Lake Attitash Assessment Report

May 29, 2014

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1.1 Purpose

Lake Attitash was selected by the United States Environmental Protection Agency (USEPA) as a pilot lake for testing new methods and new technologies in preparation for a national lakes assessment survey that took place in 2007 (water.epa.gov). Lake Attitash was also used as a case study lake for the New England Lakes and Ponds (NELP) regional assessment project which was completed and reported out in 2010 (neiwpcc.org). During the 2010 NELP project, the local Lake Attitash Association (LAA) requested assistance in trying to determine sources of nutrients within the watershed, and follow up help on some of the recommendations made by the 1999 Camp Dresser & McKee Lake Attitash Water Quality Management Plan[1]. Because of the importance of the lake as a secondary water supply source to the town of Amesbury, the importance of the lake as a major recreational resource in the area, and the magnitude of existing water quality problems in relation to the overabundance of aquatic plants and phytoplankton leading to nuisance levels and harmful algal blooms, the EPA agreed to continue focused research on the lake.

In 2011, a yearlong survey was initiated in an effort to determine current nutrient sources and loads to the lake, establish characteristics of the watershed's hydrology, and try to establish a chronology or causality leading up to the current plant and algal problems in the lake. Efforts included water sampling twice per month, sediment sampling, an aquatic plant survey, a boat landing traffic survey, flow and physical water chemistry measurements, a storm drain survey, and a single wet weather event survey. EPA biological surveys completed in prior years on Lake Attitash for fish and phytoplankton are also included in this report, as they are relevant to the current issues surrounding the lake. Details of the approach can be found in the Sampling and Analysis Plan (SAP) in Appendix A.

An additional purpose of this report is to provide insights to the public on past and present uses of the water body and the ecology of the lake, with applicability to other waterbodies in the region, and the effects of watershed management decisions that ultimately determine the quality and sustainability of the resource. The EPA New England Regional Laboratory continually works at developing new methods and utilizing new technologies that assist local, state, and tribal water quality management programs in accomplishing their missions and providing advanced methods support. Data and methods development resulting from these efforts provide additional benefits to other lake stakeholders in helping them identify and resolve some of the surrounding water quality issues of their lakes, while supporting national and regional program goals and the advancement of new technologies.

1.2 Background

Lake Attitash is a 360 acre “great pond” located within a 3.9 square mile watershed area. The lake is situated within the towns of Amesbury and Merrimac, Massachusetts. This pond is less than a mile across at its widest point, has a maximum depth of thirty-two feet, and an average depth of just less than twelve feet. The bottom composition is predominantly organic muck underlain by coarse sands and gravel and populated with an abundance of submergent, emergent, and floating aquatic plants. Surrounding land use is comprised of medium and high density residential development along most of the north, east, and southeast shoreline areas on a topography that is dominated by moderate to steep hilly terrain. The west shoreline of the lake is dominated by medium density single resident homes. Non-residential use directly adjacent to the lake consists of a boy’s camp on the south side of the lake, the town of Merrimac municipal drinking water filtration plant and wellfield, located in the Southwest quadrant of the lake, and the Sargent Farm agricultural operation in the northwest quadrant, located adjacent to the main inlet tributary to the lake. The town of Merrimac has another wellfield located in the northwest quadrant of the lake’s watershed on Bear Hill. The western half of the lake is a mixed land use of residential development dominated by elevated sandy shore lands and two significant wetland areas.

Lake Attitash has undergone a transformation typical for most urban lakes (figure 1-1).

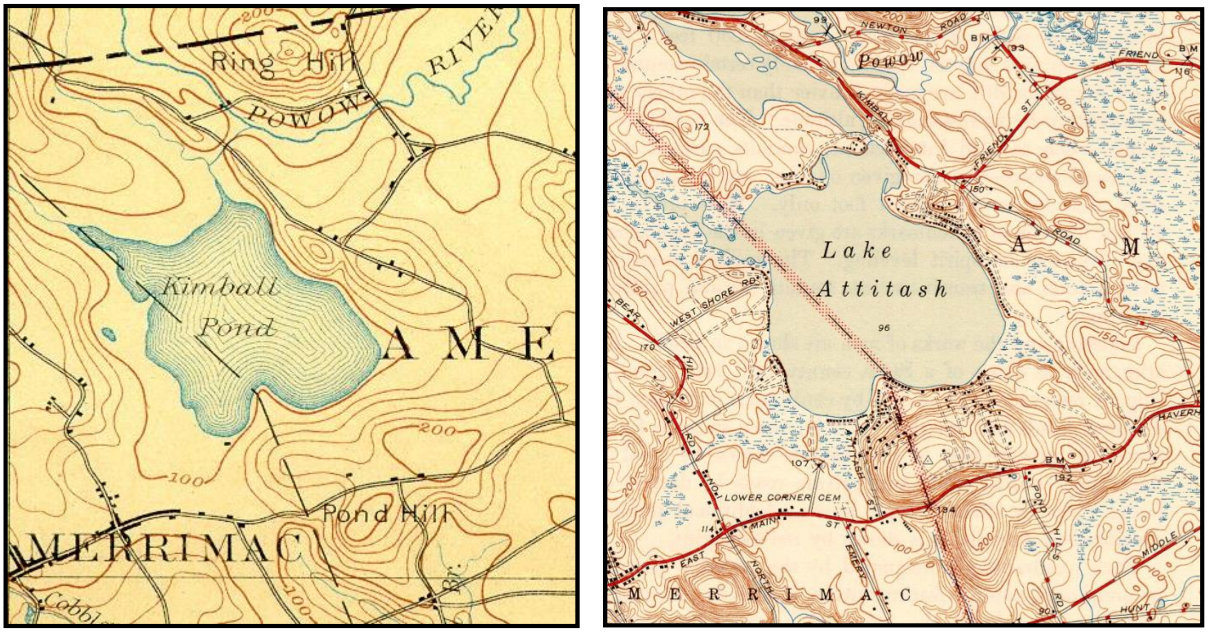

***Figure 1-1*: 1894 and 1944 topographic maps showing the density of dwellings around the lake. A report from 1912 stated that the lake was already densely populated with summer homes by that time. The name of the lake was changed prior to 1900.**

Historically, the lake shoreline dwellings were predominantly used as vacation and summer getaways. The infrastructure historically was comprised of private groundwater wells or direct lake withdrawals, and waste was handled through on-site septic systems. Residences around the lake started transitioning in the 1970s from seasonal summer cottages to permanent year round dwellings. Today the lake is almost entirely surrounded by year round homes. In the mid 1980's through the early 1990s residences around the lake were finally tied in to town sewer systems and most residences also tied in to public water supply distribution lines.

Lake Attitash has degraded from a mesotrophic lake classification in the mid-1970s, to a eutrophic borderline hypereutrophic system today. In the summer months heavy macrophyte cover occurs to nuisance levels and has been documented and mapped in most areas of the lake. Invasive plant species of water chestnut and eurasian milfoil have been observed in several locations at density levels of concern, and purple loosestrife is now encroaching into the wetland areas. The occurrence of harmful algal blooms has increased significantly over the past decade, with public health advisories posted every summer since The Massachusetts Department of Public Health began monitoring the lake in 2009.

The State put in a paved public boat launch and parking facility in the early to mid-1970s, adding significantly to the public access and use of the lake. Today, public use pressure is high (Figure 1-2), Lake Attitash being one of the only publically accessible fresh water lakes in the Northeast corner of Massachusetts. The lake receives year round use from fishing, sailing, swimming, and water skiing in the summer to ice fishing, snowmobiling and ice boating in the winter. The lake is also known as a depositional mercury "hotspot" from local and regional

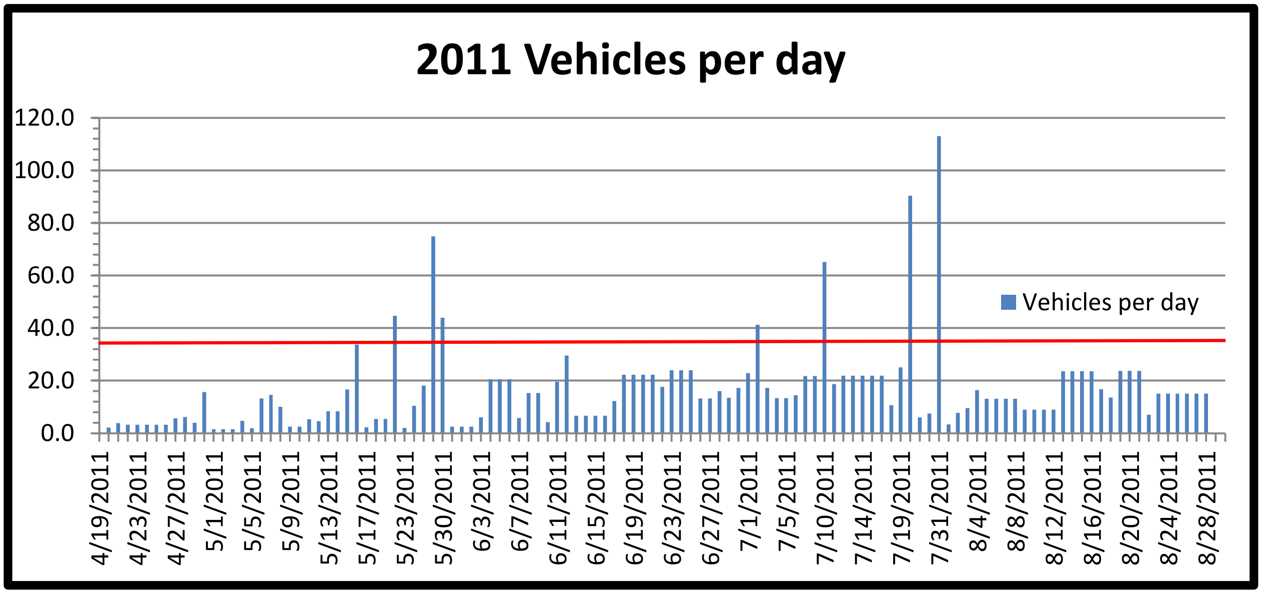

***Figure 1-2*: 2011 Daily & averaged daily use of boat ramp (red line indicates parking lot capacity).**

industrial sources. Fish tissue surveys conducted in the past by Massachusetts Department of Environmental Protection (MADEP) had revealed mercury tissue concentrations above state and federal consumption advisory levels.

An aggressive Lake Association has been very proactive in addressing water quality concerns in the lake and the surrounding watershed, and has made significant strides in recent years at mitigating external nutrient sources to the water body through infrastructure controls, public education, and best management practices. Despite these efforts, Lake Attitash continues to be plagued by water quality issues.

1.3 Previous and Current Studies

The first known report of conditions on Lake Attitash was from unpublished data from the Commonwealth of Massachusetts, Division of Fisheries and Wildlife in 1912, followed by some water quality and stocking history data in 1949 originating from the same division. In 1977 the Massachusetts Division of Water Pollution Control (MDWPC), now the Massachusetts Department of Environmental Protection (MADEP), completed a water quality study of the lake, publishing the results in 1980. This study characterized the watershed at the time, including surficial geology, hydrology, and climate. The study completed water and sediment chemistry along with biological and physical chemical characteristics (dissolved oxygen, temperature, pH, etc.) of the lake. Findings from this survey listed the lake as a mesotrophic system with good water quality and reasonably good clarity, but a hyper-dominance of aquatic plants covering approximately 70% of the lake area was documented. Subsequent water quality studies were done in 1994, by the then newly formed Lake Attitash Association (LAA), concluding that water quality appeared to be declining since the 1977 MADEP report. This report identified potential sources of elevated nutrients emanating from the Back River area and the wetland located in the Southwest quadrant of the lake. In 1998, a watershed management plan was developed for the Town of Amesbury by Camp Dresser and McKee (CDM), adding to the conclusions and recommendations from the earlier LAA water quality report. In 2002, a grant was given to the Town of Amesbury by the Massachusetts Department of Conservation and Recreation (DCR) Lakes & Ponds Program to implement some recommendations from the CDM Lake Attitash Watershed Management Plan. Recommended implementation measures included:

- Grass lined swale installations with sediment forebays to minimize sediment transport and maximize runoff infiltration to groundwater
- Installation of a Siltation curtain barrier called a ***Gunderboom*** for the Back River to control sediment transport in to the lake from the Back River
- Install new storm drain infrastructure to mitigate direct runoff in to the lake
- Install culvert flap gates and implement wetland restoration efforts
- Install stormwater wetlands to filter out pollutants, and remove invasive

phragmites
- Develop a Quality Assurance Project Plan (QAPP) and implement consistent water quality monitoring of and around the lake
- Replace failing or poorly designed catch basins
- Prepare quarterly progress reports and final report

Many of the above action items have been implemented, with the exception of wetlands restoration, phragmites removal, and a focused water quality monitoring effort. The Lake Attitash Association has been monitoring water quality of the lake in order identify problem areas and provide educational outreach to the lake shore community as the resource dollars become available. General perceptions based on monitoring efforts indicate that the water quality is getting worse.

The University of New Hampshire's Center for Freshwater Biology (UNH, CFB) utilizes Lake Attitash as a limnology training lake for students, and as a research waterbody for investigating blue-green algae and their associated harmful effects. The UNH CFB has conducted numerous surveys within the waterbody. Reports from these student research efforts can be found on the UNH CFB webpage at (unh.edu).

The USEPA Region 1 Laboratory has been utilizing Lake Attitash for the past several years as a pilot case study lake and as a waterbody to test new monitoring technologies and methods. A mercury fish tissue survey was completed in 2005, and in 2009 a comprehensive fish survey was completed. Detailed bathymetry, submerged aquatic vegetation surveys and phytoplankton were completed in 2008 and 2009, and sediment lead 210 and cesium 137 analyses was completed in 2011. EPA has also conducted aerial remote sensing on this water body in conjunction with other lakes across New England (Harvard.edu). Highlights of these activities are published in EPA's "New England Lakes & Ponds" report (epa.gov).

The most recent comprehensive Lake Attitash study prior to this report was conducted by Camp Dresser & McKee (CDM) in 1998. This work was performed under a grant from the town of Amesbury Massachusetts to develop a watershed management plan for the lake and its watershed. A final report was submitted to the Town of Amesbury in January of 1989. This work consisted of a water quality review of historical data, mapping of the watershed and a build out analysis for future planning, identification of contaminants sources and analysis of nutrient loading, and control and best management practices (BMPs) recommendations. The EPA work now completed was based in part on the recommendations outlined in the Camp Dresser & McKee report and on some of the gaps that were not able to be filled within the constraints of the grant; one of the largest was that of limited water quality and flow information to support a reliable water and nutrient budget for the lake. This was recognized and stated in the conclusions of the CDM final report.

1.4 Problem Statement

Lake Attitash is a surface water body that is presently nutrient enriched and appears to be declining in water quality. Water quality sampling in areas perceived to be contributing pollutants to the lake have sporadically revealed elevated nutrient concentrations, but most sampling efforts have not pointed to a single or consistent source of nutrient loading to the lake. The Sargent farm, whose property the main tributary to the lake runs through, has been perceived as a large pollutant source contributing to the lakes problems, due primarily to a large composting operation directly adjacent to the Back River. This has never been verified through consistent and temporally targeted sampling efforts, although MADEP and EPA completed a temporally short study, with a MADEP published report in 2012. Historical sampling above and below the farm prior to these reports had not revealed any large nutrient influxes to the system. The farm presently has a tile drainage system that drains its fields through several laterals connecting to a main pipe that discharges through a three foot culvert directly into the tributary stream/wetland to the lake. Surface flows off the adjacent hillsides to the Back River are diverted by a runoff berm to a retention pond before discharging to the Back River. This wetland has been historically trenched to dewater the wetland and is trenched all the way to the open water of the lake.

A small wetland adjacent to the lake in the southwest quadrant of the lake known as the Southwest Inlet has shown elevated phosphorus loading to the lake in the past. This has usually been coincidental with high rain events and it has been speculated that a local sewer line, which runs through/adjacent to the wetland, may be a contributing nutrient source via sewer line exfiltration during wet weather events. The southeast and northeast shores of Lake Attitash are surrounded by hilly terrain and are densely populated. The dense residential land use provides a considerable percentage of impervious surfaces for snow melt and rainfall runoff to collect nutrients which are transferred via the storm drain system to the lake. Catch basins surround the lake and provide capture of coarse particulates, but soluble nutrients are directly imported to the lake system via catch basin outlets piped directly to the lake and are readily available to nuisance aquatic plants and algae. The nutrient loading to the lake through the storm drain network had not been quantified prior to this report and is perceived as a primary source of loading to the lake.

Lake Attitash is a relatively shallow lake that has one primary inlet stream, the Back River, and one outlet, the Birches Dam. The Back River and the Birches Dam are in very close proximity to one another and it is perceived that flow from the inlet stream may not flow through the major portion of the lake. If this is indeed the case, deep water within the lake may remain stagnant with development of an anoxic layer that releases phosphorus and other nutrients from the sediments during the warmer summer months, setting up the potential for creating frequent and potentially harmful algal blooms.

1.5 Project Description/Objective

Despite good faith sampling efforts by many parties, the identification and quantification of sources of impairment within and outside Lake Attitash has been elusive. Sampling events have either been too infrequent due to budget constraints, or have not been targeted temporally or spatially to capture the suspected sources during periods when they are contributing (i.e. spring thaws, storm events). The primary objective of this effort was to quantify the in-lake and watershed nutrient contributions causing impairment and degradation, determine their sources, loading and frequency, and establish a nutrient budget for the lake and recommend appropriate best management practices to mitigate the sources. The objectives were the collection of water samples during spring runoff, wet weather events and background dry weather periods. A number of lake sediment samples were taken and flow measurements made at lake tributaries and at "The Birches" outlet dam.

The target compounds sampled through this effort were nutrients, principally phosphorus and nitrogen in its various forms. Phosphorus is well known as the limiting nutrient in lakes and small influxes beyond natural background level contributions can significantly impair lake water quality. Highly elevated levels can result in blue green algal blooms that can harbor toxic cyanobacteria. The Amesbury public water supply could potentially be at risk from cyanobacteria from Lake Attitash. Cyanobacteria toxins are not affected or filtered out by most conventional water treatment methods (toxin monitoring and treatment options are becoming available, but are costly). These potent toxins present a human and animal health risk from direct and indirect exposures. Certain strains are potent neuro and hepato-toxins and have been responsible for hundreds of deaths among people and animals worldwide. In the summer of 2009, Lake Attitash had a nine week recreational advisory imposed against physical contact between humans/pets from the Massachusetts Department of Public Health (MADPH). This advisory was issued after detection of cyanobacteria in the lake water was in excess of 300,000 cells/ml. The MADPH utilizes a risk threshold of 70,000 cells/ml as a trigger point for issuing advisories. Comparatively, The World Health Organization utilizes a low probability threshold of 20,000 cells/ml for adverse health effects and a 100,000 cells/ml guideline for moderate probability in recreational waters.

The objectives of this project were to determine and quantify the major sources of nutrient inputs into Lake Attitash and determine the flow of nutrients within the lake. This information may be used to formulate an updated watershed management plan which would include a nutrient budget for the lake that accounts for internal and external sources of nutrient loading to the extent possible. This monitoring information will be utilized to make decisions on the most appropriate best management practices for the water body. A rating curve will be developed from flow monitoring of the Birches Dam outlet. This flow data will be used to determine the flushing rate of the lake and the ability of the lake to either sequester nutrients in the sediment, or allow nutrients to pass through the lake into Tuxbury Pond and eventually out of the system.

Total phosphorus (TP) concentrations in lake water above 10ug/L can lead to increased algal growth, and concentrations from 25ug/l and above can lead to nuisance algal blooms, degraded water quality conditions, and potentially Harmful Algal Blooms (HABS) of cyanobacteria. Total phosphorus is used to measure lake water quality rather than other phosphorus species primarily for practical reasons. Phosphorus cycles between living and non-living forms and dissolved and particulate fractions depending on time of year and location within the lake system. Any concentrations of total phosphorus entering the water body in the 15ug/L range would be cause for concern. Soil phosphorus levels are also important to quantify in order to determine if phosphorus is in excess of what plants can effectively uptake, leaving the remainder to potentially runoff and contribute to nutrient enrichment of the lake.

An important species of phosphorus for Lake Attitash in addition to total phosphorus is Soluble Reactive Phosphorus (SRP), also commonly labeled Ortho-phosphate. SRP is an important analytical parameter as it represents a labile form that is readily accessible for plant uptake and can easily be transported off of the terrestrial landscape via surface runoff or subsurface flow. In many agricultural practices, application of phosphorus to crop soils builds up within the soil matrix to levels far beyond crop needs. Soil phosphorus levels critical for plant growth is usually an order of magnitude greater than concentration levels that will accelerate eutrophication in lakes and other surface water bodies. This is an important concern based on the agricultural practices taking place adjacent to the main tributary stream to Lake Attitash. Values above 15ug/L could be a cause for concern.

Nitrogen is another important nutrient effecting lake water quality and plant growth. Total Kjeldahl Nitrogen (TKN) is a measure of the organic nitrogen and inorganic components such as nitrite and nitrate, and summed to get a calculated value for total nitrogen. Spring values above 300 ug/L of TKN can support summer algae blooms. Ratios of nitrogen to phosphorus less than 10:1 (N:P) will cause algal growth if nitrogen inputs enter the lake (nitrogen limited), N:P ratios of 15:1 will cause algal growth when phosphorus enters the waterbody (phosphorus limited). Excessive nitrogen inputs are often linked to agricultural practices, lawn fertilizers, septic systems, and spring runoff events. These are all practices currently taking place within the lake's watershed.

In order to determine the watershed nutrient loading to Lake Attitash, flow measurements must be made in order to convert nutrient concentrations to pounds per year or other loading conventions and make estimates on internal and external loading rates. It is anticipated that measurements will be made at key input locations around the lake, catch basin discharge locations into the lake during wet weather, and at the outlet dam from the lake.

References

1. Camp Dresser & McKee, Town of Amesbury "Lake Attitash Watershed Management Plan," January 25, 1999

Web Links

(http://water.epa.gov/type/lakes/lakessurvey_index.cfm)

(http://www.neiwpcc.org/waterquality/wq-docs/NELP_Report_Web_Intro.pdf)

(http://www.cfb.unh.edu/)

(http://adsabs.harvard.edu/abs/2010AGUFMGC51F0796K)

(http://www.epa.gov/region1/lab/pdfs/NELP-Report.pdf)

2.1 HYDROLOGY

The Lake Attitash watershed comprises a land area of approximately 3.9 square miles and is dominated by well drained, permeable sandy loam soils of the Paxton-Hollis-Canton association[1]. The lake itself comprises 0.6 square miles of surface area (360 acres), creating an approximate 6.5 to 1 watershed area to lake area ratio. These soils allow snowmelt and rainwater to infiltrate into the ground, where it can be slowly released into the surface water bodies of the watershed. The low lying wetland and marsh areas within the Attitash watershed are comprised primarily of organic muck, and make up approximately 10% of the total watershed area. These types of soils have a high water retention capacity and low permeability.

The primary surface water inflow contributing to Lake Attitash comes from the Back River, a small tributary stream that enters in the northwest corner of the lake. Additional surface water sources entering the lake come from a wetlands complex in the Southwest quadrant of the lake named the Southwest Inlet, and another wetlands complex located on the East side of the lake in an area known as Sandy beach. Other sources of water to the lake are from storm water, seasonal surface runoff, and likely groundwater inflows. The only surface water outflow from the lake is through the Birches Dam, located in the northwest quadrant of the lake and north and east of the Back River inlet.

Once water exits the lake through the Birches Dam, it flows through a broad and shallow ponded area known as Meadow Brook. The water from Meadow Brook may be directed to flow into Tuxbury Pond (via the State Line Dam) which the Powow River flows through, or diverted directly from Meadow Brook into the Powwow River via the Arch Brook box culvert, located in the Southeast corner of Meadow Brook. Waters leaving Meadow Brook via the Arch Brook culvert join the Powow River just downstream of the Tuxbury Pond Dam (Figure 2-1). Powwow River waters may flow through Tuxbury Pond and pass through the Tuxbury Pond Dam located in the Southeast corner of the pond, or be diverted into Meadow Brook and out through the Arch Brook box culvert. Both of these outlets re-converge shortly downstream then continue on into Lake Gardner. From Lake Gardner water flows through the town of Amesbury, eventually making its way to the Merrimack River.

For this study, flow measurements were initially taken twice monthly at the major inflows to the lake, and at the Birches Dam outlet in order to determine relative flows in to and out of the system. The first flow surveys took place on March 31, 2011 at the Birches Dam outlet which was free of ice around the dam. Complete lake ice out occurred on April 3. Four additional flow surveys were completed between March and July at several locations. These were the Back River Brook at Bear Hill road crossing, the Southwest Inlet, and the Birches dam outflow. Another flow survey was completed at Sandy Beach before surface flows stopped at this site. Two significant drainage pipes that discharge into Lake Attitash (SD03 and SD05) were also included in the flow measurement surveys on two of the survey days. By mid-June all surface water inflows to the lake had ceased.

Figure 2-1: **Major Inflows & Outlet to Lake Attitash**

The Back River Brook is the major surface water inflow source to Lake Attitash, draining approximately 2.4 square miles which comprises 61% of the entire 3.9 square mile Lake Attitash watershed. Originating in a moderate wetlands complex in Newton New Hampshire, the brook travels approximately 2.5 miles while dropping approximately sixty vertical feet before entering Lake Attitash. Important landscape features along the river's path are a large wetland just south of the McClaren Trail Railroad grade crossing, the Back River crossing at Bear Hill Road, and the Sargent's Farm Millpond (Figure 2-2). The twenty acre wetland upstream of the McClaren Trail grade, where the Back River originates from, is constricted in its drainage by the historic railroad grade, creating pooled and almost stagnant water conditions shortly after spring runoff. The stream segment between the McClaren crossing and Bear Hill Road crossing is also dominated by constricted wetlands outflow and is again very low gradient, causing stagnant water conditions within this small wetland. During the 2011 flow measurements, the flow at Bear Hill crossing was 2.8 million gallons per day (MGD) on April 19, was reduced to 0.9 MGD by May 11, and by June 14 there was no flow, but pooled water was present upstream of the Bear Hill road crossing. These stagnant "backwaters" create anoxic/reduced conditions which mobilize sediment Phosphorus, allowing it to be transported further downstream in "pulses" during wet weather events.

The gradient of Back River Brook increases downstream of Bear Hill Road until it reaches the Sargent Farm Millpond, an impoundment originally built to operate a sawmill which is now gone. This millpond briefly impounds the Back River. Surface runoff from the Sargent Farm hillside fields is conveyed into a retention pond which then discharges into this millpond. The millpond appeared breached during the 2011 study, and presently only impounds a small amount of the flow from Back River Brook. This millpond structure does not function as a retention area for any surface runoff emanating from the farm. Shortly after leaving Sargent's millpond, the stream gradient once again flattens out and runs through a relatively large wetland area before entering Lake Attitash. This section of the Back River, just upstream of the millpond until just prior to entering the Lake Attitash, is bounded by several agricultural fields that drain into adjacent ditches that flow to the Back River. The Back River itself has been "ditched" through this section, providing a direct conveyance into Lake Attitash and short circuiting the natural functioning of the wetland.

Another interesting hydrologic feature within the watershed is that the major inflow to the lake from the Back River is in very close proximity to the only outflow from the lake at the Birches Dam. Both are located in close proximity to one another in the northeast quadrant of the lake. This hydro-geomorphic feature likely plays an important factor in limiting circulation within the lake.

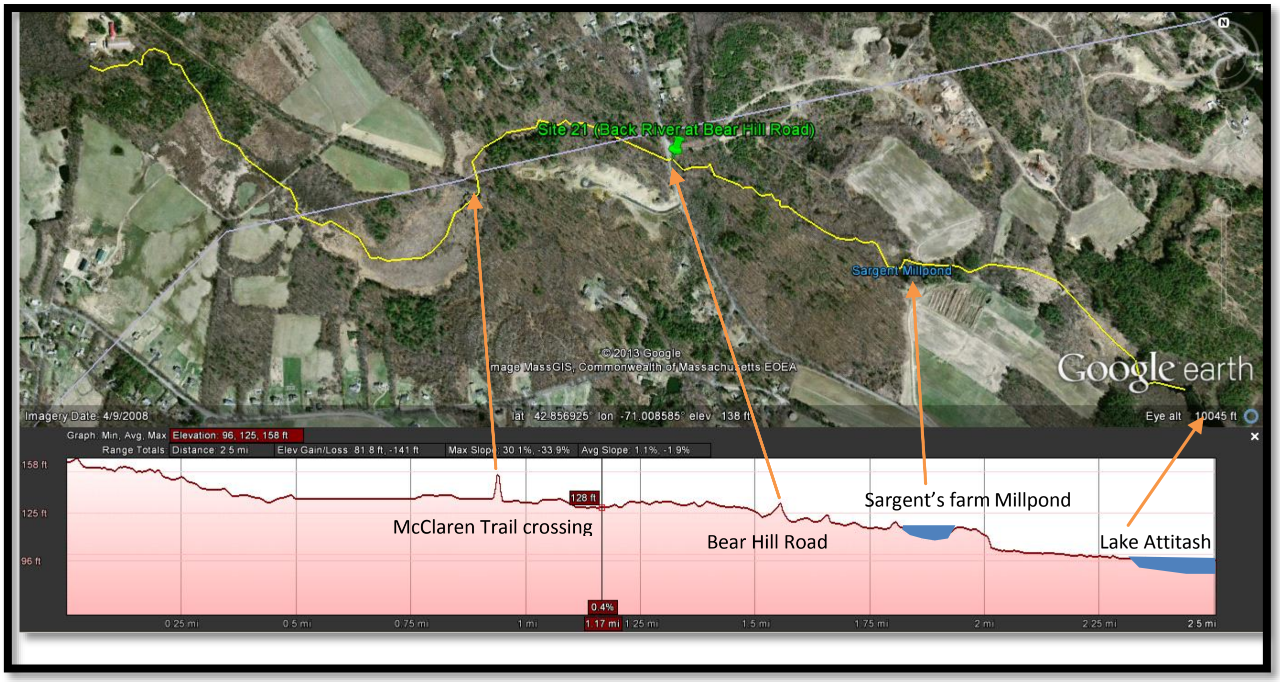

Figure 2-2: **Key hydrologic features along Back River Brook prior to entering Lake Attitash**

The Southwest Inlet to Lake Attitash drains slightly over a half square mile of land area, of which less than .02 square miles are wetlands. This subbasin represents a little over 13% of the entire watershed area. The flow from this wetland complex is restricted from entering the lake by a narrow inlet caused in part by fill for a buried sewer line that runs parallel and in close proximity to the lake, and in part from natural morphological features. Inflows to the lake from the wetland follow the same patterns as that of the Back River; by early June the lake inflows have ceased. However, unlike the other wetland areas around the lake, the Southwest Inlet is still hydraulically connected and inundated by surface water from the lake when at its "summer pool level," and demonstrates "ebb and flow" characteristics depending on the current lake elevation flux. At stable summertime "pool" level, waters within this wetland become stagnant and conditions become reduced/anoxic. This mobilizes Phosphorus from the sediments which are then transported into the lake during episodic wet weather events as water moves out of the wetland and in to the lake. These Phosphorus nutrient "pulses" have been picked up by water chemistry sampling during the course of this study and in previous surveys[2]. By May 23rd of the 2011 sampling year, inflows to the lake from the Southwest Inlet had ceased.

