AT Project, the draft fact sheet proposed a chl-a concentration of 6.0 μg/l for Class A waters.
4. Although water use classes listed above include a caveat relating to "naturally present impurities", this was not deemed applicable for situations of cultural eutrophication, which, by definition, are driven by anthropogenic processes.

The DEC findings compare well with other independent investigations. Arruda and Fromm (1989) investigated the relationship between trophic indexes and THMs in 180 Kansas lakes and arrived at a recommended chl-a threshold of 5 μg/l to attain a TTHM limit of 100 μg/l (MCL in place at that time). Colorado (Colorado DPHE, 2011) conducted a study patterned on New York's study, although with enhancements including use of the Uniform Formation Conditions method (Summers 1996) that also targeted HAA formation and

[1] *Class AA: "This classification may be given to those waters that, if subjected to approved disinfection treatment, with additional treatment if necessary to remove naturally present impurities, meet or will meet New York State Department of Health drinking water standards and are or will be considered safe and satisfactory for drinking water purposes".* (6 NYCRR Part 701).

[2] *Class A:* "*This classification may be given to those waters that, if subjected to approved treatment equal to coagulation, sedimentation, filtration and disinfection, with additional treatment if necessary to reduce naturally present impurities, meet or will meet New York State Department of Health drinking water standards and are or will be considered safe and satisfactory for drinking water purposes.*" (6 NYCRR Part 701)

alternative methods of interpretation, and determined that a mean chl-a concentration of 5 µg/l would be an appropriate threshold for direct use public water supply reservoirs.

An endpoint for phosphorus is premised on an extensive body of literature indicating that phosphorus is the limiting nutrient (or causal variable) for primary productivity in most temperate, freshwater, ponded waters. The rationale behind setting criteria for chl-a is that it provides the most widely accepted measure of primary productivity (response variable) within freshwater ponded systems.

5. DEC has focused on the response variable, chl-a as the more appropriate ambient target because of its closer relationship to NOM and DBPs which directly affect the drinking water use. Thus, demonstration of the achievement of the water quality standard for Total Phosphorus, including for a TMDL, would be informed by site-specific biomass response. This approach is consistent with the EPA guiding principles about an optional approach for developing a numeric nutrient criterion that apply when states wish to rely on response parameters to indicate that a designated use is protected (USEPA 2013). The EPA recognized that developing numeric values for phosphorus may present challenges associated with the temporal and spatial variability, as well as the ability to tie them directly to environmental outcome. Therefore, the USEPA guiding principles allow a State approach that integrates causal (nitrogen and phosphorus) and response parameters into one water quality standard.

DEC's subsequent study, *River Disinfection By-Product/Algal Toxin Study,* prepared for the USEPA recommended that the primary metric for the establishment of numerical nutrient criteria be chl-a (response variable) because it is the parameter most closely linked to autochthonous DBP precursors (DEC 2010). While consideration was given to establishing a single numerical stressor (total phosphorus) criteria for flowing potable waters, the study concluded that the available dataset could not support the establishment of a single criteria value due to the variability in the relationships between both total phosphorus and chl-a as well as between total phosphorus and THMFP. Such variability is to be expected in natural systems including ponded water as the relationship between stressor and response variables has inherent variability.

Given findings from the DEC ponded and flowing water studies, as well as findings from other comparable studies, the more appropriate approach for establishing the stressor target (total phosphorus) is to establish a criteria "band" delineated by the prediction bands for the regression relationships. USEPA has proposed such an approach for the derivation of nutrient criteria in the state of Florida (USEPA, 2010). Ideally such an approach would use site-specific information regarding the response variable to fine-tune the stressor target but would also be informed by general relationships demonstrated in robust datasets of multiple water bodies. Site-specific information, even where collected over several years under a variety of hydrological conditions, is limited to the empirical range of the measurements. In the case of impaired waters, observations generally would not include chl-a levels that meet the target threshold, so the relationship would need to be extrapolated. Therefore, a broader database of lakes, covering a broad band of trophic conditions including those which meet the target threshold chl-a level, provides additional context to a stressor-response model.

C.3 Model Development

The general approach for establishing the stressor target for Honeoye Lake was to:

- Select a criterion for the response variable (chl-a = 4 µg/l) appropriate for protection of a drinking water use in a Class AA water based on the DEC's DBP-AT Project;
- Use the (slope of the regression) relationship between mean chl-a and mean total phosphorus in combination with the 50% prediction interval to establish possible stressor criteria based on best-fit; and,
- Define the upper and lower prediction bands in which the criteria relationship would be used.
- Determine the practicality and usefulness between the options of using chl-a or TP as the target based on purpose, modeling to be used, and the specific goals of the waterbody.

The process to establish a best fit and prediction bands for the total phosphorus to chl-a relationship considered the available DEC and other quality-assured data for lakes in New York State. Figure 2 shows the total phosphorus to chl-a relationship for lakes in NYS (PWS or otherwise denoted) with at least three year of extensive seasonal data. The prediction bands are denoted by the dashed lines around the regression line of best fit. This broader database was chosen over the DEC's DBP-AT Study results because the latter only covered 21 lakes/reservoirs with a single year of data but had a similar TP to chl-a relationship. *(Figure will use µg/l units, note symbols for ponds and prediction lines (dashed)).*

C.4 Model Application

Application of the stressor-response model developed in the previous section requires specification of how and when the model will be applied. The rationale used to make decisions on how to account for assessed conditions within the model framework and how the target values will be expressed are described in the following sections.

C.4.1 Accounting for Site-specific Information

To incorporate site-specific context into the stressor-response relationship, the actual measured mean chl-a concentration is used as a starting point for the analysis. Next, the slope of the general stressor-response relationship is used to determine an appropriate mean Total Phosphorus concentration target, by solving for the response threshold of 4 µg/l chl-a. The relative improvement in the chl-a at each site is accomplished through changes in the Total Phosphorus concentration, weighted by the pre-factor from the regression equation.

For Honeoye Lake there were only actually 8 years of DEC database monitoring information since 1986, with the other years otherwise collected. Although these other sources may have ELAP labs and adequate collection methods, to assure a consistency with the statistical metric determined by using a database comprised of statewide drinking water lakes, it was desirable to use the data that was derived using the same Quality Assurance Project Plan (QAPP) criteria as that statistical database that was the basis for the chl-a vs TP correlation shown in the graph in Figure 2.

C.4.2 Site Specific NYSDEC Sampling Data as Target Basis for Honeoye Lake:

The table below provides the Honeoye Lake DEC monitoring data available from 1986 to 2017 (except for dates omitted due to data outliers). Values are the summer mean concentration per year for TP and chl-a and are only the values for those years when both values were in the DEC database.

Table 1: DEC Monitoring Data for Honeoye Lake

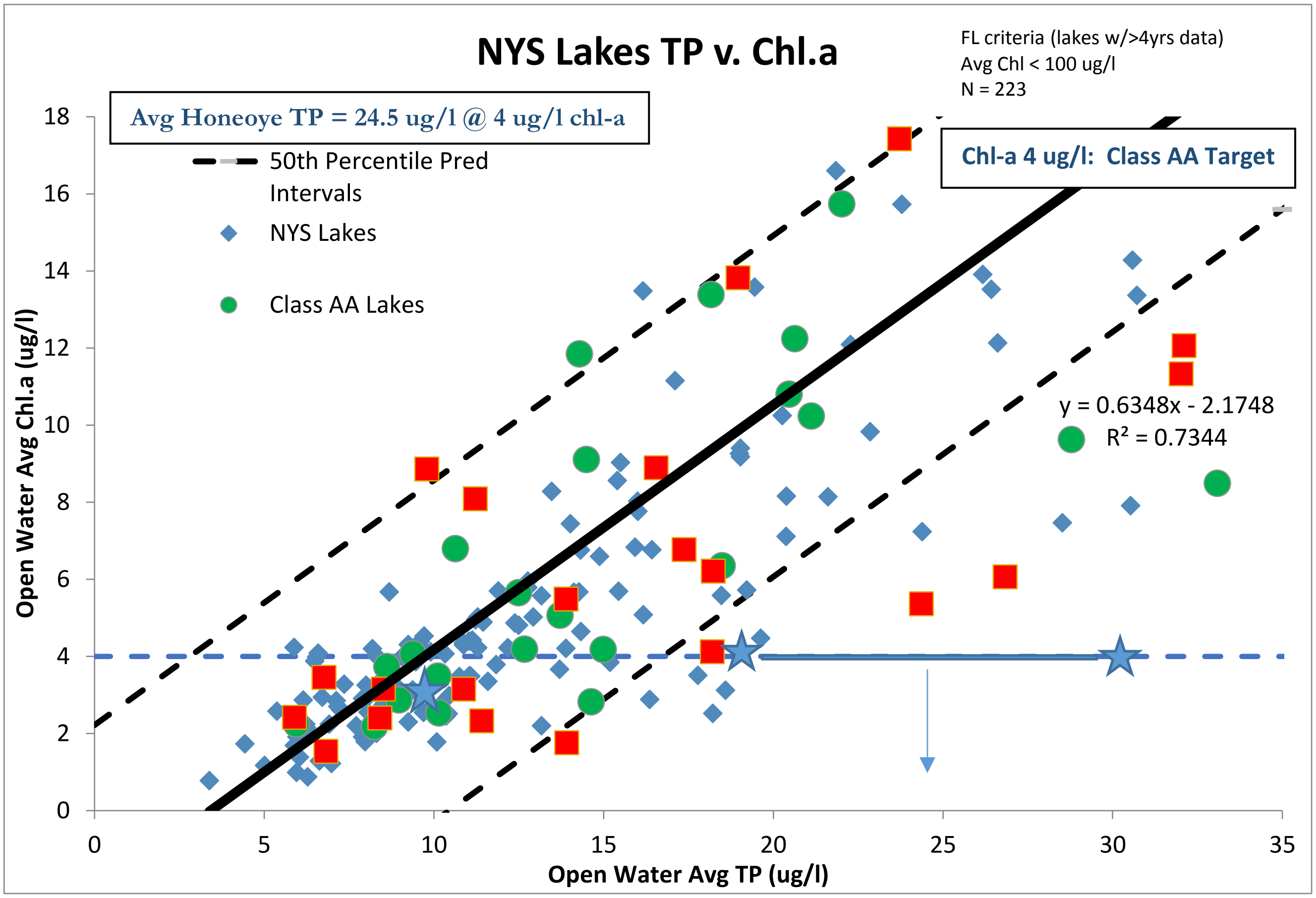
Year	TP meas (ug/l)	Chl-a (ug/l)	TP if chl-a=4ug/l
2007	27.0	17.5	5.7
2008	26.8	6.4	23.0
2009	19.4	19.6	5.2
2010	41.1	75.7	72.0
2011	26.5	35.0	22.4
2012	33.8	45.0	30.9
2013	44.4	53.5	33.7
2014	32.5	22.5	3.3
Average	**31.4**	**34.4**	**24.5**

Data from NYSDEC Lake Monitoring for the years of 2007-2014.

The final column is calculated using the equation:
[(TPmeas x regression value(0.634)) – (Chla meas- 4ug)] /0.634 = TP predicted (at 4ug/l chl-a)

Where 0.634 is the slope of the graphical correlation of TP vs Chla

Figure 2: NYS Lakes Total Phosphorus (TP) vs Chl-a



The target range for the data is not within the best fit prediction bands at the higher TP concentrations. The Chl-a is selected as the target rather than TP concentration because:

1. The TP range correlating to the 4 ug/l criteria is too wide (from 3.3 to 72.0). It is not assured to be within the predictability bands that provide a high degree of statistical confidence.

2. Chl-a is the more direct metric since it is more closely aligned with the narrative standard for the Class AA waterbody.

3. The CEQUAL-W2 lake model used for this TMDL provides a predicted correlation between Phosphorous loading and resulting chl-a concentration.

C.4.3 Application of the target concentrations

The response model was developed using average phosphorus concentrations from May through October (growing season). This was done because this was the identified critical period when phosphorus concentrations were measured and sunlight and temperature are favorable, creating the best condition for the production of algae. The associated NOM from production of algae is available for formation of DBPs. The applicability of the response model is therefore the same: an average TP concentration calculated over the May through October growing season.

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Wardlaw, V., Perry, R., and Graham, N. (1991), "The role of algae as trihalomethane precursors – a review", J. Water SRT – Aqua, 40(6), 335-345.[3] The target of 21 was chosen by using the prediction band intercept of the chl-a target, rather than calculating from the measured trophic values which yields a target 39.

APPENDIX D: UPDATE OF THE HYDROLOGIC & NUTRIENT BUDGETS OF HONEOYE INLET & LAKE

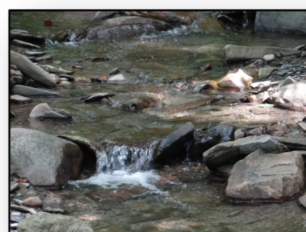
Update of the Hydrologic and Nutrient Budgets of Honeoye Inlet and Honeoye Lake

Prepared for:

The Nature Conservancy
Central & Western New York
1048 University Ave, Rochester, NY 14607
Stevie Adams, Freshwater Conservation Practitioner
585.546.8030 sadams@tnc.org

And

The Honeoye Lake Watershed Task Force
480 North Main Street
Canandaigua, NY 14424



Prepared by:

Princeton Hydro, LLC

1108 Old York Road, Suite 1
P.O. Box 720
Ringoes, New Jersey 08551
(P) 908.237.5660
(F) 908.237.5666
www.princetonhydro.com

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Contents

Primary Author(s)

Stephen Souza, PhD
Michael Hartshorne
Christiana Pollack, GISP, CFM

Contributor Kelly Doyle, PE

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1.0 Introduction

Princeton Hydro, LLC (Princeton Hydro) was contracted by The Nature Conservancy (TNC) and the Honeoye Lake Watershed Task Force (HLWTF) to update the hydrologic and nutrient budgets of Honeoye Lake. With a total surface area of approximately 1,805 acres and a mean depth of only 16 feet, Honeoye Lake is the smallest in surface area and the shallowest of the State's Finger Lakes. The New York State Department of Environmental Conservation (NYSDEC) classifies Honeoye Lake as "AA" and the lake's tributary streams as "C". Honeoye Lake is currently listed on the NYSDEC Priority Waterbody List as impaired due to water supply concerns relating to nutrients (HLWTF, 2007).

Over the past decade, the HLWTF, together with various State, County and local stakeholders, have sought to better manage nutrient (phosphorus and nitrogen) and sediment loading to the lake as part of an effort to control the lake's rate of eutrophication. Although past studies have quantified the lake's hydrologic and nutrient budgets, these data are either incomplete, dated or in need of refinement (Princeton Hydro, 2007). The impact on the lake's trophic state attributable to all of sources of inflow was examined in 2004 and 2007 by Princeton Hydro and in 2009 by Bin Zhu of the Finger Lake Institute (FLI). While Princeton Hydro relied heavily on modeled hydrologic and pollutant loading data, Bin Zhu's data was based on actual sampling of inflow conducted under both baseflow and storm event conditions. As recently summarized by the HLWTF the Princeton Hydro data is valuable for "making long term predictions" while the Bin Zhu data can be used to "apply a correction factor to account for increased nutrient loading during storm events. Additional flow and pollutant sampling data have been collected since 2000 by HLWTF and Honeoye Valley Association (HVA) volunteer monitors. All of these data point to the fact that action is needed to control and reduce pollutant loading to Honeoye Lake from all sources of stormwater inflow. The update of the Honeoye Lake watershed's hydrologic and nutrient loading database developed through this study will greatly aid future decision making particularly with respect to the management of stormwater.

Although this project examines and quantifies the hydrologic and pollutant loading attributes of the entire Honeoye Lake watershed, particular emphasis is given to the Honeoye Inlet subwatershed. The Honeoye Inlet subwatershed is the largest (by area) of the lake's nine (9) major subwatersheds. The three other relatively large subwatersheds are Briggs Gully, Bray Gully, and Affolter Creek; each of which receives drainage from a major stream as opposed to a seasonally-ephemeral stream. Largely as a result of its areal expanse the Honeoye Inlet subwatershed contributes the greatest pollutant load and generates the majority of the inflow to Honeoye Lake (Genesee/Finger Lakes Regional Planning Council, 2007). Additionally, a unique opportunity exists within the Honeoye Inlet subwatershed for the implementation of large-scale stormwater management projects. The Honeoye Inlet Wildlife Management Area is a 2,500 acre tract located almost immediately upgradient of Honeoye Lake. These lands, which were obtained by the State from TNC, are managed by the New York State Department of Environmental Conservation (NYSDEC). Interest has been recently raised by TNC, NYSDEC and the HLWTF project partners in developing a large-scale, multifunctional, stormwater management system within the Honeoye Inlet Wildlife Management Area. In general, most of the lake's watershed is characterized by relatively steep terrain. This is especially true for the subwatersheds that parallel the lake's eastern and western shorelines. Additionally, much of the lands in these eastern and western subwatersheds are forested and privately owned. This combination of steep terrain, private ownership and forested land use precludes the implementation to use of some of the more commonly utilized regional stormwater management techniques such as bioretention basins, created wetlands and retention basins. Conversely, the importance of the Honeoye Inlet subwatershed with respect to the lake's overall pollutant and hydrologic loading, combined with the amount of open land available within the Honeoye Inlet Wildlife Management Area, creates a seemingly unique opportunity for the large-scale management of stormwater loading to the lake.

This report is thus divided into two, separate but related elements. The first element, consisting of Sections 2-5 deals with the update of the hydrologic and pollutant loading database for the entire Honeoye Lake watershed, with particular emphasis given to the Honeoye Inlet subwatershed. The goal of this element of the project is to provide TNC, the HLWTF and all of the other project partners with an updated and refined hydrologic and nutrient loading database. These data will improve the project partners' understanding of the sources and overall effects of baseflow and storm-related pollutant and hydrologic loading on the trophic state and water quality of Honeoye Lake. These data will also enable all the project partners to identify not only those subwatersheds requiring the greatest management, but those subwatersheds where stormwater management is technically feasible. This will also aid in the selection and prioritization of those stormwater management implementation projects having the greatest overall benefit with respect to the long-term management of the lake.

The second element of this report, consisting of Section 6, examines more closely specific stormwater management options for the entire Honeoye Lake watershed. However, particular attention is given to the Honeoye Inlet stream and subwatershed, including multi-functional stormwater management concepts that could be constructed within the Honeoye Inlet Wildlife Management Area. These stormwater concepts are capable of meeting multiple stormwater management goals including a reduction in nutrient and sediment loading, the attenuation of peak flows, reduction in flood volumes, the restoration of previously impacted habitat, the creation of new habitat and further promotion of the recreational use of the Honeoye Inlet Wildlife Management Area.

2.0 The Honeoye Lake Watershed

As per the NYSDEC and the USEPA most of the water quality problems facing our nation's lakes and waterways are largely a function of non-point source pollution (NPS) loading directly linked to watershed development and inadequate stormwater management (NYSDEC, 2010, USEPA, 2010). Recognizing this link between the quality of a lake and the state of its watershed, the North American Lake Management Society developed a catch phrase to emphasize this relationship; "a lake is a reflection of its watershed". This catch phrase is intended to reinforce the concept that the water quality and ecological "health" of a lake is largely dictated by the quality of runoff and inflow entering the lake from the surrounding lands: its watershed. Recognition and understanding of this linkage between a lake and its watershed should facilitate the development and implementation of initiatives aimed at controlling the rate, volume and quality of stormwater inputs. Watershed management and non-point source pollutant control are "active" as opposed to "reactive" approaches to improving a lake's quality. Addressing the causes of lake quality degradation and eutrophication is what, in part, separates lake *management* from lake *maintenance*.

The watersheds of oligotrophic lakes (low productivity waterbodies) typically have been minimally disturbed or developed. Conversely, eutrophic lakes (highly productive waterbodies), are most commonly associated with watersheds that are extensively disturbed, developed or farmed. The conversion of forested land to agricultural, residential, commercial and industrial land brings about an increase in the types and amounts of pollutants transported in stormwater runoff due to increases in erosion and a multitude of anthropogenic factors. As the degree of development increases, the types and amount (load) of pollutants mobilized and transported during each storm event increases. A correlation therefore exists between watershed disturbance and increased pollutant loading. In short, there is a direct proven relationship between the degree of lake eutrophication and the intensity of watershed development. As mentioned above, this interconnectivity between a lake and its watersheds is a central theme to NPS pollution control. Basically, if the amount of pollutant loading can be reduced then the water quality of the lake should improve.

Moreover, as a watershed becomes progressively developed, changes also occur with respect to the watershed's hydrologic and hydraulic properties. The areal expanse of a watershed, along with the prevailing land uses, soil types, topography and geology all affect the quantity of runoff generated during each storm event. The intensity and duration of each storm event, coupled with other variable seasonal and climatic factors, will dictate how much runoff is produced and how quickly that runoff reaches a stream. Thus, there is an interconnection between the natural and anthropomorphic characteristics of a watershed and the volume, rate and velocity of runoff generated by every storm. While stormwater runoff is an obvious mechanism for the transport of non-point source pollutants, runoff in itself can create an additional set of water quality or environmental impacts. Increases in the volume, rate and velocity of runoff causes the scouring and erosion of the receiving stream. This leads to the destabilization of the stream's bed and banks, resulting in physical and biological impacts to the stream ecosystem. The eroded stream bed and bank material eventually settles within the stream itself or within the receiving lake. The accumulated sediment occludes habitat, physically alters flow paths and is often colonized by invasive wetland and aquatic plant species. Similarly, the development, filling, clearing or other alterations of the wetlands, riparian buffers and floodplains associated with a stream reduces the ecological and hydrological services and functions of these areas. The most common consequence of these alterations is increased flooding and the inability to naturally attenuate storm flows and pollutant loads. These impacts are eventually transferred to the receiving lake.

Thus, for Honeoye Lake there is a need to understand both the pollutant loading and the hydrodynamic interrelationships that exist between the lake and its watershed. The Honeoye Lake watershed encompasses a total of 23,349 acres (Figure 2.1), divided into nine (9) subwatersheds (Table 2.1 and Figure 2.2). The four largest subwatersheds are in relative order: Honeoye Inlet, Briggs Gully, Southwest and Southeast. The four subwatersheds that drain to perennial streams are Honeoye Inlet, Briggs Gully, Affolter Gully and Bray Gully. The five remaining subwatersheds either drain to the lake via ephemeral streams or by means of overland runoff. This is an important characteristic, in that essentially 29% of the lake's watershed area only provides inflow to the lake during storm events or during the spring thaw. This further accentuates the need for management of storm-event and seasonal loading to the lake. As noted above, past studies have documented that the majority of the lake's inflow occurs via Honeoye Inlet. The remaining eight (8) subwatersheds individually encompass far less acreage than the Honeoye Inlet subwatershed. Although smaller, by at least an order of magnitude, the drainage areas of these other subwatersheds are however more developed than the drainage area of the main inlet. Also, due to the steeper terrain that characterizes some of these other subwatersheds, the majority of development has occurred close to Honeoye Lake; within a shoreline perimeter area defined by West Lake Road and East Lake Road (Figure 2.1). While much of this development was spurred by a desire to be proximal to the lake, this development pattern is also a function of the more gentle slopes that exist closer to the lake as compared to the slopes throughout much of the headwater areas of these subwatersheds (Figure 2.2). Due to the steeper topography of these subwatersheds and the limited amount of floodplain associated with the streams, these smaller sources of inflow tend to have a "flashier" hydrology than the main inlet. These conditions have been documented in the past through the Bin Zhu/FLI study and storm sampling conducted by the HLWTF volunteers. As noted above, many of the "waterways" associated with these smaller subwatersheds tend to be seasonal sources of inflow or discharge to the lake only after a significant storm event. Thus, although these sources of inflow drain smaller subwatershed areas, their impacts on the lake are potentially significant. This is especially true in the spring and summer when short, intense storm events can quickly channel pulses of sediment and nutrient into the lake via these smaller inlets.

The modeling of both the hydrologic and NPS pollution loading of the Honeoye Lake watershed is a tedious task due to the large size of the watershed. The seasonality of precipitation and the seasonal and climactic factors affecting the amount and rate of runoff also need to be taken into account when developing the hydrologic and NPS pollution loading databases. To properly quantify the watershed's hydrology and NPS pollution loads, therefore, requires the compilation, integration, analysis and interpretation of a large amount of data (Evans 2008).

Geographic Information Systems (GIS) based land use/land cover (LU/LC) analytical tools greatly aid the application of watershed simulation models. GIS effectively increases the computational efficiency and accuracy of the integration of the watershed data that serve as the foundation for the hydrologic, hydraulic and pollutant transport calculations. *MapShed*, a GIS-based watershed modeling tool, simulates runoff, sediment, nitrogen and phosphorus loads from a watershed. *MapShed* also has algorithms for calculating septic loads and allows for the inclusion of point source nutrient loading. The tool essentially duplicates the functionality of a similar software application previously created by The Penn State Institutes of Energy and the Environment called AVGWLF, Arc-View Generalized Watershed Loading Function (Evans et al., 2002). The only significant difference with AVGWLF is that the *MapShed* GIS interface is the freeware GIS software package *MapWindow*. *MapShed* provides a link between the GIS software and an enhanced version of the GWLF watershed model. As with AVGWLF, the watershed simulation tools used in *MapShed* are based on the GWLF model originally developed by Dr. Douglas Haith and colleagues at Cornell University. Princeton Hydro utilized *MapShed* as the primary modeling tool to update the hydrologic and pollutant loads for Honeoye Lake. Sections 3, 4 and 5 of this report present and discuss the results of the *MapShed* modeling effort. The data are subsequently utilized in Section 6 to evaluate stormwater best management practices for the Honeoye Lake watershed, especially the Honeoye Inlet subwatershed.

The following description of the *MapShed* model and GWLF is largely adapted from the User manuals for both. Hydrologic loading is simulated through *MapShed* utilizing the Soil Conservation Service – Curve Number (SCS-CN) approach with daily weather (temperature and precipitation) as inputs. *MapShed* uses daily time steps for weather data and water balance calculations. Monthly calculations are made for nutrient and sediment loads based on the daily water balance accumulated monthly values. In computing the surface (runoff-related) portion of the hydrologic load, the model accounts for area-specific multiple land use scenarios, in concert with natural characteristics of the watershed such as slope, soils and geology. The model does not spatially route the watershed transport of sediments and nutrients, but rather simply aggregates loads from each source area (subwatershed). For the sub-surface (groundwater-related) portion of the hydrologic load, *MapShed* acts as a lumped parameter model using a water balance approach. No distinct areas are considered in the calculation of the sub-surface flow contributions; rather, the computed values are for the entire analyzed subwatershed. Daily water balances are computed for an unsaturated zone as well as a saturated sub-surface zone, and infiltration is computed as the difference between precipitation or snowmelt minus surface runoff plus evapotranspiration (Evans 2008).

Erosion and sediment yields are estimated utilizing monthly erosion calculations based on the Universal Soil Loss Equation (USLE) algorithm (with monthly rainfall-runoff coefficients) and a monthly composite of the KLSCP[1] values for each source area (LU/LC combination). A sediment delivery ratio based on watershed size and a transport capacity average daily runoff value is

1 KLSCP are the five parameters used in the USLE (along with watershed area (A) and Rainfall (R), to predict long-term annual soil loss .K- soil erodibility, L and S – topographic conditions, and C and P - crop management factors

then applied to the calculated erosion to determine sediment yield for each source area (subwatershed).

Surface runoff contributed nutrient loads are computed by applying dissolved N and P coefficients to surface runoff values, and a sediment coefficient to the yield portion for each agricultural land use source area. Point sources actively farmed and cultivated lands, and septic systems - are also integrated into the nutrient loading calculations, as the latter two sources are often significant nutrient and fecal coliforms sources for more rural watersheds. Urban nutrient inputs are assumed to be solid-phase and are modeled utilizing an exponential accumulation and wash-off function. Sub-surface losses are calculated using dissolved nitrogen and phosphorus coefficients for shallow groundwater contributions to stream nutrient loads while the sub-surface sub-model considers a single, lumped parameter contributing area. Evapotranspiration is determined using daily weather data and a cover factor dependent upon LU/LC. Finally, a water balance is performed utilizing supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage and evapotranspiration values (Evans, 2008).