Another area of inflow to the lake that has been altered is the small wetland directly adjacent and to the west of the Merrimac public boat ramp. This area historically was a red maple swamp prior to boat ramp construction and improvements to the Bisson Lane roadway. Due to this construction, wetlands surface flow to the lake has been diverted to flow past the Merrimac Water Department, through a narrow culvert underneath the gravel road to Indian Head Park, and then into the wetland that makes up the Southwest Inlet inflow. Prolonged inundation of the red maple swamp due to hydraulic changes from construction and diversion killed off the red maples and destabilized the roots, causing the trees to topple. This complex has since transitioned into a perennial inundated marsh shrub wetlands complex and flows are diverted through the Southwest Inlet.

Inflow from the Fourth Street storm drain located on the South side of the lake drains less than twenty acres of steep residential topography, but spring inflows are sustained for a short period because of baseflow that enters the drainage network from a first order ephemeral stream that the drainage system ties in to. Inflow on May 3rd from this source was 9,130 gallons per day, by June 1st flow was reduced to 8,400 gallons/day, and by June 14th there was no discharge into the lake from this catchment.

Sandy Beach located on the east side of the lake is another surface water inflow to the lake which enters through an approximate three to four foot wide stream channel in the northeast quadrant of the lake. This area comprises a drainage area of around 100 acres and is contributed to by the Shore Road storm water retention pond and runoff and retention pond drainage from the Olde Taverne Lane development. However, this inflow appears to contribute very little surface water inflow to the lake. A sand beach separating the wetland from the lake is a significant barrier to most surface flow entering the lake. Sandy Beach was constructed in

September of 1955 (personal communication, Lake Attitash Association). By the first week of April there was practically no inflow to the lake from this source. Sandy beach did not appear to stay consistently hydraulically connected via surface water during the summer months and appeared to provide less frequent nutrient “pulses” into the lake than did the SW Inlet and the Back River, except during significant precipitation events.

The last sustained surface water spring inflow to lake Attitash (Schaepe Drain – SD03) is found on the northeast shore of the lake and ties in a storm drain system that collects direct surface runoff from Lake Attitash Road, a small wetland complex, and two stormwater retention ponds from residential developments along Whitewood Circle and Tallowood Lane in Amesbury. On May 3rd flows from this outlet measured 57,000 gallons per day, by May 24 flows were reduced to 3,300 gallons per day, and by June 14 there was no inflow. Seasonal groundwater inflows and outflows to the lake were not assessed at the time of this survey, so their contribution or loss to lake water volumes could not be determined.

During both the 2009 and 2011 sampling years, the total monthly precipitation, with a couple of exceptions, was very close to or above the average mean monthly precipitation for the period of record, from 1931 until 2012 (figure 2-3). This suggests that many of these surface flows

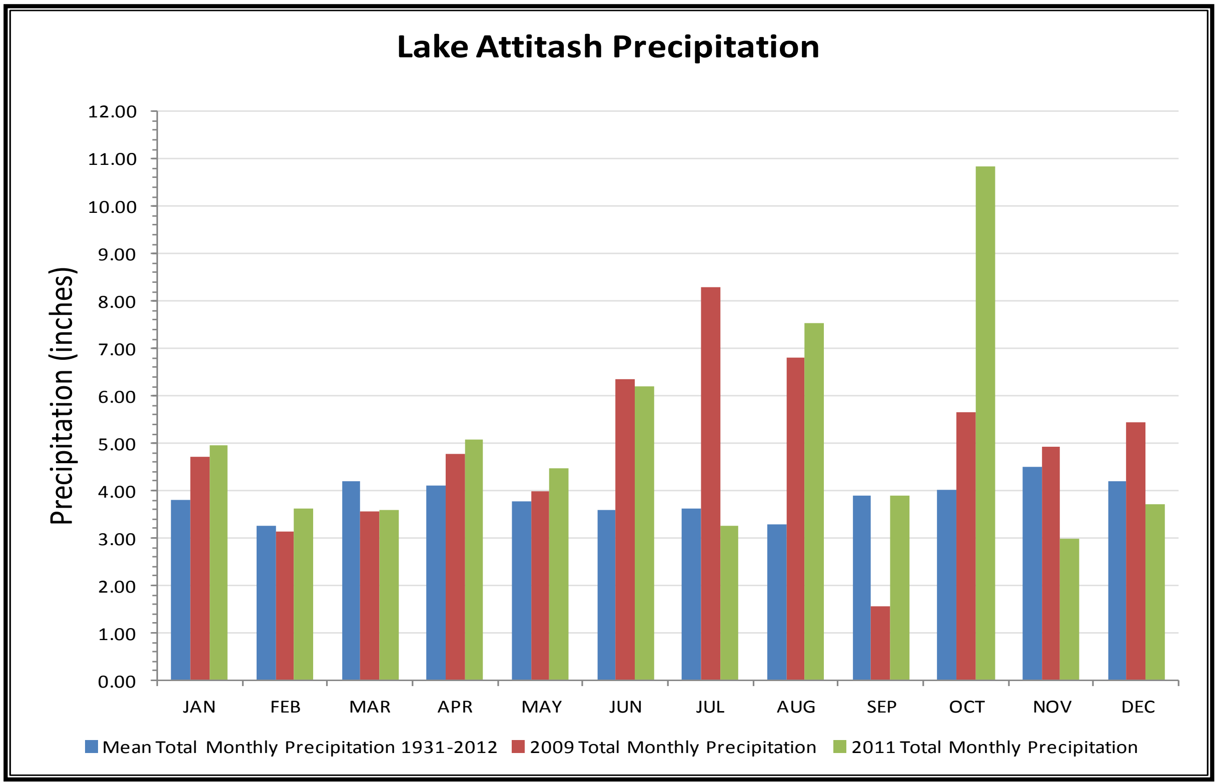

Figure 2-3: **2009 and 2011 monthly precipitation totals compared to average monthly precipitation for the period of record (POR) from 1931-2012**

could potentially be drying up sooner than mid-June during an average precipitation year. This is consistent with comments made in the 1977 MADEQE water quality study, reporting that by mid-June the Back River and Southwest inlet flows had ceased and the lake elevation at the Birches Dam was lower than the flashboards. Lacking any groundwater data, it appears lake evaporation was outstripping any inflows to the lake at this point, and this appears to be a frequent occurrence during the summer months.

Flow measurements and stage height readings were taken at the Birches Dam to determine discharge volumes leaving the lake and calculate the associated load of nutrients exiting the lake. The flow and stage height readings also help to understand how the watershed responds to runoff and precipitation events. Flow measurements at the Birches dam were initially difficult to acquire based on water level manipulations at the Birches outlet and Meadow Brook controls, and localized hydrology in general. Flashboards at the Birches dam were often undermined by outlet flows and or floated up at other times, making initial stage height readings unusable. At other times during the spring runoff period Meadow Brook pool elevations were high enough to impede outflows from Lake Attitash, making accurate discharge estimates unobtainable. Once flashboard and Meadow Brook control issues were corrected, velocity measurements and height of water above the flashboards were taken to accurately measure discharge at the Birches Dam and develop a rating curve for the structure (figure 2-4). If future efforts are to be undertaken to determine discharge rates, an in-situ level logger

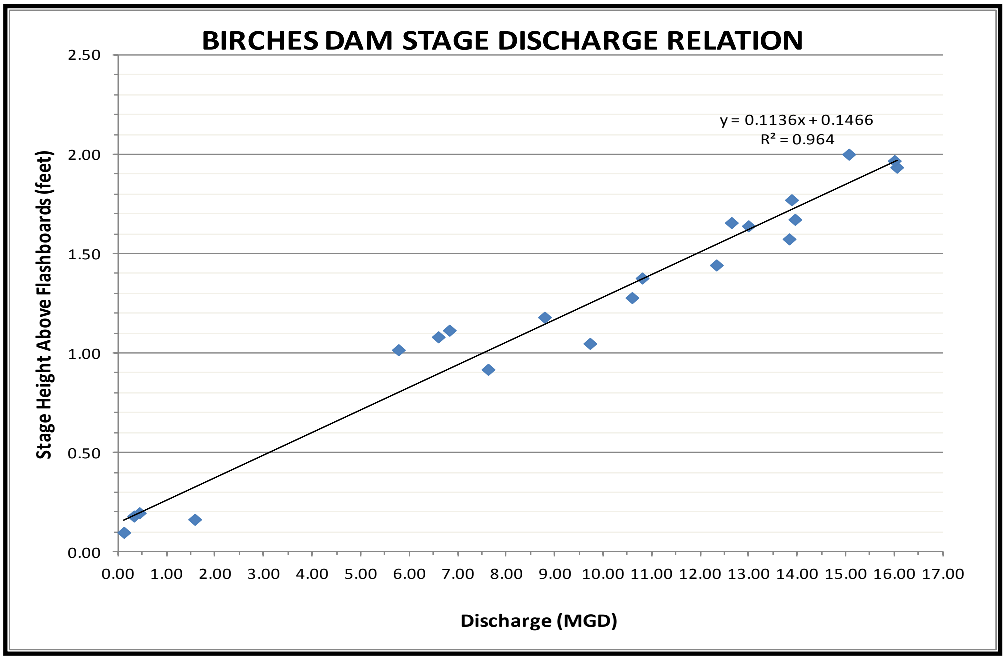

Figure 2-4: **Birches Dam rating curve developed in 2011 from velocity and water elevation measurements**

placed directly adjacent to the Meadow Brook box culvert and the Birches Dam would be an inexpensive and very beneficial addition to monitoring stage/flows from Lake Attitash.

Stage height readings at Birches dam were taken during two different sampling years, 2009 and 2011(Figures 2-5 and 2-6). For the most part, both of these years exhibited close to average or above average monthly precipitation for the first half of the year, and well above the monthly average for most of the remainder of the year. Daily stage height readings (Figure 2-5) taken in 2009 (June-September) and compared to daily precipitation for that year reveal that Lake Attitash responds quickly to precipitation events and could be considered a somewhat “flashy” system. Steady rains occurring in June maintain the Birches Dam stage height at 97.0’ while lake water discharges underneath the flashboards. Once a break in the rainfall occurs, the stage height immediately drops (6/27 and 7/10). Flashboards are secured on 7/12 and stage height responds nicely to precipitation events. The rain events show immediate changes in outlet stage height, and quickly recede back to pre-storm conditions once the event is over. This reflects the small watershed size (3.9 square miles), the urbanized residential land use and associated impervious surfaces, steep topography, and stormwater conveyances surrounding the lake. There is one scenario however where this quick response is muted, and this occurs when the lake elevation is below the summertime pool elevation and flashboards at the Birches Dam. In these instances, inflows from storm events flood back in to the wetland areas first before spilling over the dam and the rapid stage height recovery is not so pronounced.

In 2011, stage height readings were taken twice monthly up until September 23, when daily stage height readings were started for tracking a wet weather survey on the lake (section 4). These 2011 readings were taken on the same day that flow measurements were made and water samples and other lake data were collected. Although stage height readings were only taken twice monthly for much of the year’s sampling period, it still reflects the responsiveness of lake level elevation fluctuations after precipitation events (Figure 2-7).

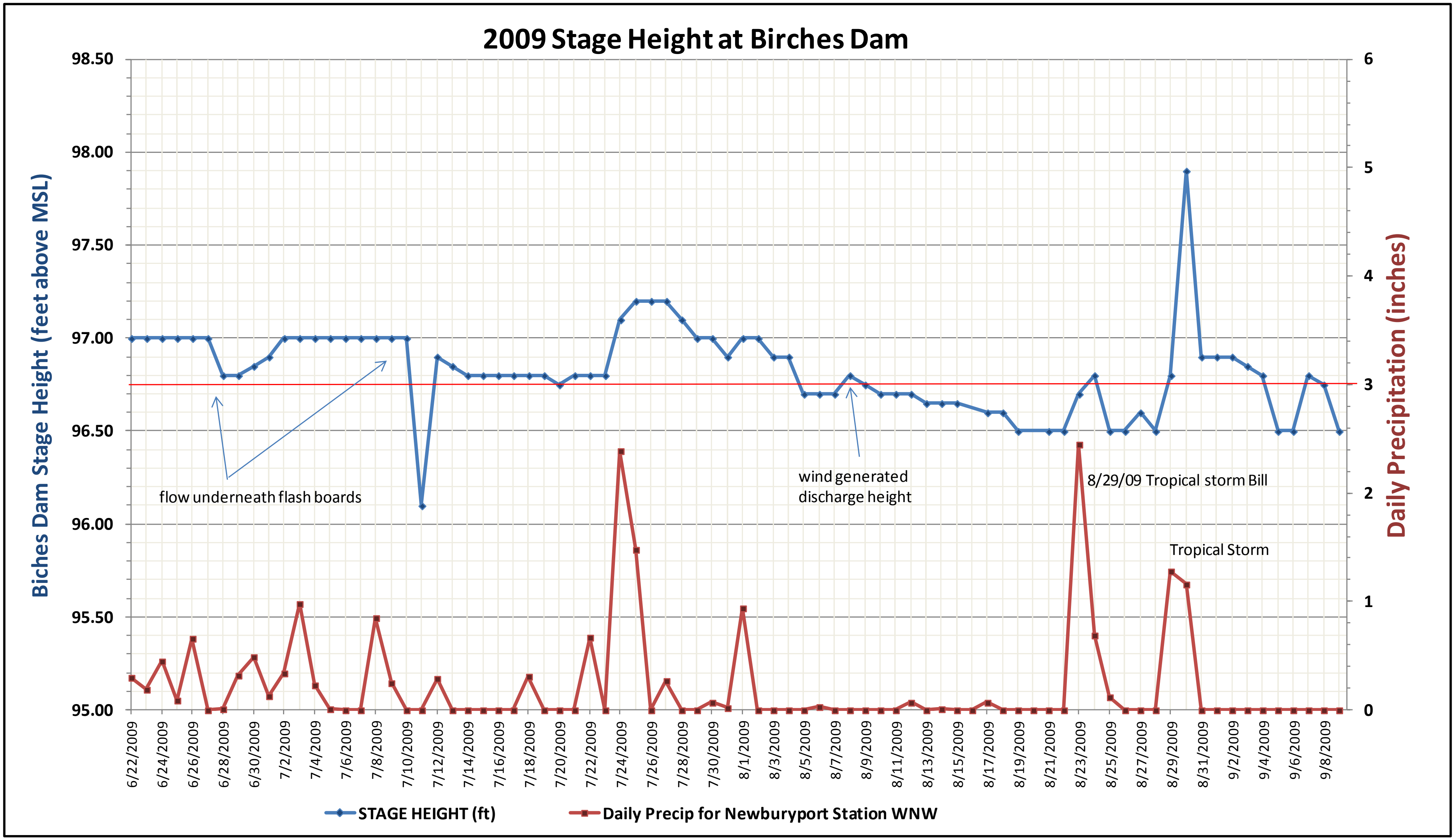

Figure 2-5: **2009 Stage height changes in relation to precipitation events**

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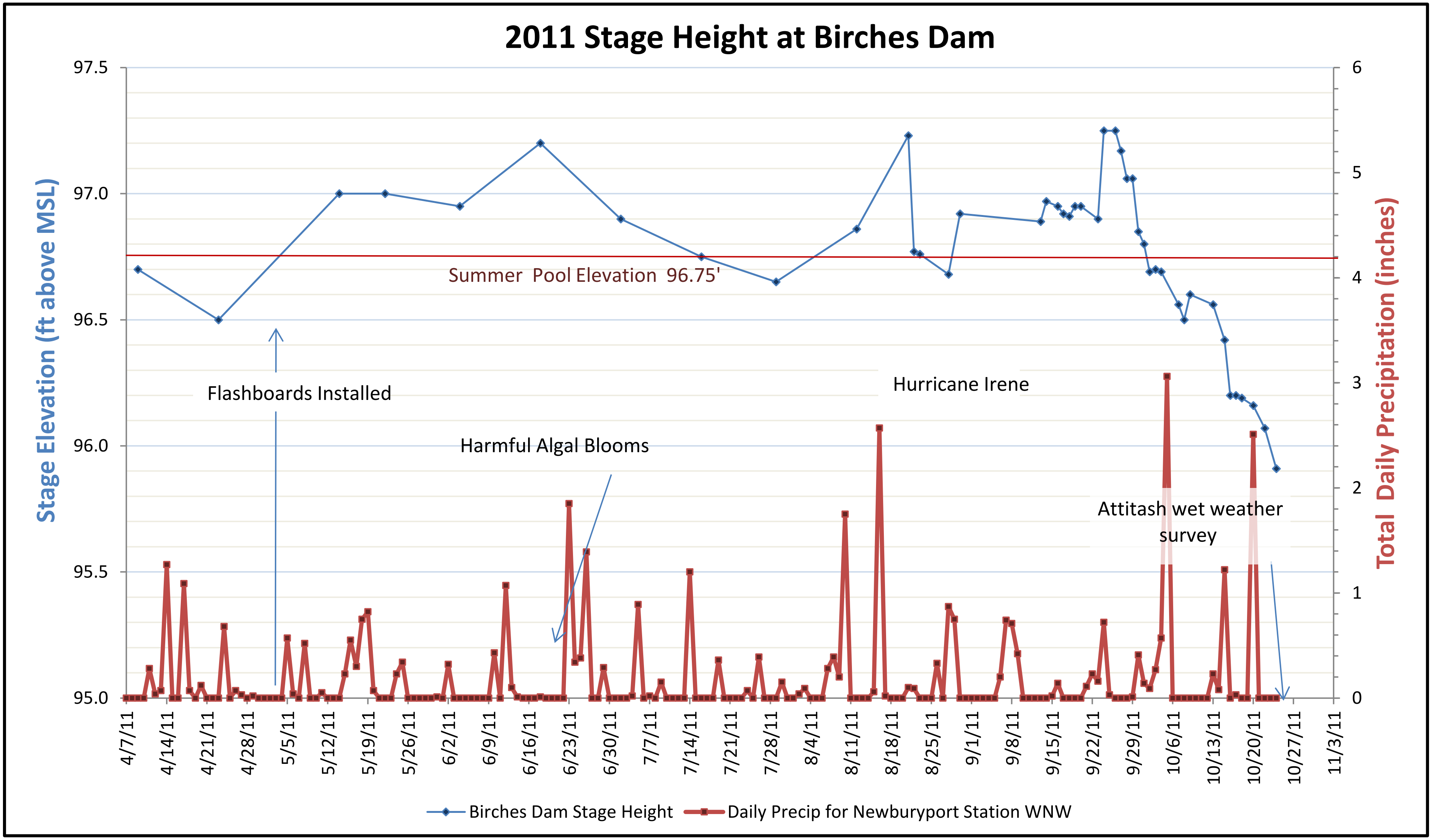


***Figure 2-6:* 2011 twice monthly stage height readings and daily precipitation**

Results from these charts reveal how quickly the lake level drops during the low flow months of June through October when no precipitation occurs, and demonstrates how during “average” years of precipitation the stage height at Birches Dam could be at or below the established pool elevation of 96.75’ MSL. The CDM report calculated an average discharge rate of 0.3 cfs (0.194 MGD) from the lake for the months of June through October. Based on the stage height readings and established rating curve for the Birches Dam in this study, along with a flow transposition exercise from a similar watershed (Beaver Brook, Pelham, NH – USGS #010965852) this discharge rate appears to be reasonably accurate. Using the 0.3 cfs discharge rate for these months, the lake has a retention time of approximately twenty years during these months, meaning very little if any water or nutrients are being flushed out of the lake during the summer and early fall months, when peak plant and algal productivity is taking place. The average daily evaporation rate for these months on Lake Attitash is 1.18 acre-ft, or roughly 384,500 gallons per day (0.59 cfs), just about twice the calculated outflow rate. Often during the summer months water levels fall below the summer pool level, indicating that evaporation (and any possible groundwater outflows/withdrawals) rates are likely outstripping all inflows to the lake.

The lake’s water level is now formally regulated under the Watershed and Waterway Management Plan[3] for the Town of Amesbury, Massachusetts (May 5, 1999). This management plan establishes that the lake shall be drawn down to an elevation of 95.0’ MSL from between September 16th to November 30th, and then brought back up to a summer pool elevation of 96.75’ MSL between March 1st and April 30th. Another hydrologic loss to the watershed comes from groundwater withdrawals. This may or may not contribute to water level fluctuations within the lake, but deserves to be mentioned. The Town of Merrimac has two principal wellfields; one located just off of Bear Hill Road on Sargent farm property, and the other located on Wallace Way near the Merrimac water treatment plant. These are considered medium and high yield aquifers, delineated as medium yield areas being able to pump between 100-300 gallons per minute and high yield areas, capable of pumping in excess of 300 gallons per minute. The Bear Hill wellfield has six wellheads

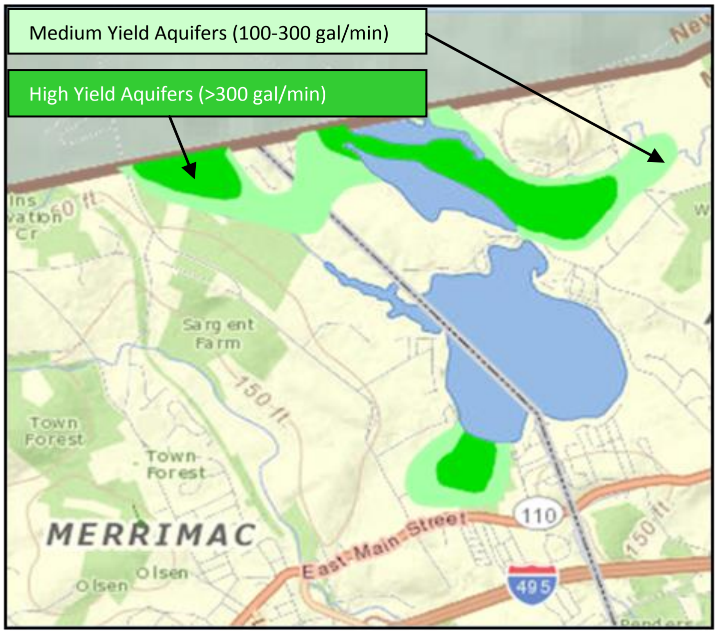


***Figure 2-7:* High and medium yield aquifers in the Lake Attitash watershed *(MassGIS)*[4]**

with pumps located approximately 35-40 feet below the wellhead. This puts them in close proximity to the surface summer pool elevation of the lake. These wells provide about two thirds of the town's water supply, pumping an average rate of 350 gallons/minute.

The Wallace Way wellfield has four wells and are approximately twenty feet below the wellhead. These wells make up the other third of the towns daily water supply, pumping at about 250-260 gallons per minute. Based on the annual pumping rates for 2011 published on-line, the combined wellfields pumped a little under 129 million gallons that year; this comes out to around 250 gallons per minute (0.56 cfs).

These flow surveys demonstrate that although Lake Attitash is considered a drainage lake, surface water inflows are brief and primarily constrained to spring runoff and wet weather events. Baseflow contributions from tributaries seem to predominantly exist only during and just after spring runoff. Groundwater contributions appear to be the dominant source of inflow during the summer months, but may at times be less than lake evaporation rates. Groundwater withdrawals may be playing a part. Groundwater influx during the summer months is likely due to balancing of lake evaporation rates and any groundwater withdrawals, as evidenced by the cooler water temperatures in the deeper sections of the lake.

Many hydrologic changes have occurred through the years to the Lake Attitash watershed, playing a part in establishing the lake's current condition. Being of such a small size, seemingly subtle changes may have profound effects; developments and associated impervious surfaces convey runoff much more quickly to, and subsequently out of the lake, rather than naturally infiltrating into the ground and migrating to the lake through subsurface flow. Well fields draw groundwater out of the system, and large agricultural fields and clearings accelerate snowmelt and spring runoff, conveying water out of the system more quickly, while reducing the baseflow contributions to tributary streams and groundwater. Truncation and short circuiting of wetland areas that are great retainers of water also reduces their function of filtering and slowly releasing water into the system. These subtle and not so subtle changes have altered the temporal movement of water through the system. Along with this, stable pool elevation controls have reduced the "flushing rate" of the lake during critical periods, limiting its ability to attenuate and move nutrients out of the system, the major present day concern. Good hydrologic watershed management, to the extent possible, is just as important as the management and control of nutrients within the watershed and water body.

References

1. Notini B.R., Chagnon E.M., Lake Attitash Water Quality Study, May 1977-April 1978, Water Quality and Research Section, Massachusetts Division of Water Pollution Control, Publication# 11, 954-120-80-6-80-CR

2. Camp Dresser & McKee, Town of Amesbury "Lake Attitash Watershed Management Plan," January 25, 1999

3. Watershed and Waterway Management Plan for Town of Amesbury, Massachusetts. Dept. of Public Works and Amesbury Lakes & Waterways Commission. Ver. 2.2 My 5, 1999 (revised September 21, 2010)

Web Links

4. Mass.gov, MassGIS Data-Aquifers, 2007 **http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/aquifers-.html**

3.1 Dry Weather Sampling

Dry weather samples were collected throughout 2011 from all of the primary inflow locations, the deep hole area, and at the Birches Dam outflow (Figure 3-1). Sampling events took place every other week, starting through the ice in late February at the deep hole and continuing through December. Samples collected at the deep hole surface utilized a tube sampler that integrated the top two meters of surface water. Deep hole samples collected at the bottom utilized a Kemmerer sampler that collected discrete samples one half meter off the bottom. Samples collected from the other site locations were "grab" samples, taken just below the water surface in new lab certified pre-cleaned bottles. Samples collected in March and April were limited to the Back River Bear Hill Road crossing, the Southwest Inlet, the Birches Dam outlet, and any storm drains that were discharging at the time. Other areas such as the deep hole and Back River near the Gunderboom filtration barrier were not collected in March and April due to inaccessibility from unsafe lake ice conditions. Samples were collected twice monthly throughout the remainder of the year to the extent possible. All samples were collected utilizing standardized EPA field protocols and an approved Sampling and Analysis Plan (SAP), and transported on ice to the USEPA Regional Laboratory for analysis.

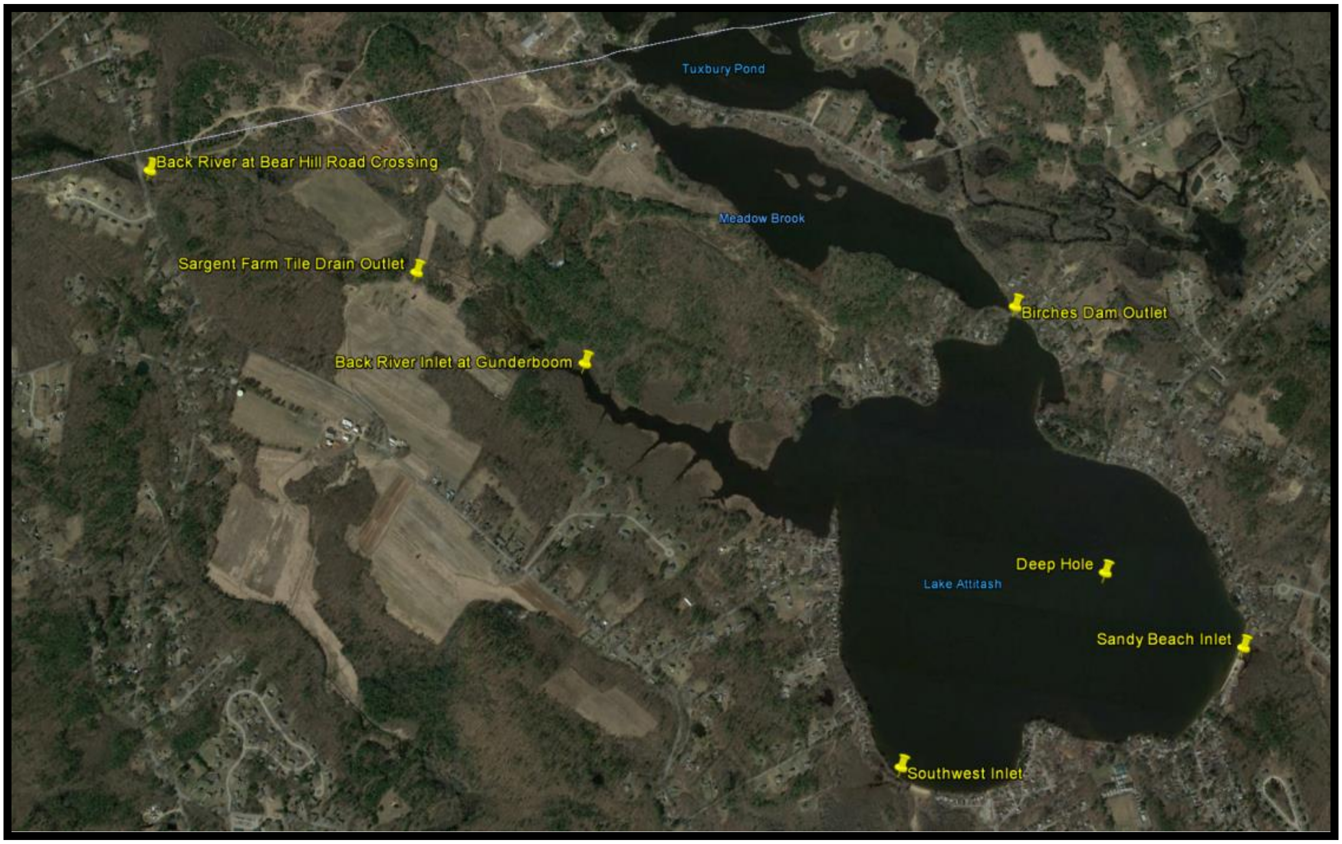


Figure 3-1: **2011 Dry weather sampling locations without stormwater outfalls.**

3.2 Phosphorus

Phosphorus in freshwater systems can be differentiated into three basic parts: particulate phosphorus, organic phosphorus, and soluble reactive phosphorus (SRP). The sum of these components is referred to as total phosphorus (TP) and is the analysis most often used as a component for determining the trophic status of a lake; the measure of the amount of living biological material in a waterbody at a given point in time[1].

The fraction of phosphorus that can pass through a .45 micron filter is considered the soluble fraction, of which most is in a form that can be readily taken up by algae, the SRP component. Soluble phosphorus levels greater than several micrograms per liter can be an indication that there is more phosphorus available to the biota than can be utilized. The particulate fraction of phosphorus is all of the material that was retained by the filter. This may include the majority of organic material such as plant fragments, algae, and zooplankton, and inorganic materials such as minerals, clays, and silts.

Figue 3-2 shows the twice monthly total phosphorus concentrations for all of the major inflows to the lake, along with the Birches Dam outflow. An important aspect of all these inflows is that they all run through some type of wetland complex. All inflows to the lake show a similar trend in TP concentrations through the course of the year. Relatively low concentrations, considered oligotrophic to mesotrophic based on TP concentration (EPA, 1988) occur in the first and second quarter of the year, escalate in June through October to concentrations considered to be eutrophic and hypereutrophic before returning in late fall to similar concentrations found in the beginning of the year. These relationships demonstrate the influence that wetland complexes have on inflow water quality to Lake Attitash as the summer season progresses, microbial activity accelerates, and anoxia dominates in the sediments. As the warmer months advance, flows from these inflow points become minimal to stagnant, allowing withheld surface waters to become anoxic. Under these conditions, the phosphorus is released from the sediments and becomes concentrated in the surface and pore water, moving downstream with small increases in flow from the summer rains. These “pulses” in TP inflow concentrations can be traced if one looks at the time of sample collection in relation to the precipitation pattern in the watershed during these low to no flow months. Figure 3-3 graphically represents the dry weather sampling days along with the precipitation pattern for 2011 from the Newburyport 3 WNW weather station. This pulse like behavior is best illustrated by looking at the Gunderboom concentrations in relation to precipitation. The highest TP concentration from the Gunderboom location occurs during the August 9th sampling event, when a sustained summer rain event occurs creating a “pulse” that jumps to almost 300 ug/L. This concentration pattern is almost identical to that of the Southwest Inlet and Sandy Beach, because they “drain” to the lake and hydraulically behave in much the same way; the wetland area just upstream of the Gunderboom is a trenched wetland and the Sandy Beach outlet is only connected seasonally. The contrast to this pattern is the Bear Hill site, where TP concentrations are significantly higher in most cases. The reason for this is because the wetlands above Bear Hill Road do not drain well and are more inundated due to flow constrictions such as from the McLaren trail railroad grade crossing and the Bear Hill Road crossing. These constrictions create more inundated wetlands where microbial activity and anoxic conditions release more TP to the ambient water.