Figure 2.1 Honeoye Lake Watershed – Aerial Photo Projection

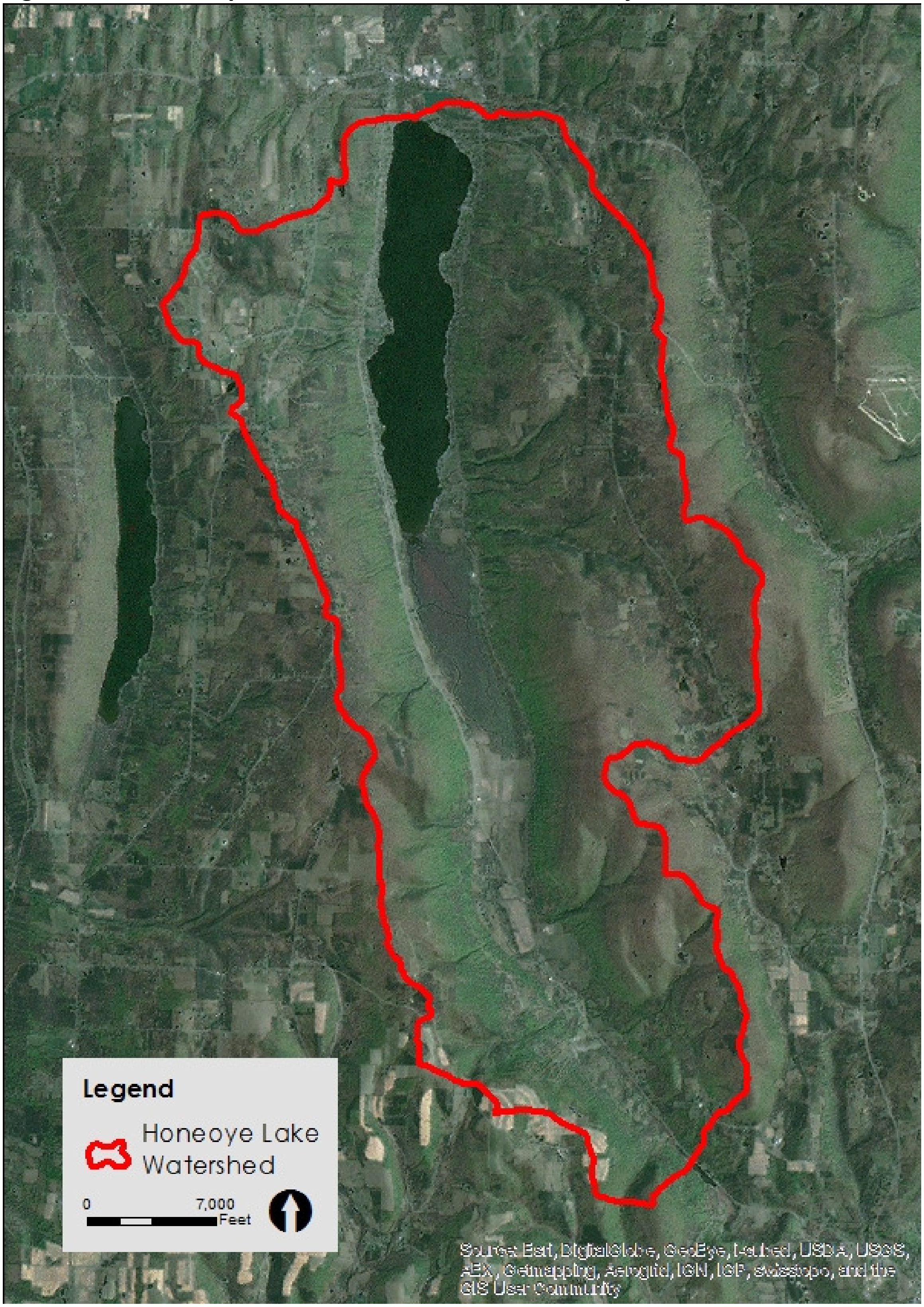


Figure 2.2 Honeoye Lake Subwatershed Boundaries – Digital Elevation Model Projection

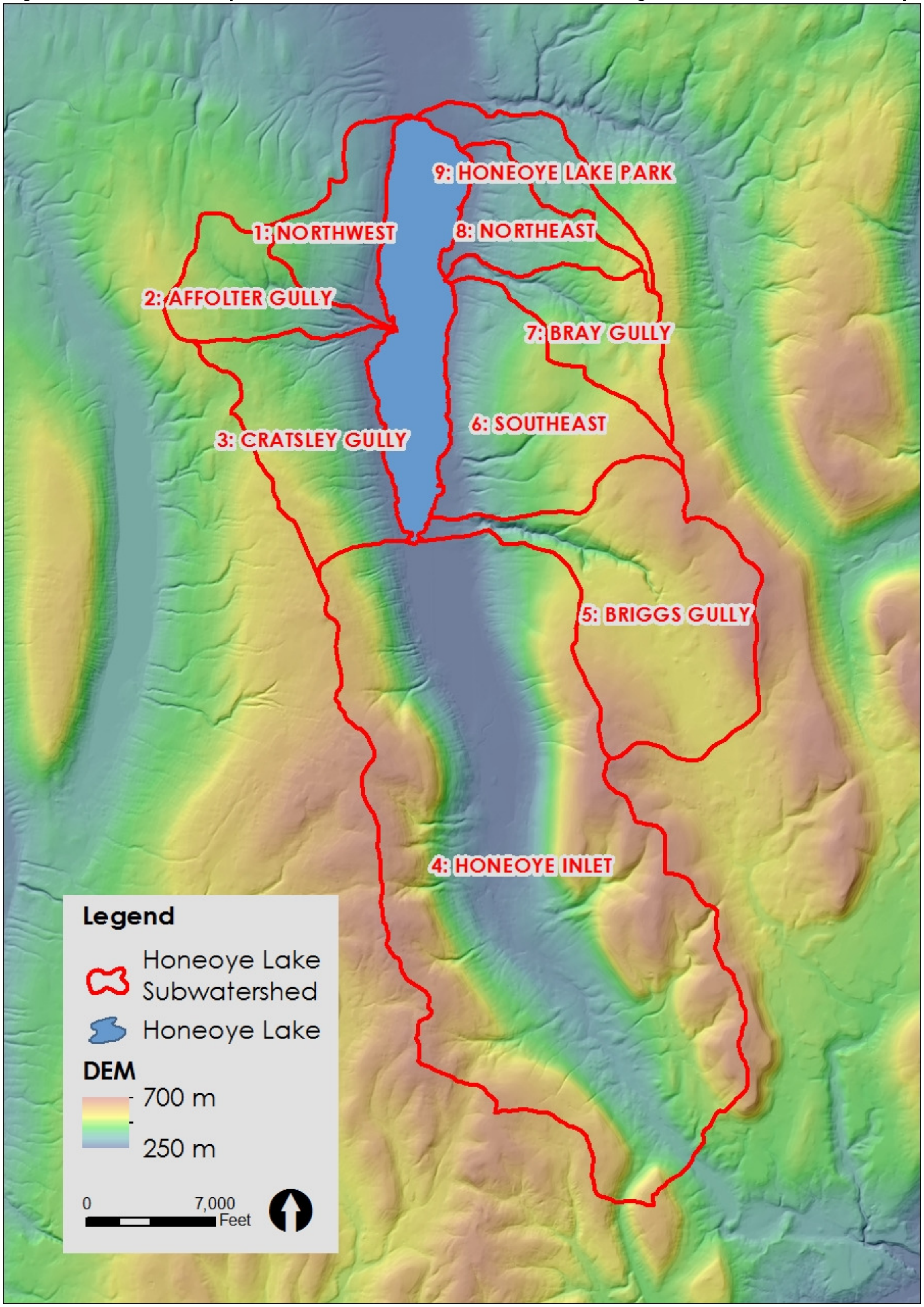


Table 2.1 Watershed and Subwatershed Areas[2]		
Subwatershed	**Area**	
	Hectares	**Acres**
1: Northwest	384	948
2: Affolter Gully	403	995
3: Cratsley Gully	781	1,929
4: Honeoye Inlet	4,572	11,293
5: Briggs Gully	1,307	3,228
6: Southeast	926	2,287
7: Bray Gully	439	1,084
8: Northeast	356	879
9: Honeoye Lake Park	285	704
Total Area	**9,453**	**23,349**

2 Please note that the sub-watershed numbering and naming used in this report may differ from those used in earlier studies of the lake. For comparative purposes previously used naming/numbering schemes include the following:
1-North Shore
2-Times Union Creek
3-Bray Gully
4-East Shore
5-Briggs Gully
6- Honeoye Inlet
7-Canadice Corners
8-Affolter Gully
9-West Shore

3.0 Methodology and Input Files

MapShed uses a variety of spatial data inputs as well as non-spatial parameters, such as climate data and length of growing season, in order to implement the GWLF model.

Listed below are the required and optional data files that were used to model the Honeoye Lake watershed, including the sources for these data:

Required -

- Watershed boundary – Princeton Hydro delineated using the 30m USGS digital elevation model
- Digital elevation model – USGS (30m resolution)
- Land Use and Land Cover – Ontario County GIS
- Streams – USGS NHD High Resolution Dataset
- Soils – NEIWPCC (New England Interstate Water Pollution Control Commission/ Penn State
- Weather – NEIWPCC / Penn State (Modeling Period: 1990 – 2004)

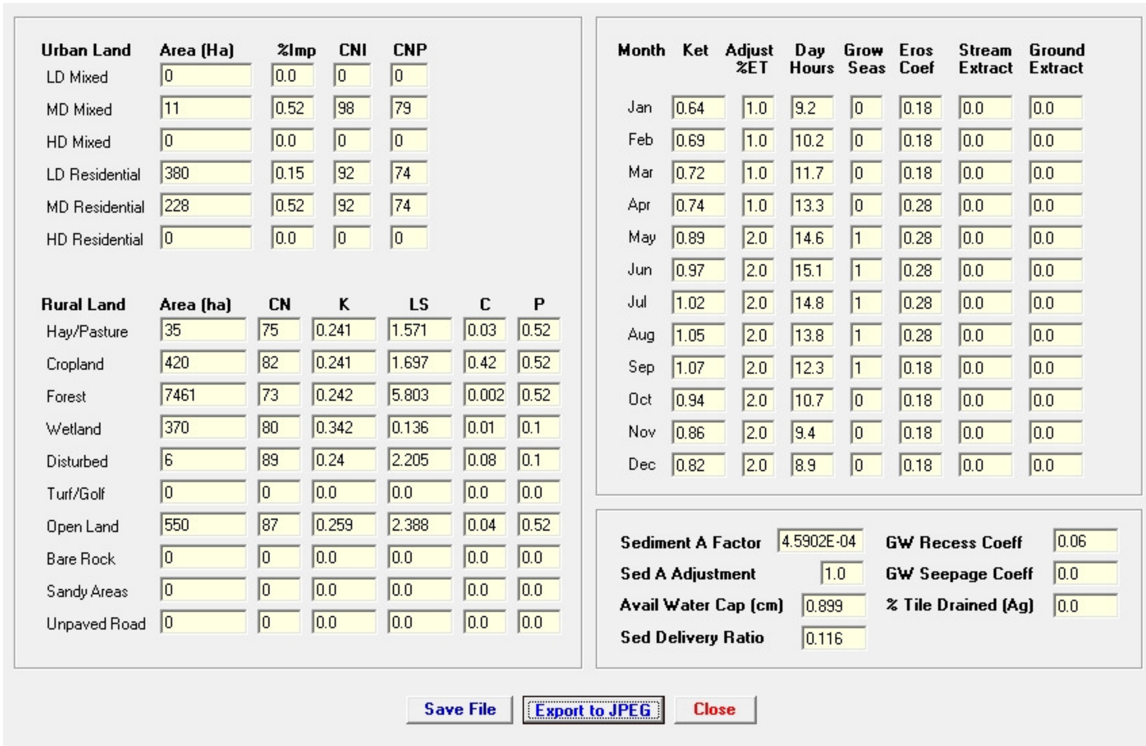
Optional -

- Soil phosphorus – NEIWPCC / Penn State
- Groundwater nitrogen – NEIWPCC / Penn State
- Septic – Ontario County GIS

The aforementioned data files served as the input parameters used to create the transport, nutrient and delivery files. Modeling was conducted for each of the nine (9) subwatersheds, the entire Honeoye Lake watershed (aggregate), and for the Honeoye Inlet Wildlife Management Area sub-section of Subwatershed 4, or the ‘project area‘, located immediately south of Honeoye Lake. Hydrologic and pollutant loading data are presented in both monthly and annualized scales over a 15-year modeling period (1990 – 2004). In addition, Princeton Hydro modeled the storm-specific hydrologic and pollutant loads associated with the 1-year, 2-year, 5-year, 10-year and 100-year frequency of occurrence storm events.

The remainder of this section details the input data applied to the model. For the sake of brevity only the input data for the aggregate watershed are presented. However, similar input files were created for each of the lake’s nine subwatersheds. The “Adjust %ET” parameter was iteratively adjusted during the hydrology calibrations of the model. This will be discussed in further detail in Section 4 of the report. As illustrated in Figure 3.1, a host of land cover, land use, precipitation and hydrologic factors are taken into account by *MapShed*. Therefore, although the model is simplistic, it is capable of generating very detailed data for each of the lake’s subwatersheds.

Figure 3.1: Transport Input File



Urban Land	Area (Ha)	%Imp	CNI	CNP
LD Mixed	0	0.0	0	0
MD Mixed	11	0.52	98	79
HD Mixed	0	0.0	0	0
LD Residential	380	0.15	92	74
MD Residential	228	0.52	92	74
HD Residential	0	0.0	0	0

Rural Land	Area (ha)	CN	K	LS	C	P
Hay/Pasture	35	75	0.241	1.571	0.03	0.52
Cropland	420	82	0.241	1.697	0.42	0.52
Forest	7461	73	0.242	5.803	0.002	0.52
Wetland	370	80	0.342	0.136	0.01	0.1
Disturbed	6	89	0.24	2.205	0.08	0.1
Turf/Golf	0	0	0.0	0.0	0.0	0.0
Open Land	550	87	0.259	2.388	0.04	0.52
Bare Rock	0	0	0.0	0.0	0.0	0.0
Sandy Areas	0	0	0.0	0.0	0.0	0.0
Unpaved Road	0	0	0.0	0.0	0.0	0.0

Month	Ket	Adjust %ET	Day Hours	Grow Seas	Eros Coef	Stream Extract	Ground Extract
Jan	0.64	1.0	9.2	0	0.18	0.0	0.0
Feb	0.69	1.0	10.2	0	0.18	0.0	0.0
Mar	0.72	1.0	11.7	0	0.18	0.0	0.0
Apr	0.74	1.0	13.3	0	0.28	0.0	0.0
May	0.89	2.0	14.6	1	0.28	0.0	0.0
Jun	0.97	2.0	15.1	1	0.28	0.0	0.0
Jul	1.02	2.0	14.8	1	0.28	0.0	0.0
Aug	1.05	2.0	13.8	1	0.28	0.0	0.0
Sep	1.07	2.0	12.3	1	0.18	0.0	0.0
Oct	0.94	2.0	10.7	0	0.18	0.0	0.0
Nov	0.86	2.0	9.4	0	0.18	0.0	0.0
Dec	0.82	2.0	8.9	0	0.18	0.0	0.0

Sediment A Factor	4.5902E-04	GW Recess Coeff	0.06
Sed A Adjustment	1.0	GW Seepage Coeff	0.0
Avail Water Cap (cm)	0.899	% Tile Drained (Ag)	0.0
Sed Delivery Ratio	0.116		

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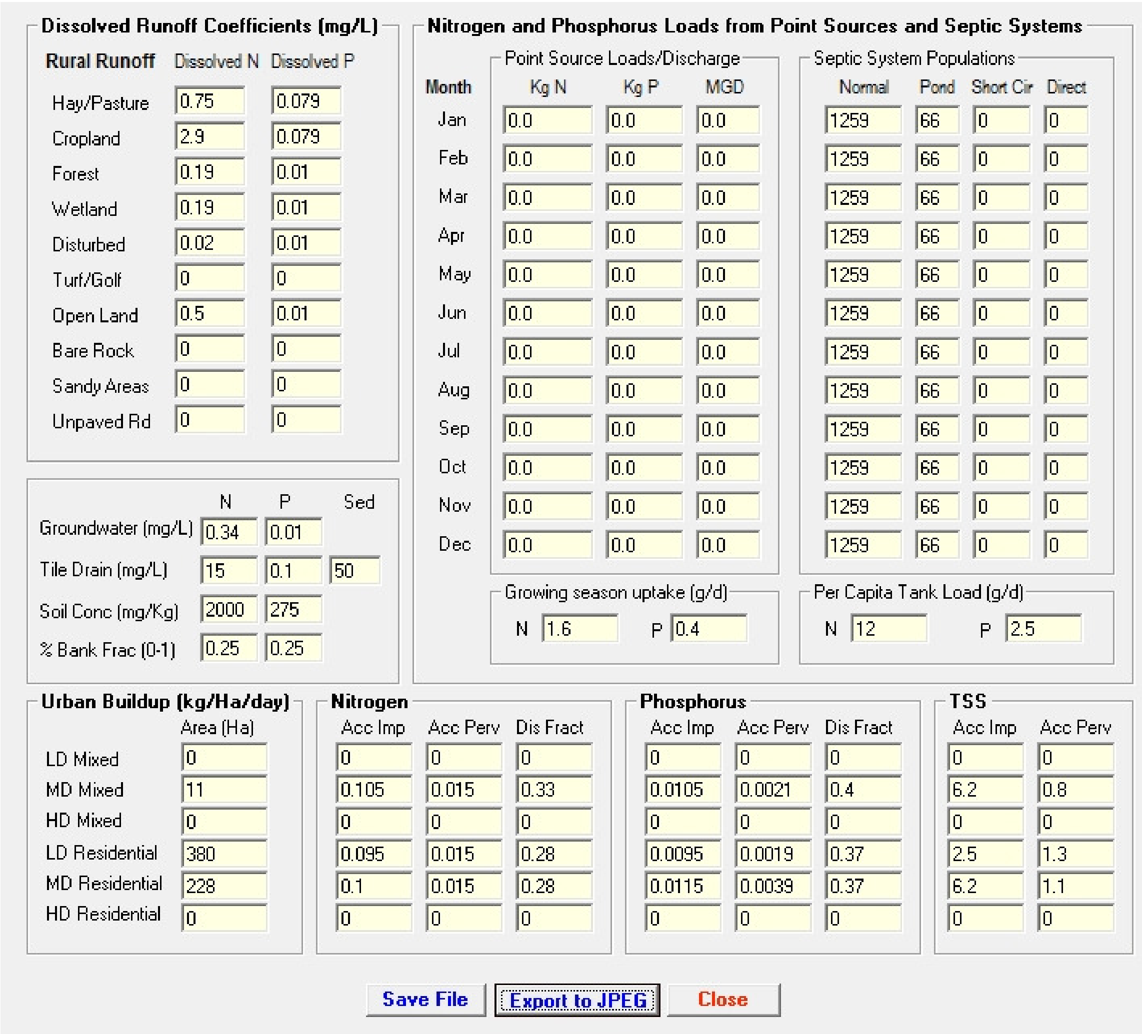
As illustrated above, for this project the Total Suspended Solids (TSS) loss rate was changed from a default value of zero to 0.25. This factor was changed in order to account for sedimentation processes throughout the watershed. In addition, Percent Drainage was adjusted on a subwatershed basis depending on the percent of wetlands in each subwatershed (figure 3.3). This adjustment accounts for the flow attenuation function of wetlands. Although, by their nature they do not function as recharge areas, they can decrease the total amount and volume of runoff by storing and detaining storm flows.

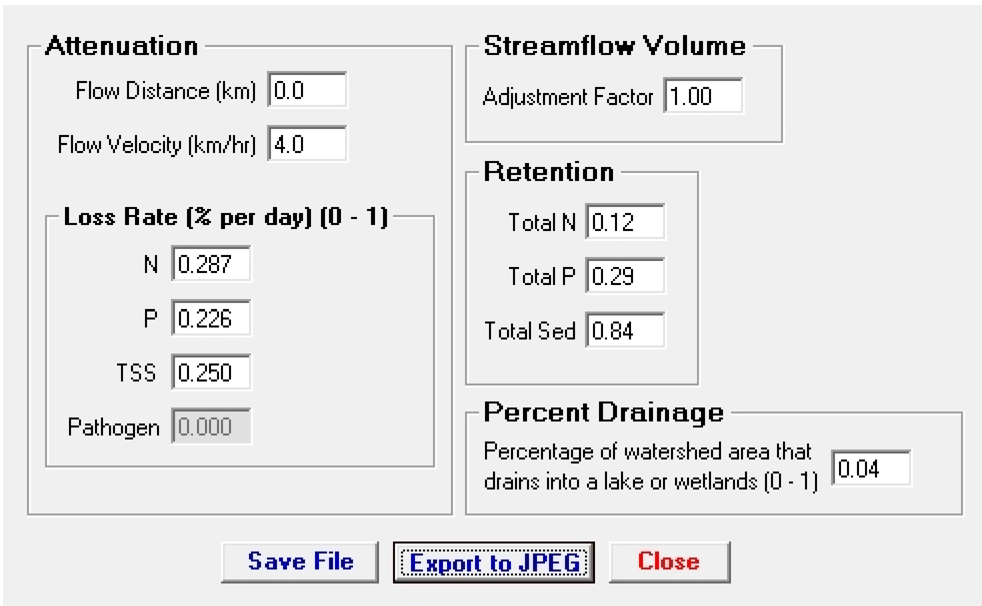
Figure 3.2: Nutrient Input File



As illustrated in Figure 3.2, the model accounted for nutrient and sediment loading originating from a variety of sources. The County GIS data served as the basis for segregating and grouping various categories of land use, thus enabling us to compute pollutant loads for rural, suburban, and agricultural lands. As shown above, developed lands were divided into mixed use and residential categories and then ranked as low, medium or highly developed. The more developed the greater the amount of impervious cover. The model also accounted for the loading attributable to the remaining septic systems occurring within the Honeoye Lake watershed. As previously noted, the model also accounted for nutrients in both a particulate (solid) and dissolved state. Soil phosphorus concentrations (Soil Concentration (mg/kg)) were variable amongst subwatersheds and ranged from 250 – 300 mg/kg dependent on the soil P GIS grid. Septic system populations were assumed to exhibit 5% failure rates, represented in Figure

3.2 as "Pond". Also as illustrated in Figure 3.2, the model accounted for vegetation related nutrient uptake that occurs during the "growing season", defined as May through September. It would be expected that vegetation during this time of year will assimilate some of the available nutrients, thus decreasing the amount of loading to the lake. It should also be noted that there are no identified point sources within the Honeoye Lake watershed.

Figure 3.3: Delivery Input File



4.0 Hydrology Calibration

The aforementioned transport input data was iteratively manipulated in order to adjust resulting stream flow to a best fit with several regional USGS gages. Four (4) regional USGS gages, which represented similar land cover characteristics with the Honeoye watershed and were within relative close proximity to Honeoye Lake, were chosen for this calibration. The streams and respective USGS gaging stations utilized for this calibration are as follows:

- Honeoye Creek at Honeoye Falls – USGS 04229500
- Ninemile Creek near Marietta, NY – USGS 04240180
- Canaseraga Creek above Dansville, NY – USGS 04224775
- Keuka Lake Outlet at Dresden, NY – USGS 04232482

The data obtained from each of the four gaging stations is presented in Figure 4.1. As depicted, the majority of the flow, regardless of the monitored stream, occurs in the spring months (months 3 and 4, March and April). The resulting calibration of the hydrologic data is depicted in Figure 4.2, which presents the initial model run, the mean flows of the four reference gages, and the "best fit" iteration (Hydrocal9).

Figure 4.1: Hydrology Calibration – Regional USGS Gages

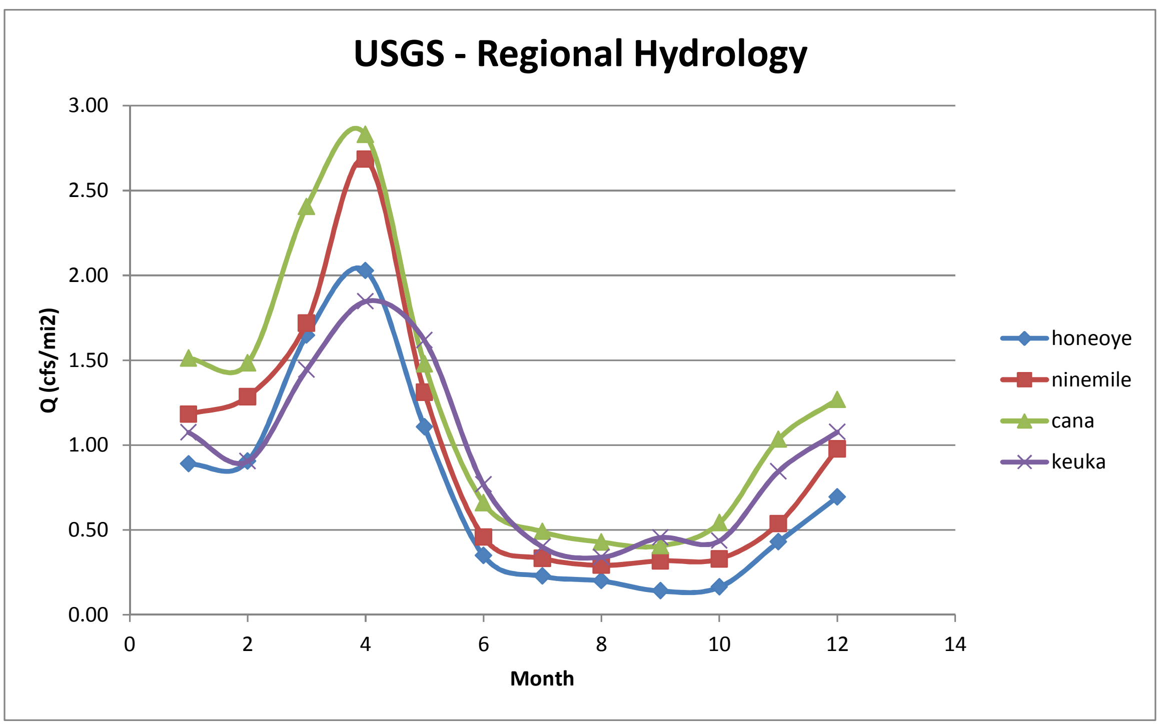
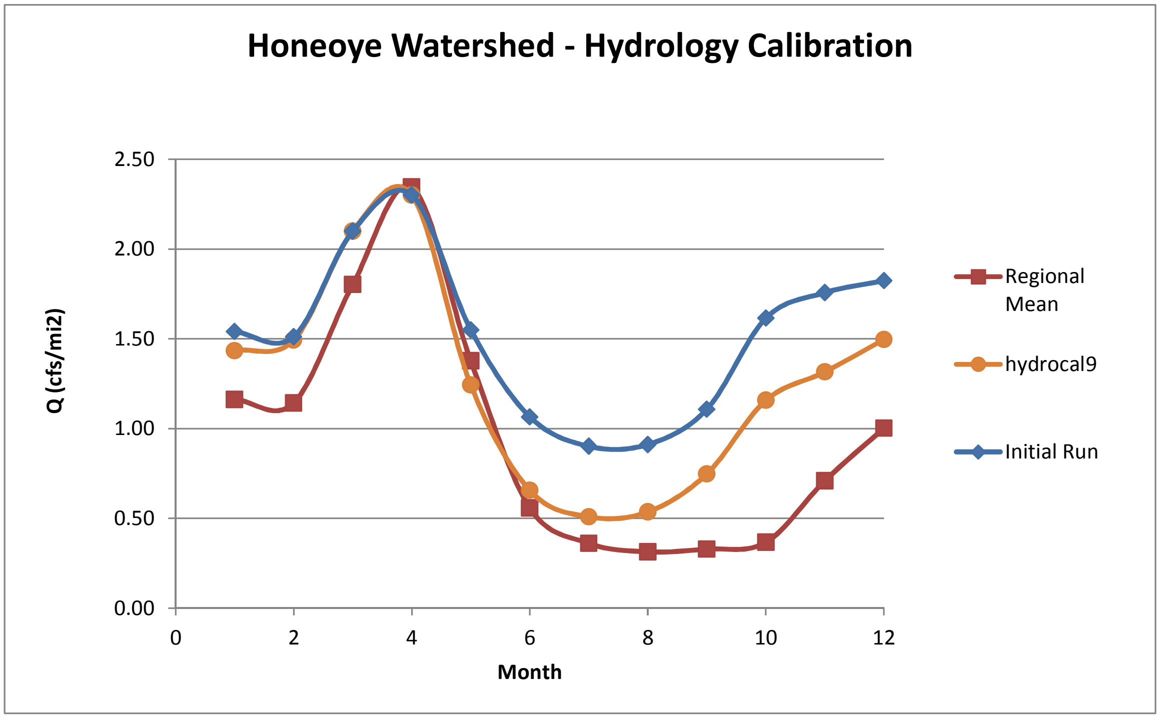


Figure 4.2: Hydrology Calibration



As previously mentioned, the lake's hydrologic data was iteratively manipulated through adjusting the "Adjust %ET" field. Specifically, a factor of 2 was applied from May through December, thus increasing the percent ET. The resulting adjusted discharge (Hydrocal 9 data) matches up rather well from the months of January through June. The modeled adjusted discharge from July through December was, however, higher than the regional gages. The difference in adjusted modeled data versus the regional data may likely be explained by the relatively unique topography of the Honeoye watershed. The prevailing slopes of the Honeoye Lake watershed, particularly the topography characteristic of the southwest and southeast subwatersheds, are steeper than the slopes characterizing the watersheds of the reference gages. The steeper topography of the Honeoye Lake watershed likely leads to both greater volumes of discharge and more rapid flows than would be characteristic of watersheds with lesser relief. As per the data presented in Figure 4.2, this effect is more pronounced during the growing season. When vegetative cover is both denser and photosynthesis is at or near peak rates, evapotranspiration and subsurface recession will also be at or near peak rates. In watersheds characterized by lesser relief (flatter topography) the rate of flow through this cover will be further reduced and the amount of runoff further decreased. Thus, although the relative rate and volume of runoff should always be greater for steeper sloped as compared to gentler sloped lands, the rate and volume of runoff will be further reduced in flatter terrain areas during the growing season when the density and photosynthetic activity of the vegetation peaks.

5.0 Results

5.1 Hydrology

Monthly stream flow for each subwatershed and the watershed as an aggregate is presented in Table 5.1.

Table 5.1: Hydrology

Honeoye Lake - Stream Inflow (cm)														
Subwatershed	Area (Ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	384	4.22	4.00	6.26	6.57	3.51	1.48	1.24	1.29	1.75	2.98	3.52	4.36	41.18
2	403	4.30	3.99	6.23	6.57	4.02	2.38	1.96	1.97	2.62	3.99	4.17	4.61	46.81
3	781	4.29	3.98	6.18	6.59	4.02	2.38	1.94	2.00	2.64	4.01	4.17	4.61	46.81
4	4,572	4.14	3.93	6.11	6.49	3.42	1.52	1.19	1.29	1.79	2.98	3.42	4.21	40.49
5	1,307	4.25	3.95	6.14	6.59	3.95	2.30	1.84	1.93	2.56	3.89	4.06	4.54	46.00
6	926	4.26	3.96	6.16	6.60	3.93	2.25	1.81	1.89	2.51	3.84	4.04	4.54	45.79
7	439	4.27	3.96	6.14	6.62	4.04	2.42	1.94	2.02	2.66	4.02	4.17	4.60	46.86
8	356	4.30	3.99	6.21	6.58	4.06	2.45	2.04	2.08	2.72	4.09	4.23	4.64	47.39
9	285	4.25	3.97	6.17	6.49	3.82	2.15	1.76	1.82	2.44	3.78	3.99	4.51	45.15
Aggregate	9,461	4.20	3.95	6.15	6.52	3.64	1.86	1.49	1.57	2.12	3.39	3.73	4.38	43.00

As per these data, the greatest amount of inflow occurs in the spring (May and April) and the least occurs in the summer (June – August). Additionally, although not the largest subwatershed in total area, Subwatersheds 2, 3, 7 and 8 are the top four contributing sources of inflow to the lake, on a per unit area basis.

Hydrologic characteristics for the watershed, when modeled as an aggregate, are provided in Table 5.2 and Figures 5.1 and 5.2.

As an aggregate, 43.00 cm of water flows into the lake via the watershed on an annual basis. Volumetrically, this equates to 4.07 x 10^7 m^3 of water entering the lake on an annual basis. This value is less than Princeton Hydro's original estimate of 4.7 x 10^7 m^3, which was calculated as part of the *Honeoye Lake Nutrient and Hydrologic Budget* (Princeton Hydro, 2007).

Honeoye Lake has an estimated volume of 3.4 x 10^7 m^3 which translates to a retention period of 0.85 years (310 days). This is generally in line with past studies of the lake, and slightly higher than Princeton Hydro's previously reported retention period of 0.75 years (275 days) Princeton Hydro, 2007). These data are in keeping with previously published computed estimates of the lake's flushing rate (Schaffner and Oglesby, 1978). Regardless, although Honeoye Lake may be the fastest flushing of all the Finger Lakes, its annualized lake hydrologic retention time of 0.75 - 0.85 years is slow. Thus, there is ample opportunity both for the settling of the sediments transported into the lake via runoff and the assimilation of dissolved nutrients by the lake's primary producers (aquatic plants, algae and phytoplankton). Slower hydrologic retention times facilitate the eutrophication process.

For management purposes it is critically important to parse out hydrology components into those associated with groundwater (baseflow) and those associated with surface flows (storm flows). Figure 5.1 provides a breakdown of stream flow into the lake showing the groundwater and surface water components.