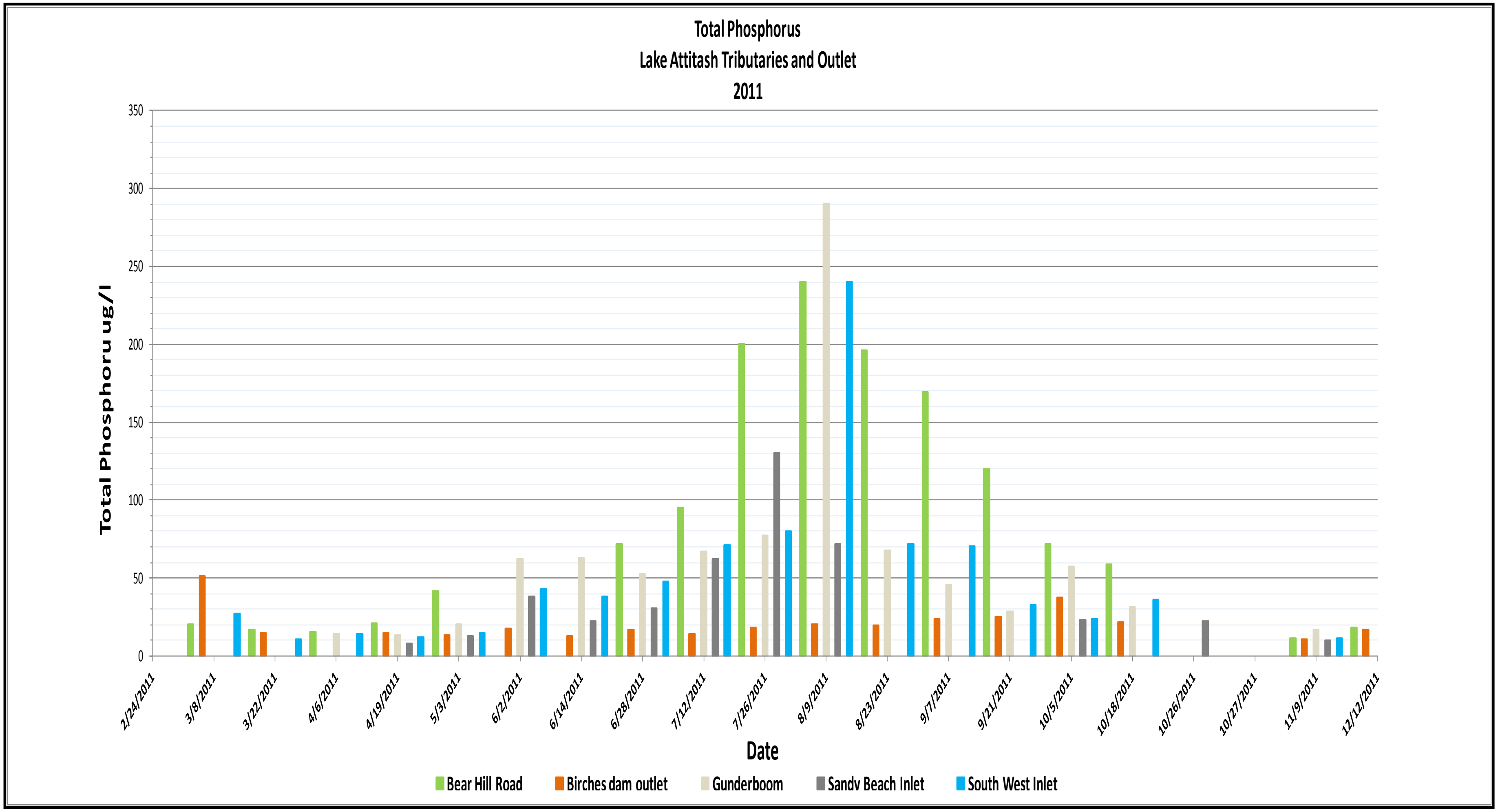


Figure 3-2: **Twice monthly phosphorus concentrations from major inflows and Birches Dam outlet.**

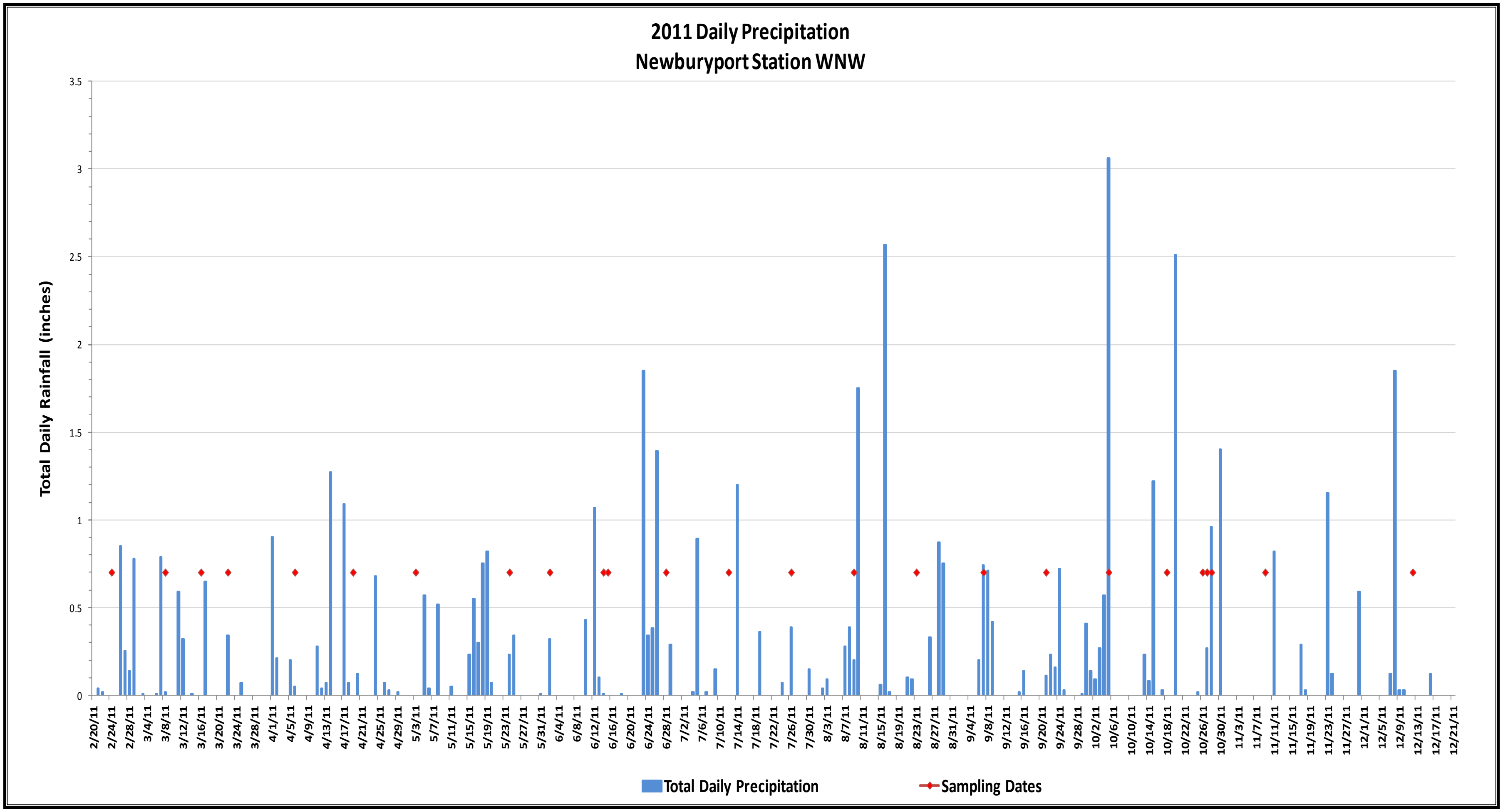


Figure 3-3: **Sampling dates relative to precipitation events in the watershed. Elevated TP concentrations correspond well to samples collected during, or just after precipitation events.**

However, as is apparent from the wet weather section of this report, the high concentrations of phosphorus in the water do not necessarily mean that it has the largest impact on the water quality of the lake, as the total amount of phosphorus from each source that actually enters the lake is the defining factor.

The TP concentrations from the Birches Dam outlet remain relatively consistent throughout the year, with the exception of an elevated concentration due to spring runoff in March, and a slight uptick in TP concentration around October 5th, likely due to the significant late fall rainstorm that occurred immediately preceding the sampling event (See figure 3-3 in this section). Comparing the 2011 monthly samples with those collected during the 1977-78 MADEP and the 1998 CDM sampling at the same locations reveal that the concentrations are relatively the same between the sampling years for the surveyed months. The exception to this occurs in the 1998 sampling effort where in July, August, and September extremely high concentrations were reported. These appear to possibly be erroneous values, as some water concentrations are higher than in-lake sediment phosphorus concentrations, and in many cases, are two to three times higher than TP concentrations that would be found in raw sewage effluent (15,000 ug/L). These 1998 TP concentrations are almost too high to be believable, with the exception of possibly one explanation that may lend credence to these values. In 1998 long standing beaver dams were located throughout the Back River, with an exceptionally large one spanning over 250 feet across the downstream area of the Sargent's farm agricultural fields and the Back River lower wetland area (Figure 3-4). January through March of that year the watershed received above average precipitation. April gave us about an inch below the monthly average and May about one inch above the monthly average, nothing too out of the ordinary. June however, dropped 10.51 inches of precipitation on the watershed, almost seven inches more than the average precipitation for that month. This quantity of rainfall would have completely flooded the wetlands behind the beaver dams and possibly flooded out lower lying fields and contributed to significant runoff volumes. It was around this time frame that the Back River beaver dams were thought to have been torn out. Draining the flooded fields would make sense, and could possibly account for much of the anomalously high phosphorus concentrations

Figure 3-4: **Large beaver dam below Sargent Farm in 1998**

and subsequent load that appears to have entered the lake that year. Sequestered phosphorus in the wetlands sediments and agricultural fertilizer and runoff from the fields would now have had a direct conduit in to the lake. With this vast amount of precipitation, it is likely that phosphorus came from many other sources as well, including other wetlands, road runoff, and domestic fertilizers, adding to the substantial load present in the lake.

Dry weather samples collected at the deep hole throughout the year show a trend typical of stratified shallow eutrophic lakes. Winter samples from the bottom deep hole area collected in February show elevated phosphorus levels (figure 3-5) compared to the surface due to winter anoxic conditions in the bottom sediments and the release of sediment phosphorus under these conditions. As spring runoff ensues and spring turnover takes place with mixing of the top and bottom waters, bottom and surface concentrations become close to equal. As June arrives, inflows to the lake and outflows from the lake have almost stopped and the water begins warming up and stratifying, increasing the biological activity on the lake bottom.

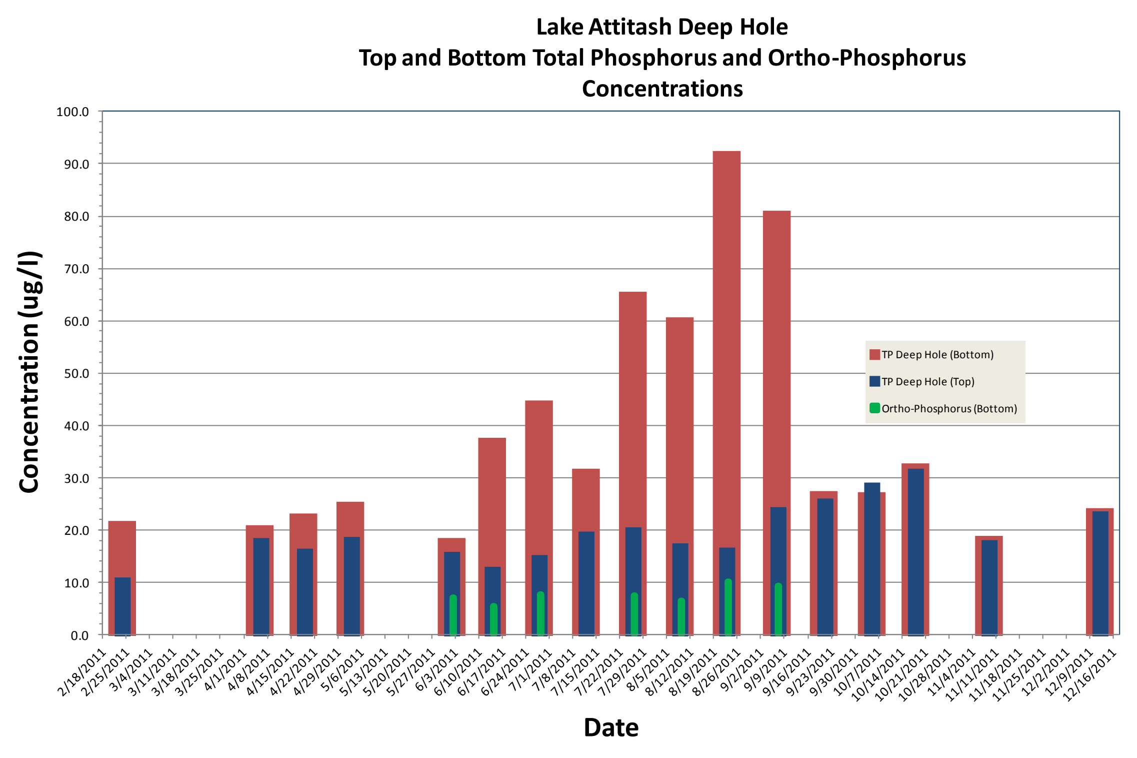


Figure 3-5: **Epilimnetic, hypolimnetic, and soluble reactive phosphorus concentrations representing internal nutrient loading to the lake.**

This activity consumes the available oxygen, and the bottom waters of the lake become anoxic and release phosphorus from the sediments. In 2011, bottom concentrations significantly increased from mid June through early September, until cooler temperatures, lake turnover, and decreasing biological activity reduced the dissolution of phosphorus from the sediments and subsequently, in water phosphorus concentrations. Soluble reactive phosphorus, that which is readily available to plants and algae, was also found in high concentrations in the bottom waters through the warmer summer months, providing a significant nutrient pool for stimulating harmful algal blooms, especially with its ability to be circulated by the high volume of powerboat traffic found on the lake during this time of year. Deep hole surface water concentrations in 2011 are very comparable to deep hole surface samples taken in 1998. No deep hole surface water samples were available for comparison from the 1978 data.

To follow up on these findings, a simple mass balance was completed during the time period of June through August to determine the internal loading to the lake. Due to the limited flow data, only June through August data was utilized when there were virtually no inflows or outflows to or from the lake, with the exception of groundwater. However, this is usually the time of year when most in-lake phosphorus becomes available to contribute to lake phosphorus loading issues. The results showed that during the July and August time frame, in-lake phosphorus was being released from the sediments and providing “internal” loading to the water column. This finding is not surprising considering the stagnant lake conditions, lack of oxygenated bottom waters, and the high phosphorus pool available from the sediments.

Based on the samples collected, the flow monitoring around Lake Attitash, and flow transposition from the Pelham, NH stream gauge, a reasonable phosphorus budget for 2011 can be constructed. Table 3-1 shows the estimated annual inflow phosphorus loads to the lake in contrast to the phosphorus load leaving the lake. For this given year there is an estimated 1,219 pounds of total phosphorus entering the lake and only 591 pounds exiting the lake. This means a little over 600 additional pounds of phosphorus load is coming in to the lake over the course of the year; in addition to the internal seasonal loads to the lake. This is in stark contrast to the 1998 CDM report that reported an inflow load of 49,305 lbs/yr and 106,199 lbs/yr outflow load. The CDM report identifies a net loss of 56,894 lbs/yr of total phosphorus exiting from the lake. As stated in the report, the outlet flow rates had the lowest degree of confidence and the same was true to a certain extent for the 2011 flow data due to the complexities of the structures and flow manipulations. The large discrepancy in outflow phosphorus loads can be explained more by the fact that the CDM report utilized limited available data that was collected by others through several years at sporadic intervals and locations, limiting the ability for an accurate accounting rather than large inaccuracies in flow measurements. The CDM report acknowledges this fact, and states that the budgets are “preliminary.”

2011 Estimated Annual Phosphorus Budget				
Item	**Source**	**Total P Concentration (mg/l)**	**Annual Flow (cfs)**	**Total Phosphorus Load (lbs/yr)**
Inflows				
Direct Precipitation	(Wetzel, 1983)	0.030	1.77	104.57
Direct Runoff subbasin	Stormwater Sampling	0.068	0.71	95.13
Back River subbasin	Mean of 2011 twice monthly samples	0.060	5.53	653.41
Southwest Inlet subbasin	Mean of 2011 twice monthly samples	0.047	1.35	124.95
Direct Groundwater	(Wetzel, 1983)	0.020	6.11	240.65
Sediment Release	Hypolimnetic TP concentration less Epilimnetic TP concentration x anoxic lake water volume			117.30
Outflows				
Birches Dam Outlet	Mean of 2011 twice monthly samples	0.019	15.97	591.25
Evaporation	Lake Area x Evaporation		1.9	0.00
Settling/Uptake	Difficult to quantify	no available data		0.00

Table 3-1: **Estimated annual phosphorus budget for the 2011 sampling year** (*sediment release is estimated from mid-June through mid-September*).

One of the biggest “unknowns” in the phosphorus budget is the contribution of groundwater phosphorus loading. However, even without any contribution of groundwater phosphorus, of which in this case would be significant, there would still be a net additional load of phosphorus to the lake of almost 400 pounds annually. The use of seepage meters in conjunction with pore water analysis would provide important information as to the impact groundwater may play in this lake. It is readily apparent that external as well as internal phosphorus loadings (almost 10% of total annual loading) are playing an important role in the dynamics of the lake.

3.3 Nitrate-Nitrogen

Nitrate is usually the most prevalent form of nitrogen found in lakes and the form that can be utilized by most aquatic plants and algae. Spring concentrations of nitrate that are in excess of 300 ug/L are considered high enough to support summer algal blooms. Surface waters in general have at least trace levels of nitrates often less than 100 ug/L, and rarely exceeding 500 ug/L in most natural systems[2]. Nitrate levels are often higher during the spring and winter months when groundwater flows are the greatest, as it is extremely mobile and easily moves and leaches from the soil matrix and into surface waters. Groundwater nitrate concentrations in areas where inorganic nitrogen fertilizers are used may reach 1,000,000 ug/l. The drinking water standard for nitrate is 10,000 ug/l.

The 2011 sampling effort reflects this seasonal variation, while revealing some interesting twists. Figure 3-6 shows the seasonal nitrate nitrogen influx from the major inflow locations to the lake. Immediately apparent are the high concentrations coming from the Gunderboom area, just downstream of the Sargent’s Farm fields and wetland, and from the Southwest inlet area. The Southwest inlet is directly connected to the lake and shows high nitrate concentrations due to spring groundwater inflows, and decaying vegetative plant material entering the lake through its direct hydraulic connection, which limits the denitrifying process in this system. The Gunderboom area shows elevated nitrate levels due to spring groundwater inflows, along with contributions from the agricultural operations in this stretch of the Back River. Nitrate contributions from subsurface tile drains emanating from these fields revealed nitrate concentrations in excess of 50,000 ug/L in May, 2011. A tributary stream running adjacent to one of the agricultural fields along this Back River section revealed concentrations greater than 2,500 ug/L. These elevated levels continue through the month of May, decreasing steadily, until groundwater and surface water inflows have come to a halt by June. These higher nitrate concentrations are being seen at the Gunderboom in part due to the trenching of the wetland immediately upstream, short circuiting its natural denitrifying function. In contrast, there is practically no nitrate contribution from the Back River at the Bear Hill Road site. This is a result of most surface water and shallow groundwater having to work its way through a relatively normal functioning wetland that is providing the denitrifying process, and withholding the majority of any plant material harboring organic nitrogen from moving downstream.

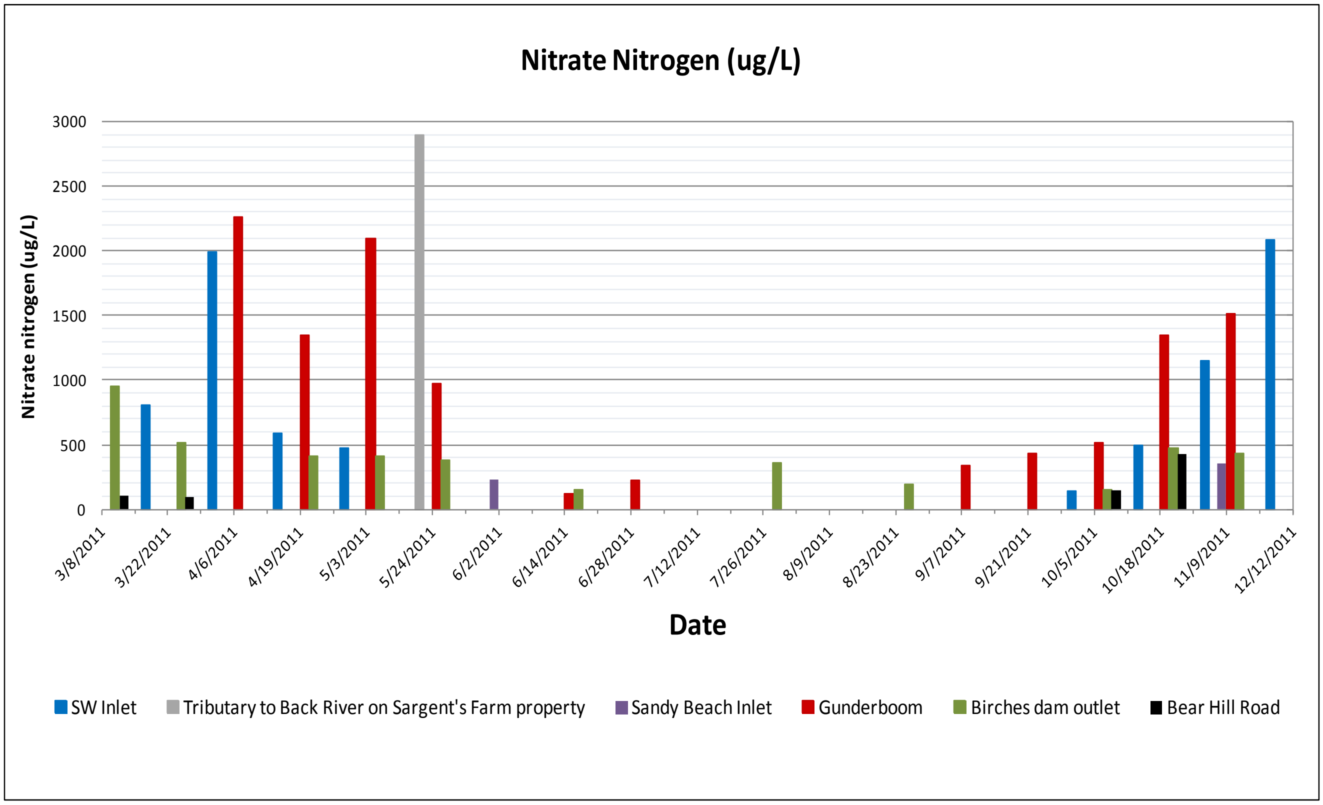


Figure 3-6: **Ambient nitrate-nitrogen concentrations from the major inflows and Birches Dam outlet during the survey period.**

Nitrate-nitrogen concentrations in the main body of the lake at the deep hole location (Figure 3-7) showed elevated levels in the spring, well in excess of what would be considered a stimulus to algal growth, and elevated concentrations through July. The surface water and bottom water concentrations are basically the same. In contrast, the 1977-78 MADEP survey report rarely detected nitrate-nitrogen at the deep hole location, and when it did the concentrations ranged between 100-200ug/L. Surface concentrations of nitrate-nitrogen were absent from June through November in 1977. No nitrate-nitrogen samples from the 1998 CDM study were collected from the deep hole area. However, samples were collected during July through early October 1998 at sites along the Back River and at the Southwest Inlet, a time frame when groundwater inflows are usually minimal. The Gunderboom and Southwest Inlet locations during this timeframe revealed reasonably comparable nitrate levels to the earlier reports, and as with the 2011 sampling, elevated levels were found along that segment of the Back River which flows through the Sargent Farm property adjacent to agricultural fields. The one exception to the 1998 values being comparable to earlier results were those samples collected from the Back River at the Bear Hill road crossing. The 1998 Bear Hill road values were significantly higher than the 2011 samples at the same location. This may have been due to less restricted flows out of the wetland during 1998 (2011 exhibited beaver dam makings on the upstream side of the Bear Hill road crossing), limiting denitrification processes from taking place, or differences in the analytical methods that were used at the time (nitrate colorimetric test vs ion chromatography utilized in 2011). It should be noted, with the exception of the Back River segment running adjacent to the Sargent Farm agricultural fields that most of these nitrate values fall within a reasonably normal concentration range of what one would expect out of these wetland areas.

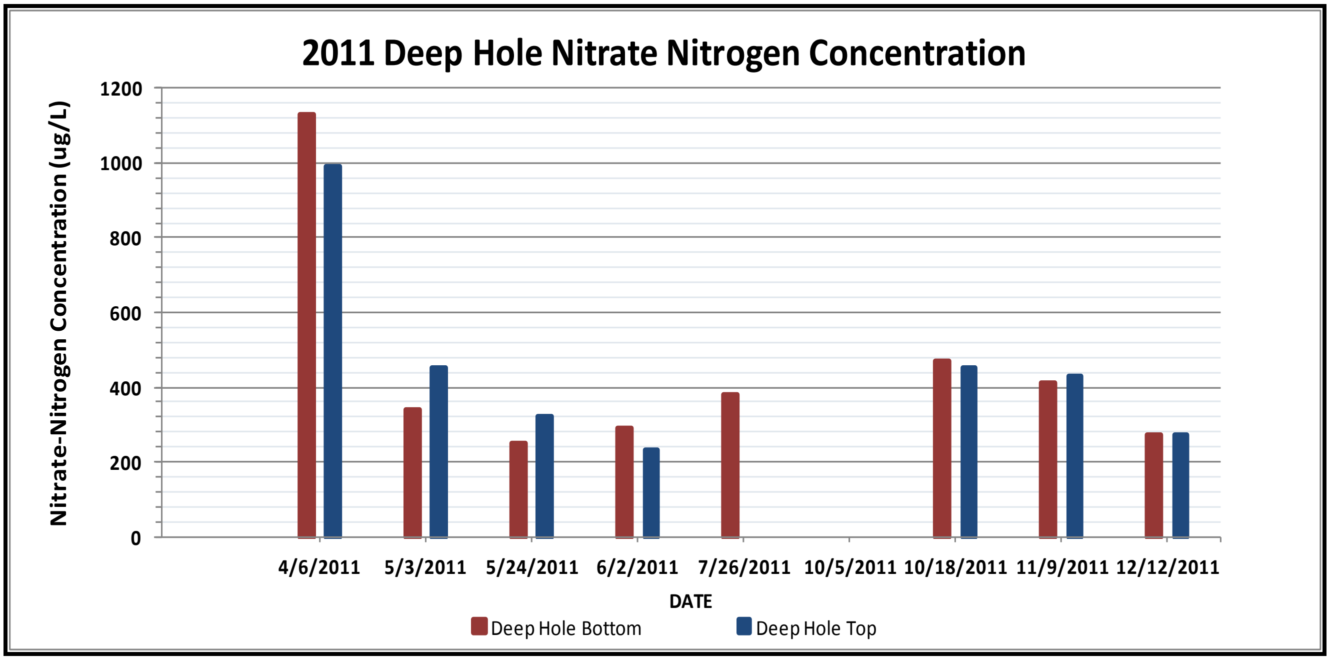


Figure 3-7: **Epilimnetic and hypolimnetic nitrate-nitrogen concentrations during the survey period.**

3.4 Nitrogen and phosphorus ratios

Although phosphorus is usually considered to be the nutrient that limits or stimulates algal production in a lake depending on its concentration, in some situations algal production in a water body may be limited by the amount of nitrogen in the water rather than phosphorus levels. Molar concentrations of nitrogen and phosphorus at ratios of less than 10:1 are usually indicative of a water body being nitrogen limited; additions of nitrogen rather than phosphorus will be the stimulus for algal production. Any nitrogen to phosphorus ratios greater than 15:1 are usually considered to be phosphorus limited and any phosphorus inputs will drive the production of algae in the lake. Values in between are considered transitional. Some literature also suggests that in addition to low N:P ratios, nitrogen limited lakes are significantly more frequent when total phosphorus values are above 30µg/L in addition to a low N:P ratio[3]. However, the majority of Lake Attitash N:P ratios for the 2011 sampling year were above the 15:1 ratio, indicating that Lake Attitash is a phosphorus limited water body. Spring ratios are higher due to seasonal nitrogen influxes from groundwater and possible agricultural sources, and lower in midsummer when anoxic conditions induce denitrification and sediment phosphorus mobilization.

Monthly TN:TP Mass Ratios							
4/6/2011	4/19/2011	5/3/2011	6/2/2011	6/14/2011	10/18/2011	11/9/2011	12/12/2011
58	29	26	16	13	15	26	12

Table 3-2: **Deep hole top two meter monthly nitrogen to phosphorus ratios during the survey year (epilimnetic nitrogen was not detected in the July samples).**

3.5 Deep Hole Lake Profiles

Profiles of physical chemistry were taken at twice monthly intervals throughout the year at the deep hole location. These measurements consisted of pH, Conductivity, Temperature, and Dissolved Oxygen, taken at the surface and at progressive one meter intervals of increasing depth until within a half meter of the lake bottom.

Areas of low dissolved oxygen within the water column identify areas that exclude the surrounding habitat from being available for use by many aquatic organisms. This can be a natural occurrence, or precipitated by increasing nutrients and/or organic materials whereby oxygen is depleted by microbes, bacteria, and other organisms through the process of decomposition and respiration. These oxygen depleted areas can also represent sources of internal phosphorus loading, released from the underlying sediments under the oxygen deficient conditions. Figure 3-8 shows the vertical progression of oxygen depletion through the course of the 2011 sample season in Lake Attitash. As the summer progresses and the lake starts warming and stratifying, biological activity increases and decomposition on the lake bottom accelerates, consuming available oxygen. As cooler temperatures start to prevail in the fall months and the lake “turns over,” dissolved oxygen levels again return to the deeper sections of the lake as biological activity and decomposition processes decline.