Table 5.2: Aggregate Hydrology

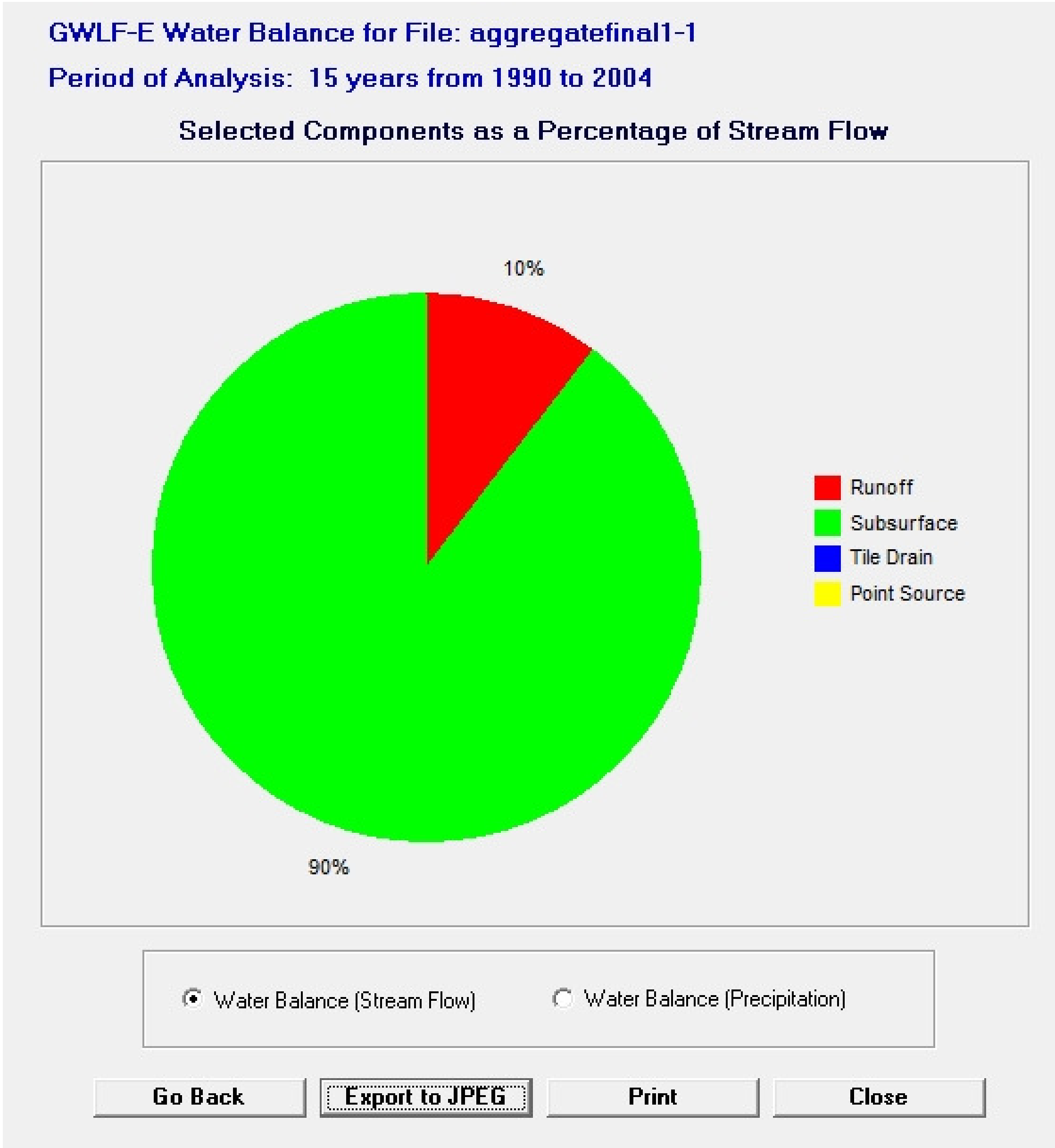
GWLF-E Hydrology for file: aggregatefinal1-1

Period of analysis: 15 years from 1990 to 2004

	Units in Centimeters							
Month	Precip	ET	Extraction	Runoff	Subsurface Flow	Point Src Flow	Tile Drain	Stream Flow
Jan	5.48	0.25	0.00	0.46	3.75	0.00	0.00	4.20
Feb	3.91	0.38	0.00	0.63	3.32	0.00	0.00	3.95
Mar	7.17	1.13	0.00	1.00	5.14	0.00	0.00	6.15
Apr	8.12	2.83	0.00	0.46	6.07	0.00	0.00	6.52
May	8.81	6.73	0.00	0.12	3.52	0.00	0.00	3.64
Jun	7.76	6.62	0.00	0.02	1.85	0.00	0.00	1.86
Jul	9.28	7.42	0.00	0.29	1.20	0.00	0.00	1.49
Aug	7.84	6.49	0.00	0.09	1.48	0.00	0.00	1.57
Sep	9.40	5.95	0.00	0.11	2.01	0.00	0.00	2.12
Oct	7.14	4.30	0.00	0.36	3.03	0.00	0.00	3.39
Nov	7.73	2.45	0.00	0.54	3.18	0.00	0.00	3.73
Dec	5.62	1.13	0.00	0.41	3.97	0.00	0.00	4.38
Totals	88.25	45.68	0.00	4.49	38.52	0.00	0.00	43.01

Go Back | Monthly Loads | Export to JPEG | Print | Close

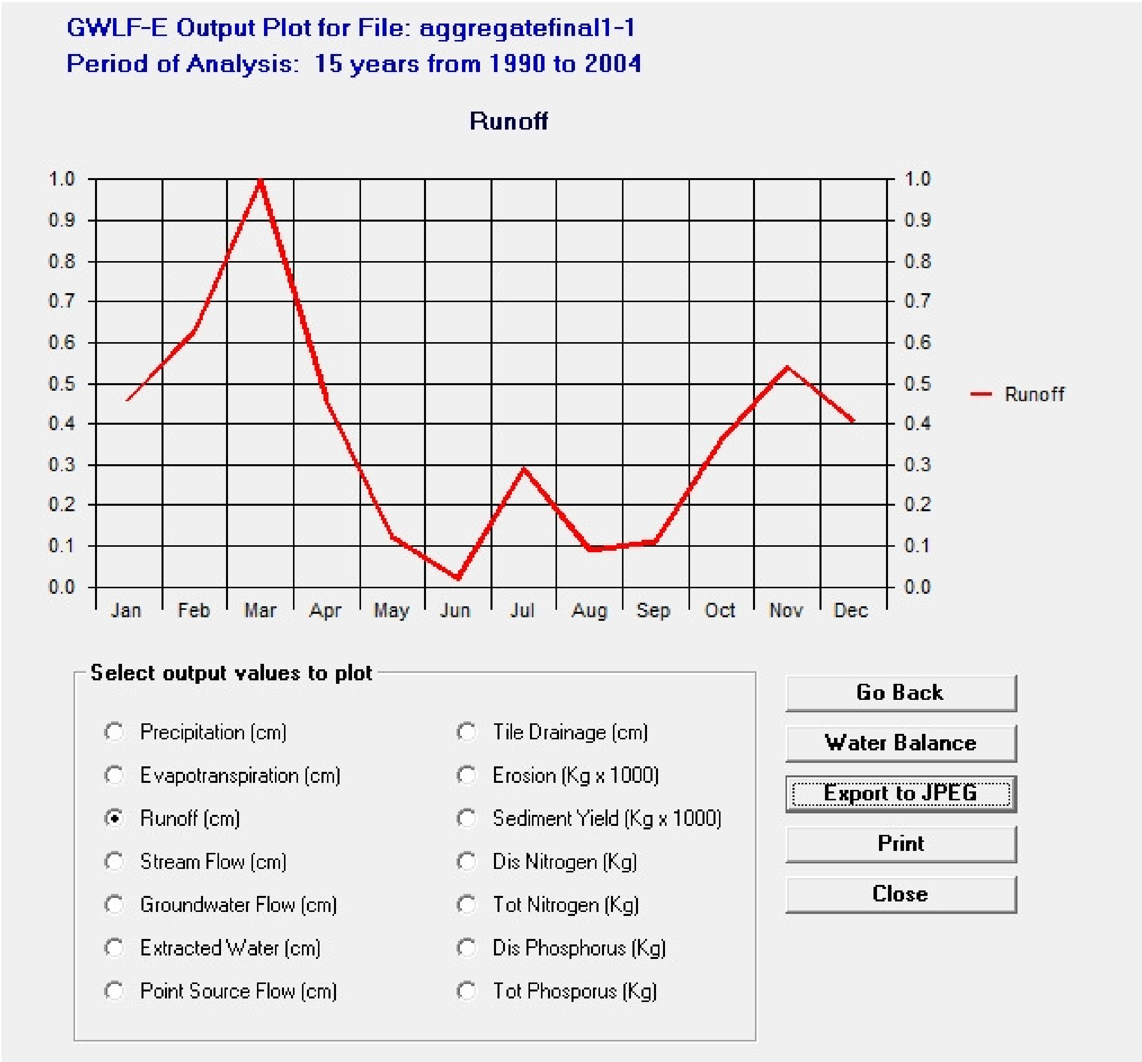
Figure 5.1: Aggregate Hydrology Stream Flow Components



As evidenced above, 90% of the hydrologic inflow into Honeoye Lake is estimated to be derived from base flow (sub-surface sources). The remaining 10% is estimated to occur via surface runoff during storm events.

In terms of management, our focus is generally placed on the “runoff” component of stream discharge as this is the component of inflow which transports much of the sediment and nutrient load into the receiving waterbody. As such, Figure 5.2 summarizes monthly runoff patterns.

Figure 5.2: Aggregate Hydrology Stream Flow Components



As per the model, peak flows occur in March, coinciding with the spring thaw when the ground is largely frozen and there is little vegetation growing. In April through June, "leaf out" and increased plant evapotranspiration decreases overland runoff. A slight increase in the surface runoff is predicted for July due to rainfall amounts and intensity patterns, but runoff declines from August through September largely due to plant evapotranspiration. A slight increase occurs from October through November due to "leaf fall", but dips again from December through February, with the winter months producing the least amount of runoff.

5.2 Pollutant Loading

Table 5.3 presents pollutant loading to Honeoye Lake on a subwatershed and aggregate basis. The Erosion Load is the total projected amount of soil/sediment mobilized from each subwatershed annually. The Sediment Load is the amount of the Erosion Load that is actually transported and conveyed into the receiving waterway. As such the Sediment Load is of greater concern in our analyses.

The dissolved N and P loads are part of the total N and P loads. Again the TN and TP loads are of greatest importance in our analyses, even though the dissolved load is readily assimilated and "biologically active".

Table 5.3: Honeoye Lake – Pollutant Loading

Honeoye Lake - Pollutant Loading							
Subwatershed	Area (Ha)	Erosion kgx1000/yr	Sediment kgx1000/yr	Dis. N kg/yr	TN kg/yr	Dis. P kg/yr	TP kg/yr
1	384	1369	310	748	1382	26	118
2	403	1057	223	961	1393	29	92
3	781	1170	310	1668	2217	53	131
4	4572	6966	1248	7138	9339	212	535
5	1307	202	52	2302	2397	68	80
6	926	241	85	1545	1710	49	68
7	439	70	27	844	888	25	31
8	356	250	71	693	854	23	42
9	285	165	59	546	663	18	33
Sum	9453	11490	2386	16445	20844	502	1130
Aggregate	9461	11173	2877	16391	20196	500	1005

On an aggregate basis, 2,877,000 kg/yr of sediment, 20,196 kg/yr of total nitrogen and 1,005 kg/yr of total phosphorus are transported to Honeoye Lake. The difference between the aggregate modeled loads and the summation of the subwatershed modeled loads is due to computational differences associated with internal raster conversions. It is important to normalize the previously mentioned subwatershed loads in order to determine which subwatersheds are contributing a disproportionate load per unit area, see Table 5.4.

Table 5.4: Honeoye Lake - Normalized Pollutant Loads

Honeoye Lake - Normalized Pollutant Loads (kg/ha)						
Subwatershed	Erosion	Sediment	Dis. N	TN	Dis. P	TP
1	3564	808	1.95	3.60	0.07	0.31
2	2624	553	2.39	3.46	0.07	0.23
3	1498	396	2.14	2.84	0.07	0.17
4	1524	273	1.56	2.04	0.05	0.12
5	154	40	1.76	1.83	0.05	0.06
6	260	92	1.67	1.85	0.05	0.07
7	158	62	1.92	2.02	0.06	0.07
8	703	201	1.95	2.40	0.06	0.12
9	581	208	1.92	2.33	0.06	0.12

Subwatershed 1 (Northwest) ranks as the highest contributor of sediment, total nitrogen and total phosphorus **on a per unit area scale**. The second highest contributor of sediments and total nutrients to the lake **on a per unit area** basis is Subwatershed 2 (Affolter Gully).

An important component of management lies in parsing out 'manageable' versus 'unmanageable' pollutant loads. For the sake of this project, 'unmanageable' refers to loads originating from forests or wetlands and loads derived from groundwater. 'Manageable' loads are assigned to those originating from all other land use types and from stream bank erosion and septic systems. Table 5.5 provides a breakdown of these loads.

Table 5.5: Honeoye Lake – Manageable and Unmanageable Pollutant Loads

Honeoye Lake - Manageable and Unmanageable Pollutant Loads

Subwatershed	Sediment				TN				TP			
	M (kg/yr)	% M (%)	UM (kg/yr)	% UM (%)	M (kg/yr)	% M (%)	UM (kg/yr)	% UM (%)	M (kg/yr)	% M (%)	UM (kg/yr)	% UM (%)
1	304	98	7	2	897	65	485	35	101	86	16	14
2	218	98	4	2	804	58	590	42	74	80	19	20
3	283	92	26	8	1007	45	1210	55	89	67	43	33
4	1023	82	225	18	2989	32	6350	68	288	54	247	46
5	23	44	29	56	392	16	2005	84	14	17	66	83
6	59	70	26	30	298	17	1412	83	20	30	48	70
7	17	61	11	39	198	22	690	78	8	25	23	75
8	66	92	6	8	316	37	538	63	24	59	17	41
9	57	96	2	4	258	39	405	61	21	62	13	38

Manageable pollutant loads are highest, on a percent basis, in Subwatershed 1, which is also the subwatershed that is the greatest per unit area basis pollutant contributor to the lake. As such, best management practices could prove to be very effective in reducing the pollutant loading of Subwatershed 1 to the lake. Conversely, while the ratio of the manageable versus unmanageable pollutant load for Subwatershed 4 is lower, the total amount of loading to the lake that could be reduced by implementing stormwater management measures in this subwatershed are significant. Additionally, unique opportunities exist within the boundaries of the Honeoye Inlet Wildlife Management Area for the implementation of stormwater Best Management Practices (BMP) having both flood and pollutant load mitigation capabilities.

5.3 Storm Specific Loading

Storm specific loading represents the hydrologic and pollutant loading that occurs under discrete storm frequencies. Princeton Hydro analyzed the effects of the 1-year, 2-year, 5-year, 10-year and 100-year 24-hour storm events as a component of the selection of appropriate best management practices. These events are defined as the probability of a storm of a given magnitude occurring within time frame, or "return frequency". Thus a 1-year storm statistically has a 100% probability of occurring at least once in a given year, a 2-year storm a 50% probability, a 5-year storm a 20% probability, a 10-year storm a 10% probability and a 100-year storm a 1% probability. It must be emphasized that these are probabilities and thus it is "possible", although unlikely, to have two or three 100-year events within a single year. The rainfall amounts associated with each of these events reflects and intensity or rate; that is the amount of rainfall occurring over a 24-hour period. Using the USDOC (1963) rainfall isopleths and guidance provided in the New York Stormwater Management Manual (NYSDEC, 2010), the 1-year event equates to 2.0” over 24 hours, the 2-year to 2.2”, the 5-year to 3.2”, the 10-year to 4.0” and the 100-year to 4.8”.

In order to conduct the storm specific analyses Princeton Hydro first determined the precipitation amounts which correlated with the aforementioned storm frequencies. The *MapShed* weather input files were then modified to allow for the input of the above storm event values. We also modified the input files to enable us to compute the spring, summer, fall and winter loads generated by each targeted storm. The model was run and the results culled and analyzed. The subwatershed specific results of this analysis are presented in Tables 5.6 through 5.15. Table 5.16 presents the storm specific loading data computed for only that portion of Subwatershed 4 contained within the boundaries of the Honeoye Inlet Watershed Management Area. It should be noted that the spring, summer, fall and winter loads are not additive. The loads listed under each storm for each season reflect seasonal differences affected by productivity, ambient soil conditions, and potential for pollutant mobilization and transport. Additionally, the loading generated by the 2, 5, 10 and 100-year events inherently include the loads generated by the 1-year event. Finally, storms up to and including the 1-year event cumulatively account for 90% of all the rainfall occurring over a given year. Thus, even the majority of rain events occurring annually are relatively small, collectively they account for the majority of the total annual rainfall and the total runoff generated from a watershed.

Some relevant findings are as follows:

- Spring and summer storms, regardless of the magnitude of the event, generate the greatest percentage of pollutant load

- The highest pollutant concentrations are associated with spring and fall events

- The 1-year (water quality) event is responsible for a large percentage (as much as 70%) of the storm-specific loads generated by the larger, less frequent events. This is because regardless of the overall magnitude of a storm, the majority of the pollutant loading occurs during the first flush of the event. As such, from the perspective of pollutant load reduction, BMPs sized to manage the 1-year event should have the greatest cost-effectiveness. Additionally, the larger events have less of a probability of occurring during any one year. Thus, designing stormwater quality improvement BMPs for the 1-year event typically generates the greatest cost-benefit.

- Comparing the 1, 2, 5 and 10-year events, the worst flooding and scour impacts appear to be caused by the 5-year storm as based on the comparative flow rates of the modeled events. The 5-year event has a 20% probability of occurring during any one year.

Table 5.6: Honeoye Lake – Aggregate Stormwater Specific Loads

Aggregate Watershed - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	673,514	28,188	43.51	245.15	0.40	13.66	0.02
	Spring	1,844,748	276,729	160.65	813.81	0.54	65.66	0.04
	Summer	411,317	174,782	373.55	326.80	0.85	30.84	0.08
	Fall	929,845	614,840	715.66	1,054.67	1.40	116.22	0.15
2-yr	Winter	802,187	33,381	43.42	286.67	0.40	15.88	0.02
	Spring	2,288,420	349,671	164.15	1,003.10	0.52	81.77	0.04
	Summer	606,093	256,394	397.05	464.36	0.82	44.78	0.08
	Fall	1,216,701	794,771	755.05	1,367.34	1.39	151.76	0.15
5-yr	Winter	1,197,484	49,614	43.27	417.46	0.39	22.99	0.02
	Spring	3,458,892	539,273	165.75	1,536.02	0.50	127.07	0.04
	Summer	1,088,318	460,033	405.02	852.63	0.81	84.53	0.08
	Fall	1,938,405	1,245,997	782.61	2,221.35	1.41	248.72	0.16
10-yr	Winter	1,365,771	56,991	45.48	473.19	0.39	25.93	0.02
	Spring	4,317,569	651,442	157.46	1,923.28	0.49	158.17	0.04
	Summer	1,722,880	646,954	378.32	1,252.82	0.77	124.03	0.08
	Fall	2,668,972	1,668,756	743.15	3,024.43	1.35	340.11	0.15

Table 5.7: Honeoye Lake – Subwatershed 1 Stormwater Specific Loads

Subwatershed 1 - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	29,638	2,187	48.92	24.97	0.59	1.75	0.03
	Spring	83,809	45,386	574.42	108.64	1.61	11.60	0.17
	Summer	18,773	30,000	1376.37	50.52	2.90	5.92	0.32
	Fall	42,299	115,380	2881.00	180.84	5.39	24.03	0.70
2-yr	Winter	35,061	2,686	49.70	29.04	0.56	1.99	0.03
	Spring	102,738	58,065	604.69	134.98	1.58	14.47	0.17
	Summer	26,775	43,772	1505.93	70.93	2.86	8.39	0.33
	Fall	54,344	147,891	3047.54	232.46	5.36	30.91	0.71
5-yr	Winter	51,709	4,388	53.53	42.07	0.55	2.80	0.03
	Spring	151,652	92,806	654.31	210.32	1.59	22.84	0.17
	Summer	44,965	80,209	1680.65	130.46	3.00	15.73	0.36
	Fall	83,194	230,568	3342.01	374.18	5.65	49.91	0.75
10-yr	Winter	58,929	5,282	52.80	47.46	0.53	3.11	0.03
	Spring	187,903	113,652	636.83	263.26	1.56	28.43	0.17
	Summer	71,110	115,609	1638.11	192.73	2.93	23.32	0.35
	Fall	113,581	314,526	3318.52	513.59	5.58	68.67	0.75
100-yr	Winter	86,034	8,730	54.94	69.29	0.52	4.48	0.03
	Spring	286,556	179,181	643.30	423.66	1.57	46.15	0.17
	Summer	133,136	208,683	1592.28	368.86	2.95	45.15	0.36
	Fall	188,816	525,981	3220.93	896.86	5.58	120.66	0.75

Table 5.8: Honeoye Lake – Subwatershed 2 Stormwater Specific Loads

Subwatershed 2 - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	30,944	1,092	22.94	23.55	0.53	0.97	0.02
	Spring	86,695	34,178	419.19	91.80	1.25	7.73	0.11
	Summer	86,695	34,178	419.19	91.80	1.25	7.73	0.11
	Fall	47,234	96,072	2194.37	149.74	3.66	18.44	0.45
2-yr	Winter	36,682	1,445	24.63	28.32	0.53	1.17	0.02
	Spring	106,706	43,697	434.81	115.85	1.25	9.85	0.11
	Summer	34,181	40,153	1127.66	66.31	2.03	7.02	0.21
	Fall	60,839	124,266	2308.15	196.30	3.78	24.24	0.47
5-yr	Winter	54,267	2,621	28.60	43.44	0.53	1.85	0.02
	Spring	158,768	68,740	454.51	184.13	1.28	16.01	0.11
	Summer	57,923	70,724	1179.37	122.07	2.16	13.23	0.23
	Fall	94,453	192,436	2387.76	321.21	4.01	39.85	0.50
10-yr	Winter	61,939	3,294	28.71	50.37	0.53	2.18	0.02
	Spring	196,843	83,717	439.55	233.91	1.28	20.30	0.11
	Summer	87,430	97,971	1127.22	177.15	2.13	19.19	0.23
	Fall	127,633	256,336	2309.88	436.65	3.95	54.46	0.50
100-yr	Winter	90,600	5,761	30.86	76.86	0.53	3.47	0.02
	Spring	301,225	131,184	442.26	383.19	1.33	33.79	0.12
	Summer	159,741	171,253	1082.00	336.42	2.19	36.74	0.24
	Fall	211,599	416,199	2178.00	754.08	3.96	94.48	0.50

Table 5.9: Honeoye Lake – Subwatershed 3 Stormwater Specific Loads

Subwatershed 3 - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	56,122	2,364	34.54	29.58	0.48	1.79	0.02
	Spring	153,836	41,756	291.87	111.00	0.90	10.53	0.09
	Summer	33,791	26,838	671.23	47.26	1.49	5.07	0.15
	Fall	77,981	101,150	1371.27	162.36	2.58	20.43	0.32
2-yr	Winter	66,745	2,874	34.79	34.60	0.47	2.06	0.02
	Spring	190,489	53,259	302.90	137.63	0.87	13.10	0.08
	Summer	49,209	39,696	741.79	67.31	1.47	7.34	0.15
	Fall	101,263	130,512	1470.77	210.21	2.59	26.46	0.32
5-yr	Winter	99,393	4,560	36.03	50.51	0.46	2.98	0.02
	Spring	286,939	83,636	313.32	212.80	0.85	20.69	0.08
	Summer	86,431	72,465	795.12	124.77	1.50	14.12	0.17
	Fall	159,193	205,420	1586.13	342.14	2.70	43.64	0.35
10-yr	Winter	114,005	5,409	35.54	57.48	0.45	3.36	0.02
	Spring	357,946	101,350	298.21	266.30	0.82	25.79	0.08
	Summer	138,069	102,943	752.00	183.94	1.43	20.90	0.16
	Fall	218,964	277,400	1529.21	468.08	2.62	60.08	0.34
100-yr	Winter	168,205	8,614	35.85	84.63	0.44	4.92	0.02
	Spring	554,447	156,905	290.51	426.60	0.82	41.47	0.08
	Summer	264,726	182,453	698.59	350.76	1.40	40.08	0.16
	Fall	370,994	455,318	1408.84	810.16	2.53	104.22	0.33

Table 5.10: Honeoye Lake – Subwatershed 4 Stormwater Specific Loads

Subwatershed 4 - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	320,097	7,613	21.53	93.30	0.36	4.45	0.01
	Spring	872,692	177,794	221.26	400.38	0.57	38.06	0.05
	Summer	184,211	124,601	575.65	171.94	0.95	19.95	0.10
	Fall	430,235	451,132	1151.06	660.21	1.85	85.68	0.24
2-yr	Winter	382,025	9,693	22.33	111.03	0.36	5.41	0.01
	Spring	1,085,815	227,092	227.63	504.15	0.55	48.77	0.05
	Summer	278,486	183,843	611.25	256.65	0.97	30.32	0.11
	Fall	568,483	585,781	1217.73	872.82	1.90	113.78	0.25
5-yr	Winter	572,176	16,514	23.92	167.45	0.36	8.61	0.01
	Spring	1,650,071	354,617	230.14	801.32	0.55	79.75	0.05
	Summer	516,336	330,057	610.74	499.33	0.99	60.34	0.12
	Fall	919,310	922,212	1239.38	1,456.80	1.97	191.43	0.26
10-yr	Winter	658,216	20,220	23.91	195.45	0.36	10.27	0.01
	Spring	2,063,192	428,239	217.33	1,012.77	0.53	100.56	0.05
	Summer	822,720	461,232	563.71	739.77	0.95	88.90	0.11
	Fall	1,272,205	1,231,224	1159.05	2,000.97	1.89	263.29	0.25
100-yr	Winter	975,494	33,625	24.49	299.40	0.36	16.52	0.01
	Spring	3,213,053	660,998	210.14	1,660.30	0.54	166.47	0.05
	Summer	1,594,344	807,256	511.13	1,437.48	0.94	172.38	0.11
	Fall	2,181,842	1,992,864	1032.43	3,478.65	1.81	457.41	0.24

Table 5.11: Honeoye Lake – Subwatershed 5 Stormwater Specific Loads

Subwatershed 5 - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	90,190	427	3.86	17.70	0.33	0.87	0.01
	Spring	243,626	7,083	31.55	46.21	0.23	2.82	0.01
	Summer	52,656	4,618	74.38	13.67	0.28	1.00	0.02
	Fall	122,415	16,954	149.11	41.61	0.42	3.56	0.03
2-yr	Winter	107,627	516	3.89	20.46	0.33	1.02	0.01
	Spring	303,427	8,980	32.26	55.79	0.22	3.49	0.01
	Summer	78,241	6,823	80.57	18.92	0.26	1.44	0.02
	Fall	160,661	21,938	159.30	53.02	0.40	4.62	0.03
5-yr	Winter	161,254	807	4.00	29.26	0.32	1.50	0.01
	Spring	462,408	13,855	32.22	83.69	0.20	5.37	0.01
	Summer	142,749	12,274	82.02	34.03	0.25	2.71	0.02
	Fall	258,140	34,463	165.17	84.92	0.39	7.53	0.04
10-yr	Winter	185,665	948	3.93	33.57	0.32	1.76	0.01
	Spring	578,909	16,643	30.22	104.78	0.19	6.88	0.01
	Summer	228,300	17,205	75.85	51.42	0.24	4.15	0.02
	Fall	356,913	45,980	154.95	115.56	0.38	10.51	0.03
100-yr	Winter	275,618	1,475	3.91	49.48	0.32	2.62	0.01
	Spring	904,368	25,406	28.78	167.73	0.19	11.04	0.01
	Summer	443,456	30,074	68.54	100.98	0.24	8.07	0.02
	Fall	612,350	74,232	137.70	200.40	0.36	18.13	0.03

Table 5.12: Honeoye Lake – Subwatershed 6 Stormwater Specific Loads

Subwatershed 6 - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	64,575	1,107	13.43	17.72	0.36	1.22	0.02
	Spring	175,328	10,425	64.47	49.80	0.36	4.01	0.03
	Summer	36,244	6,059	141.00	17.28	0.53	1.55	0.05
	Fall	87,105	21,829	269.30	49.94	0.78	4.92	0.07
2-yr	Winter	76,963	1,265	12.83	20.10	0.35	1.39	0.01
	Spring	217,876	13,012	65.24	59.10	0.33	4.84	0.03
	Summer	53,837	8,899	151.82	23.17	0.47	2.13	0.04
	Fall	113,930	28,046	285.26	62.24	0.71	6.26	0.07
5-yr	Winter	115,072	1,772	12.20	27.68	0.33	1.87	0.01
	Spring	330,599	19,716	64.54	85.32	0.30	6.90	0.02
	Summer	97,351	16,047	156.50	39.78	0.42	3.70	0.04
	Fall	181,615	44,037	301.23	96.52	0.66	9.71	0.07
10-yr	Winter	132,335	1,967	11.65	30.82	0.33	2.03	0.01
	Spring	413,496	23,631	60.49	104.23	0.28	8.34	0.02
	Summer	157,389	22,760	145.85	58.15	0.40	5.38	0.04
	Fall	251,326	59,318	286.51	129.25	0.62	13.05	0.06
100-yr	Winter	196,101	2,770	11.12	43.29	0.33	2.77	0.01
	Spring	644,289	35,515	56.74	159.81	0.26	12.63	0.02
	Summer	306,688	39,727	131.29	108.23	0.37	10.01	0.03
	Fall	430,298	96,254	256.74	218.20	0.58	22.14	0.06

Table 5.13: Honeoye Lake – Subwatershed 7 Stormwater Specific Loads

Subwatershed 7 - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	29,965	288	8.46	6.64	0.36	0.36	0.01
	Spring	80,532	3,050	41.09	17.54	0.27	1.17	0.02
	Summer	16,267	1,783	90.49	5.28	0.36	0.40	0.03
	Fall	39,828	6,551	175.11	15.80	0.52	1.40	0.04
2-yr	Winter	35,772	337	8.33	7.64	0.35	0.42	0.01
	Spring	100,410	3,840	41.82	21.08	0.25	1.42	0.02
	Summer	24,418	2,644	98.81	7.22	0.32	0.57	0.02
	Fall	52,321	8,460	188.28	20.00	0.48	1.78	0.04
5-yr	Winter	53,643	492	8.20	10.67	0.34	0.63	0.01
	Spring	153,351	5,858	41.30	30.84	0.23	2.24	0.02
	Summer	44,900	4,781	101.14	12.64	0.29	1.11	0.03
	Fall	84,149	13,329	198.38	31.35	0.46	3.04	0.04
10-yr	Winter	61,812	558	8.00	12.14	0.34	0.70	0.01
	Spring	192,215	7,018	38.58	38.30	0.22	2.74	0.02
	Summer	72,969	6,759	93.37	19.01	0.28	1.64	0.02
	Fall	116,794	17,861	186.31	42.55	0.43	4.10	0.04
100-yr	Winter	91,887	813	7.80	17.54	0.34	1.00	0.01
	Spring	300,940	10,615	36.26	60.19	0.21	4.25	0.01
	Summer	143,396	11,848	83.64	36.73	0.27	3.11	0.02
	Fall	201,195	28,935	164.94	73.01	0.41	6.95	0.04

Table 5.14: Honeoye Lake – Subwatershed 8 Stormwater Specific Loads

Subwatershed 8 - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	26,257	871	22.16	14.02	0.47	1.01	0.02
	Spring	72,725	9,956	146.70	42.74	0.74	3.67	0.06
	Summer	16,244	5,987	314.62	17.18	1.19	1.57	0.10
	Fall	37,132	22,220	629.95	48.84	1.76	5.04	0.18
2-yr	Winter	31,151	1,000	21.20	16.01	0.45	1.12	0.02
	Spring	89,677	12,503	150.76	51.31	0.70	4.33	0.06
	Summer	23,281	8,744	345.47	23.08	1.10	2.09	0.10
	Fall	47,835	28,450	669.19	61.18	1.66	6.26	0.17
5-yr	Winter	46,197	1,430	20.51	22.26	0.43	1.46	0.02
	Spring	133,993	19,381	155.94	74.82	0.65	6.10	0.05
	Summer	39,797	15,980	379.43	39.56	1.04	3.56	0.09
	Fall	74,084	44,655	734.09	94.83	1.61	9.53	0.16
10-yr	Winter	52,853	1,603	19.41	24.64	0.41	1.55	0.02
	Spring	166,736	23,468	148.94	91.70	0.61	7.30	0.05
	Summer	63,505	22,953	364.86	57.28	0.98	5.12	0.09
	Fall	101,545	60,814	721.88	127.29	1.54	12.75	0.16
100-yr	Winter	77,667	2,329	18.66	34.49	0.40	2.06	0.02
	Spring	256,802	35,989	144.44	140.73	0.59	11.05	0.05
	Summer	120,723	40,807	343.49	105.31	0.93	9.50	0.08
	Fall	170,660	100,624	680.64	215.56	1.47	21.84	0.15

Table 5.15: Honeoye Lake – Subwatershed 9 Stormwater Specific Loads

Subwatershed 9 - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	20,755	743	28.13	10.89	0.47	0.74	0.02
	Spring	57,302	7,022	131.17	32.21	0.72	2.74	0.06
	Summer	12,086	3,982	279.71	12.56	1.21	1.17	0.11
	Fall	28,742	14,789	540.91	34.90	1.70	3.84	0.18
2-yr	Winter	24,643	851	27.24	12.42	0.45	0.83	0.02
	Spring	70,747	8,779	134.12	38.51	0.67	3.29	0.06
	Summer	17,509	5,805	303.72	16.72	1.09	1.58	0.10
	Fall	37,138	18,875	571.63	43.43	1.57	4.83	0.17
5-yr	Winter	36,601	1,199	26.33	17.40	0.43	1.11	0.02
	Spring	105,951	13,410	136.62	56.26	0.62	4.76	0.05
	Summer	30,200	10,501	327.72	28.57	1.00	2.74	0.09
	Fall	57,705	29,280	621.33	67.24	1.49	7.50	0.17
10-yr	Winter	41,913	1,339	25.40	19.31	0.42	1.21	0.02
	Spring	131,995	16,230	130.34	69.06	0.59	5.80	0.05
	Summer	48,737	15,155	314.07	41.37	0.93	4.01	0.09
	Fall	79,355	39,952	611.03	90.09	1.41	10.19	0.16
100-yr	Winter	61,693	1,914	24.58	27.10	0.40	1.59	0.02
	Spring	203,733	24,869	126.05	105.92	0.56	8.66	0.05
	Summer	93,467	27,077	294.64	76.05	0.87	7.31	0.08
	Fall	133,867	66,442	576.91	152.26	1.33	17.09	0.15

Table 5.16: Honeoye Lake – Project Area Stormwater Specific Loads

Project Area - Daily Loads								
Storm Event	Season	Flow	TSS		TN		TP	
		(m3)	(kg)	(mg/L)	(kg)	(mg/L)	(kg/)	(mg/L)
1-yr	Winter	213,899	5,484	22.28	72.17	0.38	3.33	0.01
	Spring	580,943	139,306	260.55	306.14	0.65	28.91	0.06
	Summer	125,280	96,930	655.50	133.11	1.09	15.10	0.12
	Fall	290,436	354,343	1322.69	501.11	2.06	65.07	0.26
2-yr	Winter	255,162	7,041	23.26	86.09	0.38	4.06	0.01
	Spring	722,820	178,226	268.76	386.02	0.64	37.04	0.06
	Summer	187,281	143,311	707.20	197.50	1.11	22.93	0.12
	Fall	381,982	460,239	1413.26	661.58	2.13	86.30	0.28
5-yr	Winter	381,927	12,186	25.26	130.35	0.37	6.44	0.01
	Spring	1,098,819	278,908	272.35	614.33	0.63	60.50	0.06
	Summer	342,954	258,025	717.89	381.77	1.15	45.55	0.13
	Fall	614,390	725,604	1459.88	1,103.04	2.24	144.97	0.30
10-yr	Winter	439,350	15,025	25.26	152.06	0.37	7.69	0.01
	Spring	1,374,230	336,833	257.06	777.13	0.62	76.32	0.06
	Summer	546,771	361,104	664.61	565.38	1.10	67.22	0.13
	Fall	848,950	969,620	1370.85	1,515.10	2.16	199.61	0.29
100-yr	Winter	651,141	25,290	26.00	233.02	0.38	12.37	0.01
	Spring	2,141,425	520,192	248.35	1,274.03	0.62	126.32	0.06
	Summer	1,058,271	632,749	603.99	1,096.16	1.08	130.36	0.13
	Fall	1,453,752	1,570,659	1224.38	2,633.56	2.06	346.94	0.27

6.0 Stormwater Management Options for the Honeoye Lake Watershed

As stated in the introduction, the genesis of the project was the collective interest of the HLWTF, TNC and NYSDEC to reduce the pollutant loading and control flood flows associated with the Honeoye Inlet subwatershed. Additionally, with regards to the entire Honeoye Lake watershed, the HLWTF with their project partners and Honeoye Lake stakeholders have become increasingly cognizant of the stormwater induced impacts affecting the lake and the lake's tributaries. Over the past fifteen years increasing attention has been given to investigating the relationship between Honeoye Lake and its watershed. While stream sampling data (Makerowicz, et. al., 2002; Starke, 2002 and 2003) verify that seasonal and storm-event loading is affecting the lake's overall productivity, the variability in flow rates and the intermittent nature of some of the lake's sources of inflow has compounded how best to deal with this loading. Additionally, as summarized in the Honeoye Lake Watershed Management Plan (Genesee/Finger lake Regional Planning Council, 2007), there are major erosion problems affecting the lake and its tributaries. The Plan's key recommendations included implementation of a detailed inventory of eroded/eroding streams and waterways, development of a program to minimize sediment loading to the lake, and the adoption of municipal land use regulations to minimize erosion. These recommendations are termed "source control" measures as they are directed to preventing pollutant loading and mitigating erosional impacts that negatively affect all of the lake's tributaries. Steps have been taken to follow-through on these recommendations. For example, Ontario County recently initiated mitigative measures to address and correct road-side swale erosion problems by rock armoring sections of the swales and installing catch basins along portions of West Lake Road.

The results of the *MapShed* data presented in Sections 3, 4 and 5 confirm the role of storm-event loading and support the need for the implementation of better stormwater management for the entire Honeoye Lake watershed. The balance of this report pertains mostly to the presentation and discussion of the stormwater management recommendations for the Honeoye Inlet Wildlife Management Area (the focus area of this study). Princeton Hydro also evaluated stormwater management opportunities for each of the lake's nine (9) primary subwatersheds. As based on those data, this section of the report provides generalized recommendations for the four subwatersheds generating the greatest aggregate annual loads. Basic recommendations are also provided regarding the correction of other major sediment, erosional or nutrient loading problems affecting all of the lake's tributaries. It must be emphasized, though, that even for the Honeoye Inlet Wildlife Management Area the scope of this project limits us to the presentation of stormwater management concepts as opposed to actual designs. Further work will be needed to shape the concepts discussed herein into actual stormwater management and erosion control BMPs that are ready for permitting, construction or implementation.

6.1 Honeoye Inlet Wildlife Management Area

As noted in the introduction of this report, a key objective of this study was to assist the HLWTF and TNC in the evaluation of stormwater management options for the Honeoye Inlet subwatershed. As such, in accordance with the scope of work, particular attention was given to the review and analysis of potential stormwater management BMPs that could be effectively implemented and used to manage both the hydrologic and pollutant loads computed for the Honeoye Inlet subwatershed (Subwatershed 4). The stormwater concepts discussed in this section of the report are based on the data presented in Sections 3, 4 and 5, data and observations compiled during our site visits, and information provided by the project partners.

In 2002, the State of New York acquired from TNC three parcels of land, collectively encompassing approximately 2,500 acres. The aggregate land mass is located immediately south of Honeoye Lake and the Finger Lake Community College's Muller Field Station, within the Honeoye Lake Inlet subwatershed. These lands, which subsequently became the Honeoye Inlet Wildlife Management Area, are managed by the New York State Department of Environmental Conservation (NYSDEC). The Honeoye Inlet Wildlife Management Area is open to the public for both passive and active recreational use.

Two of the three parcels of land that make up the Honeoye Inlet Wildlife Management Area were originally part of the Wild Rose Ranch. These lands were extensively farmed throughout the mid-1900s. To facilitate the farming of these lands, that portion of the Honeoye Inlet stream running through the Wild Rose Ranch was channelized. Additionally, a number of drainage ditches were cut perpendicular to the stream to help dewater the wetlands and riparian lands associated with the stream. Since being acquired by TNC and NYSDEC, the farmland has undergone successional change and the majority of the lands within the Honeoye Inlet Wildlife Management Area are presently best defined as successional fields.

As documented in Section 5 of this report, Subwatershed 4, which largely drains to the lake through the Honeoye Inlet Wildlife Management Area, is responsible for the majority of the lake's total inflow and pollutant loading. Recently, TNC in concert with HLWTF, NYSDEC, Ontario County Soil and Water Conservation District (OCSWCD), and the Finger Lake Institute (FLI), began examining how best to manage the Honeoye Inlet's pollutant load as part of ongoing Honeoye Lake water quality and trophic state management and restoration efforts. The general consensus has been to construct within the Honeoye Inlet Wildlife Management Area some form of on-line bioretention stormwater treatment system. For example, OCSWCD (2012) recommended the construction of a large (100 acre) regional stormwater management system capable of controlling the stream's storm flows and decreasing its pollutant load. A general consensus is that the stormwater management system must be sustainable, have minimal structural elements, and not decrease the Management Area's ecological and recreational attributes. The BMPs presented herein were deigned in keeping with these multiple objectives.

As part of Princeton Hydro's investigation of BMPs suitable for implementation within the Honeoye Inlet Wildlife Management Area, we determined it would be beneficial to analyze the area's soil properties. It was determined that a better understanding of soil composition, along with the site's soil characteristics, such as depth to groundwater, depth to bedrock and evidence of mottling (depth of seasonal high water table), was needed to enable us to better assess BMP options. In August 2013, with the assistance of the NYSDEC, HLWTF and OCSWCD, Princeton Hydro witnessed seven (7) test pits that were excavated within the project area (Appendix A, Figure A-1). The test pit logs are provided as an appendix to this report. As based on soil samples collected from each test pit, the soils at each location were classified with respect to soil texture class, moisture, consistency, structure, color, and organic content. In general, the uppermost 1-2 feet of soil was characterized as formerly cultivated, organic topsoil. Below this organic upper horizon was typically a thick layer of clayey silt or silty clay, often with evidence of groundwater influence (mottling). Some test pits revealed layers of sand or sand and gravel, often with perched groundwater flowing through. At the bottom of the majority of the test pits we observed saturated silt and clay layers, relics of the former lakebed or original wetlands. Overall the data compiled via these soil test pits revealed the following:

- Soil conditions throughout the tested areas (as reflected in the soil log data) were relatively consistent.
- The upper soil layers (1-2 feet) for the most part could be characterized as a dark brown friable clay loam.
- From 2 feet to 4 feet the soils could be characterized as gray clayey silt with reddish mottles and some traces of organics.
- From 4 feet to the bottom of the test pit (typically 7 feet) the soils were mostly light brown coarse sand with some small gravel and silt.
- Groundwater, mottling or seepage was typically observed at fairly shallow depths (3-4 feet) from the surface. This shallow depth to groundwater will dictate the types of BMPs that could effectively be used to manage the stormwater loading associated with Honeoye Inlet (the main stream feeding the lake).

In terms of stormwater management BMP options, these data basically establish that bioretention, created wetland and/or wet meadow type BMPs should function well within this setting. Conversely infiltration and recharge based BMPs will not perform as well.

While the collective desire of the project partners is to implement some type of stormwater management system within the project area, there is also the need to ensure that the recommended stormwater management BMPs would not substantially disturb the wildlife management area or detract from its recreational use. An additional design goal was to use the stormwater management BMPs to improve or expand existing wildlife habitat (aquatic and terrestrial) and restore previously impacted habitat. As such, the stormwater management system designed for the Honeoye Inlet Wildlife Management Area should meet the following project objectives:

- Reduce pollutant loading
- Control and reduce storm flows and flood volumes
- Result in minimal disturbance of the area
- Complement, mitigate or restore existing wildlife habitat
- Accomplish all of the above and enhance the recreational use of the area.

Given the areal expanse of the Wildlife Management Area, it is possible to construct a regional basin capable of managing storms up to and including the 100-year event. However, the hydrologic data shows that in order to do so it would be necessary to significantly regrade, and alter the site. As per the NYSDEC Stormwater Management Manual (2010) the surface area of a stormwater wetland must equal between 1% and 1.5% of the contributing drainage area. This translates to a basin between 112 and 170 acres in size. Additionally, the basin must be able to accommodate at least 25% of the water quality volume (WQv) in deep water zones greater than four feet in depth. To direct flow into the basin an inlet weir or diversion would need to be constructed along the edge of the stream and the basin would need an outlet control structure to ensure that the captured stormwater is detained for the proper amount of time and is released back into the stream at a rate that does not cause downstream flooding or erosion. Finally any berms used to contain the diverted stormwater would need to be engineered to safely pass without failing the 100-year storm. A large regional basin approach is therefore inconsistent with the project's objectives of minimizing impacts to the site's recreational use, maximizing the creation of new wildlife habitat, and complimenting existing wildlife habitat. The cost estimate for a created wetland basin large enough to manage the 1-year (water quality) storm event is between $700,000 and $1,800,000 (2014 dollars) calculated as per Brown and Schueler (1997) and Weiss, et al. (2005). Factoring into this the additional costs of site survey, permitting, bid specifications, contactor selection, contractor oversight and other related costs escalates the price of such a project into the $1,000,000 to $2,200,000 range.

After careful consideration of all of the data and project objectives, it was determined that a better approach involves focusing on reconnecting Honeoye Inlet with its floodplain. As detailed below, this approach minimizes the overall disturbance of the site, while still enabling us to meet the project's pollutant load reduction and habitat creation/improvement objectives and satisfy most of the flood flow control objectives. The recommended approach is also cost-effective, ecologically sustainable, and requires minimal future maintenance.

As illustrated in Figure 6.1, there are four main elements to Princeton Hydro's recommended approach:

- **Floodplain Reconnection** - Effectively raise the existing stream bed thereby causing the stream during periods of high flows to "spill out" in to the adjacent lands. In contrast, in other locations lower the stream bank elevation and create a neighboring 'basin' to capture storm flows that have "spilled out'. Both techniques work in unison to replicate the flood storage functionality of a floodplain.
- **Ditch Plugging** - Fill some of the ditches that run perpendicular to Honeoye Inlet. Again, this will force flood flows out into the adjacent land. The fill used to plug these ditches would be obtained by creating minor depressions along-side the ditches and material excavated to create the basin. These depressions could become vernal pools if flooded long enough during the spring.
- **Lengthen Stream** - Recreate meander and sinuosity in the stream at its more northern end. Use rock grade controls to manage flows, reduce velocity and protect the recreated channel from erosional impacts during periods of higher flows.

- **Backwater Wetland** - Construct a small wetland basin at the north end of the stream to provide additional pollutant removal.

As illustrated in Figure 6.1, the primary element of this plan is the reconnection of the stream to the floodplain. This is accomplished using two different approaches. The first approach involves lowering the stream bank elevation in given locations thus allowing the stream to "jump" its banks during periods of storm flows and flood the adjacent (but presently disconnected) floodplain. In these targeted areas the adjacent floodplain would also be slightly excavated thereby creating a more pronounced depression capable of detaining and storing flood water, essentially acting as a bioretention basin. To prevent the detained flood water from easily returning to the stream, the excavated soils would be used to construct a shallow berm along the backwater edge of the depression. The elevation of the berm is less than the targeted flood elevation of the stream, but greater than the stream's baseflow elevation. Not only does this help detain the trapped flood waters, but this feature facilitates the creation of wetlands within the excavated floodplain depression. The berms would be planted with wet meadow vegetation; vegetation capable of withstanding periodic flooding as well as extended periods of exposure. The depressions would be planted with wetland obligate and facultative species. It is expected that due to the shallow depth to groundwater (seasonal high water table) and the frequency of flooding, the created floodplain depressions will remain inundated or saturated for prolonged periods of time. The trapped flood water will eventually be "lost" via photosynthetic evapotranspiration or via infiltration into the underlying soils. Due to the site's soil properties, the infiltrated flood water will move horizontally recharge and maintain the stream's baseflow, similar to what occurs in a natural floodplain environment.

The second approach to reconnecting the stream to the floodplain involves raising the streambed's elevation in given locations using rock grade controls. Raising the streambed's elevation enables the stream during periods of high flows to jump the banks more frequently and flood the neighboring floodplain. The proposed grade change is accomplished by importing and securely placing and packing large rocks and boulders in the bottom of the stream. Our plan calls for modifying only two sections of Honeoye Inlet in this manner. Each modified area would affect approximately 100 to 150 linear feet of the stream bed. When completed, the rock grade controls will resemble a natural cobble/boulder riffle similar in appearance to sections of Affolter and Bray Gullies. The grade control also facilitates raising the streambed by slowing flows and promoting bedload accumulation. To maintain longitudinal ecological connectivity, the rock grade controls will be designed to ensure the continued baseflow passage and mobility of fish and other aquatic organisms.

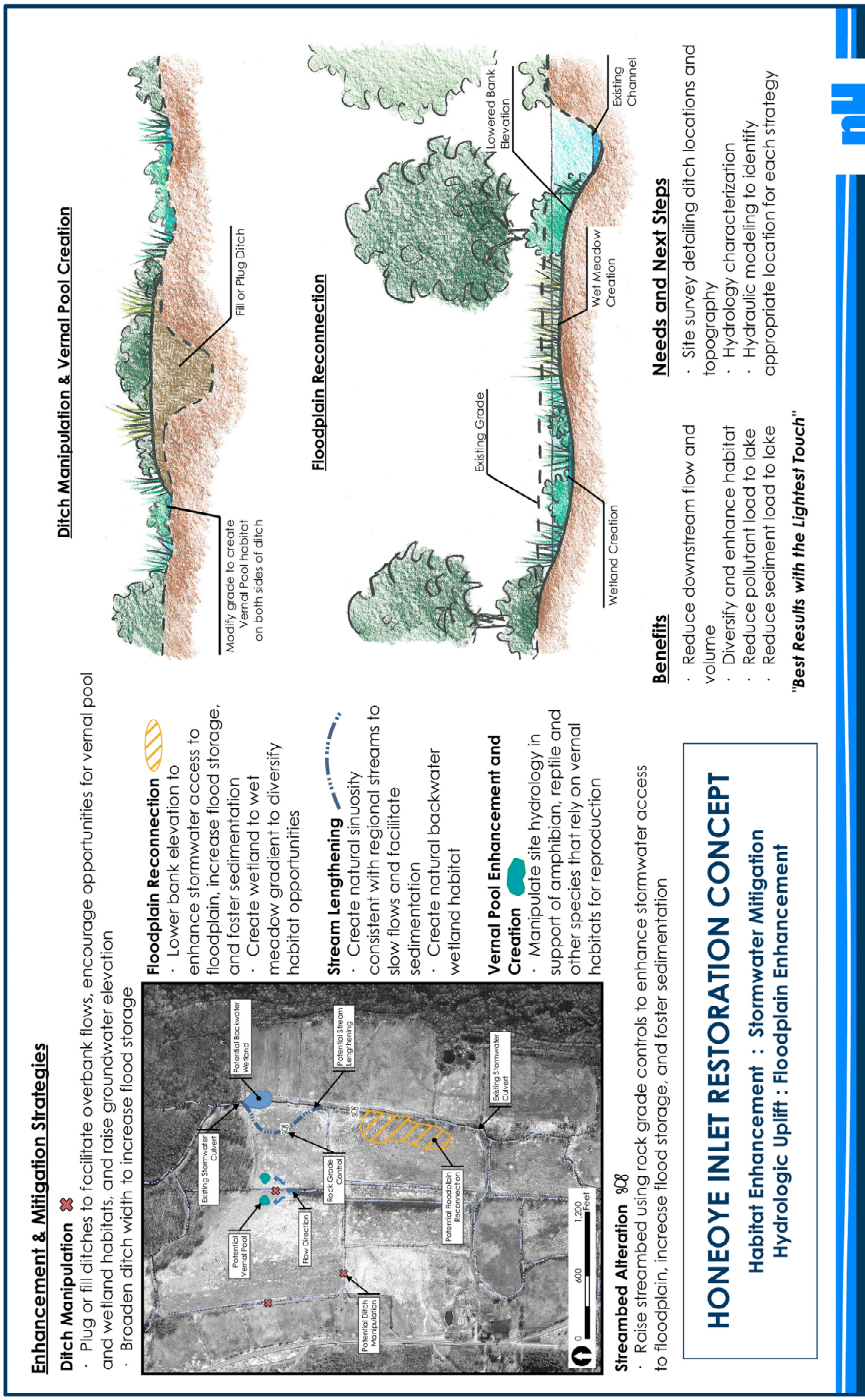
It is important to use these two stream channel modifications in tandem. Honeoye Inlet is presently significantly incised and no one single approach will facilitate floodplain reconnection while minimizing overall site disturbance. We have utilized both techniques in concert to meet similar watershed management goals. Our project experience shows that this floodplain reconnection approach is less costly, results in less overall disturbance and is more stable as compared to raising the streambed using soils excavated from the adjacent land or creating a new, shallower stream channel. With this approach all four of the project's primary objectives are met: flood attenuation, pollutant removal, habitat creation and increased passive recreational opportunities. Additionally, as compared to the creation of a large regional stormwater basin or a major realignment of the stream, there is far less disturbance of the Honeoye Inlet Wildlife Management Area, and the resulting stormwater management system blends in better with the overall existing aesthetics and habitat properties of the site.

It should be noted that consideration was given to the creation of an entirely new channel and associated floodplain. The existing stream is channelized, linear and, as noted above, incised. Thus the concept of creating a new, shallower and broader stream channel with greater sinuosity is therefore a well-founded idea. However, this approach is cost prohibitive and creates a significantly larger disturbance footprint than the proposed alterations of the existing channel. It would still be necessary to import a large amount of rock to help stabilize the new channel, especially at each new bend. Consequently, Princeton Hydro determined that the approach recommended herein, that is intended to gently guide and "persuade" the stream into a new natural, stable state meets the project's overall goal and objectives in a less invasive and less costly manner.

The modification of the stream channel and adjacent floodplain areas will require close coordination with the NYSDEC with respect to permits and approvals. Specifically a "Protection of Waters Permit" is required for disturbing, either temporary or permanently, the bed or banks of a stream, including those such as Honeoye Inlet with a "C" classification. The OCSWCD can assist with the NYSDEC Notice of Intent and provide guidance, based on their local experience and expertise, to ensure that these changes are implemented in a manner that minimizes or prevents construction related soil erosion and soil compaction impacts.

It should be noted that a similar approach has been proposed for the Owasco Flats Wetland Restoration and Riparian Buffers Initiative (Cayuga County). That project also calls for the reconnection of a channelized stream located in a historically farmed area with an adjacent recreated floodplain and wetland areas (NYS Environmental Facilities Corporation).

Figure 6.1 Stormwater Management Concepts for the Honeoye Inlet Wildlife Management Area



The second element of this stormwater management plan involves the selective plugging of a few of the ditches and channels running perpendicular to Honeoye Inlet. Some of these ditches convey runoff from both County Road 36 (West Lake Road) and East Lake Road to Honeoye Inlet. Our plan focuses on plugging two or three ditches on western side of the site. Again, we have successfully used this approach to manage stormwater runoff, especially in headwater areas. While, once again, the concept is grounded in the reconnection of the stream and its floodplain, as compared to the management of flows in Honeoye Inlet, the ditches convey far less volume and the flows also tend to be more storm-event driven and seasonal in nature. The overall approach is relatively simplistic. Basically, depressions would be excavated in an area adjacent to a ditch and the soil used to fill the ditch. During storm events the runoff flowing through the ditch will encounter the earthen “plug” and be forced into the created adjacent depressions as well as the microtopography already present at the site. Because the majority of the flows conveyed by these ditches occur during the spring-thaw, it is very possible that the created depressions could become vernal pools providing habitat for amphibians, reptiles and other species that rely on vernal habitats. Planting of these areas with appropriate species would enhance their vernal habitat properties (Kenney and Burne, 2000). Similar to the reconnected stream/floodplain effort, the ditch plugging creates habitat while controlling flows and reducing pollutant loading to the lake.

The third element of the project entails the lengthening of the northern end of the Honeoye Inlet stream channel within the proposed project area. The objective would be to restore some of the natural sinuosity of the stream and eliminate in part the channelized nature that characterizes the stream as it passes through the Honeoye Inlet Wildlife Management Area. This would be accomplished by the actual re-grading of the stream channel. Excavated soil would be used in part in the recreation of the stream and possibly to conduct some of the aforementioned ditch plugging. Rock grade controls would be used to help further manage storm flows and velocities thereby protecting the recreated stream channel from subsequent erosion and down-cutting. The amount of recreated sinuosity would be in keeping with that observed in the headwater areas of the inlet and the other streams that drain to Honeoye Lake. The design would be backed by hydrologic and hydraulic data and be conducted in a manner consistent with standard stream restoration practices (Shields, et al., 2003).

The fourth and final element of the proposed concept involves the creation of a relatively small (3-5 acres) created wetland basin. The basin would be constructed at the far northern end of the Honeoye Inlet, just before it becomes the braided, forested wetland that is within the proposed project area. The primary function of this basin would be pollutant removal and secondarily, flow attenuation. Rather than be on-line, the created wetland would be an off-line, backwater area strategically located to receive flows from the downstream culvert crossing. It would be flooded during storm events, but remain flooded by its direct connection to the stream and by excavating it to the depth of the seasonal highwater table. The created wetland basin augments the habitat value of the adjacent forested wetland area, while in-part controlling flows and reducing pollutant loading to the lake.

Again all of the project elements listed above will likely require a “Protection Of Waters Permit” due to the disturbance of the bed or banks of Honeoye Inlet and the smaller contributing tributary ditches. Additionally the disturbance of any existing wetlands will likely trigger the need for Army Corps of Engineers and NYSDEC wetland permits.

6.2 Stormwater Management Options for Other Subwatersheds

While the focus of this study was to examine stormwater management options that could be implemented within the Honeoye Inlet Wildlife Management Area, an assessment was conducted of how to address runoff and stormwater loading impacts associated with the lake's other subwatersheds. Past studies of the lake conducted by Princeton Hydro (2007) and Bin Zhu (2012) quantified the pollutant load generated by each of the lake's nine subwatersheds. Sampling conducted by the HLWTF volunteers measured the concentration of nutrients and sediments transported into the lake during storm events (Starke 2003, 2004). Also, a 2012 detailed assessment of the streams and inflows to the lake completed by the Ontario County Soil and Water Conservation District (OCSWCD) located and inventoried erosion and scour impacts in each of the tributaries that drain to the lake. Each of these studies made it clear that watershed management is needed in some capacity, whether to stem pollutant loading to the lake or ameliorate chronic and acute erosion problems.

In Section 5, the top five subwatersheds contributing the greatest and most manageable pollutant loads were identified. The normalized pollutant loading data (Table 5.4) were used to determine which subwatersheds are contributing a disproportionate load per unit area. The top three ranking subwatersheds are: Northwest (1), Affolter Gully (2) and Cratsely Gully (3), all of which are located along the lake's western shore. The fifth largest contributor is the Northeast subwatershed (8). While the Honeoye Inlet subwatershed (4) has the highest total load, these other four subwatersheds have greater per-unit-area loads. This is a function of the more residential nature of these four subwatersheds as compared to the lake's remaining subwatersheds. Combining the loading data presented in Table 5.3 (actual) and Table 5.4 (normalized), the lake's subwatersheds with the greatest stormwater management net return on the investment are Subwatershed 1 (Northwest), 2 (Affolter Gully), 3 (Cratsley Gully), and 7 (Bray Gully). In keeping with the project's scope of work, a list of BMPs are provided herein each having the ability to effectively manage the estimated pollutant loads generated by each of the top contributing subwatersheds. As will be discussed below, the majority of these BMPs should also prove effective in managing the loading generated from the lake-side developed portions of the other subwatersheds.

Princeton Hydro also evaluated the possibility of constructing basins or installing manufactured treatment devices (MTDs) along the major roadways servicing the Honeoye Lake watershed. We know from our survey of the watershed that the existing stormwater infrastructure is designed basically to move runoff as quickly as possible from the watershed into the lake. Consisting mostly of road side swales and a few scattered catch basins, the stormwater collection systems running along Route 37, West Lake Road (Route 36) and East Lake Road offer little opportunity for any major retrofits. Although it would be ideal to manage the road runoff from the surrounding watershed using large structural BMPs such as extended detention basins or retention ponds, the construction of such BMPs is not feasible due to the lack of available public land and constraints caused by the topography of the watershed, shallow depth to bedrock and the aforementioned design of the existing stormwater collection system (or lack thereof). Basically, the right-of-ways are too narrow, the flows too great and the depth to bedrock too shallow to facilitate the construction of regional basins or even the installation of any sizable MTD. The east/west cross-roads that connect to these major thoroughfares (e.g., Cratsley Hill Road, Jersey Hill Road and Wesley Road) are also too steep and have minimally developed piped stormwater networks and little publicly owned lands that would facilitate the construction of basins or the installation of MTDs. Steps have been taken by Ontario County to mitigate bed and bank erosion in some of the streams before they drain to Honeoye Lake. For example, the Affolter Gully stream channel was recently armored with rip-rap and a few catch basins and drainage pipes installed to better manage roadside runoff. Such projects should be continued. As documented in Table 5.3, these smaller subwatersheds (especially Subwatersheds 1, 2, 3 and 8) are individually and collectively important sources of erosional and sediment loading to the lake. Our findings are in keeping with the OCSWCD (2012) conclusions, the sampling results of the HLWTF, and as reported by Zhu (2009). The significance of the erosional and sediment loading impacts attributable to these subwatersheds are even more evident upon review of the normalized loading data (Table 5.4). While we support the stream stabilization efforts of the County, we suggest that larger rock be used and channel armoring be conducted in accordance with stream restoration protocols as opposed to swale maintenance practices.

Therefore, based on the generated data, our inspection of the watershed and our review of past studies, the cost-benefit ratio of any large-scale retrofits of the Honeoye Lake stormwater collection system is too high to make such projects feasible. Also for the reasons stated above, it is unlikely that much could be done to modify the existing stormwater collection system to significantly reduce nutrient loading to the lake. Additionally, referring to Figure 5.1, only 10% of the stream flow is a function of stormwater runoff, and as per Table 5.3, these smaller subwatersheds account on an individual basis for no more than 10% of the lake's annual phosphorus load (whereas 47% of the annual external phosphorus load is contributed via the Honeoye Lake Inlet, Subwatershed 4). Thus, instead of relying on larger regional BMPs, emphasis will have to be given to smaller, site-specific, Community Based Initiatives.

6.3 Community Based Initiatives

The following recommendations are considered Community Based Initiatives. Most are homeowner directed stormwater management measures that can be implemented throughout the entire Honeoye Lake watershed. While **Fertilizer and Pesticide Management** and **The Preservation or Restoration of Lake-side and Stream-side Riparian Buffers** would be most successful if supported by local ordinances, these measures can be pushed along through active public education and outreach. Small foot-print BMPs such as **Vegetated Swales, Rain Gardens**, **Alternative Landscaping** and similar techniques are intended to intercept and treat runoff on a lot-specific basis. Admittedly, it is difficult to accurately quantify the pollutant reductions or the amount of flood control that could be achieved through each of these measures. However, if done on a community-wide scale they will reduce nutrients and sediments reaching the lake.

Fertilizer and Pesticide Management - Integrated pest management (IPM) is a common sense, but technically well-structured approach to the use of fertilizers and pesticides. Although more commonly associated with large intensive use areas such as golf courses, public parks, and ball fields, it can be implemented at the homeowner level. Central to the success of IPM is the use of environmentally friendly methods to maintain pests below defined damage levels. Unfortunately, a considerable amount of over application of pesticides and fertilizers occurs during the routine care of residential lawns. Homeowners often operate under the assumption that if "a little is good, more is better". This leads to the over-application of products and an increased potential for off-site transport of pesticides and fertilizers. By applying only the quantity of fertilizer necessary for optimum plant growth, the amount that potentially can be mobilized and transported to surface and groundwater resources is minimized. Not only is this good for the lake, but will save the homeowner money. Thus, homeowners and lawn care services should be educated regarding proper lawn maintenance.

Even more important for Honeoye Lake is the use of non-phosphorus fertilizers or slow-release nitrogen fertilizers as these products actually decrease nutrient loading to the lake. Fertilizer applications must also be timed properly to account for plant needs and to anticipate rainfall events. For example, nutrients are most needed in the spring and fall, not throughout the summer. Also, rain induced fertilizer losses are greatest immediately following an application because the material has neither become adsorbed by the soil nor taken up by the plants. Fertilizer uptake and retention is promoted by proper soil pH. A detailed survey of homeowners in Virginia commissioned as part of the Chesapeake Bay Initiatives, found that less than 20% tested their soils to determine whether fertilization was actually necessary. Although soil pH can have a significant bearing on the ability of soils to retain nutrients, such testing is not commonly conducted by homeowners. The application of lime can improve phosphorus uptake and retention. Other non-chemical lawn care treatments such as de-thatching and aeration are also rarely conducted. Urban soils, even those associated with lawns, can become compacted and function almost no differently in respect to the generation of runoff than impervious surfaces. Aerating lawns helps promote better infiltration and the generation of less runoff.

An additional means by which to decrease fertilizer and pesticide use and the subsequent transport of these pollutants to Honeoye Lake is through the creation of shoreline aquascaped buffers. Where appropriate, the use of native plants or plants that have lower irrigation needs than typical suburban lawns needs to be promoted. These can be relatively narrow (10') and should be planted with wet-tolerant, native plants. Depending on the amount of light exposure this can include such plants as bulrush, spike rush and button bush (within the water), blue flag iris, cone flower, black-eye Susan, red-osier dogwood, and a variety of other attractive, easily to maintain species that do well in "soggy" soils. Guidance pertaining to the creation of aquascaped shorelines is readily available through North American Lake Management Society (NALMS), Connecticut Department of Environmental Protection (CTDEP) and the University of Connecticut.

Preservation or Restoration of Lake-side and Stream-side Riparian Buffers - Over 84% of the Honeoye Lake watershed is forested and/or consists of some type of land cover identified as either water or wetland. With the exception of the lands directly adjacent to the lake, overall development pressure over the past 2-3 decades has been fairly low. Given that forested lands generate the lowest surface runoff pollutant loads and wetlands can actually assimilate nutrients and other pollutants, measures that limit watershed disturbance and loss of additional forested lands need to be supported by the community.

The majority of development in the watershed is focused along the shoreline. With increasing shoreline development came the destruction of the critical buffer zone which exists between the open water of the lake proper and upland habitats. This buffer zone provides vital functions in terms of habitat for aquatic and terrestrial organisms and nutrient attenuation through vegetative uptake. Furthermore, this area is dually stressed as the now denuded habitat is burdened with increased nutrient pollution associated with lakeshore housing through pet wastes, fertilizers and erosion. As such, restoration of lakeshore buffers will serve to not only increase habitat for amphibians, birds, invertebrates, etc., but also serve to assimilate pollutants from non-point sources. Steps can be taken to re-vegetate these critical zone utilizing native, low growing plants that provide ecosystem function while still maintaining site lines for the lakeshore residents.