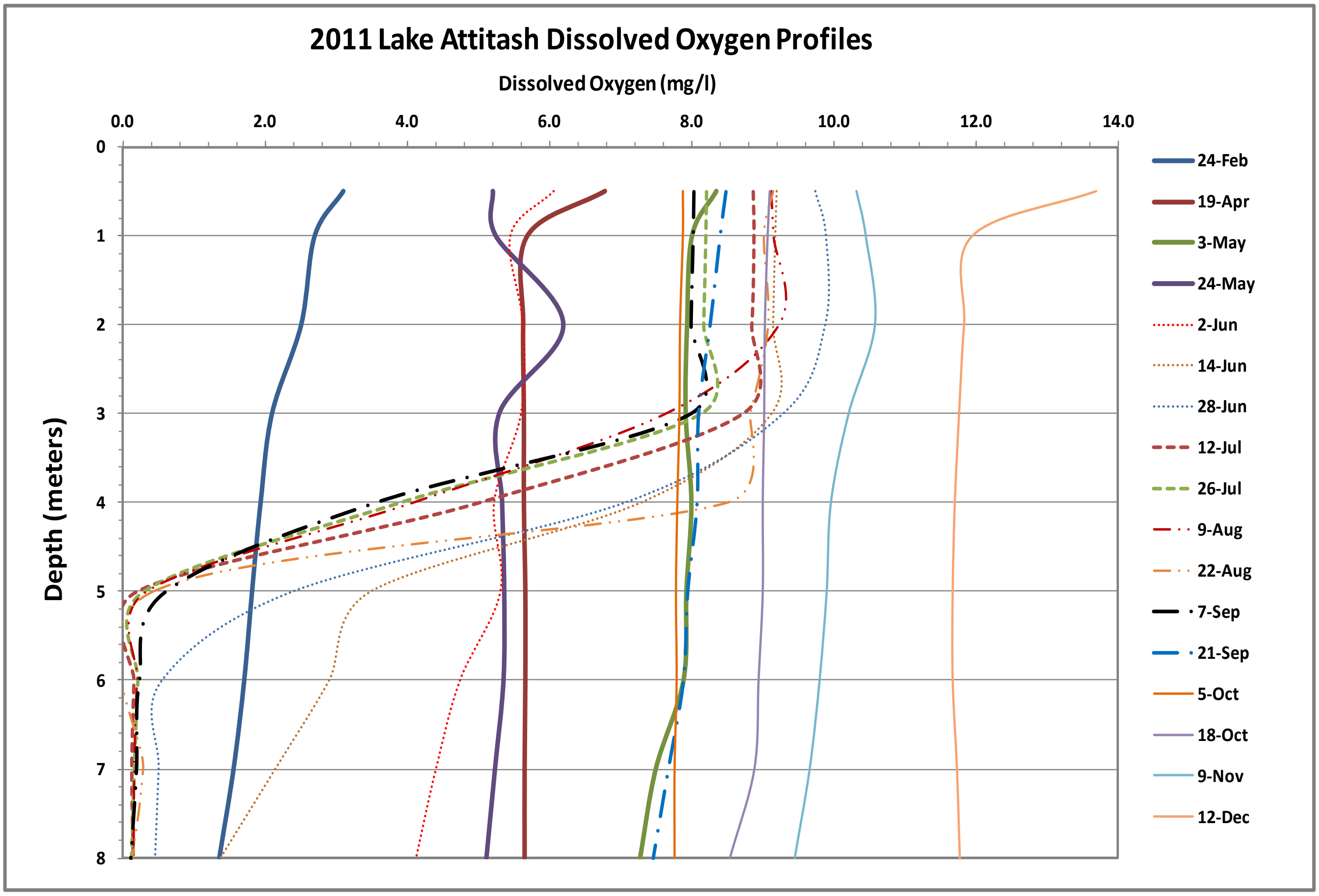
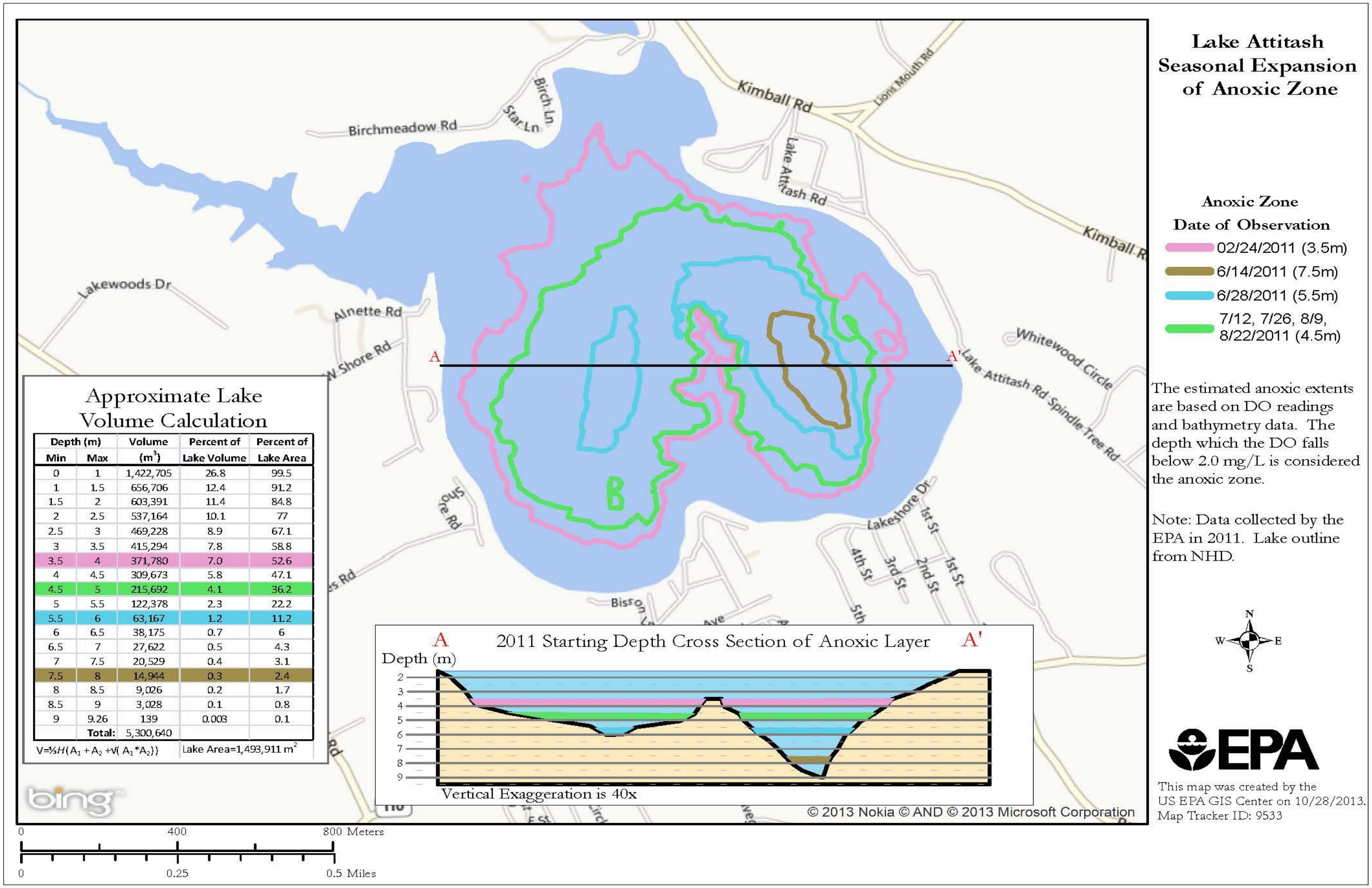


Figure 3-8: **Dissolved oxygen concentrations with increasing depth through the course of the sampling year.**

Utilizing the vertical dissolved oxygen profiles through the course of the year and the depth contours of the lake, one can track the migration of the anoxic area through the seasons and get an idea of the extent of decreased available habitat and potential area of phosphorus dissolution from the sediments. Figure 3-9 shows the seasonal areal extent of anoxia across the lake bottom and its associated depth. February shows the largest oxygen deficit, with the majority of the lake volume having dissolved oxygen concentrations under 2.0 mg/L, the concentration considered for the most part to be uninhabitable for most aquatic life. The lake volumes were utilized in conjunction with the hypolimnetic and epilimnetic phosphorus concentrations during June, July, and August to make estimates as to the degree of internal loading taking place.



Approximate Lake Volume Calculation

Depth (m)		Volume	Percent of	Percent of
Min	Max	(m^3)	Lake Volume	Lake Area
0	1	1,422,705	26.8	99.5
1	1.5	656,706	12.4	91.2
1.5	2	603,391	11.4	84.8
2	2.5	537,164	10.1	77
2.5	3	469,228	8.9	67.1
3	3.5	415,294	7.8	58.8
3.5	4	371,780	7.0	52.6
4	4.5	309,673	5.8	47.1
4.5	5	215,692	4.1	36.2
5	5.5	122,378	2.3	22.2
5.5	6	63,167	1.2	11.2
6	6.5	38,175	0.7	6
6.5	7	27,622	0.5	4.3
7	7.5	20,529	0.4	3.1
7.5	8	14,944	0.3	2.4
8	8.5	9,026	0.2	1.7
8.5	9	3,028	0.1	0.8
9	9.26	139	0.003	0.1
	Total:	5,300,640		

$V=⅓H(A_1+A_2+\sqrt{(A_1*A_2)})$ Lake Area=1,493,911 m^2

The estimated anoxic extents are based on DO readings and bathymetry data. The depth which the DO falls below 2.0 mg/L is considered the anoxic zone.

Note: Data collected by the EPA in 2011. Lake outline from NHD.

This map was created by the US EPA GIS Center on 10/28/2013. Map Tracker ID: 9533

Figure 3-9: **Migration of the hypolimnetic anoxic area through the course of the 2011 sampling year.**

As mentioned in the report from CDM in 1999, Lake Attitash had good dissolved oxygen levels throughout all depths of the lake all year round in 1977. By 1994 however, dissolved oxygen concentrations were at uninhabitable levels (2.0 mg/L) below five to six meters in depth.

3.6 Lake Temperature and pH

Microbial and biological activity increase as water temperatures warm, and Lake Attitash warms up throughout the water column over the course of the seasons. Figure 3-10 shows this temperature transition from February, where temperatures are near freezing at the surface through the ice, through the early spring and late fall early winter when temperatures are relatively uniform throughout the water column, to the summer months where cooler waters from groundwater inflows are stratified from the warm surface waters. Even these cooler waters warm up significantly during the course of the summer.

Due to the anoxic conditions, these cooler waters are unavailable to fish and other aquatic life and the upper surface waters top out at almost 28ºC (82ºF). The unavailability of cooler water temperatures in the epilimnion and lack of oxygen at depth can create stressful conditions for many fish species. The 1978 Notini survey reported annual surface water temperatures ranging from 0.0ºC to 23.0ºC and deep hole bottom temperatures ranging from 5.0ºC to 22.0ºC.

pH can be indicative of primary productivity levels and photosynthetic processes taking place within a water body. Plants and algae utilize carbon dioxide and sunlight in the production of carbohydrates, which are then ultimately converted to plant tissue. Photosynthesis consumes protons in the process, which then raises the pH levels in the waterbody. Lake Attitash is an excellent example of this, as pH values ranged from 7.0 in the spring when little algal production is taking place, to 8.0 in July, and a high of 13.0 in August before returning to a more "normal" value of around 7.0 in September after the algae has died off. Although pH values can vary widely through the course of a season as well as daily, these measurements provide another indication that algal production is quite high in this lake.

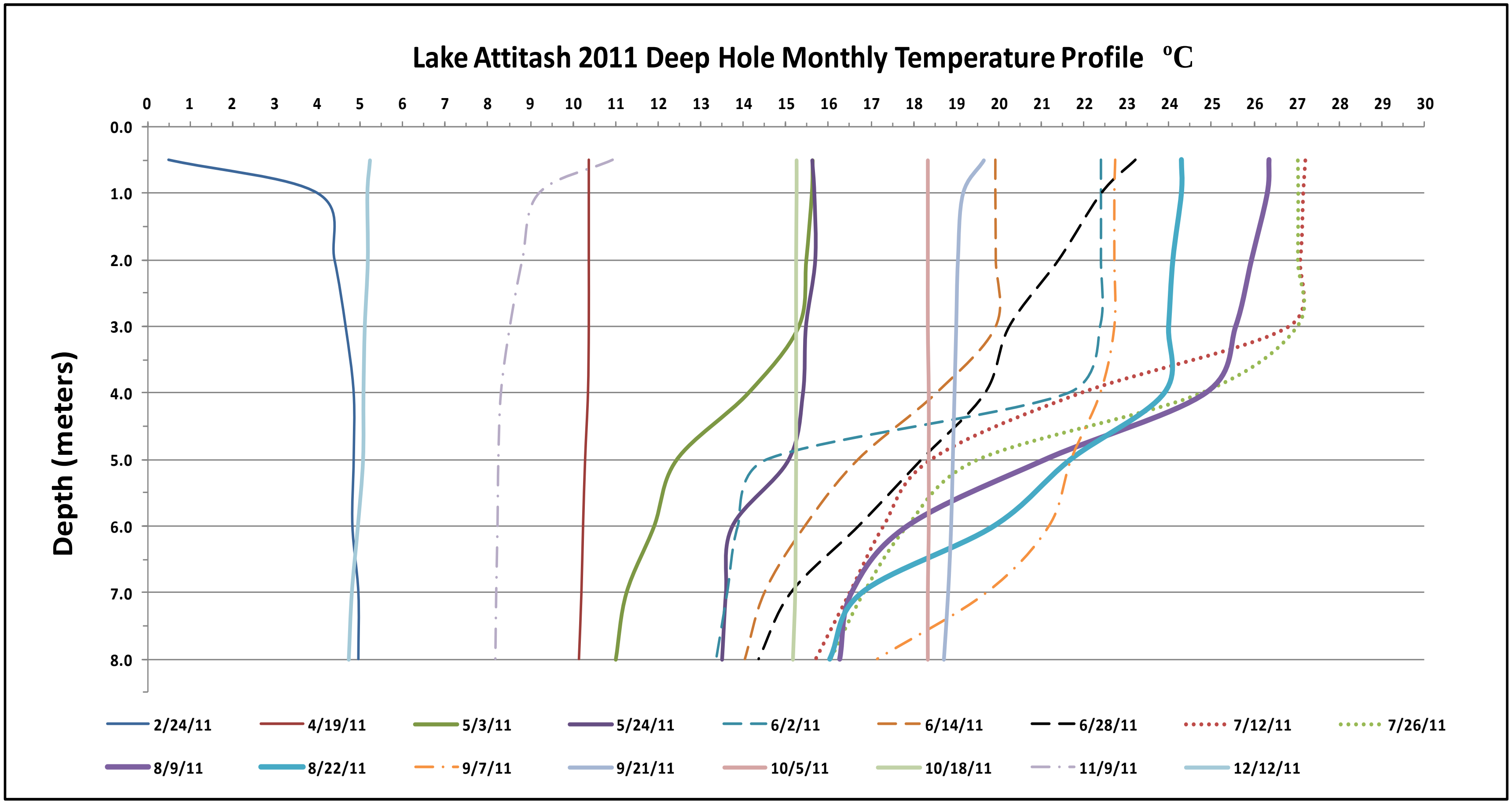


Figure 3-10: **In lake temperature transition through the 2011 sampling period.**

3.7 Chlorophyll

Chlorophyll is another important water quality parameter that is often used as a component in determining the trophic condition of a water body. The amount of this plant pigment found in a water sample is used as a surrogate for estimating the amount of algae, or biomass that is present in a water body. While not a perfect measure of biomass, when combined with measurements of total phosphorus and measures of lake water transparency, these three indicators provide a fairly robust assessment of lake trophic condition.

In 1977, samples from the Notini survey revealed chlorophyll concentrations ranging from 1.65ug/L in April 1978, to 2.93ug/L in May and 2.13ug/L in August the year before. This small sample set indicates very low productivity/biomass (excluding aquatic macrophytes) and was at concentration levels usually associated with high water clarity. Chlorophyll samples collected during the 1998 CDM study under the same time frame was a stark contrast, with values indicative of a hypereutrophic lake system ranging in values from a low of 323ug/L in May 1998, to a high of 1,970ug/L in August of 1998. Samples collected during the 2011 survey also show a distinct difference from those collected during the previous two surveys (Table 3-2). These 2011 values, while nowhere near the concentrations found in 1998, are still at concentration levels (>20ug/L) that would be considered highly eutrophic to borderline hypereutrophic[4].

2011 Total Chlorophyll ug/L													
4/20/2011	5/4/2011	5/25/2011	6/2/2011	6/14/2011	6/28/2011	7/12/2011	7/26/2011	8/9/2011	8/23/2011	10/6/2011	10/18/2011	11/9/2011	12/12/2011
4.58	21.72	8.24	3.72	4.22	4.27	6.19	6.19	13.06	21.93	21.80	15.67	5.71	6.80

***Table 3-3:* 2011 Deep hole Total Chlorophyll values for Lake Attitash.**

3.8 Transparency

Transparency is one of the three key common components utilized to assess the trophic condition of a lake. Decreasing visibility down through the water column is often determined by the density of the algae found residing within it. The tool utilized for this measurement is a secchi disk which consists of a black and white sectioned disk attached to a measuring tape or incrementally marked chain that is lowered through the water column until it disappears from view. The depth is recorded at the point that the disk disappears from view. Figure 3-11 shows the different secchi readings through various years from 1977 on up through 2011. For these readings to be the most valuable, they should be taken throughout the course of the year from at least May through September and at an acceptable frequency depending on the lake. For a lake such as Attitash, weekly measurements would be optimal.

The 1977 secchi readings show that the lowest transparency recorded occurred in mid May at a depth of approximately 2.75 meters. This could be a result of natural colored dissolved organic materials (ie. Tannins) that often make waters adjoining wetland areas “tea stained” and/or the presence of spring diatom blooms. Based on the well-used and accepted Carlson Trophic State Index (TSI), (Figure 3-12), Lake Attitash would be classified as a mesotrophic lake at this time based on the secchi disk readings. The secchi readings from 1978 however, show a very different trend, with July and August readings around one meter. This would place the lake on the upper end of a eutrophic system, even back in 1978. All readings taken in 1977 and up until the beginning of the summer of 1978 depict Lake Attitash as a mesotrophic system. From the summer of 1978 through the fall of 1998 the lake falls in the category of a eutrophic system. 2011 secchi readings show a little better clarity in July of that year, but then fall in the same range as previous years in August and September. For all practical purposes, one would be reasonably accurate in stating that the seasonal transparency of the lake has not changed much since the summer of 1978 and would be considered eutrophic based solely on secchi readings.

It should be noted that secchi readings can be quite variable depending on the time of day taken, cloud cover, surface chop, use of a viewing scope, different individuals taking the readings, etc. In order for reliable data to be collected and provide quality information on water quality trends, consistency in sampling frequency and methodology is imperative.

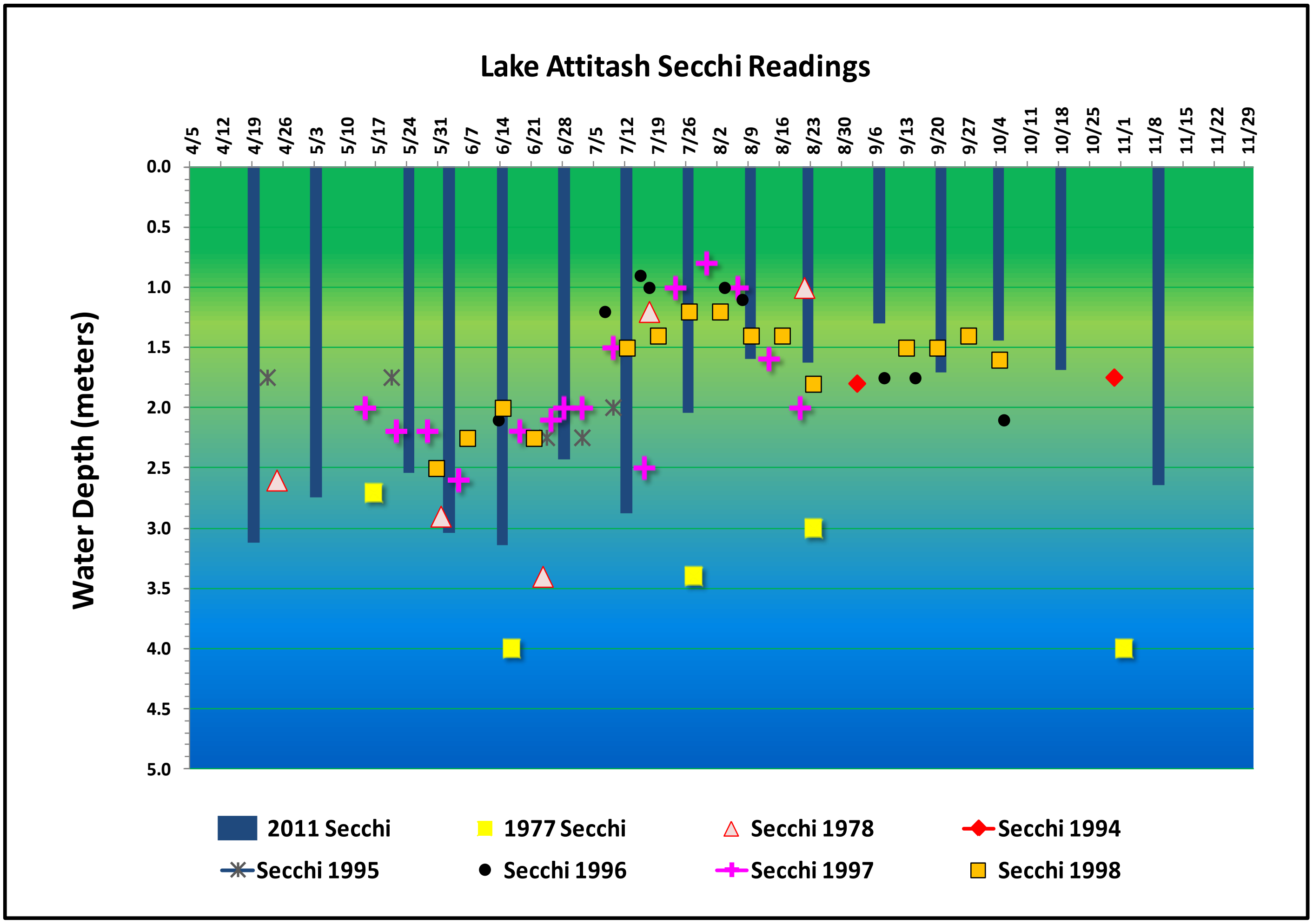


Figure 3-11: **Secchi disk readings of known sampling years.**

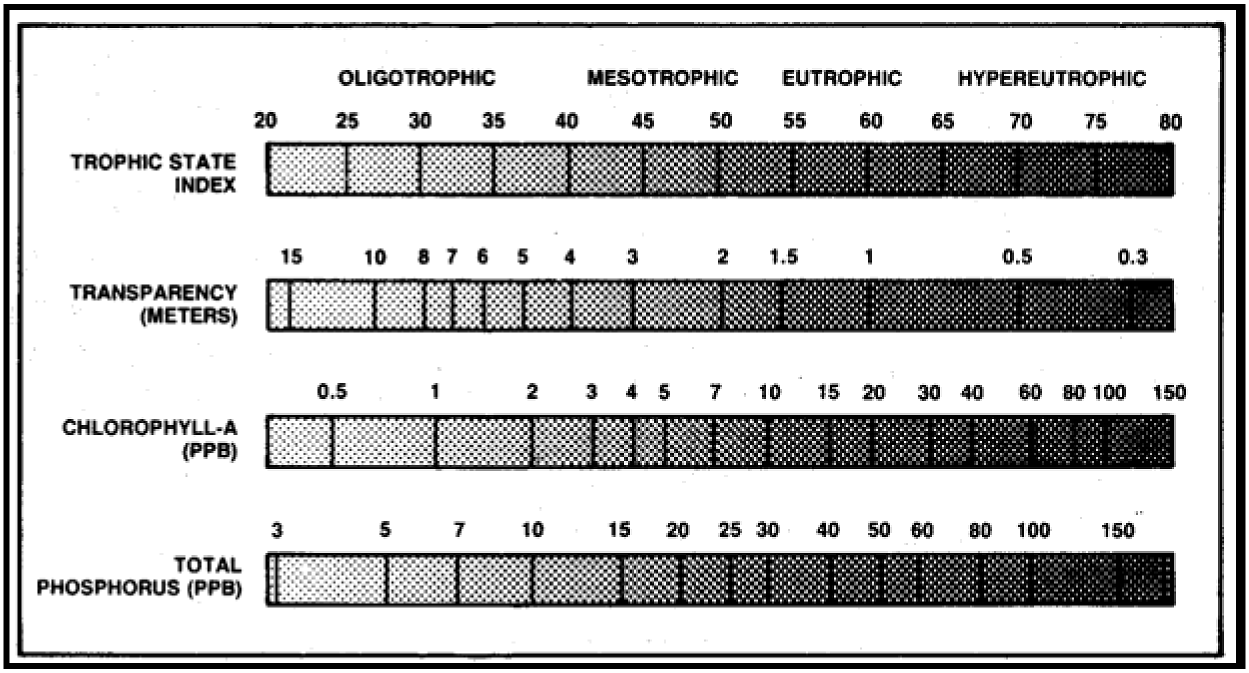


Figure 3-12: **Carlson Trophic State Index (TSI) utilizes secchi disk (transparency), chlorophyll-a concentrations, and total phosphorus values to form a combined index on the trophic condition. (PPB-Parts per billion, equivalent to ug/L)**

References

1. (Carlson, R.E. and J. Simpson. 1996. *A Coordinator's Guide to Volunteer Lake Monitoring Methods*. North American Lake Management Society. 96 pp.).

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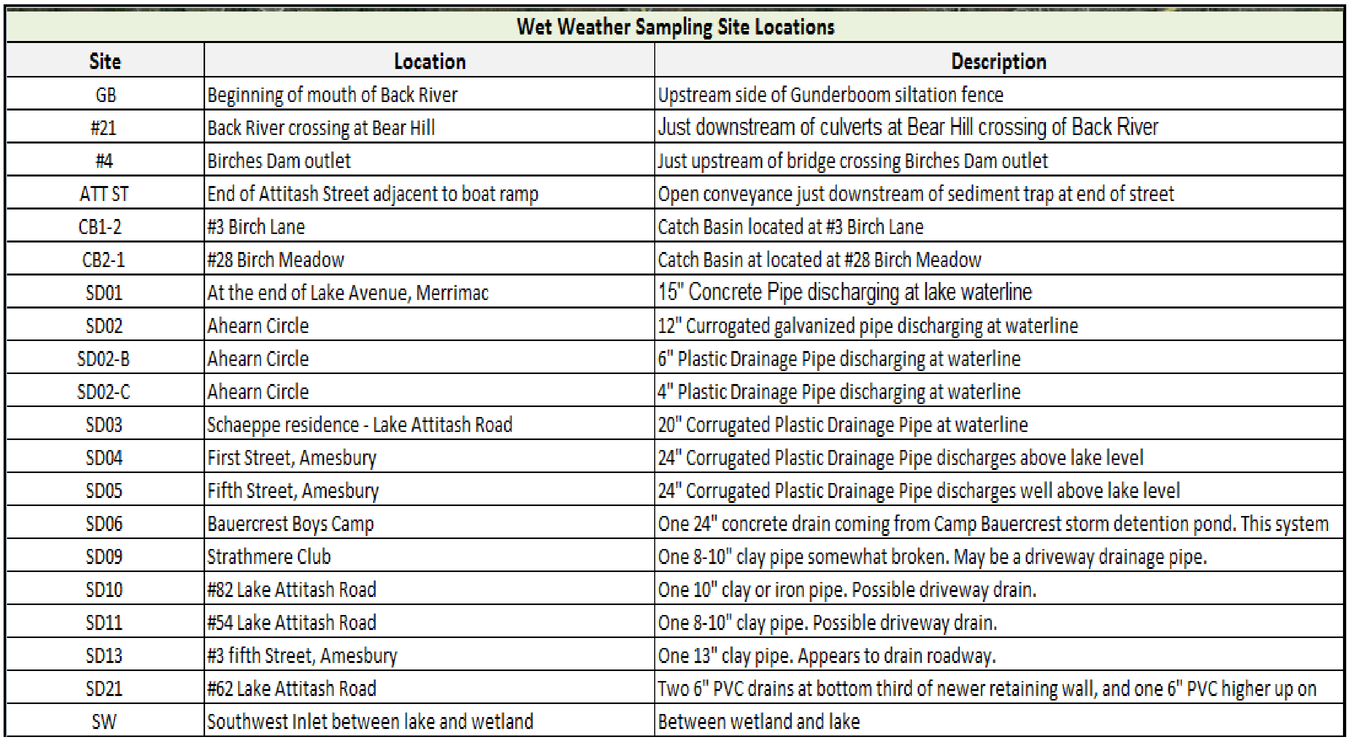
4.1 Wet Weather Survey

As an essential component of this project, a wet weather survey was scheduled in order to have some idea of the relative nutrient loading contributions from the lake's subbasins as well as from individual storm water discharge points. A discharge pipe survey around the lake identified over forty-five constructed drainages and several drainage swales, designed to discharge directly into the lake. Despite the relatively high number of pipes observed, many of these are infiltration drains from retaining walls and rarely if ever discharge. This is evidenced by the lack of any water staining on the retaining walls below these pipes and visual observations made during wet weather events. The remaining constructed storm water discharges are significant, and convey runoff from impervious surfaces and other land uses into the lake via storm water retention ponds, catch basins, or straight pipe conveyances. These locations were specifically selected for sampling because they represent the key areas where stormwater is entering the lake and provide the opportunity to capture incoming loads and determine their relative contribution of nutrients into the lake (Figure 4-1). In addition to the discharge pipes, the major inflows and selected tributaries in the watershed were sampled, along with the Birches Dam outlet (Table 4-1). Although these point source discharges do not account for all of the external nutrient loads in to the lake Attitash subbasin, they do account for the majority, and are locations where stormwater controls could or have been put in place to mitigate external nutrient source impacts. Results from the wet weather survey demonstrate the current effectiveness of these "point source" controls, and identify those areas where improvements might be made. Quantifying other external sources of "non-point" nutrient inputs is more difficult and often requires various types of hydrologic and land use modeling approaches. However, since the majority of runoff comes from these point sources in the Lake Attitash subbasin and the loading is known to be highest from these land use types, sampling these discharge points provides a reasonable estimate of wet weather loading from this subbasin in to the lake.