In addition to the preservation of lakeside buffers it is critical to maintain the integrity of buffers surrounding the streams and gullies which feed Honeoye Lake. This is particularly crucial in this watershed given the steep relief which allows for accelerated erosion and subsequent transport of sediments and pollutants to the lake.

Use of Alternative Landscaping - Utilizing alternative landscaping is a preventative pollutant load management technique that when properly implemented can reduce the need for the repeated fertilization of lawns, decrease the rate or frequency of pesticide applications and decrease irrigation requirements. Especially for the homes bordering the lake, homeowners should be encouraged to allow nature to take its course along the water's edge. Focus should be placed on maintaining natural ground covers in lieu of manicured lawns, and supplementing areas having sub-optimal ground cover with selected plantings. By utilizing a combination of design, plants and mulches, homeowners and landscapers can create a landscape that decreases maintenance, is aesthetically pleasing and is environmentally suited to the area.

Rain Gardens, Vegetated Swales and On-Site Stormwater Management - By now the general public is fairly aware of what are rain gardens and their benefits. In general, rain gardens are relatively small vegetated depressions that function as mini-biofilters or bioretention basins. They are used most often to treat roof top runoff that would otherwise simply sheet flow across a lawn or down a sidewalk. They can also be used to treat the runoff from driveways, patios or any other hardscape. Rain gardens are more than a simple planted landscaped feature. Their proper construction entails the use of sand mix subsoil that has the ability to infiltrate the collected runoff. The plant material is also selected for its tolerance for periodically wet conditions, but perhaps extended period of dry conditions. When properly planted and constructed, a rain garden can control the peak flow of runoff, reduce the volume of runoff and reduce pollutant loading, while at the same time serving as a low-maintenance, attractive amenity. A lot of the same grasses, flowering plants and shrubs used to create an aquascaped shoreline such as cone flower, black-eye Susan, red-osier dogwood, switch grass, winterberry holly and New England aster can be used in a rain garden. The ultimate plant selection is a function of the amount of runoff being captured, the infiltration rate of the soils, the amount of shade and the owners own preferences.

Chapter 5 of the NYSDEC Stormwater Management Manual (NYSDEC, 2010) provides design criteria for rain gardens. Other excellent links to documents for home owners interested in creating a rain garden are available through the NYSDEC (**www.dec.ny.gov/public/44330.html**), the University of Connecticut (**http://nemo.uconn.edu/publications/rain_garden_broch.pdf**) and via the Rutgers University web site: njaes.rutgers.edu/environment/raingarden-manual.asp**.** A community based rain garden initiative conducted by the Town of Coventry, CT is summarized in a layperson friendly, downloadable document with multiple illustrations: http://www.thamesriverbasinpartnership.org/acrobat_files/Coventry%20Rain%20Garden%20Demonstration%20Project.pdf. Ontario County also provides guidance regarding erosion control for single family dwelling construction, an often overlooked source of sediment: **http://ontswcd.com/Miscellaneous/SOIL%20EROSION%20CONTROL%20FOR%20SINGLE%20FAMILY.pdf**

Vegetated swales are shallow depressions that can be used to convey and treat stormwater runoff. Depending on the depth to groundwater such swales may also aid in the infiltration of the captured runoff. Vegetated swales perform best when used on minimally sloped (<3%) land or when constructed perpendicular to a slope. The amount of pollutant removal attained with these features is a function of slope, swale length and the roughness and composition of the vegetation.

6.4 Curtis Road Subdivision

Concern has been raised, based on recent HLWTF and OCSWCD sampling data that the townhouse subdivision located along Curtis Road in the Affolter Gully subwatershed (Subwatershed 2) is generating a substantial NPS pollutant load. There is an opportunity in this section of Subwatershed 2, because of the prevailing terrain and the availability of County land, to potentially construct a bioretention basin that could treat the runoff from this development. However before the construction of a basin is even contemplated it is highly advisable that a monitoring program be implemented to determine whether the source of the measured elevated pathogen and nutrient concentrations is due to the development's communal septic field or is due to stormwater runoff from the site. Appropriate data could be obtained by sampling a few shallow, groundwater monitoring wells. These wells would be installed up-gradient and down-gradient of the development's communal septic system. The routine (quarterly) sampling of those wells should yield enough data to determine whether the septic field is functioning properly and whether it is a major source of pollutant loading. Similarly, stormwater samples could be collected from the roadside ditch running parallel along Curtis Road, sampling upgradient and down gradient of the subdivision. The combination of the well and stormwater data could then be used to assess whether there is any major water quality benefit of constructing a bioretention basin to manage the site's stormwater runoff.

On a relative scale, the cumulative amount of impervious cover associated with this subdivision is relatively minimal, even when the entire contributing catchment area is taken into consideration. As based on a GIS delineation of the land area encompassing the development and adjacent contributing lands, the total landmass encompassing the development's drainage area (houses, driveways, lawns, septic field and adjacent woodlands) totals 61.3 acres, of which only 3.6 acres is impervious and 20 acres is mapped as lawn. Using this areal value in applying the *MapShed* pollutant loading coefficients to this 61.3 acre drainage area, the development's storm related phosphorus load is only in the range of 10-20 kg/yr, or approximately only 2-4% of the subwatershed's total annual phosphorus load.

If it was determined that the development's runoff should be treated and managed, this would be best accomplished using on-site, small foot-print bioretention stormwater management techniques similar to those recommended for the nearshore areas adjacent to the lake and for Subwatersheds 8 and 9. An additional on-site option includes allowing the lawn to grow into a meadow, mowing only twice a year. However, as noted above, because of the availability of County owned lands, stormwater management could also be accomplished off-site using the combination of a roadside vegetated swale and a bioretention basin. Chapter 5 of the NYSDEC Stormwater Management Manual (NYSDEC, 2010) provides design criteria for vegetated swales and bioretention basins.

The off-site management of the development's stormwater runoff could be accomplished as followed. At the base of the driveways leading into the development a vegetated swale would be constructed along the western edge of Curtis Road, within the roadway's right-of-way. As the runoff exits the site it would be collected in the swale and then conveyed down gradient towards the north. Approximately 500' north of the development, on the eastern side of Curtis Road, there is a parcel of County owned land. Although this lot is partially wooded it could be cleared and regraded and a bioretention basin constructed within this area. The sizing of the bioretention basin will be predicated on the runoff volumes and runoff rates conveyed from the development and the runoff from the sections of Curtis Road intercepted by the swale. The basin would need to be sized to manage the water quality event generated from the entire 60+ acre subwatershed. It will also need to be capable of safely controlling and passing the 100-year storm.

Based on the size of the development's delineated drainage area, we expect the basin to be at least one (1) acre in size. Depending on the hydrologic and physical properties of the native soils and the soil's organic content, it may be necessary to import a suitable bioretention soil mix. The soil mix needs to have enough porosity (dictated by sand content) to facilitate the infiltration of the captured runoff, but enough organic content to enable the establishment of proper vegetative cover. Depending on the depth to bedrock or seasonal high water table it may also be necessary to design the basin with an underdrain to prevent the prolonged ponding of water. The basin's outlet structure will need to ensure the proper detention of the runoff generated by storms up to and including the 100-year event. Outfall scour protection will need to be provided at the point of the basin's discharge into the stream to ensure that as the detained runoff is routed back into the stream it does not cause or exacerbate downstream erosion problems.

7.0 Cost Projections for the Recommended Honeoye Inlet Wildlife Management Area Stormwater Management Measures

Within this section of the report cost estimates are provided for each of the stormwater management measures recommended for implementation within the Honeoye Inlet Wildlife Management Area. The cost estimates that follow reflect the complete cost to finalize project designs, prepare construction plans and specifications, prepare NYSDEC application materials, implement the proposed stormwater management/ habitat creation measure and provide contractor oversight. The PRedICT module of *MapShed* includes a cost estimating tool that was examined and evaluated as part of this project. Given the assumptions needed to run the module, it was determined that PRedICT would not yield representative cost estimates. Therefore, the cost estimates are based on Princeton Hydro's past experience in conducting restoration and stormwater management projects of this nature and the prices provided herein reflect regional construction cost estimates. Finally, it must be emphasized because the cost-estimates are based on concepts and not detailed construction plans and specifications, while realistic they cannot be assumed to be definitive or final.

Also, please note that with respect to the site's topography, although the available LiDAR data was suitable for the purposes of concept development, it is no substitute for detailed site survey data. TNC should assume the need to develop detailed site survey data in advance of finalizing project designs and making any site improvements. Given the areal expanse of the Honeoye Inlet Wildlife Management Area and the need for survey data capable of identifying the site's micro-topography (1-foot contour intervals), $80,000 - $100,000 should be allocated for the preparation of a detailed site survey.

Floodplain Reconnection and Stream Grade Changes – The total cost of this element of the project is estimated to be in the range of $880,000. This is the largest and most significant project proposed for the Honeoye Inlet Wildlife Management Area. This project meets the habitat creation, stormwater management, and pollutant load reduction goals, while minimizing the amount of total site disturbance. Referring to Figure 6.1, the proposed Floodplain Reconnection and Stream Grade Changes require both "shaving down" portions of the existing stream bank and, in two locations, raising the base elevation of the existing stream bed. This will essentially cause the stream during periods of high flows to "spill out" into the adjacent lands. This is the best and most effective way of managing the runoff generated from Honeoye Inlet subwatershed and decreasing its pollutant load to the lake. Reconnecting the stream and the adjacent lands through using this combination of stream bank shaving and stream bed grade controls essentially mitigates the existing down cutting and channelization of the stream while restoring the functionality of the stream's floodplain. Compared to excavating and re-grading a new stream channel, this approach also greatly minimizes the amount of site disturbance that would be needed to achieve the same effect. Again we need to stress that the elevation of the southern culvert in the project area largely dictates the elevation of the stream bed, which in turn dictates the elevational changes that are needed to reconnect the stream and the floodplain.

As discussed above, to construct the two proposed grade controls and achieve the desired increase in stream bed elevation some amount of rock will need to be imported. The creation of the two grade controls (material and labor) represents less than 20% of the total project cost ($163,000). The majority of the cost is associated with the labor associated with the regrading of the new "floodplain" ($590,000). We have factored into the cost of the floodplain's reconstruction the importation of some organic material (rotted leaf litter) that may be needed to promote the quick reestablishment of plant cover within the re-graded floodplain corridor. The up-front costs associated with final design, plan and specification preparation and construction oversight was calculated to be in the range of $175,000.

Again referring to Figure 6.1, the restored floodplain corridor will run the length of the stream channel (east and west banks) for a total length in the range of 1,000 feet (essentially from the southern culvert to the primary grade control). Site regrading of the stream corridor will be dictated by existing topography. As noted above, this will necessitate detailed site survey data. Our concept assumes that the re-grading of the lands adjacent to the stream will be limited to a width of approximately 100 feet on either side of the stream channel. We have assumed a "cut" approximately two feet in depth. The cut material can be used as part of the ditch plugging effort or used otherwise on site as part of the new floodplain's creation. The two in-stream grade controls, created with the imported rock, are each 100 feet in length. The amount of rock that will be needed is totally dependent on the width of the stream and its depth at each location where the grade controls are created. For our purposes we have assumed that each grade control structure will require 2,000 yds^3 to create; this is a very conservative (high) material estimate.

Ditch Plugging – The ditch plugging element of the project involves filling some of the ditches that run perpendicular to Honeoye Inlet. Referring to Figure 6.1 we identified three (3) possible locations within the ditch network on the western side of the site where ditch plugging could be conducted. The total cost to conduct the plugging of theses ditches totals $7,500. The cost associated with the ditch plugging again was conservatively estimated, but does cover all construction, material and upfront engineering and permitting costs.

As noted in the Section 6, for the Honeoye Inlet Wildlife Management Area this is the easiest and most cost effective means of both managing stormwater runoff and creating new habitat. As with the reconnection of the stream's floodplain, the goal of the ditch plugging is to force flood flows out into the adjacent land. The fill used to plug these ditches would be obtained by creating minor depressions along-side the ditches. These depressions could become vernal pools if flooded long enough during the spring. Alternatively, the fill material as noted above could be obtained from the above floodplain recreation project. Overall, we have estimated that each "plug" will require the use of approximately 600 – 700 yds^3 of onsite material. With the exception of some minor regrading of the adjacent areas and perhaps some reseeding the majority of the cost is associated with creating the channel plugs.

Lengthen Stream and Recreate Sinuosity – Another element of the overall plan involves recreating some stream sinuosity in order to mitigate past channelization impacts. Referring again to Figure 6.1, the proposed plan calls for introducing a meander at the northern end of the stream. The total cost for this element of the project is $170,000, which is inclusive of all of the final engineering design costs, preparation of construction specifications and permit application materials, as well as construction labor and material costs and construction oversight.

The majority of the cost associated with this element of the project (approximately $155,000) pertains to the actual excavation of the new segment of stream channel. We have assumed that all excavated materials will be retained on site and used to re-fill the existing channelized segment of the stream channel. The plan does not require filling the abandoned channelized section of the stream to the same elevation as the surrounding lands. Thus we are not calling for the importation of any soil material for this purpose. If necessary, some of the soil excavated during the recreation of the floodplain could also be used to refill the abandoned channel segment.

However, there will be the need to import stone that will be used to basically block the southern end of the abandoned channel. The imported rock will be used to create the grade controls needed to divert flows into the new channel and to reduce stream velocities to further protect the recreated channel from erosional impacts during periods of higher flows. We have not factored into our restoration plan the use of any large trees; however their presence will be important in bank armoring. The majority of the stabilization of the new stream channel will be accomplished using bioengineering techniques (dictated in part by the projected flow rates and velocities) that rely more on seeding, plugs and perhaps some live stakes to vegetate the newly created stream banks. The revegetation of the filled, abandoned channel will be by means of seed and any volunteer plants that colonize the area upon project completion. We feel that there is an ample seed bank in the soils that will be moved from the other areas of the site to facilitate the rapid stabilization of the filled channel. However, the OCSWCD may impose different revegetation and stabilization standards.

Finally, with respect to the cost of this project, we have not factored into the design or cost the creation of fish, aquatic fauna or avifauna habitat. We recognize that this is another opportunity for the NYSDEC or TNC to increase the area's habitat diversity or create habitat for specific species. Doing so would add some additional cost to this project's total.

Backwater Wetland Basin – The final element of the project involves the construction of a small wetland basin at the far northern end of the stream. The purpose of this basin is to provide an opportunity for additional pollutant removal. This is not a "flow through" basin. Rather, it is a backwater design that functions as a stormwater polishing system only during periods of higher flows during which stream flow would back up into the basin. The basin's construction is rather simple involving limited regrading that would be conducted in concert with the stream meander project discussed above. The basin's construction does not involve the construction of an inflow or outflow control structure or the installation of any grade controls. Inflow and outflow from the basin will be dictated by stream elevation and flow. The basin itself was projected to encompass between 1 -2 acres in total area. The cost to construct this basin is projected to total $60,000, inclusive of all of the final engineering design costs, preparation of construction specifications and permit application materials, as well as construction labor and material costs and construction oversight. The cost assumes that once constructed the basin will be colonized by plants from the adjacent wetland areas. That is, no supplemental planting is being proposed as part of the basin's creation. Additionally, as is the case with the new stream meander we have not factored into the design or cost the creation of fish, aquatic fauna or avifauna habitat.

Curtis Road Bioretention Swale and Basin - The costs to construct these stormwater management features should be relatively low assuming that the work will be conducted by County personnel. The swale itself is largely in place and simply needs to be expanded and replanted. We expect the need to place stone at the point where runoff enters the swale from the two driveways. This will control any storm scour. There may be the need to install an underdrain along the base of the swale to promote the evacuation of the swale between storm events. The expanded swale will need to be lined with jute matting or similar material to prevent its erosion during the growing-in phase. A wet-tolerant seed mix should be used to vegetate the swale. *The swale should be mowed no more than once annually and to a height of no less than 8".* The projected cost to implement this element, including the installation of the underdrain, is $8,000.

The swale will need to connect to a catch basin and pipe system that will collect the runoff from the swale and convey it under Curtis Road to the bioretention basin. The dimensions of the bioretention basin will be predicated on the computed flows generated from the contributing watershed area. The basin itself, while designed to treat the runoff generated by the 1-year event, will need to be able to manage all storms up to and including the 100-year event and be able to safely pass flows exceeding the 100-year event. Although the creation of this basin will largely involve the clearing of the existing vegetation and then the excavation of the native soils, there will be significant costs associated with the construction of the basin's inlet and its outlet control structure. Based on the properties of the existing soils there may be the need to import soils having better permeability and biotreatment properties than provided by the native soils (refer to the 2010 NYSDEC BMP Manual for a specification). The importation of such a soil mix could significantly add to the overall cost. Also depending on the depth to seasonal highwater or any restrictive horizons it may be necessary to include an underdrain in the basin's design. Finally, erosion control will need to be provided at the discharge point of the basin into the stream to prevent downstream scour and erosion. While there are many unknowns associated with this basin, based on our past experience, it should be possible to construct this basin (including the crossing under Curtis Road) for approximately $150,000.

8.0 Load Reduction Projections Associated with the Recommended Honeoye Inlet Wildlife Management Area Stormwater Management Measures

The two overarching goals set by TNC and HLWTF for this project are: decrease pollutant loading (primarily phosphorus and sediment) to Honeoye Lake, and increase the habitat quality and diversity of the Honeoye Inlet Wildlife Management Area. Decreasing phosphorus and sediment loading specifically addresses the objectives of the HLWTF and the NYSDEC to control Honeoye Lake's rate of eutrophication and the associated negative consequences of eutrophication, in particular algae blooms. TNC and NYSDEC also recognize that focusing on the Honeoye Inlet Wildlife Management Area provides a unique opportunity to both manage the runoff and loading generated from the lake's largest subwatershed while reshaping and restoring the ecological attributes of this site. Through this project the HLWTF, using the updated and expanded watershed's nutrient loading database, are also able to identify other subwatersheds having the greatest pollutant loading impact on the lake.

As per Table 5.5, in addition to subwatershed 4 (which includes the Honeoye Inlet Wildlife Management Area) the four subwatersheds with the greatest manageable pollutant loads were 1 (Northwest), 2 (Affolter Gully), 3 (Cratsley Gully) and 8 (Northeast). For the Honeoye Inlet watershed and these four subwatersheds, recommendations were developed regarding how best to effectively manage or mitigate the sources of the computed pollutant loads. In our scope of work we proposed to place emphasis on the use of bioretention type BMPs given their high propensity for the removal of nutrients and sediments, the two major types of pollutants affecting the lake's rate of eutrophication and overall water quality. However, due to topographical, ownership and existing land use and land development restrictions, the construction of regional bioretention basins was found to be neither practical nor possible. Rather, with the exception of a basin proposed in the headwater section of the Affolter subwatershed, the best approaches for decreasing the sediment and nutrient loads of Northeast (1), Affolter (2), Cratsley (3) and Northwest (8) subwatersheds involves stream stabilization, the use of lot-specific rain gardens, vegetated swales, the maintenance or restoration of stream buffers and the implementation of source control measures such as reduced fertilizer use. Details of these recommendations are provided in Section 6 of this report.

The load reductions achievable through the implementation of these types of measures are not easily computed as there are too many site specific variables that affect the performance of these techniques. As such, our load reduction analyses are limited to the assessment of the performance measures proposed for the Honeoye Inlet Wildlife Management Area. We attempted to compute these reductions using the *MapShed* PRedICT (Pollution Reduction Impact Comparison Tool) module. Upon our completion of this project we found that it was not feasible to use PRedICT, or even STEPL, to analyze the pollutant removal achievable through the proposed Honeoye Inlet Wildlife Management Area load reduction measures. This was largely due to two main reasons:

1. The module is designed primarily to be used in an agricultural watershed where non-structural, agricultural BMPs are being utilized to reduce pollutant loading, and
2. None of the BMPs proposed for use in the Honeoye Lake watersheds meet the model's use "scenarios".

With respect to the latter, when dealing with "urban BMPS" PRedICT only allows for the analysis of the load reductions achieved through the use of detention basins, bioretention areas and created wetlands (referred to in the manual as urban BMPs). Table 9 of the PRedICT User's Manual (Evans, et al., 2008) identifies the percent load reductions for each of the urban BMPs as follows:

Table 8.1 PRedICT Load Reduction Coefficients for Urban BMPs			
	Sediment	**Phosphorus**	**Nitrogen**
Detention Basin	93%	51%	40%
Constructed Wetland	88%	51%	53%
Bioretention Area	10%	61%	46%

There are no assigned load reduction coefficients for the ditch plugging, floodplain reconnection or even the back water wetland basin. Additionally, none of the BMPs proposed for the Honeoye Inlet Wildlife Management Area are on-line systems. That is, none of them have defined inlet/outlet structures and they are not designed to detain captured runoff for a specified amount of time. However, while it is not possible to directly utilize the model to compute load reductions, it is possible to apply the removal efficiencies manually, with some assumptions, to arrive at the load reductions likely achievable through the implementation of the ditch plugging and floodplain reconnection elements. In essence, the ditch plugging and floodplain reconnection creates a wetland-type habitat; consequently, the following removal efficiencies are based on constructed wetland systems.

First, the ditch plugging and floodplain reconnection elements will treat most, but not all of the runoff generated from Subwatershed 4. There is a portion of the far northern end of the subwatershed and portions of the eastern side of the subwatershed that do not drain directly into Honeoye Inlet or sheet flow across that lands that will be affected by the ditch plugging. This is largely inconsequential as most of these "untreated/unmanaged" lands are minimally developed and drain to forested wetland before reaching Honeoye Lake.

Second, as detailed in Section 5.3, 1-year (water quality) events are responsible for over 70% of the lake's total pollutant loading. As such, from the perspective of pollutant load reduction, BMPs sized to manage the 1-year event should have the greatest effectiveness. For comparative purposes Table 8.2 presents the Honeoye Inlet, **1-year (water quality) event** and the **total annual loads** projected by *MapShed* to be transported into the lake.

Table 8.2 – Honeoye Inlet (Subwatershed 4) Loading		
Pollutant	**Mean 1-year Storm Computed Load**	**Total Annual Computed Load**
TSS	190,285 kg	1,248,000 kg/Yr
TP	37 kg	535 kg/Yr
TN	331 kg	9,339 kg/Yr

For the **entire Honeoye Lake watershed** the aggregate annual loading is 2,877,000 kg/yr TSS, 1,005 kg/yr TP, and 20,196 kg/yr TN. As such, the Subwatershed 4 annual loads account for approximately 50% of Honeoye Lake's total annual TSS, TP and TN loads.

Applying the PRedICT TSS, TN and TP load reduction efficiencies ascribed to constructed wetland systems, the treatment of the captured runoff by the stormwater management measures proposed for the Honeoye Inlet Wildlife Management Area decreases the respective post-treatment Subwatershed 4, **1-year storm event loads** and **total annual loads** to:

Table 8.3 – Honeoye Inlet (Subwatershed 4) Post-Treatment Loading as per PRedICT		
Pollutant	**1-year Storm Post-Treatment Load**	**Total Annual Post-Treatment Load**
TSS	41,863 kg	274,560 kg/Yr
TP	18 kg	292 kg/Yr
TN	156 kg	4,390 kg/Yr

These values represent the total loading to Honeoye Lake originating from Subwatershed 4 caused by **1-year storm events after treatment by means of the cumulative proposed BMPs**. Likewise, applying the same constructed wetland coefficients to the **total annual** Subwatershed 4 loads results in the decreased loading illustrated in Table 8.3.

However, we feel that the load reductions computed using the PRedICT module values are conservative. A review of the literature shows that most other sources ascribe higher TSS, TN and TP removal values for bioretention systems than does the PRedICT module. For example, the NYSDEC Stormwater Management Manual (2010) ranks bioretention BMPs as having good (highest ranking) nutrient, sediment and pathogen removal capabilities. Likewise the Connecticut and Pennsylvania BMP manuals (CTDEP, 2004 and PADEP, 2006) as well as the USEPA (2002) recognize bioretention systems as providing some of the highest nutrient and sediment removal efficiencies of all the classes of BMPs. The New Jersey Department of Environmental Protection (2010) assigns removal efficiencies to bioretention systems of 80% TSS, 60% TP and 50% TN. Simpson and Weammert (2009) reviewed the performance of bioretention BMPs utilized in the Chesapeake Bay area and assigned removal efficiencies as high as 90% for TSS, 85% for TN and 80% for TP. As such, applying removal efficiencies of **85%, 70% and 60%,** respectively for TSS, TP and TN provides alternative pollutant reduction estimates that are comparable to those generated using the PRedICT module. Using these alternative, standardized removal coefficients predicts the proposed Wildlife Management Area stormwater management system will reduce the Subwatershed 4 **1-year storm post-treatment loads** and **total annual post-treatment loads** to:

Table 8.4 – Subwatershed 4 Post-Treatment Loading as per Standardized Removal Coefficients		
Pollutant	**1-year Storm Post-Treatment Load**	**Total Annual Post-Treatment Load**
TSS	28,543kg	187,200 kg/Yr
TP	11 kg	161 kg/Yr
TN	132 kg	3,736 kg/Yr

These projected pollutant removals are in the same range as predicted by the Cayuga County Department of Planning and Economic Development for the previously noted Owasco Flats Wetland Restoration and Riparian Buffers Initiative (CCDPEC, 2011).

Therefore, whether using the PRedICT constructed wetland reduction coefficients or the reduction coefficients developed by others for bioretention and constructed wetland systems, a fairly high load reduction will be achieved through the implementation of the recommended stormwater management measures. However, we expect the cumulative pollutant removal capabilities of the Honeoye Inlet Wildlife Management Area's stormwater management system to be even greater. Our studies of similar systems constructed at Pennswood Village, Newtown, PA, Deal Lake, NJ and along Walnut Brook, Flemington, NJ, shows that very little of the flow diverted into similar floodplain storage systems actually migrates back into the stream system as surface flow. Rather, the captured flow either infiltrates through the soils into the surficial groundwater aquifer or is lost via evaporation and transpiration. Consequently, such systems effectively remove most, if not all, of the TSS, TN and TP load from the captured and detained flows.

In summary, the stormwater management system proposed for the Honeoye Inlet Wildlife Management Area provides a unique opportunity to effectively manage a large percentage of the annual TSS, TP and TN loading to Honeoye Lake. At the same time the stormwater management measures provide an additional benefit by actually restoring and expanding the habitat properties of the Honeoye Inlet Wildlife Management Area.

Overall, the projected costs to implement the full suite of measures proposed for the Honeoye Inlet Wildlife Management Area total between $1,100,000 and $1,400,000. Not all of this work has to be conducted simultaneously, but to reduce total site disturbance and ensure the integrated functionality of the stormwater management system it would be desirable to implement these measures as part of one large construction project. Additionally, as reflected in the lower end of the cost range, conducting all of the improvements as part of a single large project avoids multiple bidding and permit preparation costs, decreases the cost associated with contractors mobilizing and demobilizing multiple times, and decreases the amount of construction oversight time.

For the balance of the Honeoye Lake watershed, management of the watershed's stormwater loads is complicated by a number of factors. First, the majority of the lands are privately owned. Additionally, there is little available land for the construction of regional basins and the structures needed to properly manage the streams' flood flows.

Second, much of the sediment loading is a function of the watershed's steep topography and is more the result of stream bed and bank erosion than sediment inputs attributable to land development activities. This means that more meaningful reductions in TSS loading can be achieved through stream restoration as opposed to stormwater quality management.

Third, the overall watershed is for the most part sparsely developed. While the exceptions to this are the Northeast (8) and Honeoye Lake Park (9) subwatersheds, much of the total loads generated throughout the Honeoye Lake watershed originate from forested lands. Such loading is considered "background" loading and is usually characterized as an unmanageable element of the total load.

Fourth, generally the loading associated with the more heavily developed nearshore areas and subwatersheds is best managed using "small footprint", homeowner BMPs such as rain barrels, rain gardens, vegetated swales and stream-side and lake-side buffers.

Finally, watershed-based stormwater management must be a part of the overall strategy used to decrease pollutant loading to Honeoye Lake. However, given the relative magnitude of the watershed loads, the fact that much of the loading is background loading, and the limitations posed in the implementation of standard, regional stormwater BMPs throughout the majority of the watershed, the management of the lake's internal phosphorus load must remain a primary element in the comprehensive efforts being taken to control the lake's rate of eutrophication.

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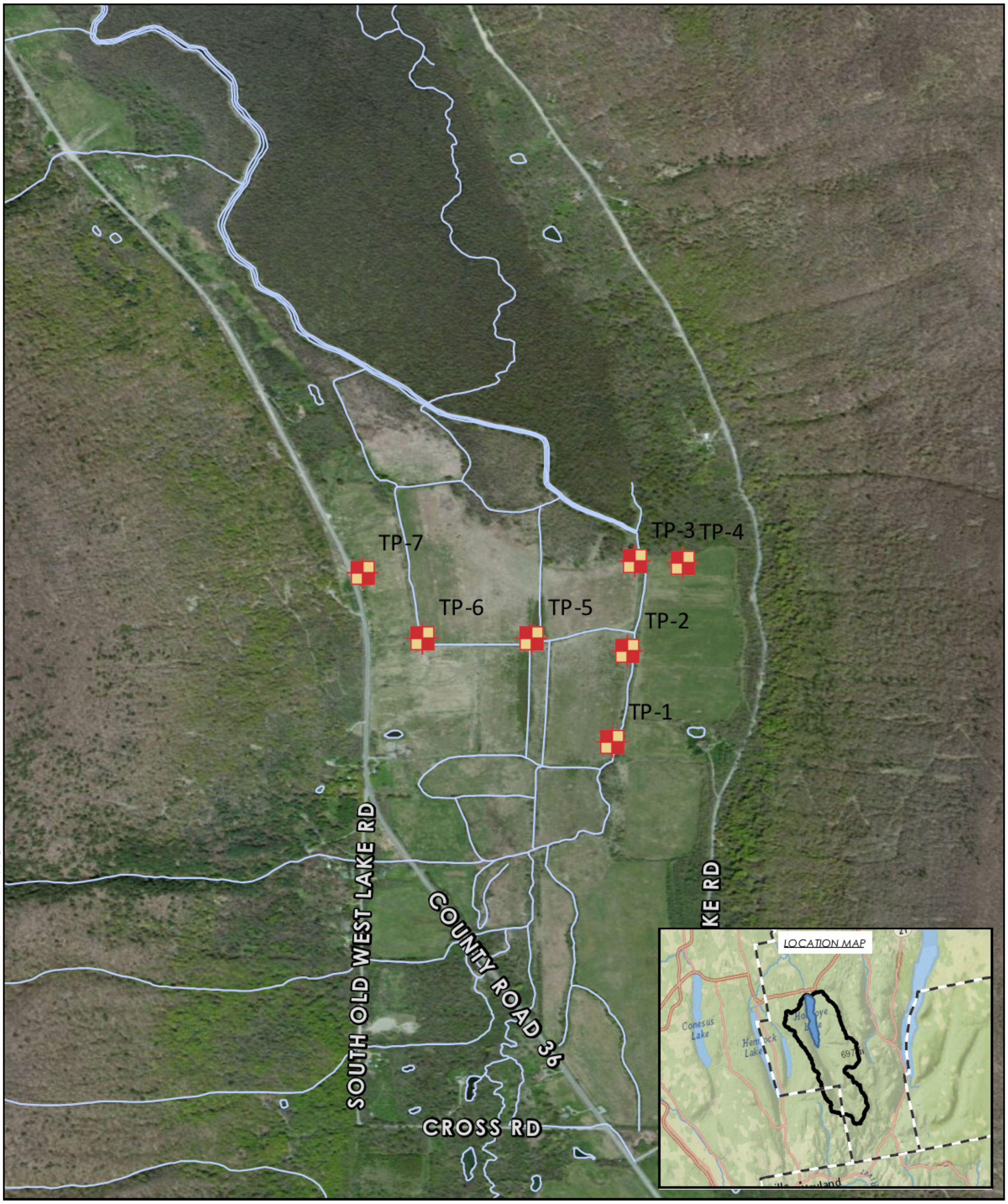
Appendix A

Soil Test Log Data



TEST PIT LOCATIONS

HONEOYE LAKE
TOWN OF RICHMOND
ONTARIO COUNTY, NEW YORK

PRINCETON HYDRO, LLC.
1108 OLD YORK ROAD
P.O. BOX 720
RINGOES, NJ 08551
*with offices in NJ, PA and CT

NOTES:
1. USGS topographic digital raster graphic obtained from Terrain Navigator Pro, Brewster, NY quadrangle.