Figure 4-2: **Lake Attitash wet weather survey sampling locations.**



Wet Weather Sampling Site Locations		
Site	**Location**	**Description**
GB	Beginning of mouth of Back River	Upstream side of Gunderboom siltation fence
#21	Back River crossing at Bear Hill	Just downstream of culverts at Bear Hill crossing of Back River
#4	Birches Dam outlet	Just upstream of bridge crossing Birches Dam outlet
ATT ST	End of Attitash Street adjacent to boat ramp	Open conveyance just downstream of sediment trap at end of street
CB1-2	#3 Birch Lane	Catch Basin located at #3 Birch Lane
CB2-1	#28 Birch Meadow	Catch Basin at located at #28 Birch Meadow
SD01	At the end of Lake Avenue, Merrimac	15" Concrete Pipe discharging at lake waterline
SD02	Ahearn Circle	12" Curragated galvanized pipe discharging at waterline
SD02-B	Ahearn Circle	6" Plastic Drainage Pipe discharging at waterline
SD02-C	Ahearn Circle	4" Plastic Drainage Pipe discharging at waterline
SD03	Schaeppe residence - Lake Attitash Road	20" Corrugated Plastic Drainage Pipe at waterline
SD04	First Street, Amesbury	24" Corrugated Plastic Drainage Pipe discharges above lake level
SD05	Fifth Street, Amesbury	24" Corrugated Plastic Drainage Pipe discharges well above lake level
SD06	Bauercrest Boys Camp	One 24" concrete drain coming from Camp Bauercrest storm detention pond. This system
SD09	Strathmere Club	One 8-10" clay pipe somewhat broken. May be a driveway drainage pipe.
SD10	#82 Lake Attitash Road	One 10" clay or iron pipe. Possible driveway drain.
SD11	#54 Lake Attitash Road	One 8-10" clay pipe. Possible driveway drain.
SD13	#3 fifth Street, Amesbury	One 13" clay pipe. Appears to drain roadway.
SD21	#62 Lake Attitash Road	Two 6" PVC drains at bottom third of newer retaining wall, and one 6" PVC higher up on
SW	Southwest Inlet between lake and wetland	Between wetland and lake

Table 4-1: **Wet weather site descriptions.**

The 1992 EPA Stormwater Manual (EPA 833-8-92-001, July 1991) displays the designated rain zones of the United States and shows Lake Attitash as being located in the Northeast Coastal Zone. As of 1992, the average storm duration in this zone was 11.7 hours and the average storm depth of rainfall was 0.66 inches. Lake Attitash has an annual average precipitation of 46.27 inches, based on daily rainfall records from 1931 up until 2011 at the West Newburyport WNW weather station, which is located approximately four miles northeast of the lake.

In order for wet weather data to be useful, it should reflect the conditions of what would be considered representative of a “typical” or “average” rain event. Based on the EPA stormwater manual, a representative rainstorm for storm water discharge permitting purposes should fall within fifty percent of the average storm duration and depth for a particular area. Although not essential for the Lake Attitash wet weather sampling effort, this criterion was used as a benchmark for determining if the selected storm was in the ballpark for what would be considered an average storm. To be representative based on the above guideline, a Lake Attitash wet weather sampling event should have a storm duration falling between six and eighteen hours, and have a total cumulative rainfall depth between 0.33 and 0.99 inches. Based on this document, the storm event should also be preceded by a minimum of three days of dry weather conditions.

The time period selected for capturing a wet weather event on Lake Attitash was late September through October. This time of year pop-up thunderstorms are usually absent and larger, more sustained weather fronts take their place. These fronts cover a much broader area than the isolated, often brief sporadic thunderstorms of the summer, making it much more likely to capture watershed wide rainfall runoff flows and make it much easier to plan, mobilize sampling crews, and implement sampling efforts. The wet weather sampling event fell on October 27, and was preceded by a day of “misting” conditions that made surfaces damp, but did not induce any runoff. The cumulative rainfall for the October 27 storm was 1.28 inches and lasted 17.5 hours. This event falls slightly on the high side of the prescribed representative rainstorm for precipitation, but meets the duration criteria. Despite this slightly higher rainfall, the storm is fairly representative and provides useful data that can be used for developing insights to relative nutrient loading contributions from the major sub basins of the watershed.


Figure 4-2: **Typical rain gauge used for the wet weather survey.**

Four rain gauges were set up around the perimeter of the lake and monitored at hourly intervals throughout the storm period in order to capture incremental and total rainfall amounts (Figure 4-2). Water samples were collected at each of the discharge locations at key time periods during the storm; a pre-storm sample was collected from those points that had flow prior to the storm, a “first flus h” sample was collected representing the initial slug (and usually highest concentration) of pollutants in the runoff, a “rising” sample representing increasing flow prior to the peak intensity of precipitation runoff, a “peak flow” sample, and a “post storm” sample which was taken several hours after the peak sample, when storm water flows had significantly receded. Collected stormwater samples were preserved on site and then transported to the USEPA Regional Laboratory in Chelmsford, Massachusetts for analysis. Sample concentrations for each of the principal analytes through each sampling period of the storm can be found at the end of this section (Tables 4-4, 4-5, 4-6, 4-7).

While the principal focus of an assessment of watershed and lake nutrients is on the loads, or the pounds of material per unit time for example, it’s important to understand the relationship between their concentration and the flow from the various sources. Figure 4-3 shows the relationship between the averaged wet weather concentrations at sampling sites compared to the loading of phosphorus through the duration of the storm period. The three lowest concentrations of phosphorus found inflowing to the lake were from the Gunderboom site, the Bear Hill Road crossing, and the Southwest Inlet, but these areas revealed the highest loadings of phosphorus. These three sites also have the highest flows in direct relation to the highest loadings; Gunderboom, Bear Hill, and Southwest Inlet respectively.

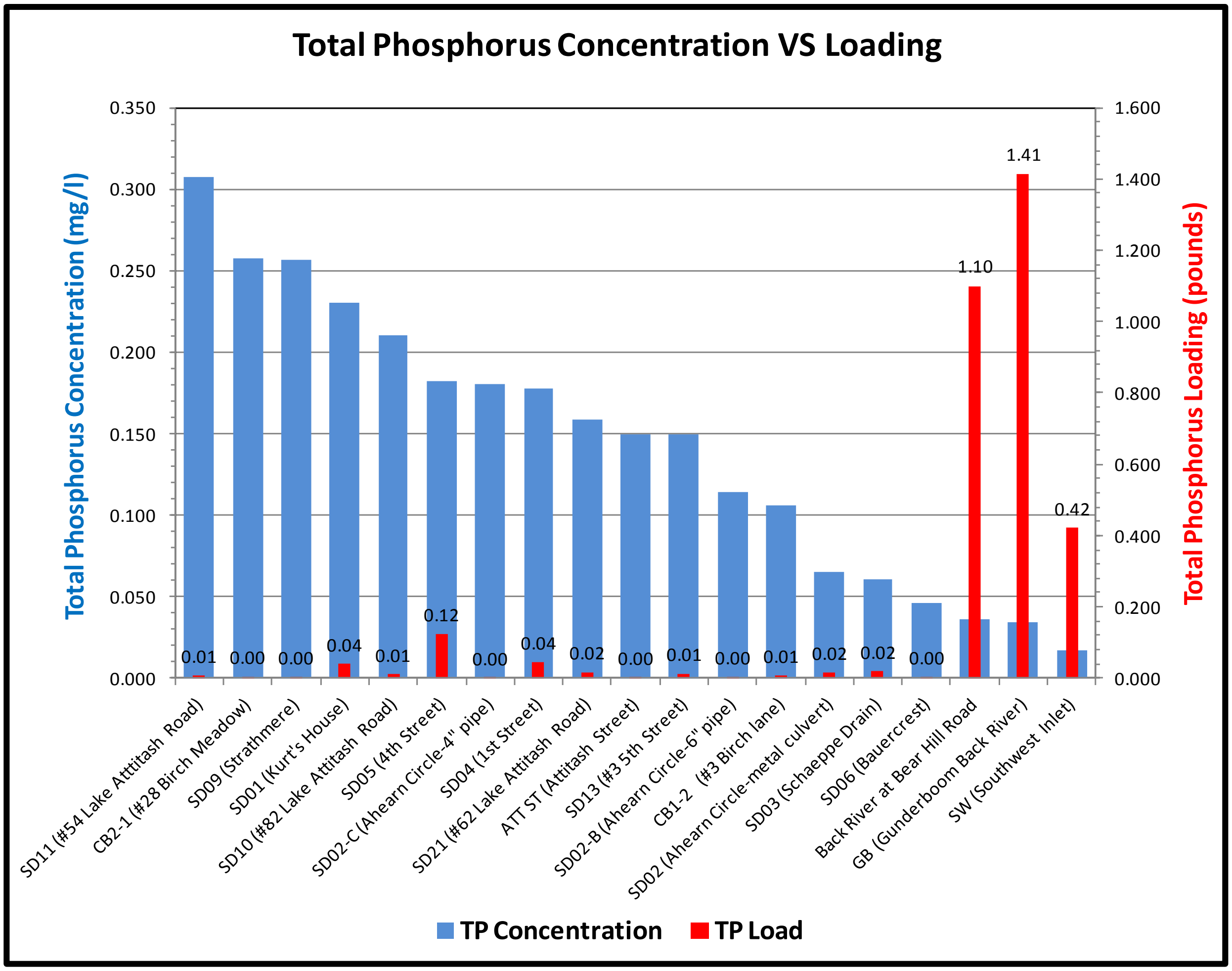


Figure 4-2: **Comparison of the averaged concentration during the wet weather survey to the actual load of nutrients.**

In order to determine the wet weather load of nutrients that entered the lake, it is necessary to measure the flow rates during the storm. This was accomplished by utilizing calibrated buckets at all of the storm drain locations, accurately measuring the volume and noting the time it took to fill the bucket to a certain volume. Flow measurements were taken every hour where possible. This worked well for most areas, and when combined with the laboratory analysis of the sample, resulted in the pounds of nutrients/pollutants entering the lake at that location from the storm event. In addition to measuring the flow/discharge rates at the various outfalls, rainfall intensity and cumulative rainfall were measured at a minimum of one hour intervals to the extent possible throughout the duration of the storm (Figure 4-4). This information helps in determining the responsiveness of various catchments, or how quickly runoff is conveyed into the lake and how well sampling correlated with the actual first flush, peak, and other periods of the storm.

Accurate flow measurements from the Back River, Southwest inlet, and Sandy Beach were more difficult to obtain than using the calibrated buckets at the point source discharge locations in the Lake Attitash subbasin. Temporary weirs were set up to measure flows at the

Southwest inlet and at the Sandy Beach outlet, but these failed during the rainstorm. One flow measurement was taken during the first flush period at Sandy Beach, and this was used as an approximate flow measurement for ballpark loading calculation purposes in that area (first flush samples usually contain the highest concentration of pollutants). For determining flows from the Southwest Inlet and Back River in lieu of direct flow measurements, the same rainfall runoff land use model coefficients were used as in the 1999 CDM report. The model works by taking the area of specific land uses in the subbasin and multiplying it by a pre-determined run-off percentage (coefficient) for that specific land use. The runoff flow volumes are then determined for each sampling interval (ie. First flush) and multiplied by the sample pollutant concentration at that interval to determine the incremental load to the lake, which is then summed with the other samples and incremental flows throughout the storm to obtain a total load estimate for the lake. The model is useful in providing consistency and for making comparisons between the sampling years.

No significant land use changes have taken place in the watershed from 1998 until the present, with the exception of the Olde Taverne Lane and Whitewood Circle developments. However, these two developments are located in the Lake Attitash subbasin where the more precise direct flow measurements were taken rather than utilizing the model, so did not influence the land use runoff model calculations. Percentages in land use types for the Southwest Inlet and Back River were left as is. Outlet flows for the Birches Dam were determined by direct field measurements of flow velocities and dam stage height throughout the duration of the storm to

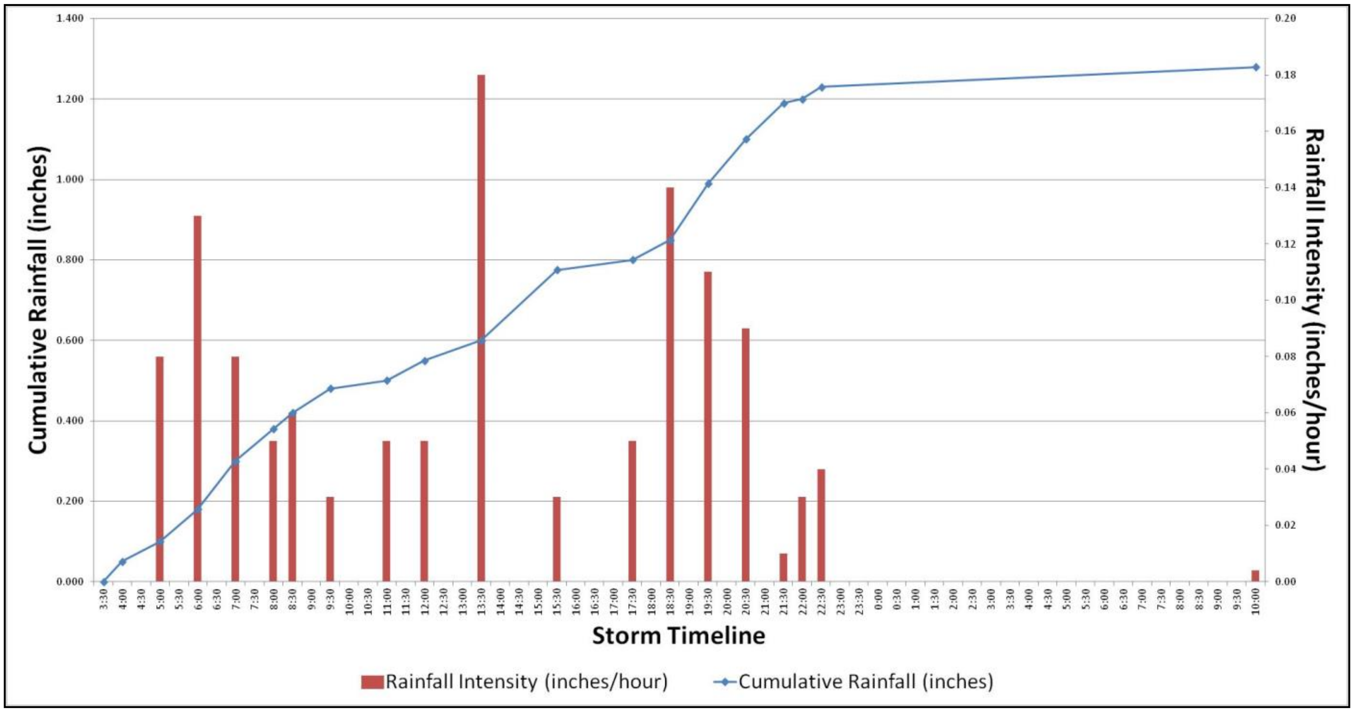


Figure 4-4: **Chart showing the intensity of the rainfall during the course of the storm. Peak intensity occurred during the "first flush," midway through the storm, and towards the end before tapering off in the late evening.**

correspond with the sampling, and also until the stage height at the dam returned to its pre-storm elevation. The total difference in stage height at the birches Dam varied by less than one tenth of an inch throughout the duration of the storm, so loadings were based on this constant flow rate throughout the sampling period.

To determine the actual loading per storm water discharge pipe, the same approach is used as that for the other two subbasins. The actual flow rate (rather than the modeled flow used in the other two subbasins) at each sampling interval was multiplied by the time interval between each sampling event (i.e. first flush, peak, etc.) and then by the concentration of pollutant at that sampling interval to determine the load of nutrients. All the sampling interval loadings were then summed to obtain the total pounds of pollutant entering the lake from that source for the duration of the storm.

Four analytical parameters were selected for the wet weather event. These were total phosphorus, total suspended solids, Total Kjeldahl Nitrogen, and NO2/NO3 (nitrite/nitrate). Total phosphorus was analyzed in order to determine the "external" load of phosphorus coming in to the lake. This is then balanced against what the load is exiting the lake at the Birches Dam to determine if there is a net gain or loss of this nutrient to the lake. If outlet loads are greater than the inflow loads, then the lake is losing this limiting nutrient and less is available to aquatic plants and algae; an improving condition. If more is coming in to the lake from off of the landscape than what is going out at the Birches Dam, than conditions are getting worse and more or different management controls/approaches may be needed.

Total suspended solids are those solids/particulates found in water that do not pass through a standard sized filter (usually 0.45 microns). These materials are often grease, dirt, and other organic and inorganic debris that are washed off of roadways, roofs and other impervious surfaces. This material often diminishes the water clarity and quality in waterbodies. It can create turbid conditions that promote warming of the water, cover the bottom of the lake with material that smothers bottom dwelling aquatic life, depletes available oxygen through its decomposition, and promotes algal and nuisance aquatic plant growth by the release of nutrients like phosphorus that entered the waterbody attached to these particles. Total suspended solids can be very effectively removed by the use of well designed and maintained BMPs, or Best Management Practices. Removal efficiencies can be as high as eighty percent. Some of the most common BMPs used in the Lake Attitash sub basin include catch basins and retention ponds. These devices give time for the suspended solids to "settle out" prior to stormwater entering the lake. Many of these control structures were installed shortly after the 1998 CDM report which recommended their installation. Others were already in the process of being installed, and others were put in as common construction practices in later residential developments.

Sources of nitrogen can come from a variety of places and in a variety of forms, and how it interacts in the environment is complex. It is often considered the second most important nutrient for the growth of aquatic plants and algae in lakes. Most of the natural nitrogen input comes from the atmosphere (which is made up of 78% nitrogen) and is taken up by plants. Some sources of nitrogen may come out of the atmosphere from rainfall, or incorporated in organic debris by bacteria that is then washed into the water body. Other significant sources (especially nitrate) can be from lawn and agricultural fertilizers and septic systems.

Total Kjeldahl Nitrogen (TKN) is a method (Johan Kjeldahl, 1883) that determines the amount of organic nitrogen and ammonia in a sample. TKN is often representative of that fraction of nitrogen that is found in particulate form, usually from decaying organic plant materials. The other key components making up the total amount of nitrogen in a sample is the nitrite and nitrate (NO2/NO3) forms. These are predominantly considered the inorganic forms of nitrogen and are converted from ammonium to these other forms by bacteria. Of these latter two, nitrate is the most prevalent form of nitrogen in lakes (nitrite is quickly converted to nitrate) and is the principle form of nitrogen used by plants. This form of nitrogen leaches easily through the soil matrix and can be a major pollutant concern, leading to eutrophication in lakes through the proliferation of aquatic plants and algae. Analysis of the organic and inorganic forms of nitrogen are usually done through different analytical procedures, and then summed to determine a “total nitrogen” value for a waterbody. Despite derivation of a “total nitrogen” value, it is equally important to evaluate the separate forms, as they can be indicative of specific sources of pollutants.

Table 4-2 shows the results of the wet weather nutrient loadings for each of the three major subbasins for the duration of the storm sampling period, and the load discharged from the Birches Dam outlet during the storm period. The highest phosphorus loading comes from the Back River area at the Gunderboom sampling site, as discussed earlier. This phosphorus load is pretty much equal to what is leaving the lake through the Birches Dam during the wet weather sampling period. The Back River upstream site at Bear Hill also shows relatively higher phosphorus loadings than the other sites, but is pretty consistent with the loading coming from the Gunderboom. Smaller loadings come from the other inlets. Overall, there is a slight net increase in total phosphorus loading in to the lake than what is exiting; no other locations appear to be a significant source of TP loading to the lake during this storm event.

Suspended solids loading into the water body show the highest loadings coming from the Lake Attitash subbasin. This would be expected based on the disproportionate amount of impervious surfaces (solids wash off pavement very well) surrounding the lake compared to the Back River drainage area or that of the Southwest Inlet, where wetlands naturally filter or settle out many of these coarser particulate materials. The lake subbasin discharge volume during this storm made up approximately 4% of the total runoff flow, but almost 50% of the suspended solids loading to the lake and 14% of the TP load. The suspended solids loading from upstream of Sargent’s farm at the Bear Hill road site and the Gunderboom are consistent and don’t reflect any anomalous loadings. The Southwest Inlet shows somewhat higher loadings which might be attributed to its direct hydraulic surface water connection to the lake and the large amount of coarse organic materials that move directly in to the lake from this wetland.

There is a significant net loss of suspended solids from within the lake through the Birches Dam outlet. This is likely attributable to some extent from the large amount of organic plant matter and algae being discharged from the lake during this time of year, as vegetative and wetland plants are dying off. Large amounts of plant material and algae were observed exiting the lake during the rain event.

Kjeldahl Nitrogen loading is highest at the Back River Gunderboom site followed by the Bear Hill road site, and then the Southwest Inlet. These sites are all dominated by wetland complexes and reflect nitrogen accumulations in close relation to the amount of suspended solids measured. Concentrations of TKN varied only slightly among all the sites and do not identify any excessive loadings of organic nitrogen. There is a net loss of organic nitrogen leaving the lake through the Birches Dam outlet.

Attitash Sub Watershed Wet Weather Loadings					
Site	**Estimated Runoff Volume (gallons)**	**Storm Event TP Loading (pounds)**	**Storm Event Total Suspended Solids (lbs)**	**Storm Event Total Kjeldahl Nitrogen (lbs)**	**Storm Event NO2/NO3 (lbs)**
Totals for Lake Attitash Subbasin Drains	303773	0.313	49.818	2.816	2.649
Southwest Inlet	1373273	0.421	30.191	14.201	18.673
Back River at Gunderboom	5092198	1.414	20.524	45.298	225.246
Sandy Beach	757483	0.139	ND	5.058	ND
Back River at Bear Hill Road	3667971	1.101	21.504	25.486	ND
Birches Dam Outlet	11712092	1.439	336.820	91.497	23.406

Table 4-2: **Individual subbasin wet weather loadings.**

Sampling of nitrite/nitrate nitrogen (NO3/NO2) revealed an interesting trend. Loading of this pollutant of concern at the Gunderboom site was more than ten times higher than any of the other site locations. Although flows are much higher in the Back River than at the other inflows and account for approximately 68% of the total inflow during this storm, the Back River at the Gunderboom site accounts for over 90% of the NO2/NO3 loading. The concentrations at this site were equal and in some instances greater than those concentrations found at the worst stormwater discharge sites in the lake subbasin. Upstream Back River samples of NO2/NO3 at the Bear Hill road crossing site were all below analytical detection limits. This indicates that the source of nitrates is coming from downstream of the Bear Hill road crossing and upstream of the Gunderboom site, or within the Back River segment that contains Sargent farm agricultural fields. Consistently high nitrate concentrations were found at this site even during the pre-storm sampling. Dry weather sampling on the Sargent farm property also revealed elevated levels of nitrates in the surface waters and from a tile drainage outlet on the property. The balance between outgoing nitrate nitrogen from the lake and that coming in off of the surrounding landscape show a significant net gain in nitrogen loading to the lake for this storm event.

It should be noted that the drinking water standard for nitrate is 10 mg/l, of which concentrations never got that high during the wet weather sampling event. However, concentration levels exceeding 0.3 mg/l can stimulate and support summer algal blooms (UMass Amherst water watch partnership). Wet weather concentrations ranged between four and six milligrams/liter throughout the storm sampling period.

4.2 Stormwater Discharge in the lake Attitash Subbasin

Loadings were calculated for all of the designated stormwater discharge sampling locations and compared to determine their relative loading contributions to the lake (Table 4-3). The 4th street discharge (SD05) had the largest volume of flow for this storm event, having twice the amount of flow as the next largest discharge site around the lake. It is located in a hilly area with lots of impervious surfaces, a first order stream, and some wooded areas. Total phosphorus loading at this site was less than one tenth of a pound. The total amount of phosphorus loadings from all of the stormwater discharges ended up being a little more than one third of a pound, approximately 22% of the entire storm event phosphorus load to the lake.

Lake Attitash Subbasin Wet Weather Loadings

Site	Estimated Runoff Volume (gallons)	Storm Event TP Loading (pounds)	Storm Event Total Suspended Solids (lbs)	Storm Event Total Kjeldahl Nitrogen (lbs)	Storm Event NO2/NO3 (lbs)
SD05 (4th Street)	101044	0.123	19.176	0.946	0.051
SD02 (Ahearn Circle-metal culvert)	47279	0.016	1.372	0.437	0.491
SD03 (Schaeppe Drain)	35150	0.018	1.244	0.361	ND
SD04 (1st Street)	30529	0.045	5.343	0.289	0.064
SD01 (Kurt's House)	25583	0.040	15.645	0.241	1.315
SD13 (#3 5th Street)	19147	0.013	0.085	0.133	0.085
SD21 (#62 Lake Attitash Road)	10890	0.018	0.809	0.082	0.575
CB1-2 (#3 Birch lane)	8276	0.008	1.416	0.051	0.009
SD10 (#82 Lake Attitash Road)	7991	0.010	1.565	0.101	ND
SD06 (Bauercrest)	7323	0.003	0.046	0.039	0.006
SD11 (#54 Lake Atttitash Road)	3304	0.007	1.862	0.048	0.007
SD02-B (Ahearn Circle-6" pipe)	2491	0.003	0.164	0.029	0.025
CB2-1 (#28 Birch Meadow)	2276	0.005	0.761	0.028	0.001
ATT ST (Attitash Street)	991	0.001	0.201	0.010	0.007
SD09 (Strathmere)	822	0.003	0.047	0.009	0.006
SD02-C (Ahearn Circle-4" pipe)	677	0.001	0.079	0.013	0.006
Totals	303773	0.313	49.818	2.816	2.649

Table 4-3: **Estimated loadings from Lake Attitash storm drains and outfalls.**

Total suspended solids analysis revealed that the greatest amount of flow resulted in the greatest amount of total suspended solids, again the 4th street discharge site, inputting a little over nineteen pounds of solids into the lake. The 4th street discharge has a catch basin located just “upstream” of the discharge outlet and it receives some very turbulent flow during storm runoff periods due to the steep terrain. Some improvements might be able to be made if flows could be slowed so that materials had more of an opportunity to settle out prior to the discharging to the lake. Overall, total suspended solids were low in the subbasin and demonstrate the efficiency and effectiveness of good stormwater controls and best management practices.

The next highest loading rate with almost sixteen pounds of solids was from site SD01 (vicinity of Kurt’s house). While this site had the second highest loading of solids to the lake, with only three pounds less than the 4th street discharge, it only had one quarter of the amount of flow volume. SD01 is a direct conduit storm drain from the street to the lake and has no storm mitigation measures presently in place. This is also an area of hilly terrain that has high flow runoff velocities which are then capable of carrying more suspended materials. There is a rain garden slated to be installed up gradient of this discharge, which should alleviate a good share of future contributions of solids to the lake. However, some type of catch basin prior to the rain garden would prove very beneficial. SD10 and SD11 show elevated TSS levels. These two locations appear to be driveway drains that drain runoff off the driveways through clay pipes that discharge into the lake. These two sites provide 4% of the runoff flow while providing 7% of the TSS load. Small driveway improvements could reduce this load further. CB1-2, the catch basin at #3 Birch Lane, also contributes a fair amount of TSS load compared to its flow volume. However, this sample was collected at the inflow point (along with CB2-1) to the catch basin so does not reflect the capture efficiency of the device or the true discharge load to the lake. The CB1-2 and CB2-1 sites were sampled at the catch basins/drain grates because the discharge outlets were all or partially submerged in the lake and representative samples could not be collected. These were considered important discharge sites and were still sampled, in part to get a relative sense of pollutants in these areas prior to entering BMPs, and as a measure to show the efficiency of the catch basins and retention ponds in the other areas around the lake. These samples were still included in the loading estimates as the difference in nutrient loading between the storm grate inflow and the lake discharge is minimal.

Total Kjeldahl Nitrogen levels follow right in sync with the amount of flow and the amount of TSS being contributed by each of these sites to the lake. The greatest flows have the greatest loading of TSS and the greatest loadings of TKN. The four highest loadings come from runoff areas that have woodlands or wetlands associated with them, a good source for organic material that is often rich in organic nitrogen.

The SD01 storm drain has by far the highest NO2/NO3 loading to the lake. SD01 contributes only 8% of the total flow from the entire storm drains combined, yet yields 50% of the NO2/NO3 loading from these discharges. This is one of the most densely populated areas around the lake. Nitrate sources could be from pet wastes, lawn fertilizers, and/or any leaking septic systems that might still be existing (it is thought that there are still a few houses not connected to public sewer. SD21 reveals the next highest loading rate, contributing 22% of the nitrate load but only 4% of the flow. This could be indicative of the same sources as for SD01. Ahearn Circle (metal culvert) is the last significant relative contributor, comprising 18% of the nitrate loading from the lake subbasin and comprising 16% of the stormwater flow.

Best management practices only work as well as they are maintained, and it appears that both towns of Merrimac and Amesbury do a very effective job at keeping the catch basins cleaned out regularly and maintained. One of the biggest problems in many areas is that these best management control structures are not maintained and their efficiency is reduced considerably if not attended to. Only a few storm drain discharge locations around the lake were indicative of problems besides the previously mentioned SD01 storm drain pipe, located in the vicinity of “Kurt’s house.” One was at Ahearn Circle, where a trench drain leading to a series of retention basins was clogged and water was naturally diverted to the lake rather than through the pollutant control structures. This has since been fixed, along with the diversion of a direct discharge pipe coming from the pond on West Shore Road. Another location is the retention basin at Bauercrest. This problem was only discovered after sampling, when it was found that there was no lag time between the first flush of the storm and the discharge time at the

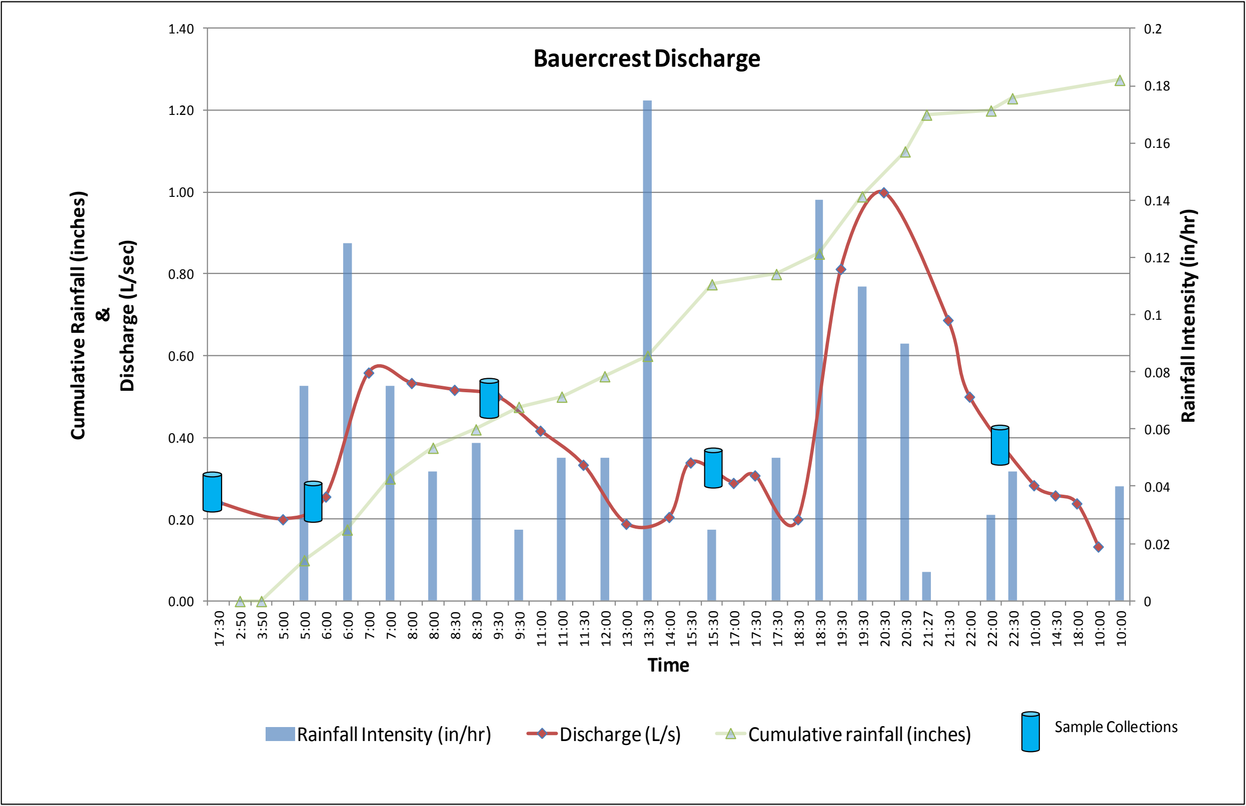


Figure 4-5: **Discharge volume follows very closely to rainfall intensity revealing that the catch basin is allowing rainwater to flow directly through the BMP, rather than "retaining" the flow long enough for suspended solids to settle out.**

retention basin outlet (Figure 4-5). This revealed that storm flows into the retention basin were not being held back, but instead stormwater was going directly through the system without there being time for materials to settle out before discharging to the lake. This particular BMP was also lacking a forebay, a critical design that ensures coarse particulates settle out prior to stormwater entering the larger basin area, where it can infiltrate into groundwater or be additionally filtered prior to entering the lake. Further observations revealed a large "sand bar" directly out into the lake from the discharge pipe. It appears that the retention basin filled in with coarse sediments quickly, possibly right after construction, up to the level of the "invert" discharge pipe, short circuiting the entire system (Figure 5-6). Despite the almost complete failure of this BMP, it should be noted that for this particular storm the catch basin captured 2.4% of the subbasin flow and around 1% or less of the TP, TSS, TKN, and NO2/NO3 load.

Figure 4-6: **Sediment and debris filled in to level of yellow invert cages, short circuiting the detention BMP**

Wet Weather Total Phosphorus							
Collection Date	10/26/2011	10/27/2011	10/27/2011	10/27/2011	10/27/2011		
Collection Time	1530	0515	0905	1550	2300		
Site	**Pre-Storm**	**1st Flush**	**Rising**	**Peak**	**Post Storm**	**Units**	**Notes**
GB (Gunderboom)	24	27	25	65	21	ug/l	
#21 (Bear Hill Road)	32	36	33	39	36	ug/l	
#4 (Birches Dam)	20	22	16	14	13	ug/l	
ATT ST (Attitash Street)			190	110		ug/l	Onlys 1st flush and rising collected
CB1-2 (#3 Birch lane)		140	120	100	63	ug/l	No pre-storm flow
CB2-1 (#28 Birch Meadow)		340	280	240	170	ug/l	No pre-storm flow
SD01 (Kurt's House)	46	520	260	120	22	ug/l	
SD02 (Ahearn Circle-metal culvert)	33	140	45	44	30	ug/l	
SD02-B (Ahearn Circle-6" pipe)		160		120	62	ug/l	No pre-storm flow
SD02-C (Ahearn Circle-4" pipe)		210	200	130		ug/l	No pre or post storm flow
SD03 (Schaeppe Drain)	39	58	72	70	41	ug/l	
SD04 (1st Street)	13	270	140	210	91	ug/l	
SD05 (4th Street)	18	250	170	190	120	ug/l	
SD06 (Bauercrest)		28	65	36	55	ug/l	No pre-storm flow
SD09 (Strathmere)		295	325	293	114	ug/l	No pre-storm flow
SD10 (#82 Lake Attitash Road)				210		ug/l	No pre or post storm flow (no analysis for 1st flush or rising)
SD11 (#54 Lake Atttitash Road)		460	430	220	120	ug/l	No pre-storm flow
SD13 (#3 5th Street)		300	170	75	52	ug/l	No pre-storm flow
SD21 (#62 Lake Attitash Road)		96	230	220	90	ug/l	No pre-storm flow
SW (Southwest Inlet)	43	22	17	16	15	ug/l	

Table 1-4: **Total phosphorus concentrations during the major stages of the wet weather event.**

Wet Weather Total Suspended Solids							
Collection Date	10/26/2011	10/27/2011	10/27/2011	10/27/2011	10/27/2011		
Collection Time	1530	0515	0905	1550	2300		
Site	**Pre-Storm**	**1st Flush**	**Rising**	**Peak**	**Post Storm**	**Units**	**Notes**
GB (Gunderboom)	ND	3.3	ND	ND	ND	mg/l	
#21 (Bear Hill Road)	ND	4.8	ND	ND	6.8	mg/l	
#4 (Birches Dam)	5	4.5	3.8	3.5	3	mg/l	
ATT ST (Attitash Street)			21	28		mg/l	No pre, 1st flush, or post collected
CB1-2 (#3 Birch lane)			7	24	10	mg/l	No pre-storm flow
CB2-1 (#28 Birch Meadow)			36	47	18	mg/l	No pre-storm flow
SD01 (Kurt's House)	6.4	63	140	35	8.8	mg/l	
SD02 (Ahearn Circle-metal culvert)	4.3	3.8	4.8	3.8	2.8	mg/l	
SD02-B (Ahearn Circle-6" pipe)		42		47	4.8	mg/l	No pre-storm or rising flow collected
SD02-C (Ahearn Circle-4" pipe)		26	27	9.5		mg/l	No pre or post storm flow
SD03 (Schaeppe Drain)	ND	ND	5	5	3	mg/l	no samples collected during wet weather?
SD04 (1st Street)	ND	42	24	25		mg/l	no post storm collected
SD05 (4th Street)	6.3	17	23	50	10	mg/l	
SD06 (Bauercrest)	6.3	3.7	3	ND	ND	mg/l	
SD09 (Strathmere)		10	2.5	ND	ND	mg/l	No pre-storm flow
SD10 (#82 Lake Attitash Road)		13	15	28		mg/l	No pre or post storm flow
SD11 (#54 Lake Atttitash Road)		29	55	77	30	mg/l	No pre-storm flow
SD13 (#3 5th Street)		5.7	13	27	6.3	mg/l	No pre-storm flow
SD21 (#62 Lake Attitash Road)		13	11	11	ND	mg/l	No pre-storm flow
SW (Southwest Inlet)	18	ND	ND	ND	ND	mg/l	

Table 4-5: **Total suspended solids concentrations during key stages of the wet weather event.**

Wet Weather Total Kjeldahl Nitrogen (TKN)							
Collection Date	10/26/2011	10/27/2011	10/27/2011	10/27/2011	10/27/2011		
Collection Time	1530	0515	0905	1550	2300		
Site	**Pre-Storm**	**1st Flush**	**Rising**	**Peak**	**Post Storm**	**Units**	**Notes**
GB (Gunderboom)	1	1.1	1.1	0.8	1.2	mg/L	
#21 (Bear Hill Road)	0.9	1	1	0.6	0.8	mg/L	
#4 (Birches Dam)	1.5	1.3	1.1	0.9	0.8	mg/L	
ATT ST (Attitash Street)			1.5	0.8		mg/L	No pre, 1st flush, or post collected
CB1-2 (#3 Birch lane)			1.00	0.80		mg/L	rising average of 2 samples (0.8, 1.2)
CB2-1 (#28 Birch Meadow)		2.7	1.5	1.4	1.5	mg/L	No pre-storm flow
SD01 (Kurt's House)	0.5	2.5	1.2	0.9	0.6	mg/L	
SD02 (Ahearn Circle-metal culvert)	1.5	1.3	0.9	0.8	1.4	mg/L	
SD02-B (Ahearn Circle-6" pipe)		1.50		0.90	1.00	mg/L	No pre-storm or rising flow collected
SD02-C (Ahearn Circle-4" pipe)		1.60		1.30	4.50	mg/L	No pre or post storm flow
SD03 (Schaeppe Drain)	1.4	1.1	1.5	0.9	1.3	mg/L	no samples collected during wet weather?
SD04 (1st Street)	1.1	1.8	1.8	0.8	1	mg/L	
SD05 (4th Street)	0.8	1.2	1.3	0.9	1.2	mg/L	
SD06 (Bauercrest)	0.7	0.6	0.7	ND	0.6	mg/L	
SD09 (Strathmere)		1.3	< 0.5	0.5	< 0.5	mg/L	No pre-storm flow
SD10 (#82 Lake Attitash Road)		2.20	2.3	1	1	mg/L	First Flush average of 1.9 and 2.5
SD11 (#54 Lake Atttitash Road)		3.5	2.4	1.4	1.3	mg/L	No pre-storm flow
SD13 (#3 5th Street)	0.6	1	0.9	0.9	0.7	mg/L	No pre-storm flow
SD21 (#62 Lake Attitash Road)				1.1	1.3	mg/L	No pre-storm flow
SW (Southwest Inlet)	1.8	1.4	1.4	0.8	1.6	mg/L	

Table 4-6: **Total Kjeldahl Nitrogen concentrations during key stages of the wet weather survey.**

Wet Weather Nitrate/Nitrite by Ion Chromatography							
Collection Date	10/26/2011	10/27/2011	10/27/2011	10/27/2011	10/27/2011		
Collection Time	1530	0515	0905	1550	2300		
Site	**Pre-Storm**	**1st Flush**	**Rising**	**Peak**	**Post Storm**	**Units**	**Notes**
GB (Gunderboom)	3.9	4.3	4.2	5.7	6.2	mg/L as N	
#21 (Bear Hill Road)	ND	ND	ND	ND	ND	mg/L as N	
#4 (Birches Dam)	ND	ND	ND	ND	0.58	mg/L as N	
ATT ST (Attitash Street)			0.9	0.7		mg/L as N	No pre, 1st flush, or post collected
CB1-2 (#3 Birch lane)		1.3	ND	ND	ND	mg/L as N	No pre-storm flow (1st Flush 1.0, Dup = 1.5)
CB2-1 (#28 Birch Meadow)		2	ND	ND	ND	mg/L as N	No pre-storm flow (1st Flush 2.5, Dup = 1.5)
SD01 (Kurt's House)	9.6	7.8	5.3	2.8	8.7	mg/L as N	
SD02 (Ahearn Circle-metal culvert)	0.97	0.69	ND	3.4	ND	mg/L as N	
SD02-B (Ahearn Circle-6" pipe)		1.3		1	1.5	mg/L as N	No pre-storm or rising flow collected
SD02-C (Ahearn Circle-4" pipe)		2.3	1.8	0.98		mg/L as N	No pre or post storm flow
SD03 (Schaeppe Drain)	ND	ND	ND	ND	ND	mg/L as N	no samples collected during wet weather?
SD04 (1st Street)	5.2	1.9	ND	ND	0.51	mg/L as N	post storm sample labled (SD04)
SD05 (4th Street)	0.54	0.77	0.58	ND	ND	mg/L as N	
SD06 (Bauercrest)		ND	0.45	ND	ND	mg/L as N	
SD09 (Strathmere)		1.4	ND	ND	ND	mg/L as N	No pre-storm flow
SD10 (#82 Lake Attitash Road)				ND		mg/L as N	No pre or post storm flow
SD11 (#54 Lake Atttitash Road)		1.4	0.52	ND	0.55	mg/L as N	No pre-storm flow
SD13 (#3 5th Street)	1.2	0.92	0.94	0.79	ND	mg/L as N	No pre-storm flow
SD21 (#62 Lake Atttitash Road)		10	5.9	5	7	mg/L as N	No pre-storm flow
SW (Southwest Inlet)	2.1	2.1	1.5	1.2	2.3	mg/L as N	

Table 4-7: **Nitrate/nitrite concentrations during key stages of the wet weather event.**

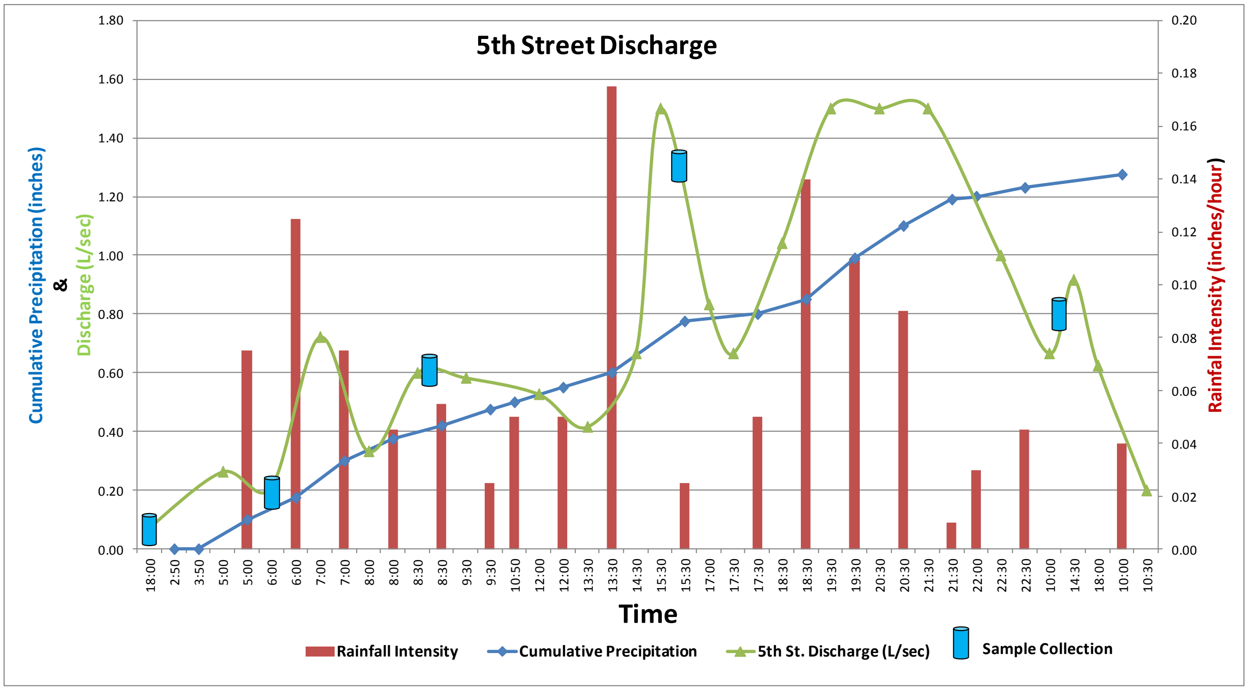


Figure 4-7: **Clay pipe that drains 5th street roadway. Straight through conveyance as discharge flow rate directly follows rain intensity.**

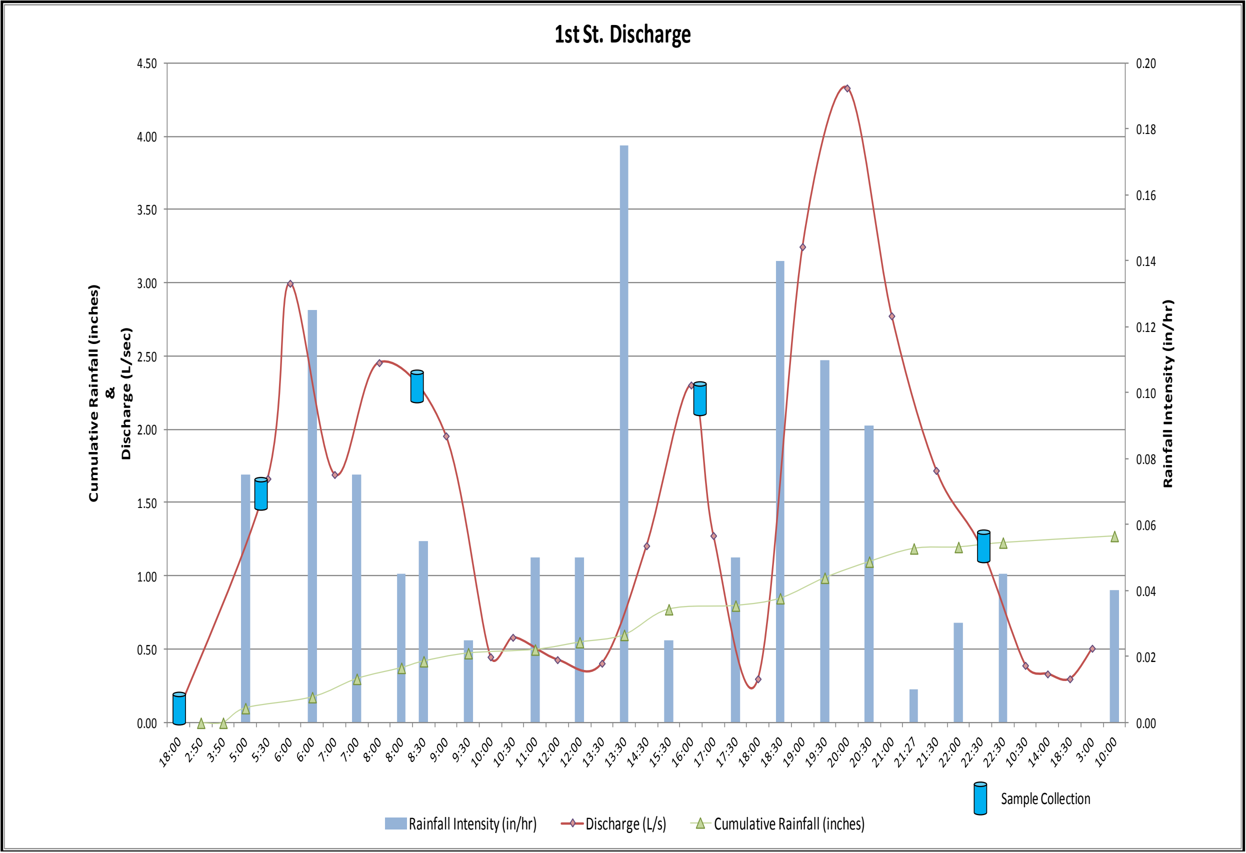


Figure 4-8: **A catch basin system which retains stormwater only for a brief period before discharging. Approximately a half hour lag time between rainfall and significant discharge.**

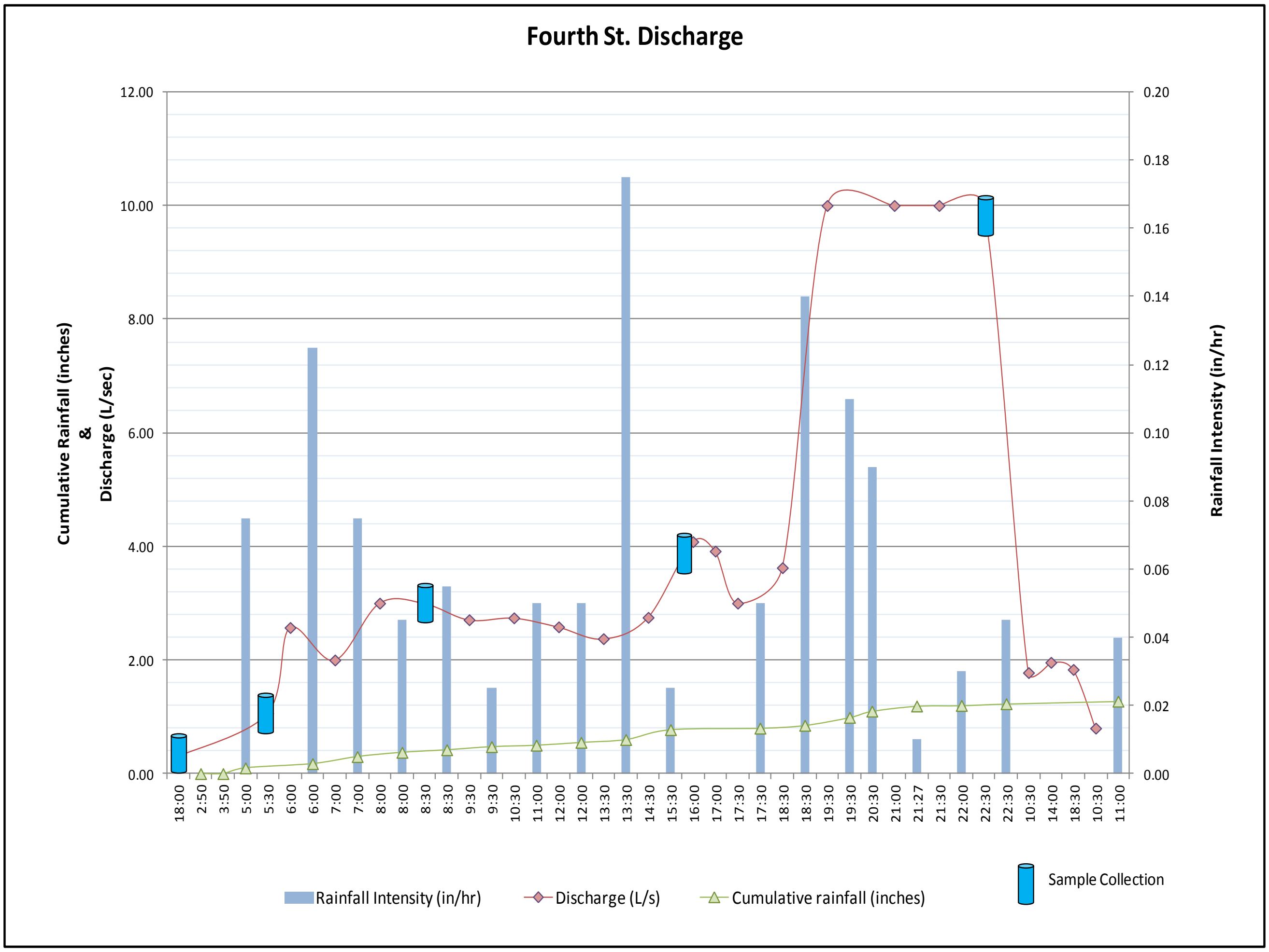


Figure 4-2: **Catch basin shows inital first flush and then flows remain fairly constant through two thirds of the storm duration, reflecting the rain intensity. Flow rate increase dramatically at the end of the storm due to ground saturation and baseflow contributions from the stream system.**

5.1 Lake Attitash Sediment

The earliest known records of sediments in Lake Attitash come from data collected in July of 1912 by the Massachusetts Division of Fisheries and Wildlife[1]. It was reported that the bottom sediments of the lake at that time consisted of mud and rock. Shoreline areas consisted of natural sandy and rocky areas, interspersed with varying depths of organic muck that was limited to small wetland marsh areas abutting the lake. Anthropogenic sources of sediment originated later from a common practice along the shorelines of seasonal cottages of adding “beach sand” and filling in of low lying areas, at that time considered “only good for mosquitos.” This practice continued long after these cottages were converted into year round residences. As an example, in 1950 over 30,000 cubic yards of gravel were brought in to fill in 7.5 acres of backwater area near the Birches Dam, covering 500 feet of lakefront which was accompanied by large quantities of beach sand to overly the gravel. Sandy beach on the eastern shore of the lake and the Merrimac public town beach also brought in large quantities of beach sand. In some cases, beach sand was hauled in and deposited on the ice in front of cottages during the winter months to provide beach areas in the summer (Buzzel, personal conversation).

Public and private beaches around the lake deposited these large quantities of sand through the years, and it was recommended as late as 1977 (Notini) that depositing beach sand was a viable lake management tool for controlling the growth of aquatic plants. It wasn’t until June of 2009 that the Amesbury Conservation Commission officially put an end to the practice in Lake Attitash. Other likely sources of early sediment inputs would have been from runoff from paved and unpaved roads, soil loss from agricultural areas and erosion from non-vegetated surfaces, and minor contributions from windblown dirt and debris.

More recently, other sediments began accumulating in the lake. Unlike the earlier contributions from mud, coarse sediments from mineralized rock, and beach sand, these newer materials are extremely fine organic materials originating from the seasonal senescence of aquatic plants and phytoplankton. Although there have always been a small amount present in the lake, the contribution has significantly increased over more recent years.

The major growth period for algae and aquatic plants is during the summer months, dying and settling to the lake bottom during the late fall and early winter. Bacteria and aquatic organisms consume these materials along with the available oxygen, and are the dominant process in the decomposition of organic materials in aquatic environments. Once deposited, these sediments can reveal a seasonal depositional record of aquatic plant/algae growth and can be very informative as to understanding the history of a lake and its watershed.

In 1978, the Massachusetts Department of Environmental Quality Engineering (MADEQE) collected a sediment dredge sample from the deep hole area of Lake Attitash and analyzed it for various heavy metals and nutrients. In 2005, three sediment core samples were collected by USEPA through the Back River area and three core samples were taken from the deep hole area of the lake. These samples were sectioned to analyze the more recently deposited top sediments and the older historically deposited bottommost sediments. These upper and lower sections were homogenized individually and analyzed for metals, pesticides, total organic carbon, and total phosphorus. In 2007, a single sediment core was taken from the deep hole area of the lake and incrementally dated through analysis of lead 210 (Pb-210) and Cesium 137 (Cs137) levels at one centimeter increments. In 2011, EPA again collected sediment samples, however this time utilizing the same approach that was used in 1978 by MADEQE (hand held dredge) and running analysis for the same parameters. The EPA 2011 dredge samples were taken from the deep hole area and the Northwest and Southwest quadrants of the lake (Figure 5-1). These samples were analyzed for various metals, total phosphorus, and total organic carbon.

Figure 5-1: **Locations of sediment core and dredge sample collections.**

Dredge samples are often taken in order to determine recent sediment deposition chemistry/history and to capture the sediment in immediate or close proximity to the overlying water column, since metals and nutrients can often be transferred across this sediment water interface and have the greatest potential impacts on water quality. Sediment core samples are often taken so that they can be sectioned with depth and analyzed. This sectioning can reveal a chronological record of depositional history, chemistry, and biology that can turn back the clock and give insights to water quality and landscape conditions from the present to pre-colonial times or much earlier.

Pb-210 is a natural radioactive form of lead found in soils and is associated with atmospheric fallout from the decay of radon gas in the atmosphere. Pb-210 should not be confused with “stable lead,” the lead that is deposited on the landscape from anthropogenic sources such as leaded gasoline, waste incinerator fallout, etc. Pb-210 is deposited on landscapes and water surfaces at a relatively constant rate in an area, where it mixes with materials and eventually settles out, such as at the bottom of Lake Attitash. The greatest concentrations of Pb-210 are found at the sediment water interface, where the newest sediments are deposited. With the half-life of Pb-210 being a little over 22 years, Pb-210 concentrations decrease (due to half-life decay) the deeper you go into the increasingly older sediments. This dating system is accurately measured back about one hundred years from the present, and is extrapolated for any earlier dating. Simplistically said, if the lake bottom sediments have been minimally disturbed, this steady decay rate allows you to establish a reasonably accurate time line for when the sediment at a certain depth was deposited, and the annual rate of sediment deposition. Figure 5-2 shows the calculated dates from the lead 210 dating in relation to sediment depths for Lake Attitash. The shaded areas represent the top and bottom sediment core depth intervals that were taken in 2005 for chemical analysis. Interesting to note, is that around 40cm (16 inches) deep in the deep hole sediment cores, the sediment starts transitioning from the dark organic material to lighter, mineral dominated sediments. This is a typical transition in lake sediments as one goes deeper down in the core and into the older sediments, although transition depths vary from lake to lake. Based on the depth at which this transition occurs in Lake Attitash and the Pb-210 dating, it appears to have taken place somewhere around the 1920’s to 1930’s. This finding reinforces the observation from the Massachusetts Fish and Wildlife 1912 report that the lake bottom was dominated by mud and rock at that time, and noticeable accumulations of organic material did not occur until later. Another finding that lends support to this is the occurrence of freshwater mussel shells found in the deep hole area, suggesting that at some point in more recent time this bottom area was well oxygenated with minimal organic material, making it suitable habitat for these invertebrates. The 1978 Notini report supports this, helping to establish a time frame after which organic sedimentation began to rapidly increase and subsequent anoxic conditions became manifested.

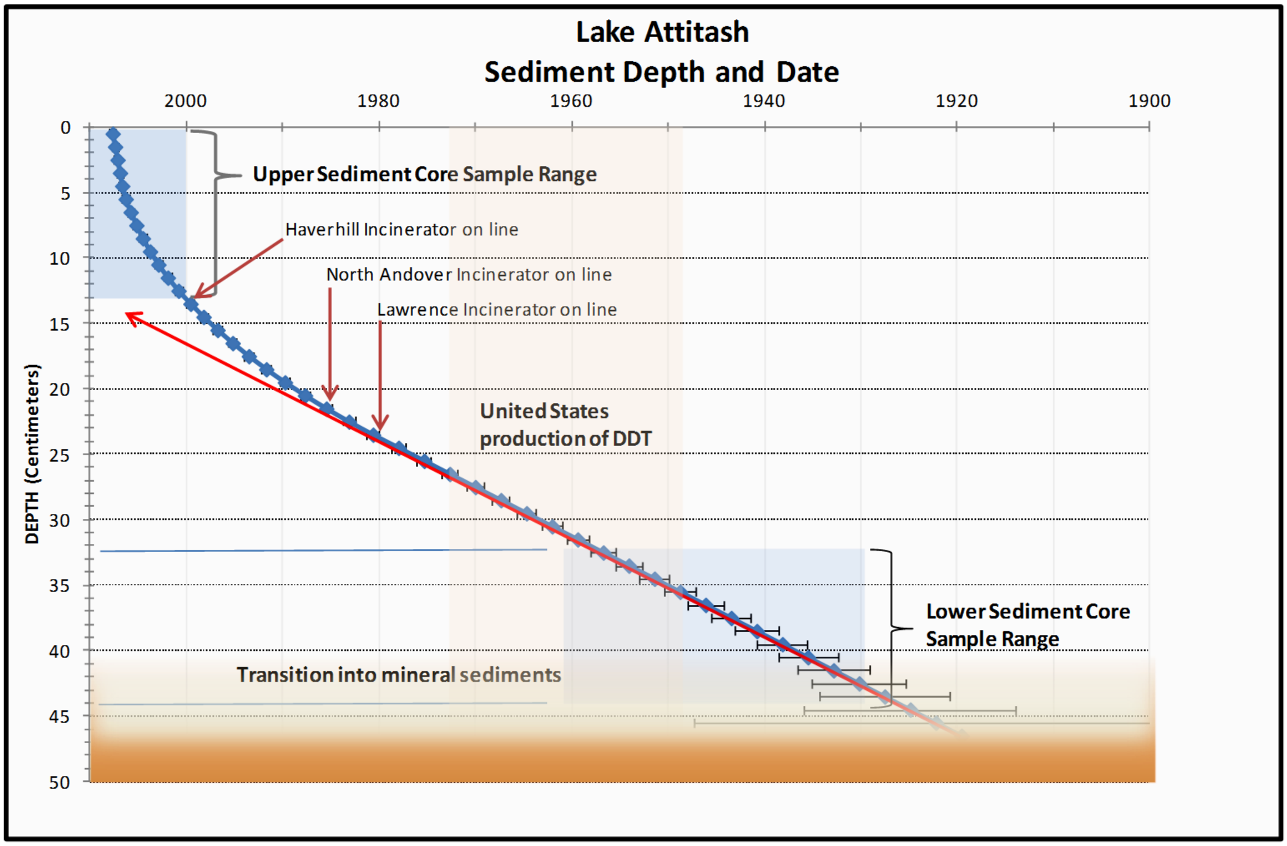


Figure 5-2: **Sediment deposition timeline showing key markers and acceleration of organic deposition rate.**

The Pb-210 dating reveals that the rate of organic deposition remains constant from the mineral transition area (around 40cm) up until around the early to mid-1980s, at which point a significant acceleration in the deposition rate occurs. Over half of the organic deposition (plant and algae growth) in Lake Attitash has occurred in the last thirty years. This noticeable change point will be addressed further in the document text.

Top sections of the sediment cores were taken from the sediment surface to a depth between 10 and 12 centimeters, and bottom sediment core sections were taken at 25 to 43 centimeters in depth. These core sections were then homogenized separately and analyzed for the various parameters stated above. Table 5-1 shows the list of parameters, the associated core depths and locations, and the accompanying results which are discussed below.