0 1,000 2,000 Feet

Map Projection: GCS North American 1983

APPENDIX E: THIRTY YEARS MONITORING THE FALL STANDING CROP BIOMASS

THIRTY YEARS MONITORING THE FALL STANDING CROP BIOMASS OF MACROPHYTE COMMUNITIES IN HONEOYE LAKE

Bruce Gilman[1], John Foust and Jason Hanselman
Department of Environmental Conservation and Horticulture
Finger Lakes Community College
3325 Marvin Sands Drive
Canandaigua, New York 14424

FingerLakes COMMUNITY COLLEGE

[1] corresponding author, contact at www.bruce.gilman@flcc.edu

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This fourth intensive inventory of the aquatic plant communities of Honeoye Lake was sponsored by the Towns of Canadice and Richmond, and the Finger Lakes-Lake Ontario Watershed Protection Alliance (FL-LOWPA) with funds administered through the Aquatic Vegetation Management Program, Ontario County Department of Planning. The Grants Office, Central Services Office, and Purchasing Office at Finger Lakes Community College (FLCC) provided essential on-campus support. A pontoon boat and aquatic sampling equipment that are an integral part of field courses taught by faculty of the college's Department of Environmental Conservation and Horticulture were used for completing this research.

Many individuals helped during this inventory and special thanks belong to my department colleague and "captain" of the pontoon boat, John Foust, for his watchful eye while others were underwater collecting aquatic vegetation samples, for his accurate processing of samples on the boat, and for his recording of all relevant site conditions. Ryan Staychock, department technician, admirably substituted for John Foust on several occasions. The student intern, Jason Hanselman, helped establish and retrieve the temporary transect lines, and often collected vegetation in the shallower sections of those transect lines. He is commended for his quick learning of the sampling technique as well as the identification of the dominant aquatic plant species. Both John and Jason assisted the principal author with the time consuming job of sample sorting by species, and the ultimate determination of dry weight biomass.

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INTRODUCTION

Macrophyte communities grow in the littoral zone of Honeoye Lake, a region where sufficient light is available along the bottom in the springtime to allow aquatic vegetation to develop from overwintering structures (e.g., bulbs, fragments, rhizomes, seeds, stolons, tubers, and turions), begin photosynthesizing, and grow upward in the water column. Some plants stay submerged in the water (submersed species), others have leaves floating on the surface (free-floating and floating attached species) and the remainder grow out of the water (emergent species). These habits of growth are often associated with decreasing water depth, respectively.

In Honeoye Lake, examples of submersed plants include water marigold (*Bidens beckii*), coontail (*Ceratophyllum demersum*), elodea (*Elodea canadensis*), water stargrass (*Heteranthera dubia*), Eurasian water milfoil (*Myriophyllum spicatum*), naiads, (*Najas* spp.), large-leaf pondweed (*Potamogeton amplifolius*), curly-leaf pondweed (*Potamogeton crispus*), sago pondweed (*Potamogeton pectinatus*), mall pondweed (*Potamogeton pusillus*), clasping-leaf pondweed (*Potamogeton richardsonii*), flat-stem pondweed (*Potamogeton zosterformis*), stiff white water buttercup (*Ranunculus longirostris*) and eelgrass (*Vallisneria americana*). Free-floating aquatic plants have their leaves just above the surface and roots hang free in the water beneath them. They are easily moved by winds and water currents. Common examples include lesser duckweed (*Lemna minor*), star-leaved duckweed (*Lemna trisulca*), greater duckweed (*Spirodela polyrhiza*), common bladderwort (*Utricularia vulgaris*), and the watermeals (*Wolffia* spp.). To the untrained eye, duckweeds and watermeals are often mistaken for green algae. Floating attached species have broad leaves at the water surface but they are rooted to the benthic substrate. Floating leaves are connected to the bottom by a petiole in water lilies (*Nuphar variegata* and *Nymphaea odorata*) or by stems with narrow underwater leaves in some pondweeds (*Potamogeton epihydrus* and *Potamogeton natans*). Emergent species are rooted in the shallow, shoreline waters where their basal portions are submerged but most leaves, branches and stems occur in the air directly above the water surface. Examples include button bush (*Cephalanthus occidentalis*), water willow (*Decodon verticillatus*), arrow arum (*Peltandra virginica*), pickerelweed (*Pontederia cordata*), and giant bur-reed (*Sparganium eurycarpum*). Most Honeoye Lake macrophyte communities are dominated by vascular plants but may also contain macro-algae like stoneworts (*Chara* spp.), aquatic mosses (*Fontinalis antipyretica*), and mosquito ferns (*Azolla caroliniana*). In recent years, quantities of filamentous green algae (e.g., *Hydrodictyon*, *Spirogyra*) have become more abundant as a matted growth on the lake bottom or as strands tangled with submersed vascular plants.

Diverse macrophyte communities are an essential component of healthy aquatic ecosystems. Their roots and other anchoring structures help keep bottom substrates in place. This reduces sediment re-suspension, thereby helping to minimize shoreline turbidity and benthic deposition that might otherwise have undesirable impacts on life stages of lake organisms, in particular, developing fish eggs residing on the lake bottom. Macrophyte stems and leaves can reduce wave energy thereby helping to protect lake shorelines from erosion. On a daily basis, macrophytes can enhance the dissolved oxygen supply in the water through their photosynthetic activity. Macrophytes may also improve water quality as they help control algal abundance by competitively “binding up” significant portions of a lake’s nutrient budget. Most importantly, macrophytes are a critical habitat for many lake organisms, providing both food and shelter. Many invertebrates rely on aquatic plants during specific life history stages. Filter-feeders attach to plants as they ingest particles from surrounding waters. Insect larvae and nymphs cling to plant stems as they search for food. Algae attached to macrophytes are grazed on by snails and midges. Caddis fly and moth larvae feed directly on aquatic plant tissue. Habitat structure created by macrophytes provides food and shelter for juvenile and adult fish. Invertebrates living on aquatic plants are a fish food source. Some fish also graze directly on underwater leaves and stems. The architecture and density of aquatic plant cover influences the success of fish populations. For waterfowl and shorebirds, aquatic plants offer food, shelter and nesting materials. A diversity of plants can provide food throughout the seasons. Many waterfowl and shore birds consume invertebrates living on aquatic plants. Mammals, too, benefit from aquatic plants. River otters patrol the macrophyte communities hunting for food. Muskrats feed on shoreline emergents, especially giant bur-reed and cattail. Beaver dive down to dig out and feed on vegetation such as water lily tubers.

To assist the Ontario County Aquatic Vegetation Management program, this research provides recent information on aquatic plants within Honeoye Lake and, when compared with previous studies, helps to document long term ecological changes within the macrophyte communities. Specifically this report provides reliable and consistent data collected along multiple transects within the lake’s littoral zone, documents patterns in fall standing crop biomass, identifies the relative importance of species that comprise the aquatic vegetation, brings particular emphasis on the changing role of aquatic invasive species, and compares 2014 data to similar data from 1984, 1994 and 2004.

LITERATURE REVIEW

Residing in one of several north-south glacially scoured valleys of western New York (Fairchild 1895), modern Honeoye Lake is a relic of a much larger Glacial Lake Honeoye that drained southward into Glacial Lake Naples when the retreating continental ice sheet margin blocked all north draining routes. By 11,500 years ago, a lake similar in surface dimensions to the modern lake was present in the valley but it was considerably deeper. Centuries of watershed erosion deposited silts and clays in the deeper waters of the lake, while coarse sands and gravels built points and beaches along the shoreline. The modern Honeoye Lake is the shallowest of the eleven Finger Lakes and has the second smallest surface area. Morphometric features of the lake are presented in TABLE 1.

European settlement in the Honeoye valley began the domestication of the lake's watershed lands. An excellent historical summary is presented in the opening chapter of The Honeoye Lake Book (Honeoye Lake Watershed Taskforce 1999). A year after its publication, FLCC was gifted the former Emil Muller home located in the southern Honeoye valley, soon to become the college's Muller Field Station. Shortly thereafter, faculty began a series of biological studies of the area including an extensive land use/land cover mapping project (Gilman 2004). Results of the mapping project and other watershed information are summarized in TABLE 2.

Water quality concerns and the formation of "lake protection" groups closely followed the rapid post-World War II development of the watershed. Historic photographs clearly depict an early 1900s agricultural landscape being replaced by residences and seasonal cottages. Abandoned hillside farmland began the slow process of natural succession back to forest cover. In these early decades, human activities negatively impacted the lake and left behind a legacy of nutrient pollution documented in bottom sediment cores (Gilman 2001). Due to the lake's shallow nature and frequent bouts of summer anoxia at depth, these legacy nutrients continue to represent a significant component (i.e., internal loading portion of the nutrient budget) of the lake's overall nutrient budget and contribute to its eutrophic condition. Hydrologic and nutrient models for Honeoye Lake (Princeton Hydro 2007, 2014) detail the challenge of nutrient management and set realistic goals for lake restoration. Macrophyte harvesting is one technique among the many best management practices being used to address the concerns of declining lake health (Gilman 1991). A summary of recent water quality data is presented in TABLE 3.

Relevant information on the historic composition and fall standing crop biomass of macrophyte communities of Honeoye Lake are presented in reports by Gilman (1985, 1994 and 2004). His intensive work in Honeoye Lake detected 18 aquatic plant species in 1984, 19 species in 1994 and 20 species in 2004. By comparison, similar macrophyte inventory work in the Wayne County Bays of Lake Ontario lists 13 species for East Bay, 17 species for Port Bay and 24 species for Sodus Bay (Gilman and Smith 1988). With the exception of heavily polluted Onondaga Lake, most central and western New York water bodies have similar species richness.

The maximum fall standing crop biomass determined for Honeoye Lake was 1373 g/m^2 in 1984, 513 g/m^2 in 1994, and 526 g/m^2 in 2004. These determinations fall within the range of values reported from other regional water bodies. Recent Owasco Lake research reports a maximum value of 1263 g/m^2 (Gilman et al. 2008). A maximum value of 1470 g/m^2 is listed for Conesus Lake (Makarewicz et al. 1991), and a maximum value of 1217 g/m^2 for Sodus Bay, 579 g/m^2 for Port Bay and 512 g/m^2 for East Bay (Gilman and Smith 1988). The maximum value for Canandaigua Lake was 719 g/m^2 (Gilman, unpublished data). After extensive milfoil herbivore defoliation in Waneta Lake the maximum fall standing crop biomass was 218 g/m^2 (Johnson et al. 2000). Fall standing crop biomass varies according to site conditions within lakes.

MATERIALS AND METHODS

Correct identification of macrophytes is a necessary prerequisite to their successful management. General guides appropriate for Honeoye Lake include Hotchkiss (1967), Rawinski et al. (1979), and Borman et al. (2014). Regional technical references include Ogden (1974), Ogden et al. (1976), and Hellquist and Crow (1985). Information on aquatic invasive species is available at websites of The New York Flora Association (www.nyfa.org), the New York State Federation of Lake Associations (www.nysfola.org), and the Finger Lakes Partnership for Regional Invasive Species Management (www.fingerlakesprism.org). Voucher specimens of most macrophyte species observed in Honeoye Lake were collected during the 2014 research, identified to species, and placed in the Finger Lakes Herbarium at FLCC. Vascular plant taxonomy follows Mitchell and Tucker (1997) with revisions recommended by the New York Flora Association.

One hundred aquatic macrophyte inventory stations were grouped five per transect following the protocol of previous research. The 20 transects were nearly equally spaced along the shoreline (FIGURE 1) and documented by GPS readings to facilitate return to each transect for future research. A preshrunk mooring line was temporarily anchored by grappling hook at the shoreline, then extended out perpendicularly towards the lake center and held in position by a heavy navy anchor. The line was kept afloat by four boat bumpers and a mast buoy. Each flotation device also served as the location of an inventory station. The first station was located about 3 meters (10 feet) from the shore and subsequent stations were equally spaced from the first at 30.5 meters (100 foot) intervals. Due to the high number of inventory stations, it was anticipated that most of the variability in littoral zone macrophyte communities would be sampled.

At each station, the standing crop biomass of aquatic plants was hand pulled at substrate level within a weighted ½ m^2 quadrat frame. The sampling process was facilitated by the use of snorkeling and SCUBA equipment. Each biomass sample was placed in a mesh bag underwater, rinsed in lake water, transferred to a plastic bag in the boat and labeled with site information. Biomass samples were returned to the college and temporarily refrigerated prior to laboratory sorting. Water depth was measured by staff gage or sounding line. Substrate quality was only visually assessed and recorded for each station. No sediment analyses were conducted based on the assumption that substrate conditions, which were tested for texture, pH and nutrient levels in previous research (Gilman 1984, 2001), were likely similar for this study year.

In the laboratory, biomass samples were sorted by species and any clinging, incidental sediment and large attached organisms like zebra mussels were removed from the plants. Sorted species were placed in individual brown paper bags, labelled, and transferred to the college greenhouse for air drying. If necessary, samples were brought to a stable weight by oven drying at 105 ºC prior to weighing on a top loading analytical balance. For all 100 inventory stations, fall standing crop biomass (g/m^2) was calculated by summing the dry weights of all component species within each sample. For the macrophyte community of the entire lake, a synthetic species importance value (IV) was computed as the mean of relative density and relative dominance derived from frequency of species occurrence and biomass totals, respectively. Comparison of IV scores across the four study years (1984, 1994, 2004, 2014) documents the long term variability of the macrophyte communities and might reveal directional changes in composition.

Additional ecological descriptions were determined individually for all 100 samples. These included the number of species detected (referred to as richness [n]), the degree to which all species in a sample were equally abundant (known as evenness and calculated as the J' index of Pielou), the concentration of dominance expressed as the fractional weight of the most abundant species compared to the weight of all species, and the overall sample diversity determined by calculation of Shannon's Index (H'). These statistical measures are commonly used to characterize species abundance relationships in natural communities.

To assure that transect locations were being replicated as closely as possible, individual site water depths for 1984, 1994, 2004 and 2014 were tested for similarity through regression analyses and tested for significance by calculation of correlation coefficients. This was deemed necessary as the 30 year project interval began prior to the availability of GPS coordinates and the time span captured a change from historic cottage numbers to a modern 911 emergency based numbering system.

RESULTS

Macrophyte communities in Honeoye Lake during 2014 were dominated by plants with a basal rosette of long, linear leaves, by short aquatic plants with small leaves, or by tall aquatic plants with flexuous stems and a concentration of reduced or finely dissected leaves. Of the 19 species detected, 17 were vascular plants, one was a moss, and one was an inclusive/collective algal category. The community composition was dominated by native species including eelgrass (*Vallisneria americana*), coontail (*Ceratophyllum demersum*), flat-stem pondweed (*Potamogeton zosteriformis*), water stargrass (*Heteranthera dubia*), small pondweed (*Potamogeton pusillus*), elodea (*Elodea canadensis*), star-leaved duckweed (*Lemna trisulca*), large-leaf pondweed (*Potamogeton amplifolius*) and clasping-leaf pondweed (*Potamogeton richardsonii*). Invasive species included Eurasian water milfoil (*Myriophyllum spicatum*) and curly-leaf pondweed (*Potamogeton crispus*). The fall abundance of aquatic plants in Honeoye Lake inventory stations is described in TABLE 4.

Twenty three of the 100 inventory stations had no vegetation and for 22 of them it was likely due to water depth so extreme that light intensity was not at the compensation level necessary to support aquatic plant photosynthesis. These stations ranged in water depth from 330 to 930 cm with a mean depth of 516 cm. The one station that was an exception to this explanation was a very shallow, near shore site (depth = 50 cm) strongly influenced by wave energy and rocky substrate, a combination that may hinder aquatic plant colonization and long-term persistence. In previous research, shallow depths at the south end of the lake basin contained emergent species including water willow (*Decodon verticillatus*), arrow arum (*Peltandra virginica*), pickerel weed (*Pontederia cordata*) and giant bur-reed (*Sparganium eurycarpum*) but these, although still present in 2014, were not found within the quadrat tosses. Spatial distribution of aquatic plants among the twenty transects is presented in TABLE 5.

Species richness per transect was greatest at the south end of the basin (transects A and T) where 15 macrophytes were detected, and in the northeastern corner of the lake (transects I, J and K) where 12-13 macrophytes were captured within the samples. Species richness per transect remained fairly high along the western shoreline, ranging from 8-11 macrophytes. The eastern shoreline was similar with the exception of transects E, F and G where macrophyte richness was lower, ranging from 1-6 species. This middle portion of the eastern shoreline corresponds to a region of the lake where benthic slope gradient is the greatest.

Eelgrass, coontail, flat-stem pondweed, Eurasian water milfoil, water stargrass, curly-leaf pondweed, small pondweed, elodea, star-leaved duckweed and large-leaf pondweed were widely distributed in Honeoye Lake during 2014. This dominance may result from their reproductive strategies. Eelgrass reproduces vegetatively with creeping stems called stolons which frequently root down forming large colonies in shallow lake bottom sites. It also produces a floating seed capsule at the top of a spiral stalk that may propagate the plant if the seeds are not consumed by migratory waterfowl. The basal rosette of long linear leaves moves flexuously with lake currents and leaf fragments may form by natural processes. These fragments do not form roots and, therefore, do not initiate new eelgrass beds. Coontail seldom roots to the lake bottom but instead grows tangled with other submersed aquatic plants, relying on their substrate attachment to hold itself in place. Coontail grows from overwintering fragments of the previous season. The pondweed species produce flowering spikes that emerge from the water surface, are pollinated by insects then form keeled seeds, but their persistence in the littoral plant communities is more strongly dependent on overwintering buds called turions. These are produced along branch tips at the end of the growing season. Curly pondweed and large-leaf pondweed grow in deeper waters, the former in the cold waters of springtime and the latter in the warm summer waters. Both grow quickly to the water surface and may then spread horizontally across it. Water stargrass forms dense but matted colonies that seldom reach the surface. It is especially abundant in protected coves along the shoreline. Elodea tolerates a range of water depths and will even grow stranded along the beach. Fragments quickly produce adventitious roots and propagate the plant. Flowering and seed production is rare in Elodea. The tiny but ubiquitous star-leaved duckweed floats beneath the surface amongst other macrophytes.

Macrophytes occurred out to a depth of 372 cm (12.2 feet) in August 2014. This depth closely correlates with the maximum depth of vegetation inferred by the Lowrance HDS GPS/depth finder sensing technique and interpretation provided by the Contour Innovations © Mapping Service (T. Gronwall, personal communication). Water depth for each inventory station is provided in TABLE 6. Water depth correlation coefficients among the sample years (TABLE 6) indicates a highly significant relationship and suggests excellent sample transect replication through time.

Fall standing crop biomass for each of the 100 inventory station is presented in TABLE 7 and results ranged from 0 to 518.64 g/m^2 (highest value at the middle inventory station, transect C). The mean fall standing crop biomass of all inventory stations was 105.22 g/m^2.   Fall standing crop biomass for each of the 20 transects is summarized in TABLE 7 and results ranged from 0.39 to 264.52 g/m^2 (highest value for transect B which occurs within the New York State protected wetland at the southern end of the lake and were no vegetation harvesting is permitted). Individual inventory station biomass data was summarized to produce a depth distribution of the fall standing crop biomass with these results (TABLE 8): in the 0 – 100 centimeter zone, fall standing crop biomass averaged 113.95 g/m^2 (n=23 inventory stations), in the 101 – 200 centimeter zone, fall standing crop biomass averaged 198.98 g/m^2 (n=24), in the 201 – 300 centimeter zone, fall standing crop biomass averaged 122.73 g/m^2 (n=21 inventory stations), and in the 301 – 400 centimeter zone, fall standing crop biomass averaged 36.53 g/m^2 (n=15). Biomass was absent in the 401 – 500 centimeter zone (n=9), the 501 – 600 centimeter zone (n=5) and the 600+ centimeter zone (n=4). Based on lake bathymetry, the total 2014 lake wide fall standing crop biomass is estimated to have a dry weight of 412,067 kg.

Six submersed species (eelgrass, coontail, water stargrass, Eurasian water milfoil, elodea and large-leaf pondweed) accounted for approximately 95% of the macrophyte community fall standing crop biomass in 2014. Other species (small pondweed, star-leaved duckweed, curly-leaf pondweed, clasping-leaf pondweed) were as or more frequent but due to their small size or presence only as a vegetative propagule did not have significant biomass. Species occurrences were associated with water depth. Eelgrass was most abundant in shallow areas while elodea and coontail were found in intermediate depth zones. Water stargrass had maximum abundance in silt-rich substrates within bays off deltaic points. Eurasian water milfoil and large-leaf pondweed typified deeper zones but were also detected in intermediate depths. The combined importance values of eelgrass and coontail account for over 50% of the 2014 macrophyte community (TABLE 9).

Ecological indices, essentially a macrophyte community profile, are presented in TABLE 10. Based on submerged quadrat frame area (½ m^2), sample richness averaged 4.7 species. Of more interest to aquatic plant ecologists is how these species shared resources (i.e., the degree to which some species are common while others are quite rare) and how the submerged aquatic vegetation is structured (i.e., are there canopy-forming plants or other types of layering in the community). Resource sharing (Pielou's J' index) was low while concentration of dominance was high, suggesting that dominant species patches were larger than the frame area. Overall mean diversity (Shannon's H' index) was intermediate indicating limited numbers of rare species and few canopy-formers. The mean H' value detected here would also be used to describe a community of two equally common species, what biodiversity ecologists have termed the effective number of species. The maximum H' value measured, occurring in transect C, indicates more biodiversity, with an effective number of species equal to five. Sampling across the growing season would capture more submersed aquatic species due to species turnover (i.e., temporal partitioning of niche space) and enhance ecological indices of diversity.

DISCUSSION AND RECOMMENDATIONS

Similar investigations in 1984, 1994 and 2004 allow for long-term trend analyses in macrophyte community structure and function. Trends are hypothesized to result, in part, from changes in water quality following the installation of a perimeter sewer system in 1980 (Larsen 1971), the introduction and establishment of an invasive zebra mussel (*Dreissena polymorpha*) population in the late 1990s (Pearsall and Richardson 2001), and resource competition between macrophyte and phytoplankton communities driven in part by changes in internal nutrient loading associated with frequent summertime bouts of deep water benthic anoxia (Princeton Hydro 2007) as well as changes in external nutrient loading associated with an increased frequency of extreme storm events (Harvieux and Gilman, study in progress). These storm events can secondarily be coupled with poor runoff water quality as influenced by changing human land use practices in the watershed and the inability of natural systems to accommodate these storm intensities and total rainfall volumes.

The role of other factors and their potential regulatory effects on macrophyte community structure and function are poorly understood but may prove significant when relevant data becomes available. These include a phosphorus "pump" from the near-shore shallow sediments mediated by the planktonic cyanobacterium, *Gloeotrichia echinulata*, which has become increasing abundant in the recent decade. Although these near-shore sediments are normally oxic and trap phosphorus, the resting cells of *Gloeotrichia* are thought to have a luxury uptake of sediment phosphorus prior to their forming gas vesicles and rising up into the water column. When these blue-green algal cells die, their absorbed phosphorus is effectively released into the open water zone, stimulating the growth of other phytoplankton and, perhaps, limiting the light and nutrients available to the macrophyte community. Harvesting of macrophytes has been used as a management technique to improve lake-based recreational opportunities, and also to remove phosphorus in absorbed forms in the plant biomass. After careful study of macrophyte management alternatives (Honeoye Lake Watershed Taskforce 2008), mechanical harvesting was selected as the technique most environmentally acceptable, politically feasible and socially responsible. While successfully removing significant biomass, unanswered scientific questions remain about unintended consequences of harvesting. Fragments escaping from cutting operations may, in the case of some species, be viable propagules that could, if habitat space is available, initiate new stands of underwater vegetation. Cut stems still rooted to the bottom in harvested areas may leak plant sap into the water but it is unknown if this has a "fertilizer" effect within the macrophyte communities. The incidental capture of juvenile fish while harvesting has been studied (Gilman and Smith 1988) and judged inconsequential, but the impact on adult fish communities of opening the structure of the macrophyte beds when harvesting lanes are cut has not been examined in detail.

Over the 30 year period of these replicated studies, changes have been detected in the extent, composition and structure of the macrophyte communities. The community response to changes in water clarity (z_{sd}) has altered the maximum depth of the littoral zone during the years of record. The deep edge of the submerged plants was 4.30 meters in 1984, moved out to 5.70 meters by 1994, stood at 5.35 meters in 2004 and retreated back to 3.72 meters in 2014. The distribution of macrophyte biomass prior to mechanical harvesting (1984) peaked in the 1 – 2 meter depth zone but this has been consistently cut by one third with harvesting (1994, 2004, 2014) in this zone (FIGURE 2). In subsequent decades, biomass shifted to deeper waters as clarity improved but in 2014 has returned to shallower waters reminiscent of the 1984 graph profile. This may be a response to reduced clarity brought on by the increase in blue-green algae as well as increases in inorganic turbidity associated with more frequent, intense storm events. Thirty year transect dry weight fall standing crop biomass totals (FIGURE 3) follow the pattern of the lake-wide data with few exceptions. These exceptions, where higher than anticipated biomass was detected in 2014, included transect H just south of Trident Marine along the east side of the lake, transect O in the Twin Bay region north of California Point along the west side of the lake (mechanical harvesting is not possible in this location due to numerous tree stumps in the water) and transect Q just south of California Point. As the area inhabited by macrophytes has shifted and the depth distribution of their biomass has changed, so has the estimated total lake wide plant biomass. The fall dry weight standing crop biomass was estimated at 527,359 kg in 1984, dropping to 333,443 kg in 1994, rising to 463,720 kg in 2004 and stabilizing at 412,067 kg in 2014. Variability in the extent, composition, and structure of macrophyte communities appears to be the norm and predictions concerning their future structure and function should take this variability into account. Ongoing assessment of macrophyte communities (e.g., annual rake toss studies, collection of side scan sonar information and periodic, 10 year fall standing crop biomass research) is recommended. Continuation of a boat launch steward program is also recommended as an efficient, educational practice for quickly discovering the introduction of new aquatic invasive species. Such an early warning system is especially critical with the highly invasive plant, *Hydrilla verticillata*, already growing in nearby Cayuga Lake and the New York State barge canal system.

Anecdotal evidence regarding macrophyte community composition is known back to 1946 (TABLE 11). While there may be bias in the early years of this dataset caused by taxonomic ambiguities, sampling intensities and locations surveyed, all studies show dominance by eelgrass. Species that increased over the years include small pondweed, flat-stem pondweed, elodea, star-leaved duckweed, water stargrass and white water buttercup. Coontail, curly leaf pondweed and large leaf pondweed have remained fairly constant while Eurasian water milfoil and water marigold appear to be decreasing. The overall richness of the macrophyte communities has remained remarkably similar since 1984 when a precise sampling protocol was first used and repeated every decade thereafter. This consistent, long-term biological dataset is unmatched in the Finger Lakes of New York State.

Long-term changes in dry weight fall standing crop biomass for dominant species are presented in TABLE 12. While eelgrass remains as the biomass leader, coontail and water stargrass have seen notable increases during the last two decades while water marigold and Eurasian water milfoil have dropped precipitously. In the latter case, herbivores have been verified feeding on submerged leaves and, perhaps, contributing to the biomass decline (Bob Johnson, personal communication). The scientific literature has also suggested that Eurasian water milfoil may experience an autoantibiosis, that is, over time its decaying remains may modify the substrate in a way that hinders or inhibits future milfoil growth. No experiments have been performed on Honeoye Lake sediment to confirm this hypothesis.

The combined importance value of invasive species (Eurasian water milfoil, curly leaf pondweed, various leaved water milfoil) rose from 9.2% in 1984 to 39.0% in 1994 but then began a steady decline to 14.5% in 2004 and finally 11.0% in 2014. Over the same time period, the combined importance values of eelgrass, coontail, water stargrass, Eurasian water milfoil, elodea and large-leaf pondweed have consistently accounted for 76-82% of the community total. This suggests the inertia for plant production is consistently high in eutrophic Honeoye Lake, but the partitioning of biomass among individual species is driven by local conditions that are subject to change annually. Relative dominance values (FIGURE 4) best demonstrate this annual variability.

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Table 1

MORPHOMETRIC FEATURES		
Watershed area	38.3 sq. mile (24497 acres)	99.14 km^2 (9914 hectares)
Lake area	2.8 sq. mile (1804 acres)	7.30 km^2 (730 hectares)
Lake length	4.1 miles	6.60 kilometers
Lake width	0.88 miles	1.49 kilometers
Maximum depth	31.6 feet	9.6 meters
Mean depth	16.1 feet	4.9 meters
Lake volume	10.2 billion gallons	38.6 million cubic meters
ADDITIONAL DESCRIPTIVE INFORMATION		
Hydraulic retention time	estimated at 292-352 days	
Surface elevation	803 feet (244.8 meters)	
Length of shoreline	9.6 miles (15.45 kilometers)	
Annual lake discharge	estimated at 7.58 billion gallons	
Perennial tributaries	Honeoye Inlet, Briggs Gully, Bray Gully, Affolter Creek complex	

Table 2

LAND USE AND LAND COVER		
Lacustrine cover types	Natural lakes and ponds	1841 acres
	Man-made ponds	84 acres
Palustrine cover types	Forested mineral soil wetlands	876 acres
	Open mineral soil wetlands	107 acres
Terrestrial cover types	Barrens and woodlands	42 acres
	Forested uplands	15551 acres
	Open uplands	2200 acres
	Cultural	3783 acres
Terrestrial cultural land uses include 1360 acres of residential land, 1132 acres of conifer plantation, 985 acres of cropland, 112 acres of outdoor recreation, 105 acres of pasture, and miscellaneous smaller human uses.		
(detailed descriptive land use/land cover categories in Gilman (2004).		