	Aug 3, 2005 Sectioned Deep Hole Core Samples						2005 Back River Core Samples			1978 Dredge Sample (3/9/78)	2011 Sediment Dredge Samples (August 22)				
Analytes (mg/Kg)	001A	001B	002A	002B	003A	003B	1	2	3	Deep Hole	SED 1 (Deep Hole)	Back River #1	SW Quadrant #2	NW Quadrant #3	Sed Gunderboom
Core Section Depth	(0-10 cm)	(33-43 cm)	(0-10 cm)	(31-43 cm)	(0-12 cm)	(25-37 cm)	(0-13 cm)	(0-13 cm)	(0-13 cm)						
Aluminum	14000	13000	15000	12000	14000	14000	8900	10000	9600		17000	13000	14000	13000	11000
Arsenic	27	ND	ND	ND	25	ND	ND	ND	ND		23	26	22	21	19
Barium	110	77	110	76	110	82	67	85	73						
Cadmium	ND	ND	ND	ND	ND	ND	ND	ND	ND		ND	1.4	1.3	1.5	ND
Calcium	5400	4500	5700	4300	5200	4800	5700	8300	7200		6000	4800	5600	5700	5900
Chromium	33	28	36	28	34	30	20	22	21	50	42	33	35	34	27
Copper	40	14	41	13	39	15	11	15	13	51	45	43	43	43	13
Iron	35000	20000	36000	19000	33000	22000	15000	17000	17000	47,000	34000	44000	33000	32000	26000
Manganese	880	430	810	430	700	460	560	920	670	740	1100	1200	1300	1600	1300
Lead	250	29	270	22	250	30	31	46	35	200	270	220	220	210	28
Zinc	220	68	240	66	220	72	76	100	87	220	240	210	210	210	87
TOC	145000	129000	169000	138000	151000	136000	154000	177000	185000						
Mercury	0.54	0.1	0.49	0.09	0.48	0.1	0.16	0.25	0.21						
Total Phosphorus	1700	830	1730	730	1630	770	500	790	660	1,100	1600	660	540	420	590
Total Kjeldahl-N										7,800					
4,4'-DDE (ug/Kg)	24	2	33	1.9	22	1.2	4.7	1.3	ND						
4,4'-DDD (ug/Kg)	19	ND	23	ND	16	ND	ND	4	ND						
4,4'-DDT (ug/Kg)	4.2	ND	3.8	ND	4.4	ND	ND	ND	ND						

***Table 5-1:* Concentrations reported out on a dry weight basis**

5.2 Iron

Iron is a common natural element found in the soils, sediments, and bedrock of New England and upon weathering and dissolution is readily taken up by aquatic plants as an essential nutrient. Iron can play a key role in lake systems by adsorbing certain metals and nutrients such as phosphorus under oxygen rich conditions, where it then precipitates out of the water column. Under reduced/anoxic conditions, Iron will return to a dissolved state, releasing these co-precipitates back into the water column. Analysis of the Attitash sediment samples for Iron show relatively consistent concentration levels between the upper core sections and the dredge samples. This makes sense since the depth of the dredge sample is very close to the depth that was taken for these upper core samples. Modest differences occur between the top and bottom core samples which could be attributable to differences in total organic carbon and mineral content between the top and bottom samples, minor differences in the sample collection depths, and the migration of iron in the sediment itself due to changing redox conditions. The concentrations at these depths however are consistent with Iron concentrations measured in other lakes and watershed soils in the are[2,3] and are representative of natural weathering processes in these lake systems. Other elements also indicative of natural weathering and depositional processes are Calcium and Aluminum. These elements show the same characteristics, remaining relatively constant in concentration throughout the sediment profile and are not indicative of any additional “non-natural” inputs in to the lake.

5.3 Lead

Prior to the 1950s, a dominant use of lead in New England which promoted environmental problems was its combination with Arsenic to make a pesticide called lead arsenate. Lead Arsenate was heavily used in New England orchards where fruit trees were literally drenched with these chemicals. Ingestion or inhalation of lead particulates in sufficient quantities and over varied periods of exposure can cause toxicity in many of the body organs, damage neurological development, and promote learning and behavioral disorders. Young children are particularly susceptible to neurological impairments. A 2007 research study revealed a high correlation between childhood lead exposure and later crime rates[4]. While Arsenic is very soluble and easily migrates through the soils and into groundwater, Lead is predominantly insoluble and binds well with the soil and sediments. Many orchards operating during this time period still have high lead concentrations in their soils today.

Another anthropogenic source of lead leading to environmental problems was its use in gasoline. Originally formulated in the 1920s (and known to be a significant human health hazard even at that time), its heaviest use was from 1950 through 2000. In 1979, U.S. automobiles released over 208 million pounds of lead into the atmosphere. By 1989, restrictions by the EPA on lead use reduced lead emissions to less than five million pounds nationwide. It was finally banned for use in highway transportation in 1996[5].

Small lead particles from exhaust emissions can travel long distances once they enter the atmosphere, falling back to the landscape attached to dust particles or incorporated in rainfall. Some of the lead deposited on the landscape finds its way into waterbodies through surface runoff, while the major pathway is directly from atmospheric deposition.

Another large source of lead in the environment (along with Zinc, Cadmium, Chromium, Mercury, Barium, Manganese, Copper, and Arsenic) is from the incineration of medical and domestic wastes. The combustion of these waste materials sends small ash particulates and flue gases up through the stack where they are carried by prevailing winds and are eventually deposited on the landscape. Three municipal waste incinerators and one medical waste incinerator were erected in the Merrimac Valley in the 1980s. The Ogden Mills, Lawrence incinerator was constructed in 1980, the North East Solid Waste Committee (NESWC), North Andover incinerator in 1985, and the Ogden Mills, Haverhill incinerator in 1989. These facilities operated for a period of almost ten years with limited emissions controls on their exhaust stacks. Lead concentrations (and other metals constituents of waste incineration) in the deep hole area and other locations around the lake show an increase in concentration levels since the 1978 Notini survey, reflecting deposition from the newly operating incinerators in the valley. The sediment lead concentrations from the 1978 dredge sample are elevated above background levels, but less than the 2011 dredge samples, reflecting anthropogenic inputs prior to incinerator emissions, with one of the most likely inputs being leaded gasoline sources. Deeper sediment core lead levels are comparatively quite low, and likely reflect conditions from historic regional emissions (ie. factories) sources prior to more localized impacts. Additional sources of lead would come from automobile exhaust from the construction and use of Interstate-495, completed through the town of Merrimac around 1965, and emissions from two cycle boat motor use after the construction of the Attitash public boat ramp around 1974, greatly intensifying motorboat use on the lake. This increase of lead from pre-existing historical conditions is represented in the 1978 sediment sample collected by MADEP, showing the increasing trend in lead deposition within the lake, prior to waste incinerator construction.

5.4 Mercury

Different forms of Mercury are a common by-product of waste incinerators and coal fired power plants, and the Haverhill area was identified as a localized hot spot for mercury from local sources (incinerators) since the 1990s. In 1990 a moratorium was placed on new municipal solid waste facilities and tough state emissions regulations came in to effect in the late 1990s. By the year 2000, these facilities were required to install state of the art scrubbers and filters. Along with dominant local sources, the New England region has been prone to mercury issues for more than two decades due to prevailing winds carrying power plant emissions from the Midwest and depositing these materials on the New England landscape. Once deposited into waterbodies, inorganic mercury is converted by certain bacteria into an acutely toxic form called methyl mercury, where it is readily taken up by biota and begins to accumulate in the organisms tissues. Waters particularly susceptible to this methylation process are usually high in organic material and low in pH, such as marsh and wetland areas. Methylated mercury is known as an acute neurotoxin and as an endocrine disrupter, and has had significant effects on pisciverous birds, such as common loons, and other top level aquatic predators in New England. As organisms are consumed by others further up the food chain, the mercury concentrations become increasingly magnified and can cause significant ecological and human health problems. Fish advisories have been posted throughout the region in an effort to limit human consumption of fish in specific waterbodies, including Lake Attitash. Top of the food chain freshwater species such as largemouth bass and pickerel typically have some of the highest mercury concentrations. Since the stricter state regulations and moratorium, Mercury levels in Lake Attitash fish tissue have fallen dramatically (Section 6 - Fish). However, in 2012 the state incinerator moratorium was lifted as part of a revised master plan.

The Lake Attitash sediment core sections show distinct differences in mercury sediment concentrations between the upper and lower sections in the deep hole area, again reflecting the influence from more recent local emissions sources compared to historical background concentrations. The Back River sediment mercury concentrations are similar to the bottom sediment core concentrations from the deep hole. This is likely due to the Back River being a seasonally dynamic fluvial system, and “flushing” these materials into the main body of the lake during spring snow melts and significant rainfall runoff events.

The National Oceanic and Atmospheric Administration (NOAA) publishes Screening Quick Reference Tables to assist in characterizing sediment that harbors various organic and inorganic contaminants (NOAA.gov). These screening levels have been established to identify contaminant concentration levels found in freshwater and marine sediments that could potentially incur harmful effects on aquatic life and the environment, and to help guide decisions on cleanup efforts, such as at hazardous waste sites. The concentrations found in the upper core sections at the deep hole are well above some of the National Oceanic and Atmospheric Administration’s (NOAA) screening levels for freshwater sediments[6]. The lower deep hole sediment core concentrations and the top core sections from the Back River area also reflect concentration levels that are near or slightly above some of these screening levels. Although these NOAA published concentrations are to be utilized for screening purposes only, they do reflect a consensus (averaged values) among the scientific literature that these levels have demonstrated detrimental effects on aquatic life. Almost all of the metals and pesticides found in Lake Attitash are above at least some of these screening criteria levels.

5.5 Pesticides

In addition to the screening analysis of the sediments for metals, a pesticide screen was incorporated for DDT and its degradation products. DDT, otherwise known as Dichlorodiphenyltrichloroethane, is another reasonably good marker for establishing a time frame for sediment deposition and is found in the upper sediments of the Lake Attitash core samples. Agricultural and commercial use of DDT pesticides started in the late 1940s and continued with approximately 25 years of production and 675,000 tons applied domestically during this time period[7]. Peak usage year was 1959 with 40,000 tons applied nationally. United States production for domestic markets ended in December of 1972, but the U.S. continued to manufacture DDT for foreign markets until around 1985, although it was still heavily used domestically long after production ceased. DDT is extremely persistent in aquatic environments, as it is a hydrophobic and lipophilic compound; it is very insoluble in water, but very soluble in fats and readily taken up by aquatic organisms. A 2005 survey by EPA of Lake Attitash fish tissue (See Section 6 - Fish) showed low level concentrations of DDT degradation products (and polychlorinated biphenyls) in sampled yellow perch, largemouth bass, and eastern chain pickerel. DDT persists in aquatic environments and can be easily taken up and accumulated in plants and the fatty tissues of animals. Because of DDT's widespread industrial and domestic use and its slow rate of degradation, it still is ubiquitous in the environment.

From an environmental standpoint, DDT is probably best known for being the causative link in thinning of the eggshells in the bald eagle (although its degradation product, DDE, is actually the causative agent) resulting in the population declining to near extinction in the seventies. Forty years after DDT production has ceased, it can still be found in its non-degraded form in the upper sediments of Lake Attitash. DDT and its degradation products of DDD (Dichlorodiphenyldichloroethylene) and DDE (Dichlorodiphenyldichloroethane) in Lake Attitash are all above the Probable Effects Screening Levels (PEL – Canadian Sediment Quality Guidelines-SQUIRT) considered having an impact on aquatic life.

Based on the Pb-210 dating for the lake where the sediment cores were taken, and the history of its use and production, it is possible that higher DDT concentrations might be found within the mid ranges of the sediment core depths (area where the sediments were not analyzed), which was during the time period where higher use and production would tend to be located (Figure 5-2). The upper sediments display greater DDT/DDE/DDD concentrations than the deeper cores, possibly a result of continued domestic use of the product and the subsequent washing off the landscape into the water body long after production ceased. The bottom core sample displays much lower concentrations due to the fact that much of this sediment core section was deposited before production of the pesticide began.

5.6 Phosphorus

Phosphorus in sediments and lake water play a major role in the water quality conditions found in a lake and are often the focus of lake management efforts in the control of nuisance aquatic plants and/or harmful algal blooms. The deep hole top core samples from 2005 and the deep hole dredge sample from 2011 reflect the highest concentrations of Total Phosphorus (TP) in the lake. Comparing the deep hole dredge sample taken in 1978 with the 2011 deep hole dredge and top deep hole core samples, it appears that deep hole TP concentrations may be increasing. The lake was not anoxic in this vicinity in 1978 where it now is, and the 2011 sample was taken at the time of year when this area was under reduced conditions. This likely accounts for at least some of the increases in phosphorus concentration due to upward migration in the sediment and the chronic seasonal deposition of phytoplankton and associated organic phosphorus. Dredge samples analyzed for Phosphorus are slightly higher in the Back River area compared to other areas of the lake outside of the deep hole, but fairly uniform in relative concentrations around the lake. These dredge samples are also very similar in concentration levels to the bottom sediment core sections from the deep hole and indicate that TP levels may have been elevated historically, at least through the period of organic deposition from the early 1900s onward.

The amount of Phosphorus presently residing in the lake was estimated using the data from a bathymetric survey that EPA completed on Lake Attitash using newly acquired hydroacoustic equipment and software. This technology was utilized with geographic information system (GIS) software to develop reasonably accurate estimates of the lakes depth of organic material and sediment volume (Figure 5-4). Comparison of bathymetry transects with one another across the lake yielded similar results, with the depth of the organic sediments consistently being close to one half meter in thickness. This corresponds well with the actual sediment cores that show the organic sediment to mineral sediment transition starting just shy of a half meter in depth (40-45cm).

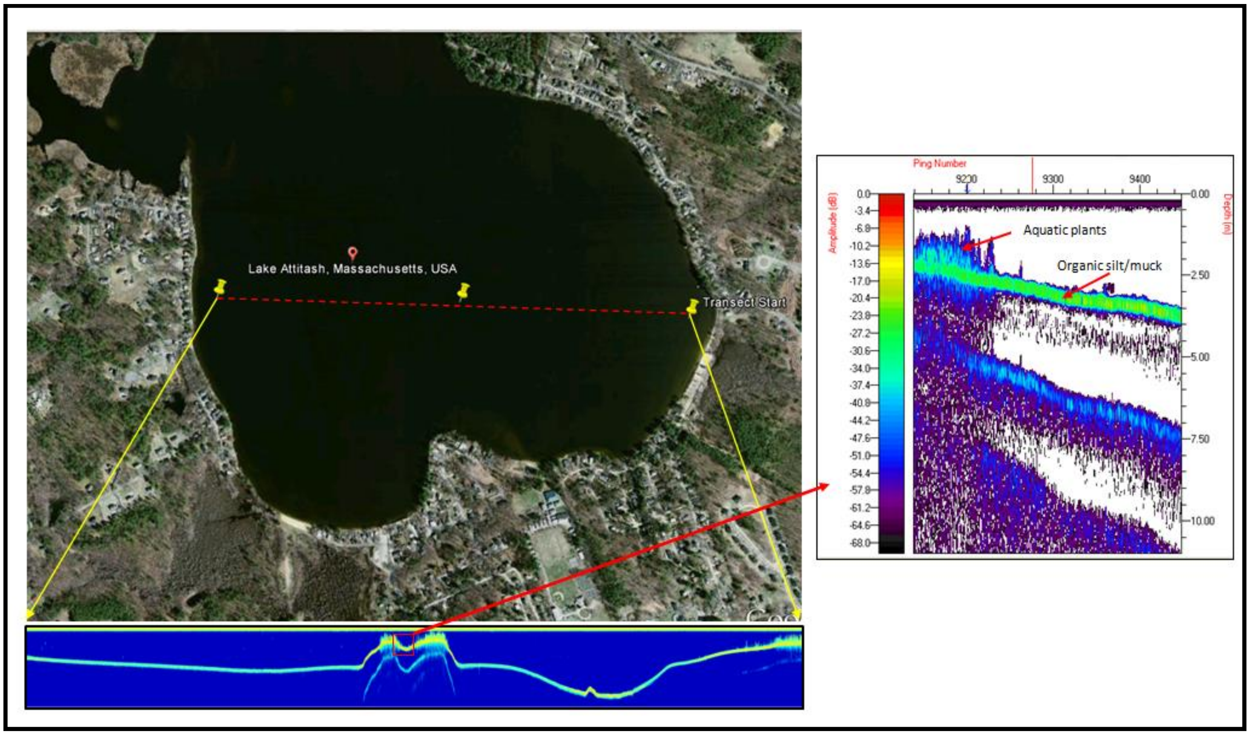


Figure 5-4: **Lake transect depicting cross sectional bottom profile of lake (not to scale). The inset shows a transect section indetail, delineating submerged aquatic plants and the depths of the organic sediments. As in most cases, organic sediment thicknesses are approximately half a meter.**

Laboratory analysis of the lake Attitash sediments reveal that on average these sediments are made up of approximately 10% water by weight. Of the remaining 90% (by weight), approximately 30% of the top sediments and 22% of the bottom sediments are made up of organic material, predominantly from aquatic plants and phytoplankton. The remaining percentage (70-78%) is made up of inorganic materials comprised almost entirely of silicate diatoms (Figure 5-5). When looking at this sediment material on a dry volume instead of weight basis, the organic plant materials in the sediments make up over 80% of the sediment volume (but only 20-30% of the weight).

Utilizing the averaged dredge sample phosphorus concentrations (a more conservative estimate) and the GIS calculated volume of organic lake sediments (approximately 600,000 cubic meters) as determined by the bathymetry survey work, a reasonable estimate of sediment in-lake Total Phosphorus appears to be around 330 tons. This represents an enormous reservoir quantity of potentially available phosphorus to fuel aquatic plant growth and

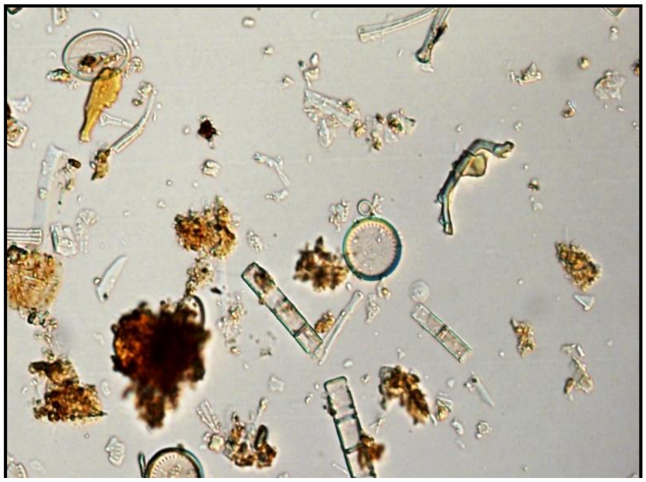


Figure 5-5: **Silicate diatoms from Lake Attitash sediments (photo courtesy UNH Center for Freshwater Biology)**

proliferation, as well as promote development of harmful algal blooms. Based on estimated year round outflows from the lake and current lake management practices, removing phosphorus to reasonable background levels that would limit aquatic plant growth and HABs would take many many years. In the lake's current state, this represents a significant challenge for managing nuisance aquatic plants and preventing harmful algal blooms.

As it presently appears, outflows from the lake other than during rain events do not occur during the summer months, with water loss from lake evaporation and possible groundwater outflows often outstripping groundwater inflows to the lake. This severely limits any potential in-lake phosphorus removal during the summer periods when phosphorus can become mobilized from the sediments and potentially "flushed" out of the lake.

The CDM report commented that at the time of the Notini survey, there was an estimated 350 year round homes on septic. It was estimated that this number of homes (at 15mg/l phosphorus in the effluent-CDM literature search) could have contributed as much as 3,000 pounds per year of phosphorus to the lake. Based on this loading estimate from septic and on the amount of Phosphorus presently residing in the lake sediments, it would take that same number of homes 220 years to put that amount of phosphorus in to the lake. It is readily apparent based on these numbers that the majority of in-lake phosphorus was contributed by other sources.

Many factors go into interpreting sediment samples, and by no means does this provide an exhaustive investigation. It does however, identify some definitive markers from human pollutant activities that help to characterize these sediments from a human and aquatic health perspective, and establish a reasonable timeline on their deposition. The results found and summarily explained in this document are also very consistent with a more detailed sediment survey completed by MassDEP and Boston University on sediments in Lake Cochichewick located in North Andover, directly downwind of the Haverhill waste incinerator[2].

More explanations to the timelines and possibly other contaminant sources for these analytes could likely be gleaned from sediment samples that were analyzed at more discrete (i.e. 1cm) increments, representing a more refined depositional history of contaminants. Other factors such as sediment grain size, percentages of organic materials in the sediments, seasonality of sample collection, heterogeneity, pore water analysis, and redox conditions play important roles in understanding sediment deposition and its constituents as well as having an effect on metals and nutrient concentrations. It should be noted again that almost all of the metals and the organic pesticides sampled from Lake Attitash are above at least some of the preliminary threshold screening criteria levels put forth by the National Oceanic and Atmospheric Administration (NOAA). The sediment sampling for Total Phosphorus also reveals the enormous quantity of in-lake Phosphorus that is potentially available for plant and algal uptake, and the potential challenges that wait in nutrient and plant management for this waterbody.

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6.1 Lake Attitash Fish

Fish have long been identified as reasonably good markers of environmental problems. Many contaminants deposited or applied on the landscape eventually find their way into water bodies where they are taken up in the tissues of the organisms residing in them, usually through food chain pathways. Since fish are relatively long term residents of lakes and are at the top of the food chain, they have the unfortunate ability to accumulate and concentrate contaminants over time, even if these contaminants occur at low concentrations. One such contaminant that has been of principal concern regarding its effects on aquatic systems over the last few decades has been mercury.

The Merrimac valley has long been known as a hotspot in the region for mercury deposition from local emissions sources, and mercury has long been a major constituent of emission gases from fossil fuel and waste to energy plants where it is deposited on the landscape and eventually washed into water bodies. Once in the aquatic system, it is transformed by bacteria and microorganisms into a detrimental form that has been harmful to human health and wildlife. Mortality has been shown to be high in pisciverous birds such as the common loon and mallard duck, which feed upon small fish and aquatic invertebrates, and more recently investigators are finding it may have an even greater impact on terrestrial organisms. Mercury may also manifest itself in biota resulting in sublethal effects, such as reduced fecundity or impaired cognitive and motor skills[1,2].

In 2005, the USEPA was piloting non-lethal methods in the region for testing mercury concentrations in fish muscle tissue through the use of biopsy plugs. Small tissue samples could be taken from fish easily without inducing mortality, and the fish could be returned to the water body. This has proven to be an effective approach without having to sacrifice popular and prized game fish for the sake of minute volumes of fish tissue necessary for mercury analysis (Figure 6-1).

Figure 6-1: **Extracting a tissue sample from a Lake Attiash Largemouth Bass**

The fish species selected for the pilot consisted of two top of the food chain pisciverous predators, eastern chain pickerel (*Esox Niger*) and largemouth bass (*Micropterus salmoides*). The third species selected was a “generalist feeder” yellow perch (*Perca flavescens*). These species are commonly collected because they are target species for recreational fishing, are often caught for human consumption, and are the most likely to bioaccumulate mercury and other toxins as they consume other species further down the food chain.

Some fish were taken during 2005 to look at other contaminants that may be moving through the food chain. This included a suite of pesticides, polychlorinated biphenols, commonly known as PCB's, which were used in certain pesticides and electrical transformers (production ceased in 1979), and the pesticide DDT and its degradation products. Results in Table 6-1 show that the pesticide dibutyl chlorendate (an agricultural chemical and herbicide), the PCB Decachlorobiphenol, and the DDT degradation product DDE, were found at trace levels in most of the fish tissues that were analyzed. Total mercury was found in all analyzed fish tissue.

Fish Species	Mercury (ug/g)	Pesticides (ug/kg)		
	Total Hg	Dibutyl Chlorendate	Decachlorobiphenyl	4,4' - DDE
Eastern Chain Pickerel 001	0.269	16.5	13.04	4.18
Eastern Chain Pickerel 003	0.18	14.3	12.78	4.2
Eastern Chain Pickerel 004	0.206	15.4	12.14	3.04
Eastern Chain Pickerel 005	0.182	15.6	11.8	*
Eastern Chain Pickerel 006	0.159	14.6	13.74	*
Yellow Perch 002	0.27	15	12.22	*
Yellow Perch 007	0.115	NR	NR	NR
Yellow Perch 008	0.104	14.7	11.54	3.1
Yellow Perch 009	0.137	NR	NR	NR
Yellow Perch 010	0.105	NR	NR	NR
Yellow Perch 014	0.164	NR	NR	NR
Yellow Perch 015	0.137	NR	NR	NR
Yellow Perch 016	0.189	NR	NR	NR
Yellow Perch 017	0.187	NR	NR	NR
Yellow Perch 018	0.18	NR	NR	NR
Yellow Perch 019	0.171	NR	NR	NR
Yellow Perch 020	0.116	NR	NR	NR
Largemouth Bass 040	0.692	16	13.04	*
Largemouth Bass 041	NR	15.2	10.80	*
Largemouth Bass 042	0.309	14.5	11.68	*
Largemouth Bass 043	0.191	14.2	13.32	2.82
NR= not run. * Level under detection limit.				

Table 6-1: **2005 Fish tissue contaminant concentrations**

Most of these chemicals are found to be very persistent in the environment, still residing in sediments due to their extremely slow degradation rates, and entering the food chain long after being banned from production (because of their known environmental and human health impacts). The one exception to this has been mercury, which has shown a dramatic drop in yellow perch and largemouth bass (the two species analyzed by MADEP) over an eleven year time span Figure 6-2. The Federal Food and Drug Administration has used an advisory level for fish consumption of one part per million (1 microgram of mercury/gram of fish tissue) and Massachusetts has used an advisory level of half that. This dramatic reduction of mercury concentrations in fish tissues is due to a 91% drop in mercury air emissions across Massachusetts since the mid-1990s, a direct result of state and federal clean air act regulations and regulatory oversight[3]. This clean air success story has directly benefitted the aquatic environment by drastically reducing the deposition of power plant mercury emissions onto the landscape that eventually wash into the water bodies. Health benefits are not only attained for the fish themselves, but also for the humans that like to catch and consume them, and the pisciverous birds such as eagles, ospreys, and the common loon that rely on them as their principal food source for survival.

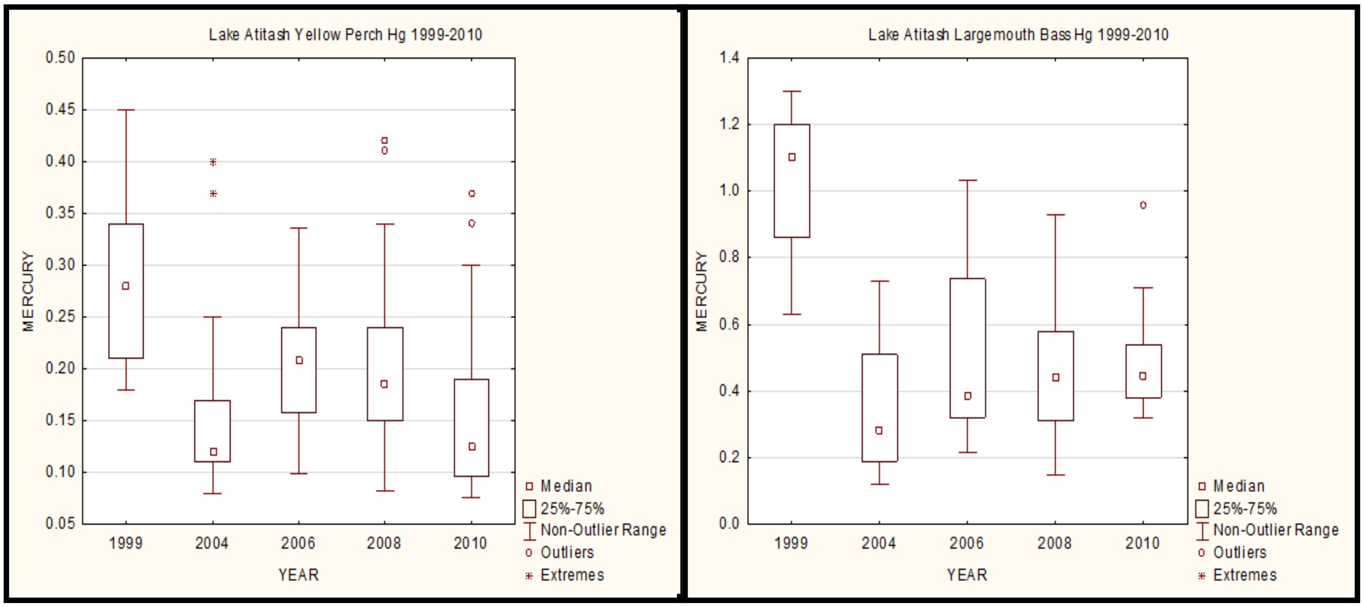

Figure 6-2: **Yellow perch and largemouth bass mercury tissue concentrations from 1999 through 2010 (Mg/Kg). (Mercury tissue data provided courtesy of MADEP Office of research & Standards)**

Fish populations and population dynamics can affect the water quality and overall condition of a lake. An ecologically balanced lake, from a fisheries standpoint, will have a good ratio of predator fish (ie. Largemouth bass, pickerel) to prey/forage species. When a lake becomes imbalanced, such as from over fishing with removal of top of the food chain predators, the lake may become overpopulated with forage species. Many forage species and juveniles are planktivorous in nature, feeding on the zooplankton of the lake which subsequently leads to a lack of zooplankton to feed upon the phytoplankton, causing the phytoplankton to become overly abundant. This imbalance is commonly known as a “trophic cascade.” [4] The trophic interactions are more complex than this basic explanation, but research has found that changes in top predator fish populations has had significant effects on prey species and the overall ecology of a lake.

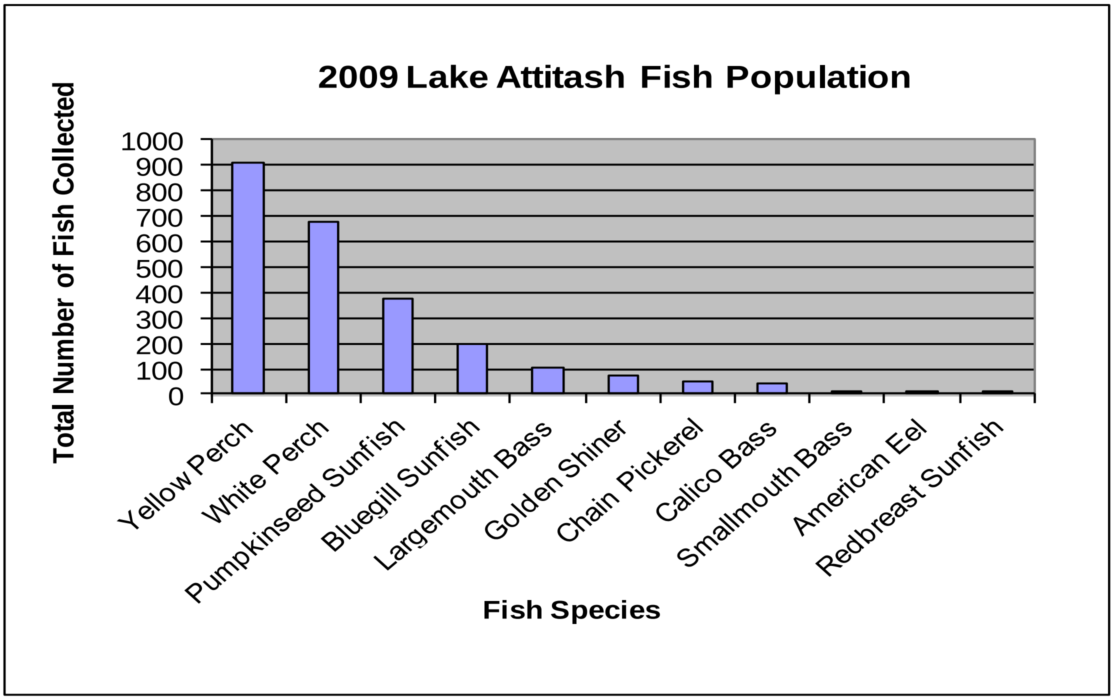

Figure 6-4: **Relative abundance of fish species captured during electrofishing survey**

Since this trophic cascade condition was initially somewhat suspect as one cause of problems in Lake Attitash, the EPA undertook a cursory fisheries assessment of the lake. The objective was not to initiate a fish population survey of the lake or an in depth trophic level assessment, either of which is a significant and time consuming undertaking, but more to get an idea of the relative abundance of fish species in the water body and a cursory idea of the size and distribution of top level predators and forage fish species. A heavily weighted forage species population coexisting with a depauperate predator population could potentially be indicative of an imbalanced trophic system. Night time electrofishing efforts took place in late May of 2009 and consisted of five transects of approximately fifteen minutes of actual shock time, each spaced at a relatively uniform distance from the shore in water approximately three to eight feet in depth. It should be noted that electrofishing approaches for fish capture are somewhat selective.