Table 3

LAKE WATER QUALITY		
Nutrients	total phosphorus	10-450 µg/L
	nitrate nitrogen	0.1-2.2 mg/L
	total kjeldahl nitrogen	200-930 µg/L
Buffer capacity	moderate	55-75 mg $CaCO_3$/L
Specific conductance	moderate	190-225 µmhos/cm
Active acidity (pH)	slightly alkaline	7.45-8.69
Major dissolved ions	cations: Ca, Mg, Na	anions: HCO_3, SO_4, Cl, CO_3
Water clarity (z_{sd})	low to moderate	1.0-5.0 meters
Algal abundance	chlorophyll *a* concentration	10-25 µg/L, locally higher
Trophic status	Carlson Trophic State Index	usually > 51, eutrophic

Table 4

FALL 2014 ABUNDANCE OF MACROPHYTES IN HONEOYE LAKE			
		% occurrence	
Common name	Scientific name	All sites	Vegetated sites
Eel grass	*Vallisneria americana*	63	82
Coontail	*Ceratophyllum demersum*	60	78
Flat-stem pondweed	*Potamogeton zosteriformis*	47	61
Eurasian water milfoil	*Myriophyllum spicatum*	46	60
Water stargrass	*Heteranthera dubia*	37	48
Curly-leaf pondweed	*Potamogeton crispus*	35	45
Small pondweed	*Potamogeton pusillus*	35	45
Elodea	*Elodea canadensis*	34	44
Star-leaved duckweed	*Lemna trisulca*	32	42
Large-leaf pondweed	*Potamogeton amplifolius*	26	34
Clasping-leaf pondweed	*Potamogeton richardsonii*	17	22
Attached algae		7	9
Southern naiad	*Najas guadalupensis*	7	9
Whorled water milfoil	*Myriophyllum verticillatum*	6	8
White water buttercup	*Ranunculus longirostris*	6	8
Sago pondweed	*Potamogeton pectinatus*	5	6
Slender naiad	*Najas flexilis*	3	4
Various-leaved milfoil	*Myriophyllum heterophyllum*	2	3
Aquatic moss	*Fontinalis antipyretica*	1	1

Table 5

FALL 2014 SPATIAL DISTRIBUTION OF MACROPHYTES IN HONEOYE LAKE																					
	Transect code																				Total
Common name	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	Transects
Eel grass	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20
Coontail	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	17
Flat-stem pondweed	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	18
Eurasian water milfoil	X	X	X	X		X		X	X	X	X		X	X	X	X	X	X	X	X	17
Water stargrass	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	17
Curly-leaf pondweed	X		X	X				X	X	X	X	X	X	X	X		X	X	X	X	15
Small pondweed	X			X		X	X	X	X	X	X	X	X	X	X		X	X		X	15
Elodea	X	X	X			X		X	X	X	X		X		X	X	X	X	X	X	15
Star-leaved duckweed	X	X	X					X	X	X	X	X	X	X	X	X	X			X	14
Large-leaf pondweed						X	X	X	X	X		X			X	X	X	X	X	X	12
Clasping-leaf pondweed	X	X	X	X							X									X	6
Attached algae	X		X							X	X				X					X	6
Southern naiad	X										X					X				X	4
Whorled water milfoil								X	X	X	X	X									5
White water buttercup	X	X	X						X												4
Sago pondweed			X									X	X			X				X	5
Slender naiad	X		X						X												3
Various-leaved milfoil	X																				1
Aquatic moss																				X	1

Table 6

FALL 2014 WATER DEPTH (cm) FOR MACROPHYTE INVENTORY STATIONS					
	Distance from shoreline (meters)				
Transect	3	33.5	64	94.5	125
A	60	98	111	126	148
B	45	136	198	262	320
C	21	80	132	276	360
D	28	170	372	490	530
E	50	270	610	855	930
F	40	192	390	530	740
G	54	220	310	351	442
H	53	182	218	251	282
I	51	189	232	263	293
J	50	149	198	253	265
K	43	71	131	197	232
L	31	158	279	320	330
M	35	246	320	370	420
N	41	271	340	400	447
O	32	111	161	229	266
P	29	273	488	570	600
Q	55	180	260	320	355
R	35	159	308	495	547
S	41	192	252	405	449
T	70	118	150	178	197

CORRELATION COEFFICIENT (r) FOR WATER DEPTH BETWEEN SAMPLE YEARS			
	1984	1994	2004
1994	0.93	-	-
2004	0.94	0.93	-
2014	0.92	0.90	0.93
r = 0.20 ($p < .05$), r = 0.26 ($p < .01$)			

Table 7

FALL 2014 TOTAL DRY WEIGHT FALL STANDING CROP BIOMASS (g/m^2) FOR MACROPHYTE INVENTORY STATIONS								
	Distance from shoreline (meters)						Mean	
Transect	3	33.5	64	94.5	125		all sites	vegetated
A	325.27	308.72	220.78	137.23	135.03		225.41	225.41
B	194.05	325.80	350.38	240.06	212.31		264.52	264.52
C	28.53	140.03	518.64	300.58	7.14		193.28	193.28
D	38.52	24.55	0.58	0.00	0.00		12.73	21.22
E	0.87	1.06	0.00	0.00	0.00		0.39	0.97
F	134.91	151.97	0.00	0.00	0.00		57.38	143.44
G	0.81	29.95	15.38	0.00	0.00		9.23	15.38
H	241.79	174.91	81.52	255.33	85.13		167.74	167.74
I	106.10	256.79	179.08	147.68	3.36		138.60	138.60
J	0.00	282.89	212.96	44.24	128.39		133.70	167.12
K	37.04	4.03	54.51	96.14	40.97		46.54	46.54
L	25.51	243.31	3.26	0.88	0.00		54.59	68.24
M	31.53	251.03	1.49	0.55	0.00		56.92	71.15
N	56.00	34.46	0.00	0.00	0.00		18.09	45.23
O	228.55	19.93	394.64	299.85	205.16		229.63	229.63
P	86.15	21.08	0.00	0.00	0.00		21.45	53.62
Q	205.59	209.49	146.88	245.67	17.28		164.98	164.98
R	213.68	189.63	46.67	0.00	0.00		90.00	150.00
S	79.66	390.40	78.17	0.00	0.00		109.65	182.74
T	133.48	187.73	57.45	45.00	95.73		103.88	103.88

Table 8

FALL 2014 TOTAL DRY WEIGHT FALL STANDING CROP BIOMASS (g/m^2) OVER WATER DEPTH GRADIENT		
Water depth (cm)	Biomass (g/m^2)	Sample size (n)
0-100	113.95	23
101-200	198.98	24
201-300	122.73	24
301-400	36.53	15
401-500	0	8
501-600	0	5
600+	0	4

Table 9

FALL 2014 MACROPHYTE COMMUNITY PROFILE FOR DOMINANT SUBMERSED SPECIES IN HONEOYE LAKE						
Species	Fall standing crop biomass	Occurrences	Relative dominance	Relative frequency		Importance value
Eelgrass	50.31 g/m^2	63	47.9%	13.5%		30.7%
Coontail	30.92	60	29.4	12.8		21.1
Water stargrass	9.47	37	9.0	7.9		8.5
Eurasian water milfoil	4.53	46	4.3	9.9		7.1
Flat-stem pondweed	2.03	47	1.9	10.1		6.0
Elodea	2.39	34	2.3	7.3		4.8
Small pondweed	0.93	35	0.9	7.5		4.2
Curly pondweed	0.39	35	0.4	7.5		3.9
Large-leaf pondweed	1.94	26	1.8	5.6		3.7
Star-leaved duckweed	0.12	32	0.1	6.9		3.5

Table 10

FALL 2014 DIVERSITY INDICIES FOR THE MACROPHYTE COMMUNITY IN HONEOYE LAKE DERIVED FROM 100 SUBMERGED QUADRAT (½ m^2) SAMPLES				
Index	Mean		Minimum	Maximum
Richness (n)	4.7		0	13
Evenness (J’)	0.4056		0.0028	0.8941
Dominance	0.7342		0.3656	0.9998
Diversity (H’)	0.7286		0.0019	1.6690

Table 11

HISTORICAL RECORDS OF AQUATIC PLANT OCCURRENCES IN HONEOYE LAKE. ABUNDANT (a), COMMON (c), FAIRLY COMMON (fc), PRESENT (p) AND NO DATA (-) AS NOTED IN THE SCIENTIFIC LITERATURE.

Species	1946	1952	1970	1984	1994	2004	2014
Eelgrass	a	a	a	a	a	a	a
Large-leaf pondweed	a	fc	-	c	c	c	c
Curly-leaf pondweed	-	fc	-	c	c	c	c
Small pondweed	-	-	-	-	fc	c	c
Sago pondweed	-	-	p	p	-	p	p
Clasping-leaf pondweed	c	fc	p	p	p	fc	fc
Flat-stem pondweed	-	-	p	fc	a	a	a
Slender naiad	c	-	c	p	fc	p	p
Southern naiad	-	-	-	-	fc	p	p
Elodea	c	-	c	fc	a	a	a
Star-leaved duckweed	-	-	-	fc	c	a	a
White water buttercup	-	-	-	-	p	fc	c
Coontail	c	c	fc	fc	a	a	a
Water stargrass	fc	-	p	c	c	c	c
Native milfoil	-	-	-	-	p	p	p
Eurasian water milfoil	c	-	-	c	a	c	fc
Great bladderwort	-	-	-	p	p	p	p
Water marigold	-	-	-	fc	fc	fc	p

1946 study by Stone and Pesko (cited in Larsen 1971)
1952 study by Reed and Carpenter (cited in Larsen 1971)
1970 study by Forest (cited in Larsen 1971)
1984 study by Gilman
1994 study by Gilman
2004 study by Gilman and Foust
2014 study by Gilman, Foust and Hanselman

In addition, these vascular species have been collected in Honeoye Lake during the last three decades: common water starwort (*Callitriche palustris*), lesser duckweed (*Lemna minor*), various- leaved milfoil (*Myriophyllum heterophyllum*), ribbon-leaf pondweed (*Potamogeton epihydrus*), brown pondweed (*Potamogeton natans*), greater duckweed (*Spirodela polyrhiza*) and water meal (*Wolffia* spp.). The following species are only known historically: shining pondweed (*Potamogeton illinoensis*) and white-stemmed pondweed (*Potamogeton praelongus*).

Table 12

LONG-TERM CHANGES IN DRY WEIGHT FALL STANDING CROP BIOMASS (g/m^2) OF DOMINANT SPECIES IN HONEOYE LAKE, 1984-2014.					
Species	Dry weight standing crop biomass (g/m^2)				
	1984	1994	2004	2014	net change
eelgrass	60.77	16.28	23.74	50.31	-10.46
coontail	8.95	10.49	39.24	30.92	+21.97
elodea	5.48	4.65	10.63	2.39	-3.09
water stargrass	5.27	5.15	16.13	9.47	+4.20
water marigold	4.03	1.27	1.44	0.00	-4.03
large-leaf pondweed	3.86	5.98	12.98	1.94	-1.92
Eurasian water milfoil	2.79	57.49	18.08	4.53	+1.74
star-leaved duckweed	0.33	1.82	3.56	2.03	+1.70
curly-leaf pondweed	0.21	0.39	1.87	0.12	-0.09
clasping-leaf pondweed	0.15	0.10	1.10	0.93	+0.78
flat-stem pondweed	0.05	0.31	0.13	1.27	+1.22
small pondweed	0.00	0.50	0.30	0.39	+0.39

Table 13

LONG-TERM CHANGES IN IMPORTANCE VALUES OF DOMINANT SPECIES IN HONEOYE LAKE, 1984-2014.					
Species	Importance value (%)				
	1984	1994	2004	2014	net change
eelgrass	44.2	12.7	15.0	30.7	-13.5
coontail	8.6	9.9	22.1	21.1	+12.5
elodea	6.5	7.3	10.0	4.8	-1.7
water stargrass	8.0	5.2	11.4	8.5	+0.5
water marigold	6.0	1.5	1.6	0.0	-6.0
large-leaf pondweed	7.3	7.0	10.1	3.7	-3.6
Eurasian water milfoil	6.2	34.9	13.8	7.1	+0.9
star-leaved duckweed	3.8	3.4	3.5	3.5	-0.3
curly-leaf pondweed	3.0	4.1	0.7	3.9	+0.9
clasping-leaf pondweed	0.6	0.6	0.4	2.4	+1.8
flat-stem pondweed	1.6	5.8	4.7	6.0	+4.4
small pondweed	0.0	0.9	1.3	4.2	+4.2

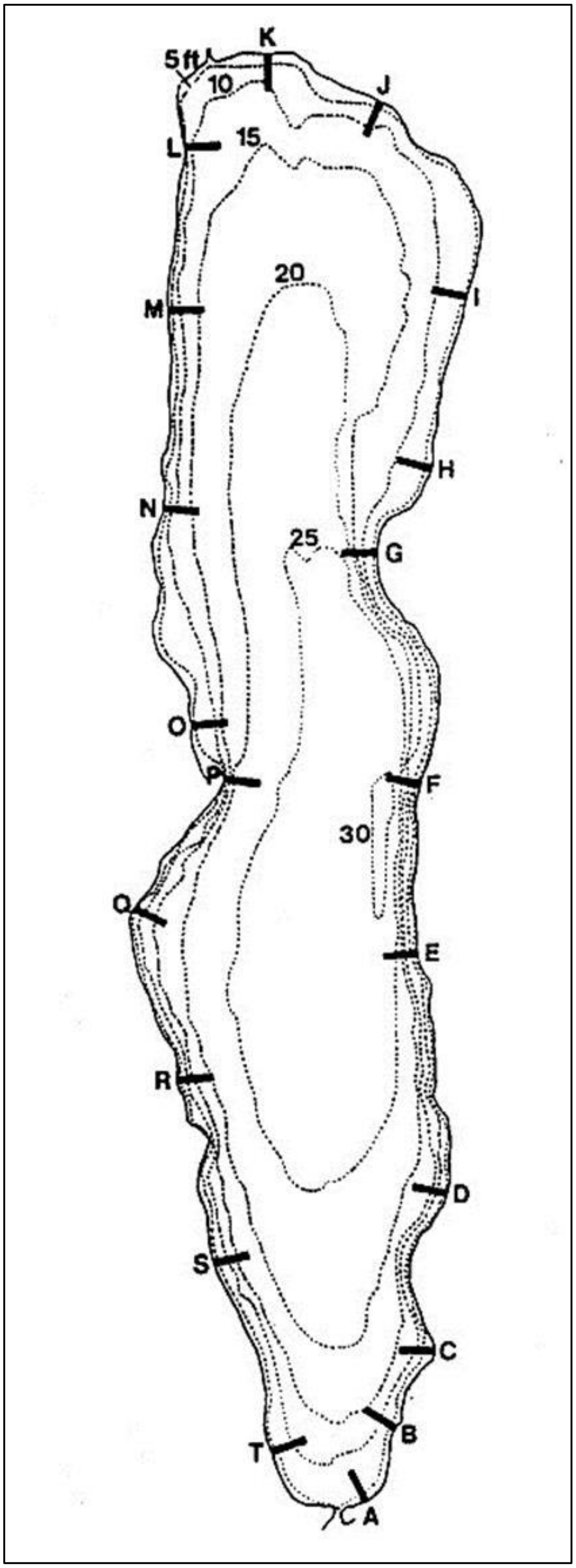


FIGURE 1

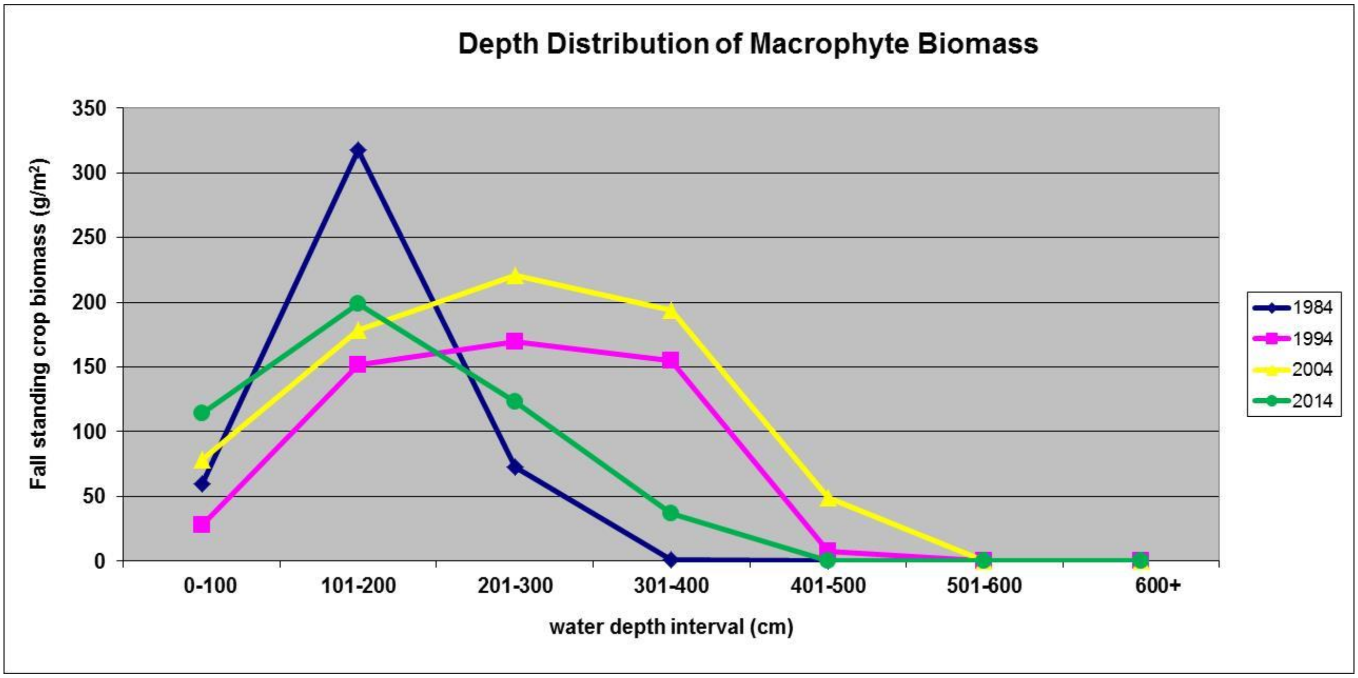


FIGURE 2

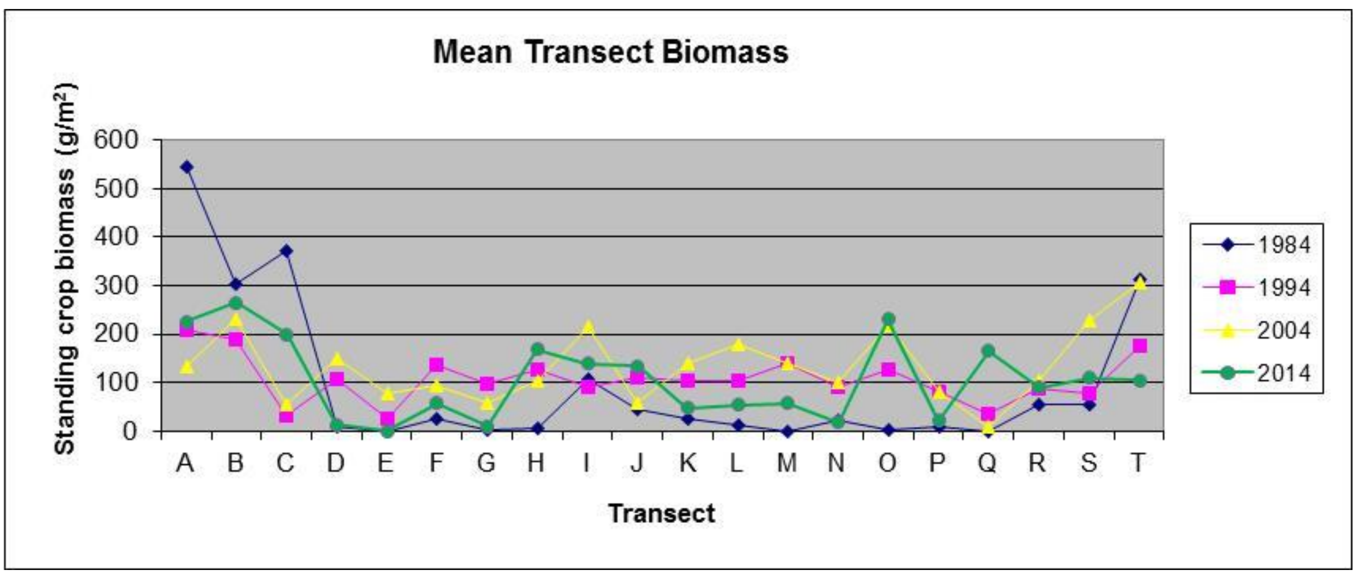
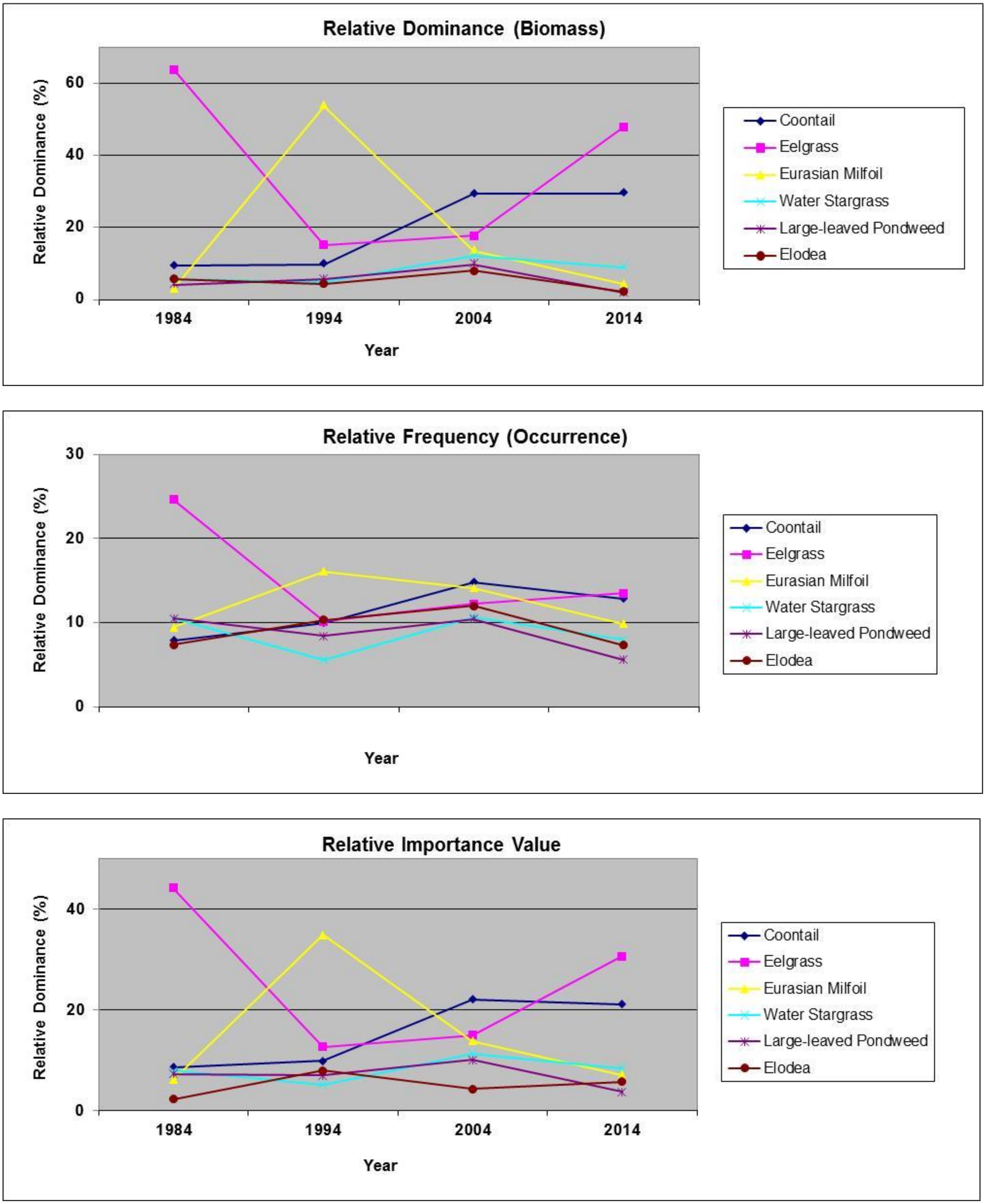


FIGURE 3



Relative Dominance (Biomass)
Relative Dominance (%)
60
40
20
0
1984
1994
2004
2014
Year
Coontail
Eelgrass
Eurasian Milfoil
Water Stargrass
Large-leaved Pondweed
Elodea
Relative Frequency (Occurrence)
Relative Dominance (%)
30
20
10
0
Year
Coontail
Eelgrass
Eurasian Milfoil
Water Stargrass
Large-leaved Pondweed
Elodea
Relative Importance Value
Relative Dominance (%)
40
20
0
1984
1994
2004
2014
Year
Coontail
Eelgrass
Eurasian Milfoil
Water Stargrass
Large-leaved Pondweed
Elodea

FIGURE 4

APPENDIX F: HONEOYE LAKE MACROPHYTE MANAGEMENT PLAN

Honeoye Lake Macrophyte Management Plan
Final - April 30, 2008

Prepared by:
Honeoye Lake Watershed Task Force
Macrophyte Management Committee

For:
Honeoye Lake Watershed Task Force
Town of Richmond
Town of Canadice

Available at: http://www.co.ontario.ny.us/planning/honeoye_lk.htm

Problem Statement

Honeoye Lake is currently listed as "Impaired" on the NYS DEC Priority Waterbody List due to water supply concerns relating to excessive nutrients. These nutrients, primarily phosphorus and nitrogen, can cause heavy growth of aquatic macrophytes and can contribute to nuisance algae blooms. Excessive plant growth may negatively affect recreational opportunities including fishing, boating, swimming and water skiing.

The eleven Finger Lakes of New York State were formed by the erosive scouring action and subsequent deposition of damming moraines by continental ice sheets during the Pleistocene Epoch. These lakes have many things in common such as their north-south orientation and linear shape, but also have many differences especially with regard to their surface area, depth and volume. These differences play a major role in determining the underwater light environment, seasonal temperature patterns and length of growing season, all factors that contribute to macrophyte growth. In general, the shallow Finger Lakes are biologically more productive and this fact must be taken into account in lake management plans since sensible management cannot drastically change the natural morphometry of a lake. The relationship between total phosphorus, one measure of lake productivity, and depth and volume is shown in Figure 1 for all eleven Finger Lakes. As predicted based on depth and volume, Honeoye Lake should be one of the most productive Finger Lakes and, indeed, it is. Knowing this morphometric limitation, no management technique can or should attempt to change a Honeoye Lake into a Skaneateles Lake.

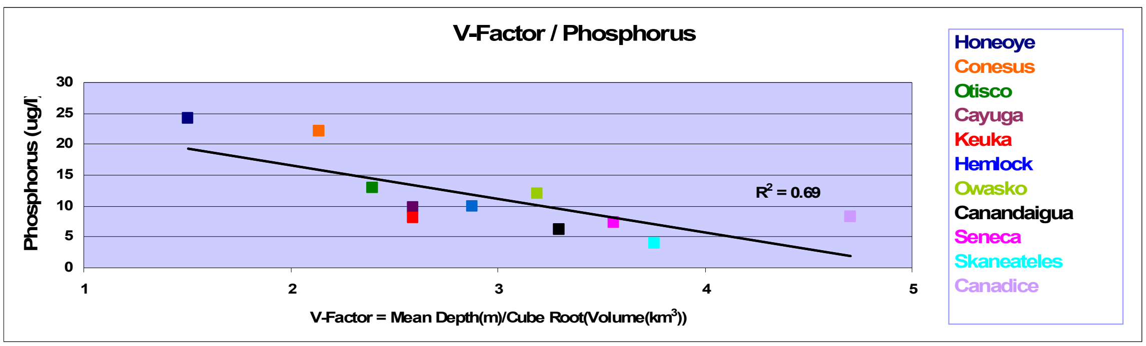


Figure 1- Relationship between Total Phosphorus and Lake Morphology for New York State Finger Lakes

The Honeoye Lake Watershed Management Plan summarizes the present state of the lake and watershed, including nutrient levels and their effect on the trophic state of the lake. Land uses commonly associated with nutrient enrichment, such as agricultural, industrial, commercial, and high density residential, are not common in the watershed, except for the high density shoreline residences. Most of the external sources of nutrients flow into the lake from streams or directly from the shoreline.

Honeoye Lake seldom stratifies in the summer and does so only temporarily and weakly due to its relatively shallow depth and exposure to wind-induced mixing. However, during periods of calm weather sufficient stratification occurs such that the deep waters have the potential to become anoxic, which can cause the release of internal phosphorus from sediments into the water column in deeper areas of the lake. Testing over the past five years has verified the summer anoxia and high concentrations of phosphorus in water collected from depths greater than seven meters. An alum application was completed in 2007 to reduce the release of phosphorus from the lake bottom sediment in an attempt to reduce the severity of late summer algae blooms.

The total annual phosphorus load in the lake is 70% from external sources and 30% from the lake's sediment related internal phosphorus load. However, this internal load is very seasonal in nature and peak internal loads often reach 90% during mid to late summer and are a major reason for an increase in a lake summer algae blooms. Macrophyte growth, however, is determined by sediment phosphorus levels in the shallower areas of the lake.

The watershed plan includes recommendations on steps to be taken to minimize nutrient flow into the lake. The highest priority action items are related to reducing erosion. These action items include stabilization of severely eroding streambanks and shoreline and the adoption of municipal practices and regulations that minimize erosion from development, highway maintenance, and timber harvesting.

The plant productivity of Honeoye Lake is a major reason for its highly regarded fisheries. Macrophyte stands provide excellent fish habitat, including spawning sites, feeding areas and protective refuge for juvenile fish from predators. Macrophytes also play an important role in stabilization of shorelines by holding bottom substrates in place thereby mitigating the erosive effects of waves, prop wash, and boat wake. Macrophytes also compete with algae for nutrients. For these reason, it is important that excessive macrophytes that interfere with recreational pursuits be managed but not eliminated.

Dr. Bruce Gilman of the Finger Lakes Community College has devoted more than twenty years documenting and analyzing the aquatic macrophyte communities of Honeoye Lake. His inventories during the fall of 1984, 1994 and 2004 were conducted along 20 different transects around the lake at distances of 10, 100, 200, 300 and 400 feet from shoreline for a total of 100 different sample locations each year. Figures 2-4 summarize the major results of these comprehensive studies:

Although variation in plant biomass exists around the lake, there is significant biomass at most locations along the shoreline to impact recreational opportunities (Figure 2 & Appendix A)

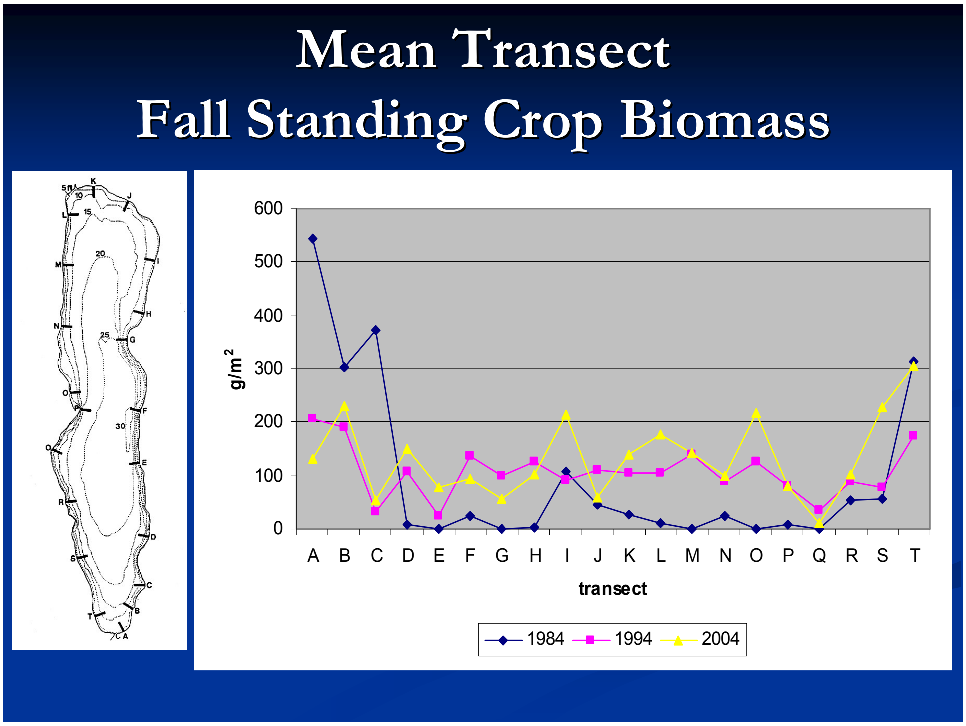


Figure 2- Fall Standing Biomass by Transect

Two common invasive macrophytes in Honeoye Lake are curly leaf pondweed and Eurasian milfoil. Since curly leaf pondweed dies off in early summer it was not commonly abundant in Dr. Gilman's fall sampling. While there has been a shift in the most dominant species, eelgrass and coontail have remained in the top three over the 20 year period (Figure 3). Eurasian milfoil, an invasive species that is a major problem in many northeastern U.S. lakes, is also present in Honeoye Lake but its dominance has been reduced from a peak of 54% in 1994 to 13% in 2004.

Figure 3- Shift in Macrophyte Species Comparison

The increase in transect plant biomass over the past 20 years has been primarily in the deeper waters due to increased water clarity (Figure 4). There has been little change in weedbed density in vegetated sites in the shallow areas. The increasing water clarity is related to the installation of a perimeter sewer system (1980) and the introduction of invasive zebra mussels (*Dreissena polymorpha*) , first collected from the lake on May 30, 1998.

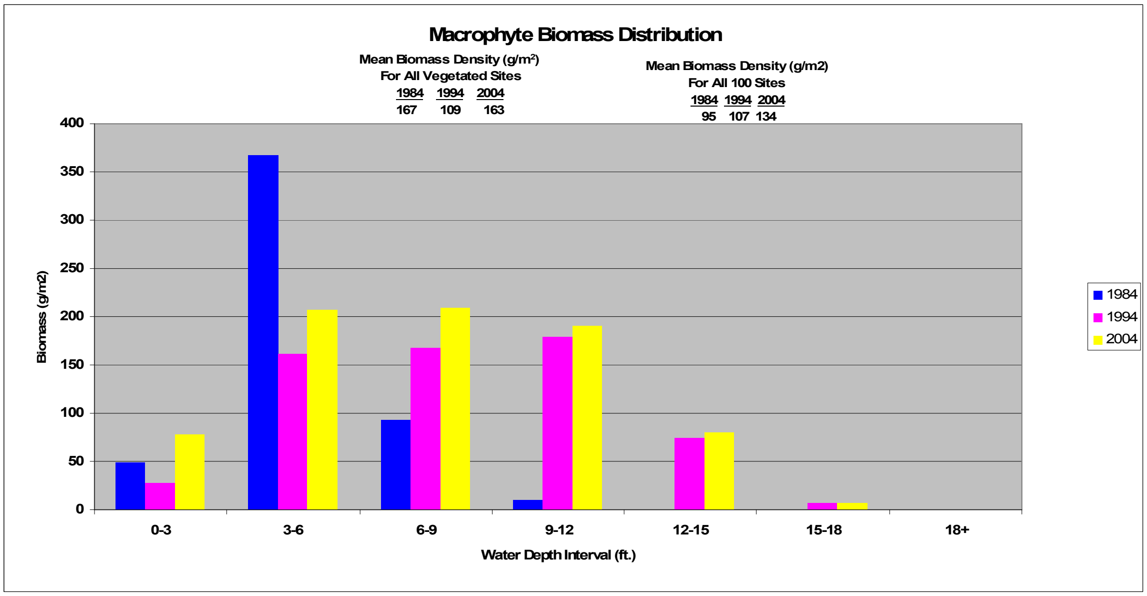


Figure 4- Macrophyte Biomass Distribution with Water Depth

The only known occurrence of a rare or endangered species is the water marigold (*Megalodonta beckii*), which commonly occurs only in the most southern portion of the lake, outside the area that is presently harvested. Isolated occurrences have occurred in a couple of other shallow water locations.

There are several wetland buffer zones located at the extreme northern and southern portions of the lake, which are also located outside the area that is presently harvested.

Management History

A near-shore aquatic macrophyte harvesting program to enhance recreational opportunities in the lake was initiated in 1987 and, through 2004, used a single mechanical harvester. A second machine was added in 2005, since there was the perception that a single harvester was not sufficient to maintain the conditions necessary for enjoyable recreational use. This change nearly doubled the total amount of vegetation harvested. Figure 5 provides the total wet tonnage and harvesting rate through this 20 year period. Nutrient removal rates per harvester are estimated to be 630 pounds (286 kg) of nitrogen and 99 pounds (45 kg) of phosphorus on an average annual basis. An ongoing aquatic macrophyte harvesting program may be of long term benefit because of the nutrients that are removed in the plant biomass.

While aquatic macrophyte harvesting may only temporarily reduce the current plant biomass, there is general support to continue harvesting to enhance recreational use of the lake by reducing vegetation in the upper portions of the water column. The cost of the aquatic macrophyte harvesting program has been shared between the towns of Richmond and Canadice, and New York State through funds from the Finger Lakes- Lake Ontario Watershed Protection Alliance program.

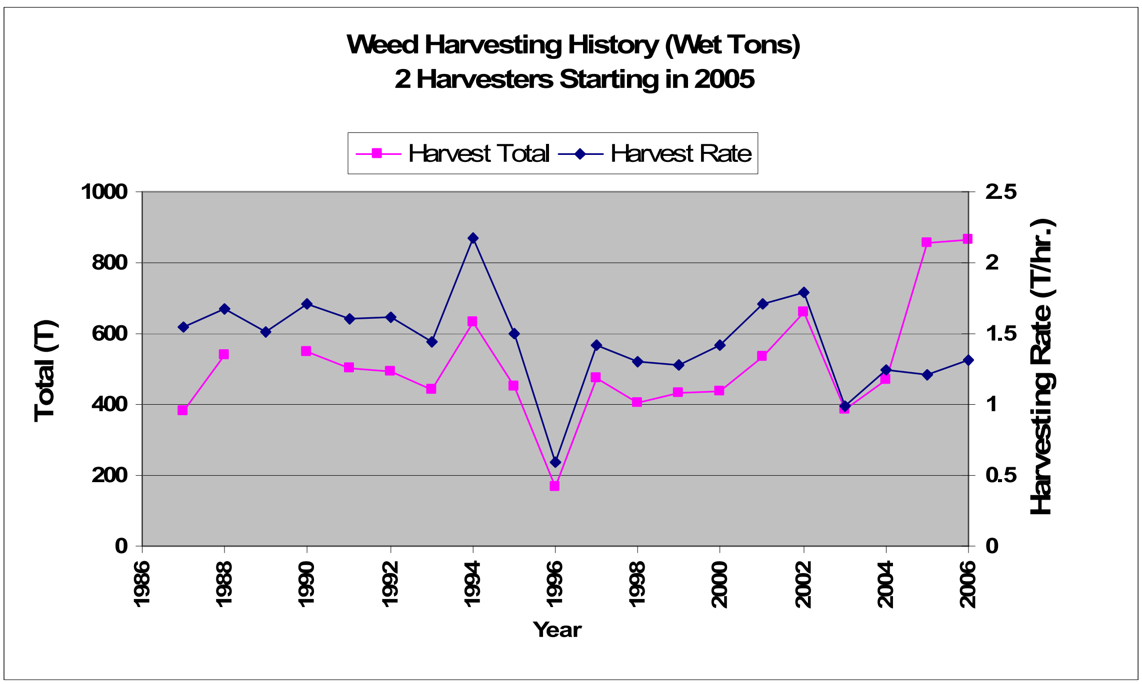


Figure 5- Weed Harvesting History

In addition, some residents have controlled aquatic macrophytes in the near shore area around their docks and beach by using benthic mats, hand pulling, raking, and small suction dredging units.

Management Objective

The objective of this plan is to:

*Develop an **ecologically** and **scientifically** sound Macrophyte Management Plan (MMP) to facilitate **balanced recreational use** of Honeoye Lake including **boating, fishing, swimming and other uses**.*

This will result in the following benefits to lake users:

Enhancing recreational lake opportunities while protecting aquatic plant habitats for the functions and values they provide. This will be achieved by selecting aquatic macrophyte management strategies that are focused on providing biomass reduction in the top few feet of the water column in areas most frequented by recreational lake users.

Aquatic macrophyte management alternatives suited to the upper water column and especially the near shore lake environment will be evaluated here. Since the lake is not dominated by a single species, all techniques, not just those designed for invasive species, will be considered.

The macrophyte management techniques chosen are expected to be implemented during the summer season since the macrophytes die back each fall and the recreational opportunities affected by excessive macrophytes are primarily summer endeavors.

No management techniques will be implemented in the New York State protected wetlands (Appendix B) and their respective 100 foot buffer zones at the south and north ends of Honeoye Lake. All management techniques will be appropriately timed to avoid impacts on lake fisheries.

Management Alternatives

A consulting firm, Princeton Hydro, evaluated nearly all known macrophyte management techniques that have been used on other lakes. These included mechanical harvesting, lake level drawdown, benthic barriers, hand and suction harvesting, hydroraking / rotovating, dredging, herbivorous insects, grass carp, contact aquatic herbicides, systemic aquatic herbicides, shading (adding dye to the water), and treatment of the sediments with either a lime or alum slurry. The evaluation criteria used were:

> Does it meet our management objective?
> Is it fundable?
> Are we likely to be able to get a NYS DEC permit?
> Is it acceptable to lake stakeholders?

A meeting was held with NYS DEC personnel from both the Albany and Region 8 Offices on October 3, 2006 to understand their concerns and discuss their recommendations.

Tables 1 and 2 summarize the ranking results of analyzing the efficacy of the various methods within each evaluation criteria identified above, for both local shoreline management that could be accomplished by individual residents and whole lake management that would be expected to be done by governmental entities. The color coding is as follows:

Green - This option is viable for this evaluation criterion
Yellow - This option is potentially viable for this evaluation criterion
Red - This option is rejected for this evaluation criterion

Table 1 - Evaluation of Shoreline Management Techniques

Techniques	Meet Objective	Fundable	Permittable	Acceptable to Stakeholders
Benthic Barriers	**Yes**	**$1/ft^2$**	**Not Required**	**Yes**
Weed Roller/ Lake Sweeper	**Yes**	**$1K-$5K**	**Not Required**	**Yes**
Hand Pulling	**Yes**	**~$0 -$500/acre/yr**	**Not Required**	**Yes**
Suction Harvesting	**Yes**	**~$500+/acre/yr**	**Yes**	**Yes**

All of the above techniques are potentially practical for individual residents to use in fairly small areas around docks, beaches and swimming areas.

1. Benthic Barriers are a cost effective way to limit growth through the reduction in sunlight available for plant germination at the lake bottom. They also provide a physical barrier through which aquatic plants have great difficulty growing.
2. Weed Rollers/Lake Sweepers are a relatively new device used mostly to control weed growth in small areas by the repetitive gentle agitation of the surface sediments which impedes plant growth due to mechanical damage to the plants or the creation of a sediment habitat unsuitable for plant colonization.
3. Hand Pulling is largely restricted to small areas and is labor intensive. It is the ultimate selective plant management technique, however, since it removes individual plants one at a time.
4. Suction harvesting has many of the same advantages as hand pulling but involves a SCUBA diver using a flexible hose that is connected to a vacuum pump to dislodge plants which are then pumped to the surface into a container for proper off-lake disposal.

Table 2- Evaluation of Whole Lake Management Techniques

Techniques	Meet Objective	Fundable	Permittable	Acceptable to Stakeholders
Mechanical Harvesting	Yes	$60,000/yr	N/A	Mixed
Systemic Spot Herbicides	Mixed	~$240,000+/3yr	2+ Years	Mixed
Hydroraking / Rotovating	Localized	~$250+/acre/yr	2+ Years	Mixed
Herbivorous Insects	Mixed	~$1,000/acre	Yes	Yes
Systemic Whole-Lake Herbicides	Mixed	~$500,000/3yr	2+ Years	Mixed
Contact Spot Herbicides	No	~$120,000/yr	Yes	Mixed
Grass Carp	No	~$120,000+	No	Mixed
Lake Draw Down	No	$$	No	Mixed
No Management	No	$0	N/A	No
Lime or Alum Slurry	No	?	No	Mixed
Shading (Adding Dye to Water)	No	?	No	Mixed
Dredging	No	~$20,000+/acre	No	No

Viable whole lake management strategies are subdivided into physical/mechanical alternatives, biological control alternatives, chemical control alternatives and a no action alternative. Each technique is then discussed in detail as it relates to macrophyte management in Honeoye Lake.

Physical/Mechanical Control Alternatives

1. Continue to use mechanical harvesting as the center piece of the macrophyte management control program based on past performance related to removal of nutrients and reducing weeds in the upper levels of the water column. This technique is well suited when there is no dominant species that needs to be controlled.
2. Hydroraking could be considered as a supplemental management option to decrease weed densities in areas that are difficult for the harvesters to effectively operate. However, it is very costly and would be difficult to get NYS DEC permit approval.
3. Lake drawdown is not practical for a number of reasons: no dam or control structure, insufficient elevation differential, NYS protected wetlands at north and south ends of lake, possible exposure of residential water intakes during drawdown.
4. Dredging is not practical due to excessive cost, the inability to achieve sufficient depth change to preclude weed growth, and the detrimental ecological effects of significant bottom sediment disruption.

Biological Control Alternatives

1. Herbivorous Insects should continue to be investigated but at this time they don't appear to be a practical control method since, in most cases, they target a specific macrophyte species, some herbivorous insects are already present in the lake, their cost is excessive for treatment of large areas and have not proven to be unequivocally successful in neighboring small lakes.
2. Grass carp are not practical due to their high cost, they are not recommended where they may escape to adjacent waters, they re-suspend lake sediment and create turbid conditions, and

their preference to eat desirable native macrophytes might lead to future infestations with the invasive curly leaf pondweed and/or Eurasian milfoil.

Chemical Control Alternatives

1. Contact herbicides should not be used primarily due to the fast acting nature of these chemicals in killing plants which then rapidly decay resulting in negative side effects including dissolved oxygen depression and the release of soluble reactive phosphorus. The significance of the phosphorus release is that the timing of the treatments, and the subsequent introduction of phosphorus from the dying plants into the water, often results in mid- and late-summer algae blooms, a condition that is counterproductive to the overall management of Honeoye Lake. Although it can be argued that contact herbicide treatments could be conducted on a localized scale, thereby minimizing the chance for these types of problems, the distribution of problem vegetation tends to be fairly uniform along the lakeshore.
2. Fluridone (SONAR) and 2-4D are two aquatic, systemic herbicides licensed for use in New York. NYS DEC restricts the use of both from the perspective of timing, allowable treatment area and dosage. Due largely to costs and regulatory restrictions, a whole lake application using either of these chemicals is not feasible.
3. Some consideration should be given to the use of pelletized versions of either 2-4D or SONAR as a supplementary means of controlling nuisance weeds where structures may impede effective weed harvesting. Its efficacy is greatly diminished in areas having very soft sediments where the pellets will settle into the mud. NYS DEC does restrict the use of 2-4D to treatments between late spring and mid-summer, and it cannot be applied in waters shallower than 2 feet. In addition, there is at least a 24 hour use restriction for the drinking of treated waters and irrigation may be prohibited for a much longer period of time. Unlike 2-4D, which is a fast acting systemic herbicide, SONAR is slow acting. This has a number of benefits in terms of avoiding or minimizing the aforementioned secondary water quality impacts associated with contact herbicides. However, the slow acting nature of this chemical necessitates that it remain in contact with the target plant(s) for a long period of time (usually 30-60 days). Water currents and wave action can result in the drift or dilution of the chemical and diminish its effectiveness. A large problem with SONAR is its water use restrictions. Treated waters cannot be used for irrigation for 60-90 days following treatment. Even more important is that areas within ¼ mile of potable water intakes cannot be treated. With the number of residential intakes on Honeoye Lake this presents a significant problem and would greatly restrict the areas in which this product could be used even with a spot treatment approach.
4. The use of alum or lime slurry to control weeds is not practical since it does not appear that the New York State will, at any time soon, be in a position to issue the SPDES permit needed to authorize such treatments. So although these techniques remain promising, they cannot be considered feasible at this point in time.
5. The use of dyes to darken the water thereby reducing the amount of light and hence reducing the growth of macrophytes is not practical. The cost-effectiveness of this control option is low and the aesthetic effect of making the lake look artificial is undesirable to stakeholders.

No Action Alternative

1. This alternative does not address the problem caused by excessive aquatic plant growth reducing the recreational enjoyment of the lake.

Recommendations

Based on the above research, analysis and evaluation, the recommendation is to continue to utilize Mechanical Weed Harvesting as our primary Macrophyte Management Control strategy with the following suggestions:

1. Continue to manage the Mechanical Weed Harvesting Program through the Ontario County Planning Department (OCPD).
2. OCDP Weed Harvesting Program Manager in conjunction with the Honeoye Lake Watershed Task Force (HLWTF) will develop an annual Macrophyte Management Plan based on maximizing the objective for recreational lake user's benefits while also maintaining the ecological services provided by the aquatic plant communities.
3. The OCPD Weed Harvesting Manager and HLWTF will develop an aggressive communication strategy (e.g., annual management strategy, periodic progress reports during the weed harvesting season, annual weed harvesting report at the end of the season, etc.) with the HLWTF, Town Boards, and the lake residents through the utilization of existing venues (e.g., local board meetings, OCPD & Honeoye Valley Association (HVA) web sites, and direct mail communication).
4. Refurbish the Town of Richmond Weed Harvester after the 2007 season. Cost estimated to be ~$ 12,000.
5. Develop a funding strategy (e.g., State Member Line Item funding, County Funding support, local town five year funding reserve fund strategy, etc.) to buy two new mechanical harvesters by 2012.
6. Maintain the annual macrophyte management budget at its current level of $60,000 (Richmond $26,250, Canadice $8,750 and FL-LOWPA $25,000) for 2007.

Encourage private lake front property owners to take appropriate macrophyte management actions (benthic barriers, hand and suction dredging, hand pulling) to improve recreational lake usage for activities like fishing, boating, swimming, skiing, etc.

Continue to evaluate any new macrophyte management alternatives that are approved by the NYS DEC.

For example; continue to evaluate the potential of using new systemic aquatic herbicides for spot treatments to augment the mechanical harvesting program. For example, Renovate 3 is being evaluated by the NYS DEC. It has only a 36-48 hour water use restriction. This might address the most significant concern regarding using an aquatic herbicide for spot treatments.

Aquatic Plant Monitoring Program

Comprehensive diver conducted surveys performed by a professionally trained limnologist of the fall standing crop biomass will continue to be conducted on a ten year cycle, using the same procedures described in the earlier Problem Statement section.

In addition a volunteer monitoring program will be conducted each summer using a rake toss method. This program will be conducted twice each summer, once in late June and again in late August. The rake toss will be conducted along seven different transects at different sites around the lake at 10, 100, 200, 300 and 400 feet from the shoreline. Six of the sites are located in areas of the lake that are harvested and one in a location where no harvesting occurs. The species collected at each location will be identified to obtain an estimate of the distribution of the various species of macrophytes in the lake. Professional assistance will be available to identify some of the rarer species.

Lake Water Quality Monitoring

A lake water quality monitoring program performed using volunteers includes measuring temperature and dissolved oxygen profiles from the surface to the bottom in one meter intervals and taking water samples at the surface, 4 meters, and 8 meters at the deepest location in the lake. Water clarity will be measured using a Secchi disk. The water samples will be analyzed by a state-certified laboratory for total phosphorus (TP) and soluble reactive phosphorus (SRP). Chlorophyll-a will be measured for the surface water sample. These monitoring events will be performed on the following schedule.

February- 1 time through the ice
May- 1 time
June- 2 times
July- 2 times
August- 2 times
September- 1 time

Stream Water Quality and Flow Monitoring

Eight major tributaries will monitored by a professionally trained limnologist once a month for a year to establish baseline data. In addition, at least six hydro meteorological events will be sampled for each tributary. The tributaries to be monitored will include the Inlet, Afolter, Bray, and Briggs streams, and four additional tributaries located at 159 West Lake Road, Cratsley Hill Road, Trident Marine, and Honeoye Lake Park.

Point discharge will be estimated for each tributary for each sampling date by the usual method of measuring the cross-sectional area of the tributary and tributary water velocity. Water samples for each sampling event will be analyzed for total phosphorus (TP), soluble reactive phosphorus (SRP), total Kjeldahl nitrogen, Nitrate + Nitrite, and total suspended solids (TSS). Chemical analysis will be performed by a state-certified laboratory.

References

Gilman, Bruce, An Inventory of the Aquatic Weedbeds of Honeoye Lake with Suggestions for Their Management, Community College of the Finger Lakes, 1985

Gilman, Bruce, Weedbed Communities of Honeoye Lake: Ten Years Later, FLCC, 1994

Gilman, Bruce, Weedbed Communities of Honeoye Lake-2004 PowerPoint Presentation, 2006

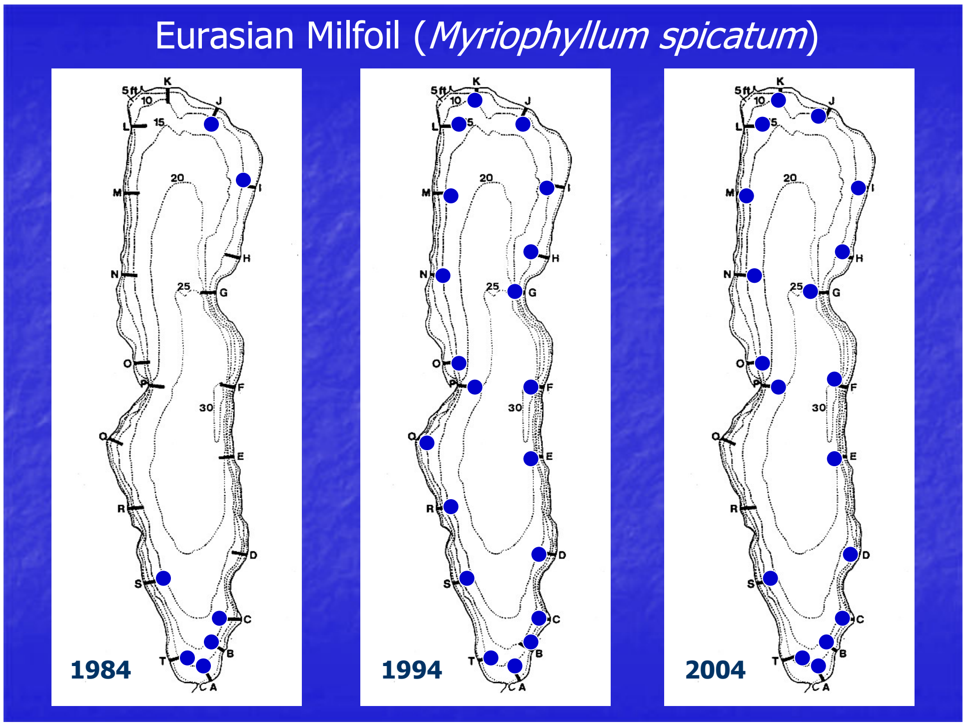
Honeoye Lake Watershed Management Plan, October, 2007 available at:
http://www.co.ontario.ny.us/planning/honeoye_lk.htm

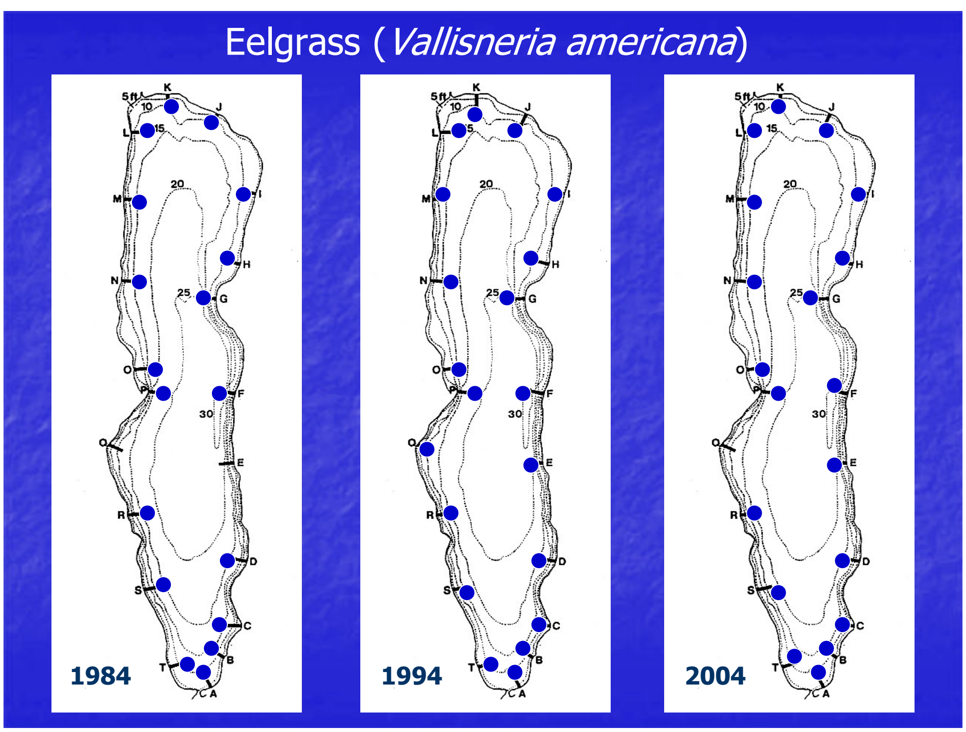
Princeton Hydro, Alternative Macrophyte Control Options-Honeoye Lake, 2006

Meeting Notes from Honeoye Lake Macrophyte Management Plan Committee Meeting on October 3, 2006 with NYS DEC personnel from both the Albany and Region 8 Offices

Appendix A

Maps Showing Distribution of the Most Commonly Found Aquatic Plants in Honeoye Lake





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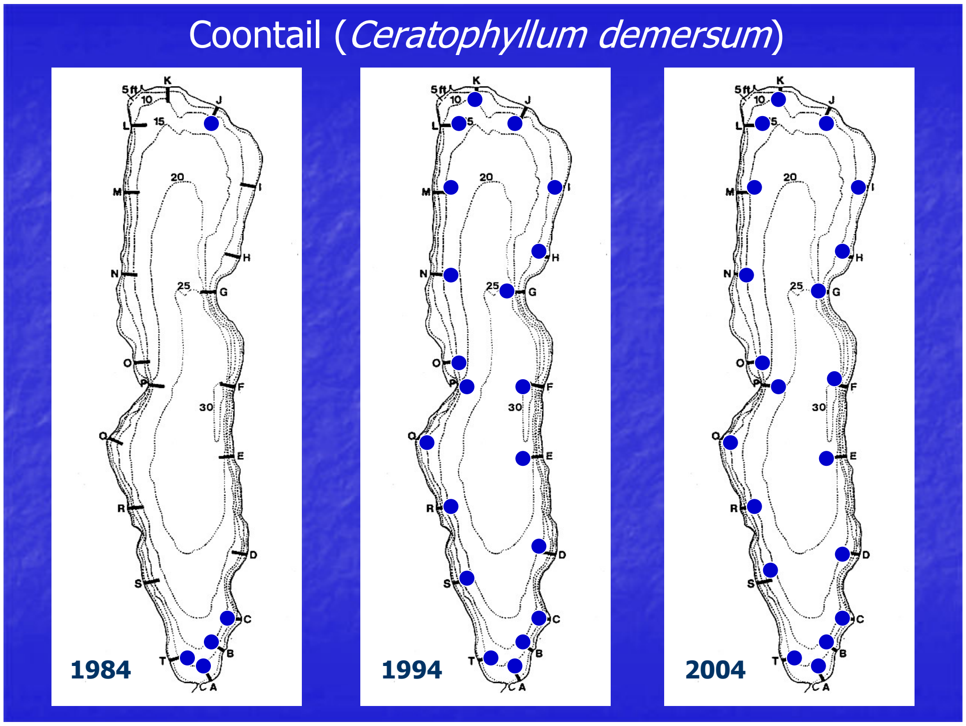

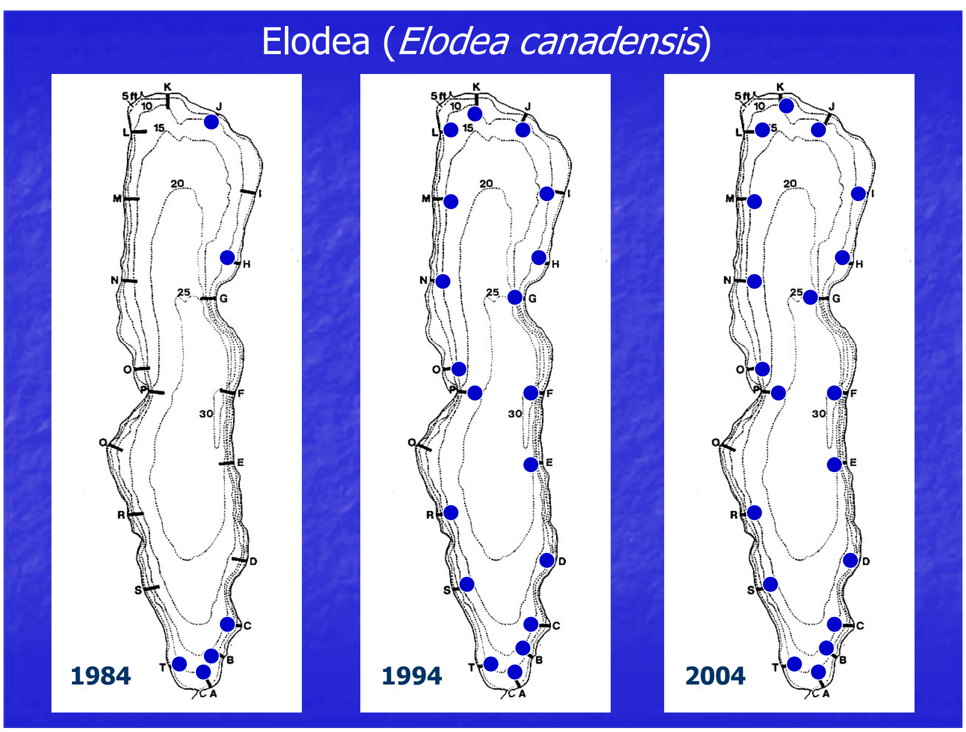

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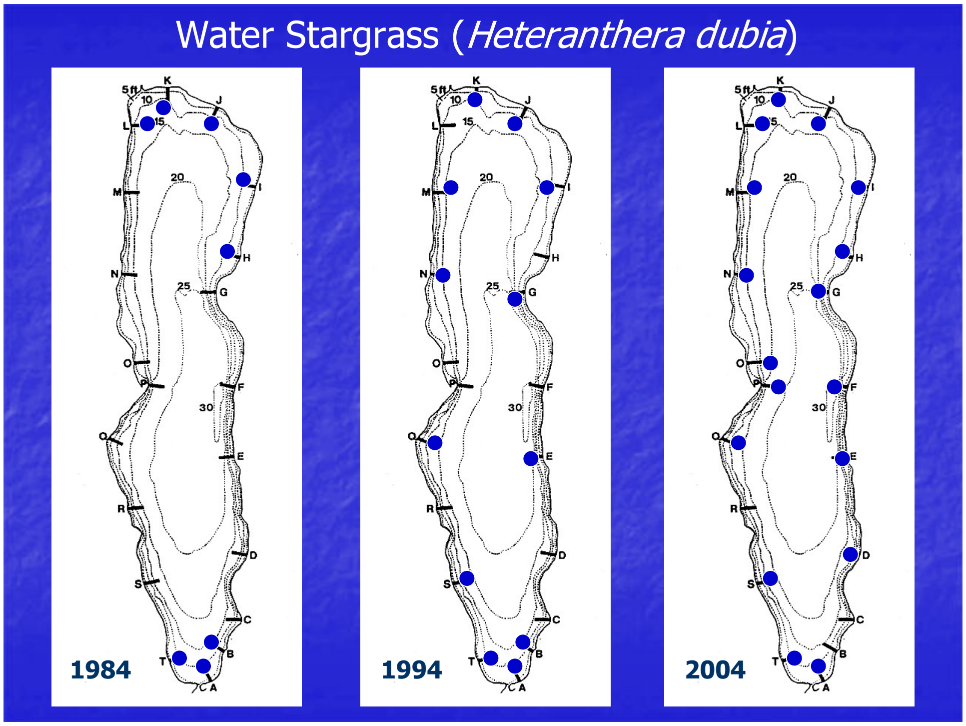

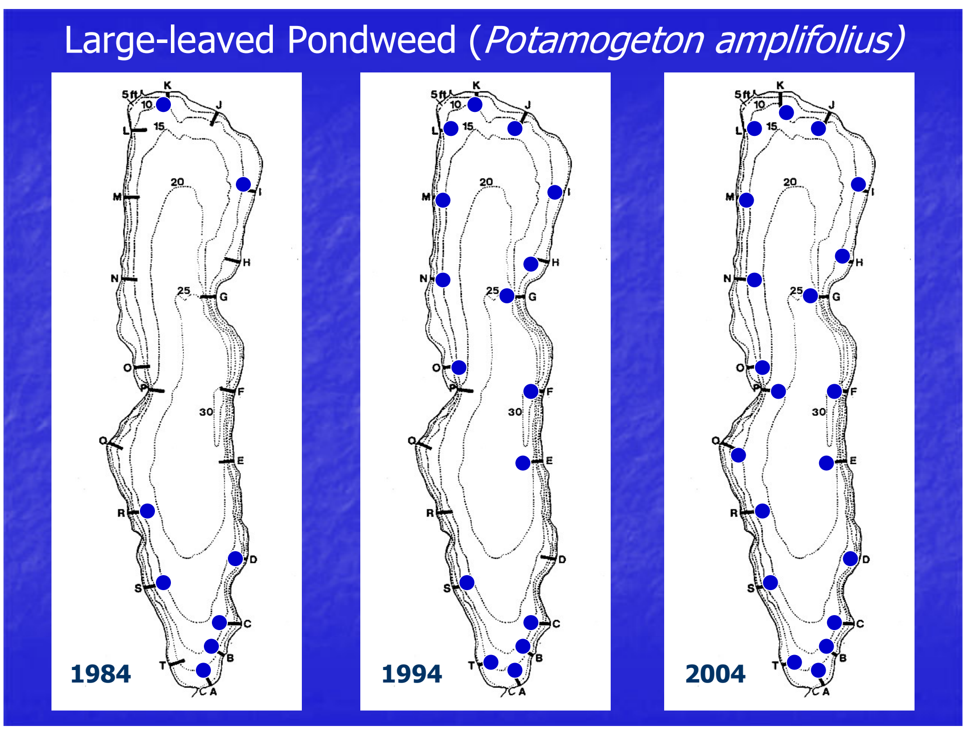

Appendix B
Honeoye Lake Protected Wetlands

North End

South End