Figure 6-3: **May 2009 Electrofishing Transect Locations**

Bottom feeding fish such as bullhead and eel are often under represented as they do not come off the bottom when stunned so are not picked up by the netting crew as often as fish that reside in the water column. Other species, such as the Killifish and young of year of other species, may also be under represented due to preferred habitat/refuge being far up in the shallows or in aquatic plant beds.

Figure 6-4 shows the distribution of fish species from this effort. Over the course of a little under three hours of fishing time, 2,444 fish were caught with a catch rate of fifteen fish per minute. Yellow perch were the most abundant fish caught. The primary food source of juvenile yellow perch is zooplankton, switching to macroinvertebrates and juvenile fish as they mature. They are not a preferred prey species of largemouth bass due to their spiny fin rays as compared to softer rayed fish such as bluegills and various minnows.

White perch were the second most abundant species caught. These fish are actually a member of the temperate bass family rather than perch, as the name implies. These fish are also planktivorous as juveniles and upon maturing to adults convert more to a fish diet favoring yellow and white perch (Scott & Crossman). White perch are a prolific species, partly due to an extended spawning period and the large egg production for a fish of this size. These fish thrive in warmer waters.

More work would need to be done to determine if a trophic cascade is actually taking place within the lake and if it is being stripped of its primary grazers of phytoplankton due to a lack of top level predators and the overabundance of forage species. Considering the now known extent of other nutrient based issues in the waterbody, it is more likely that these other stressors are playing a much bigger part in the continuing eutrophication issues of the lake, masking any effects that may be occurring from the lack of zooplankton grazing. However, other signs of ecological stresses in the fish community have emerged including bacterial infections (suspected Columnaris) identified by fragmented and frayed fins, fin erosion, gill discolorations, and skin ulcerations. Internal anomalies were not investigated. Fish are more susceptible to infections when they are under stress or in crowded conditions.

Fish kills have also occurred in the past (first documented in August, 1978), but usually as a single species die off, such as bluegills. This is usually indicative of a species specific stressor, or a stressor that may affect a particular species at a vulnerable time, such as during the spawning period when they are already under duress. Multi species fish kills are more indicative of a toxicant or widespread stressor that impacts not only vulnerable species, but those that prior to, were in relatively healthy condition. Causes may stem from lack of dissolved oxygen levels during ice over conditions causing winter kill, or overly warm water temperatures whereby higher dissolved oxygen concentrations cannot be maintained. Although fish kills are often considered a natural

Figure 6-5: **Ulcerations, eroded and split fins on Lake Attitash Eastern Chain Pickerel**

occurrence, they often occur where there is an overpopulated fishery, or in lakes and ponds that naturally would not have fish due to their being uninhabitable because of ice over low dissolved oxygen conditions, high summer temperatures, or other naturally occurring stressors. A fishery may survive several years until an abnormally cold winter creates the heavy ice cover that eventually does in the fish. Stocked ponds and small shallow lakes often run into these sorts of problems in colder climates.

The 1978 Notini report listed that the lake has been stocked since as early as 1949 with smallmouth bass, bluegills, hornpout, white and yellow perch, pickerel, and crappies. In the early 1990's northern pike were introduced into the lake as a top predator species. EPA has captured a few during other electrofishing activities in the lake, and these were found to be in poor condition. Only one smallmouth bass was captured during the EPA 2009 survey. One species, the banded killifish, was

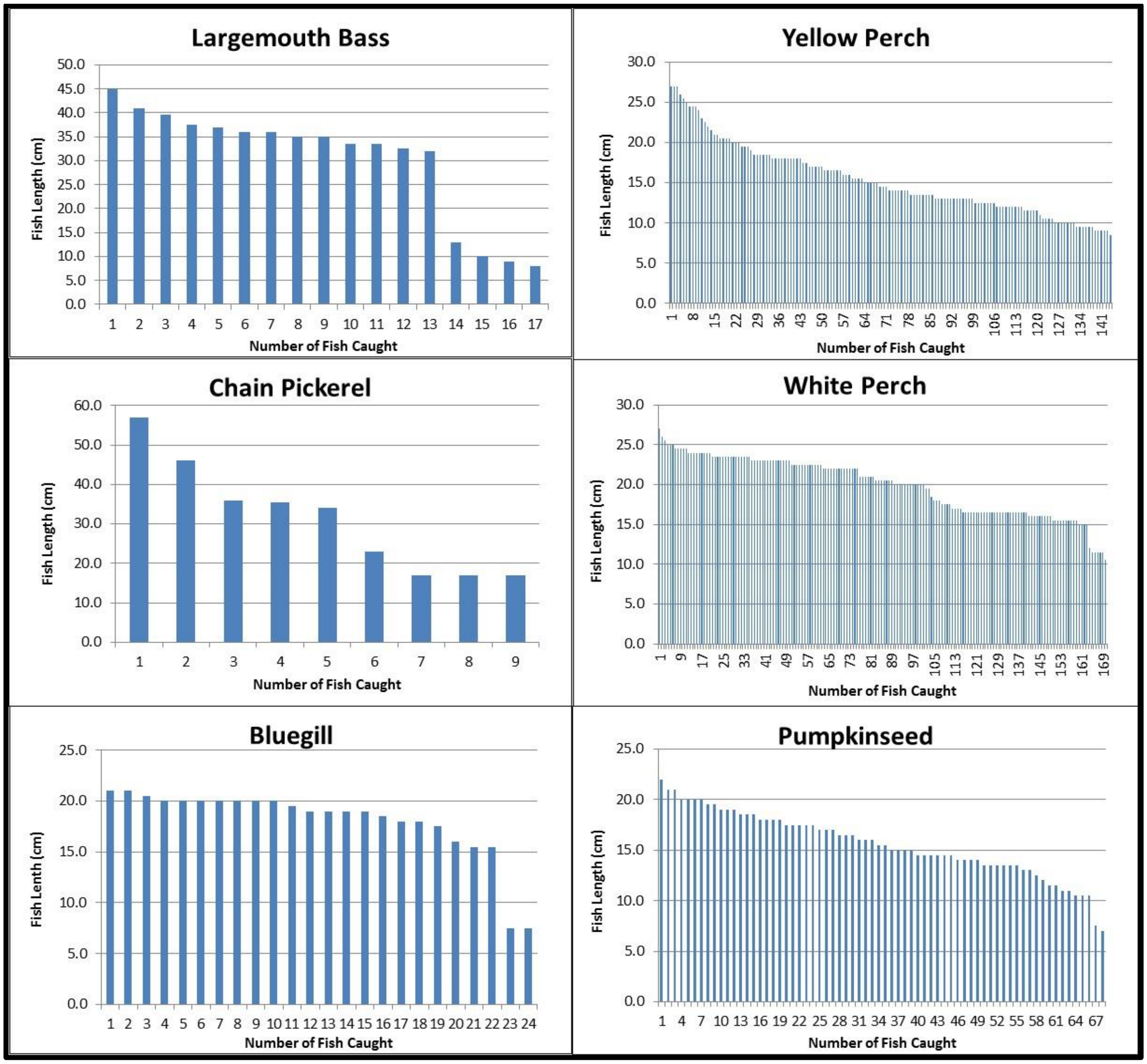

Figure 6-6: **Size distribution among dominant fish species captured.**

stated as being abundant in the 1978 survey, yet EPA has not found this species in Lake Attitash to date. A later fish survey specifically targeting this species and its habitat niche turned up empty. Killifish may have been extirpated from the lake due to predation, winter drawdown effects, or other environmental stressors.

Based on the preliminary fish work that EPA conducted on the lake, there appears to be an overabundance of "panfish" within the lake, a group of species that often utilize zooplankton as a primary food source when they are juveniles. Bluegill, Pumpkinseed, and Yellow and White Perch appear to be prolific and found in a good range of size classes (Figure 6-6). Top level predator species appear to be less than one might expect, based on this level of effort, and the largemouth bass appear to be missing a year/age class or two. This can occur due to natural causes, or could be a reflection of the abundance of forage fish feeding on the eggs of predator game fish, fishing pressure, or other factors. The data to date is inconclusive for making these determinations.

Although effects from atmospheric deposition have decreased significantly over the past decade and are reflected in the reduced mercury tissue concentrations of the fish, other environmental stressors remain. Elevated water temperatures, legacy pollutants, hydrologic changes, excessive nutrients and associated harmful algal blooms, and other factors all play a role in the overall health of the fisheries and the top level consumers that utilize them.

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7.1 Macrophytes

The 1912 Massachusetts Fisheries and Wildlife report on Lake Attitash stated that aquatics plants residing in the lake at that time were limited and amounted to about three native species, located in the north and northwest areas of the lake. For many lakes found at these latitudes, it is not uncommon for the majority of aquatic macrophytes to be confined to the northern shorelines (especially in nutrient poor lakes), as these areas receive the largest amount of sunlight through the course of the year, and plants can become well established. By the time of the 1978 MADEQE Notini report however, the species count had expanded to about twenty and now covered 75% of the entire lake bottom area. These plants were found throughout the lake from the shallows out to a depth of fifteen feet and were hyperdominated by naiad (*Najas sp*.), wild celery (*Vallisneria Americana*), and waterweed (*Elodea canadensis*).

In 2010, the USEPA also completed an intensive aquatic plant survey using traditional field survey methods and accompanying plant identification, in conjunction with a hydroacoustic plant survey within the lake. Results from these efforts showed that the lake was hyperdominated by Naiad and Elodea. Naiad dominated the shallower near shore areas and Elodea dominated the deeper areas around the lake. Water celery was also abundant and found to primarily coexist with the Naiad, much the same as what the Notini survey found. The EPA survey added two aquatic invasives and a wetland invasive to the species list. The aquatic plant coverage on the lake bottom at this time was at least equal to the coverage found in the 1977 survey.

Figure 7-1: **Elodea laden anchor in Attitash**

Elodea is found to be most abundant in fine organic sediments and easily over winters by carrying on photosynthesis even under or frozen within the ice[1] (Bowmer *et. al.,* 1995). This plant produces few seeds, and primarily propagates by fragmentation. It is relatively disease resistant, very tolerant of low light conditions, and has the ability to take up phosphorus from the sediments through its root system. For these reasons it has been highly successful in Lake Attitash and appears to be thriving (prior to chemical treatment) in the deeper depths below the winter drawdown level and in the very low light conditions of the lake. It has also been shown to have minimal or little affect from winter drawdown management practices (dec.ny.gov). Heavy boat traffic in the summer months assists in fragmenting the plants and adding to their dispersal. Elodea is consumed by freshwater invertebrates, waterfowl, beavers, and muskrats.

Naiad (*flexilis*) is an annual plant that dies back completely in the fall, relying on its seeds to germinate and reproduce the next year's plants. This plant can also spread by stem fragmentation during the summer growing season[2]. The seeds survive well in the sediments, and this plant has been known to increase in density after winter drawdown management efforts (ny.gov). For these reasons it has been highly successful (prior to chemical treatment) in the lake. It is another plant that survives well under low light conditions and is one of the most important aquatic plant food sources for migratory waterfowl, various marsh birds, and muskrats.

Water celery, another very abundant plant in the lake, is another critically important food source for waterfowl, shorebirds, and muskrats. Winter drawdown may have no impact, or be variable for this plant depending on specifics of the drawdown due to its root structure of hardy rhizomes and tubers.

The hydroacoustic survey effort tested new technology for plant surveys that could efficiently map plant colonization densities across the lake bottom and transpose the information to Geographical Information System maps (GIS) (Figure 7-2). This effort was completed simultaneously with the bathymetric survey on the lake and provided good assessment coverage in areas where lake water visibility was nonexistent. Acoustic plant coverage was unobtainable up through the Northwest inlet portion of the Back River due to the very shallow depths, but field efforts from the traditional plant survey effort showed this area to be heavily colonized with a wide diversity and abundance of native plants, along with the presence of two invasive species, water chestnut (*Trapa natans*) and eurasion milfoil (*Myriophyllum spicatum*). Purple loosestrife (*Lythrum salicaria*), a wetland invasive plant, was also observed to be gaining a foothold in this area.

Anecdotally, conversations with longtime residents living around the lake repeatedly stated that there never used to be plants of any significance, except farther out towards the middle portion of the lake. Residents claimed that they had to swim one or two hundred yards out into the middle of the lake before they encountered any weed beds. This runs counter intuitively to lake ecology, where plants colonize the shorelines and shallower areas of lakes up until the point where the sunlight ceases to penetrate the water, and energy from the sun can no longer be provided in order to carry out photosynthesis and subsequently, plant growth. This area and depth of light penetration is commonly known as the photic, or tropogenic zone of the lake. Residents also claimed that plants didn't appear in shallower waters until the early 1970s, where by 1977 they had propagated to nuisance densities in all but the deepest areas of the lake.

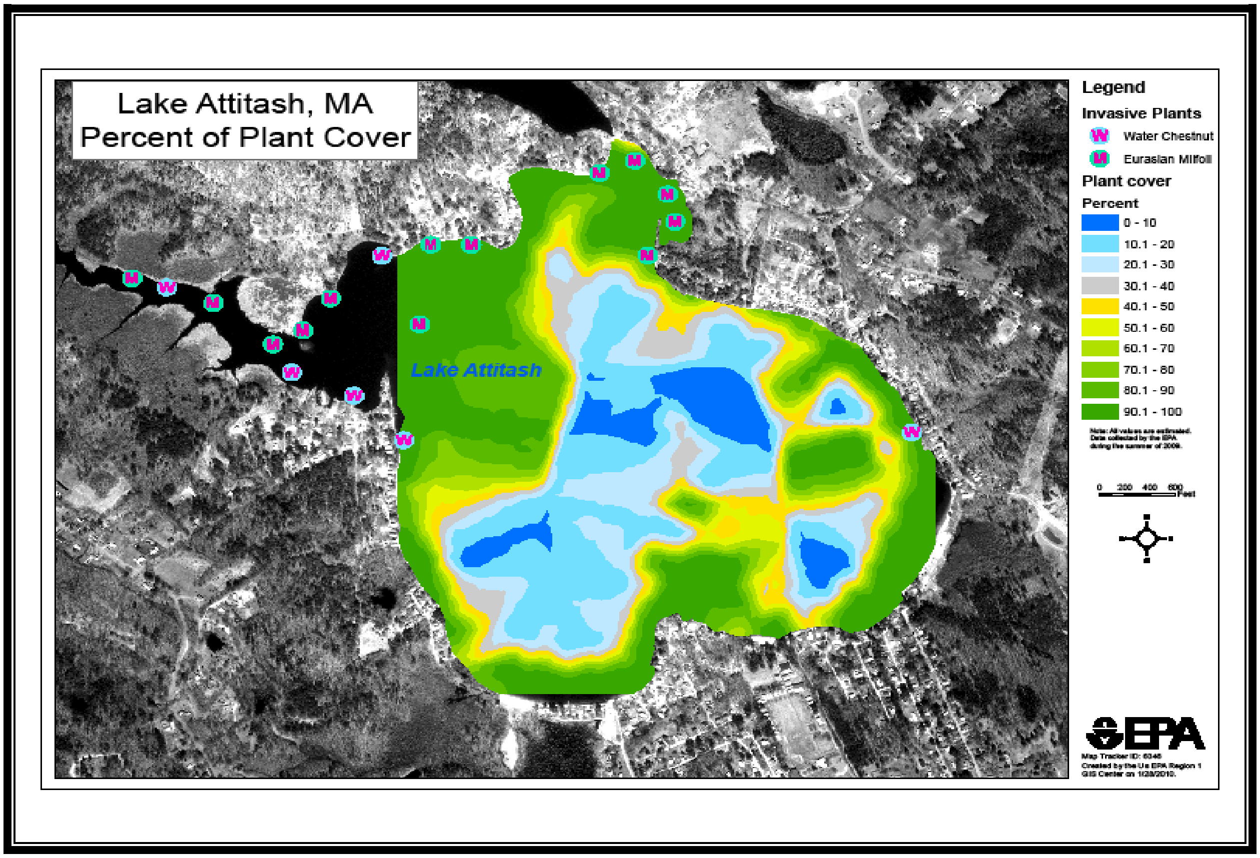


Figure 7-2: **GIS map showing plant densities and specific locations of milfoil and water chestnut. Dominant plants at the time of the survey were elodea, naiad, and water celery.**

From around the 1920s up until the late 1960s to early 1970s, manipulation of lake water levels took place several times a summer, with levels fluctuating at times by more than three feet. In the late 1950s the lake water level was controlled from Tuxbury Pond, rather than the Birches Dam. This degree of hydro manipulation was captured in many old postcards and photographs of the lake (Figures 7-3 and Figure 7-4). In 1966, water flowage rights were sold by the Massachusetts Electric Company to the Town of Amesbury. Water levels did not appear to be closely regulated for the next couple years by the town, and in general were kept relatively low according to comments in the Notini report and from Amesbury newspaper clippings from the day. There does appear to be one exception however; a December 1959 newspaper article reports that a year round resident at the time (Shute) complained to the Amesbury town selectman that since the time that the town took over jurisdiction of the water rights, the water was kept at “a very high level year round.” Because of the elevated water table, any significant rain resulted in a flooded dry well and failure of the septic system. What the exact elevation was at that point is unknown, but up until this point at least, based on the historical anecdotal information, it would make sense that plants were limited to the center of the lake because during the summer plant growing season, the lake was constantly being drawn down, disallowing any opportunity for aquatic plants to gain a foothold in the inshore areas of the lake. During this time period of continual “lake flushing,” the lake exhibited good water clarity indicative of minimal algal growth, so the photic zone penetrated deep enough in the lake to support aquatic plants out in the deeper areas, even when the lake was temporarily refilled to a reasonable “pool level.”

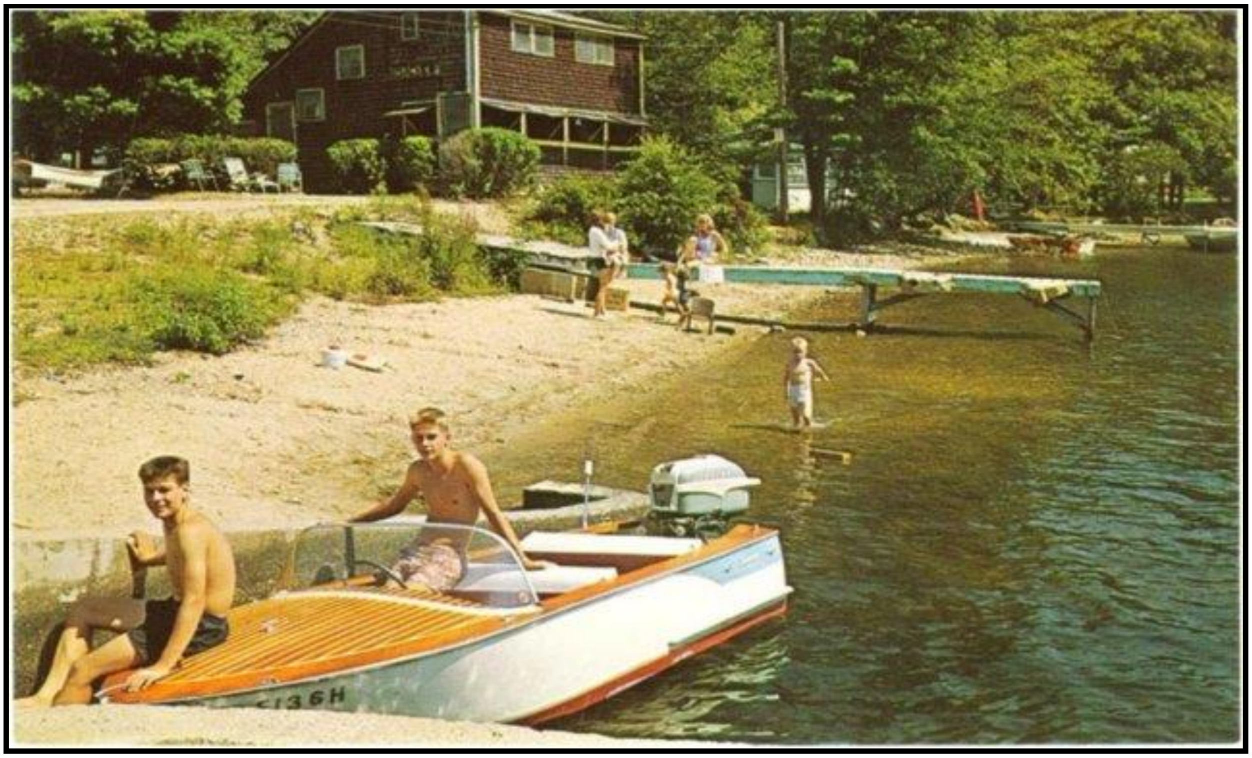


Figure 7-3: **This photograph (Circa 1960) shows that Lake Attitash is still undergoing natural or induced summer drawn down, and that the water clarity still appears to be good.**

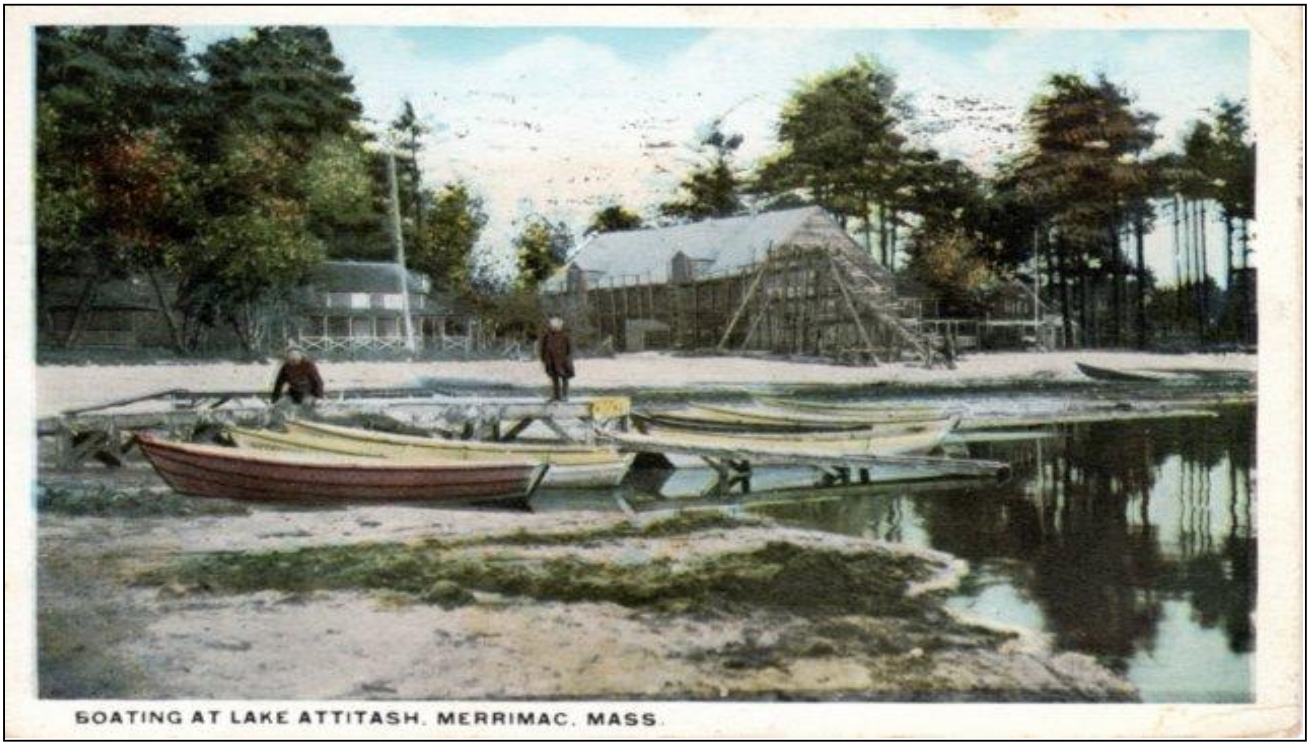


Figure 7-4: **Historic postcard (Circa 1929) showing ice house at present boat landing site and revealing the significant lake drawdown and presence of decaying aquatic vegetation on the shoreline; plants were not able to gain a foothold in nearshore areas due to hydromanipulations.**

In 1969 the Massachusetts Department of Public Works, Waterways Division began construction of a public boat ramp on the lake. In 1973, the launch area was expanded to accommodate approximately thirty paved parking spots and a concrete ramp. By 1973, it would appear that a permanent pool was now established during the summer months in order to make the large new public boat ramp viable. By the mid-1970s residents were becoming increasingly concerned about the amount and size of boats on the lake “some exceeding 300 horsepower in size.” Long term residents have stated that not only was the new boat ramp and parking area completely filled with vehicle and trailers during the summer months, but that they were parked end to end from the entrance of the parking area out to route 110 on both sides of Lake Attitash Avenue, a distance of one third of a mile. This amount of powerboat boat activity would have created a large amount of underwater turbulence and plant fragmentation, hastening its distribution and establishment throughout the lake.

With the lake now at a relatively permanently established pool level at least for the summer months to accommodate water recreation, aquatic plants now had the opportunity to proliferate during the summer growing season, rather than not being able to establish a foothold due to the frequent summer drawdowns for prior hydropower use. In addition, the lake now was harboring septic system effluent from three hundred plus ever increasing year round residents and any agricultural inflows from the Back River. Septic system failures were now becoming commonplace. All of these nutrient sources (not including any lawn care, stormwater, etc. inputs) were now remaining for the most part within the lake, as summer outflows are and historically have been extremely low, excluding the draw downs, of course. The historic and frequent summertime draw downs, though not very amenable to power boating and some other forms of recreation, did have the benefit of inducing ground water inflows into the lake and thereby flushing out septage effluents (and increasing the subsurface travel distance for septage filtration from groundwater to surface waters), algae, dessicated plant material, and other nutrients and replacing a large proportion of the lake water volume with fresh groundwater.

Now that plants were firmly established and densely colonized over seventy percent of the lake area, they became a nuisance problem for many of the recreational uses of the lake. The Notini report recommended that winter drawdown should be considered “for the purpose of clearing weeds from beaches and shore-front homes,” and around 1980 (personal conversation Bill Stasiuk, former LAA member during that time period) winter drawdown management practices began. In addition to the recommended winter drawdowns, the Notini report also stated that an “adequate flushing rate” should be maintained. This did not accompany the drawdown practices.

Winter draw down for lakes such as Attitash are problematic. With the drawdown area dominated by naiad, an annual plant anyway, winter drawdown does not help much, and may in fact exacerbate the plant problem. Any plants killed by the drawdown management practice end up frozen or dessicated on the exposed shoreline until the spring thaws, when runoff starts and the lake begins to refill to pool level. Most of these plants do not leave the lake, as the flushing rate and circulation within Lake Attitash is minimal, and their organic material contributes to the organic detrital and nutrient load on the lake bed. The phosphorus and other nutrients once sequestered in the living plant material are now available to support new plant and algae growth and the cycle begins again, adding more organic detritus to the lake bottom year after year, and the nutrients remaining in the system forming a constant feedback loop. The release of nutrients from decaying plants is often quickly utilized by algae. This pattern is readily apparent from examination of the deposition rates determined from the paleo-sediment analysis, where aquatic plant/algae deposition rates accelerated rapidly during the mid-1980s (see section 5). It was after the Notini report in 1978 that Lake Attitash became anoxic, indicating that the oxidation rate of the bottom organic material by bacteria was now outstripping the available oxygen in the water column, again an indication of a large influx of organic material.

The application of chemical herbicides for macrophyte control can play a similar role, as in 2012 when a large scale herbicide application laid the groundwork for large scale nutrient release and its availability to phytoplankton. The herbicide treatment was very effective at killing off the majority of aquatic plants in the lake, which was the principal goal of the effort. However, this left a very large amount of organic detritus on the lake bottom which adds to the anoxia problem, and a large pool of readily available nutrients, as evidenced by the large and frequent algal blooms occurring throughout the summer of 2013. In addition, rooted plant material is compromised causing more fine sediments and detritus to be exposed and subject to resuspension by wind and boat traffic. An additional unintended consequence was the absence of migratory waterfowl visiting the lake that fall. The prolific aquatic plant life, while a nuisance for many human users of the lake, was an important food source for migratory waterfowl, making Lake Attitash an important stop over along their migratory route. Aquatic macrophytes also play an important ecological role in providing essential refugia habitat to juvenile fish and invertebrates; a balanced aquatic plant community is an important ecological component in warm mesotrophic lakes.

Winter drawdowns may have an impact on freshwater mussels. Most mussel species prefer coarser substrates such as sands and gravels and are not found in fine organic silt environments such as that found in most areas of present day Lake Attitash. They also cannot survive in anoxic environments which appear to be increasing in the lake, and their limited mobility enables them to move only several feet through the course of a month to find suitable habitat. This means that their optimal habitat zone may be shrinking significantly, being "corralled" between the summertime anoxic and silty areas and that of the winter drawdown zone. Sediments samples taken through the course of the EPA's efforts have turned up mussel shells in the deep hole sediments, indicating (as in the 1912 MDFW report) that the lake was comprised of mud and gravel, supportive of these invertebrates at those depths. Large shoals of dead mussels have turned up on the winter shores of the lake in recent years and may be in part indicative of detrimental drawdown effects (Figure 7-5).

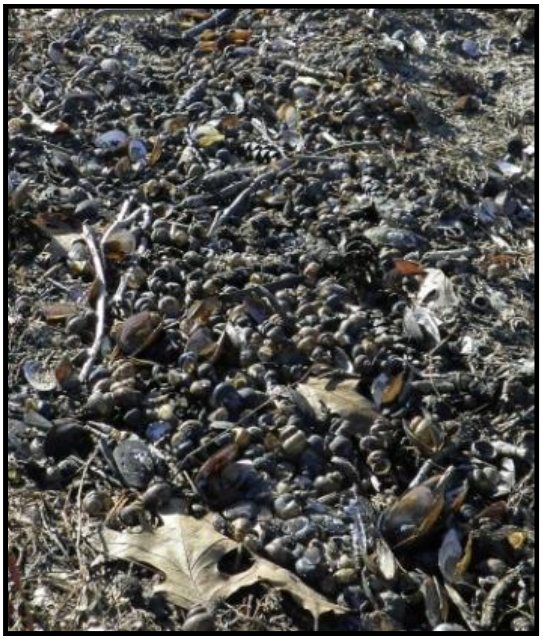
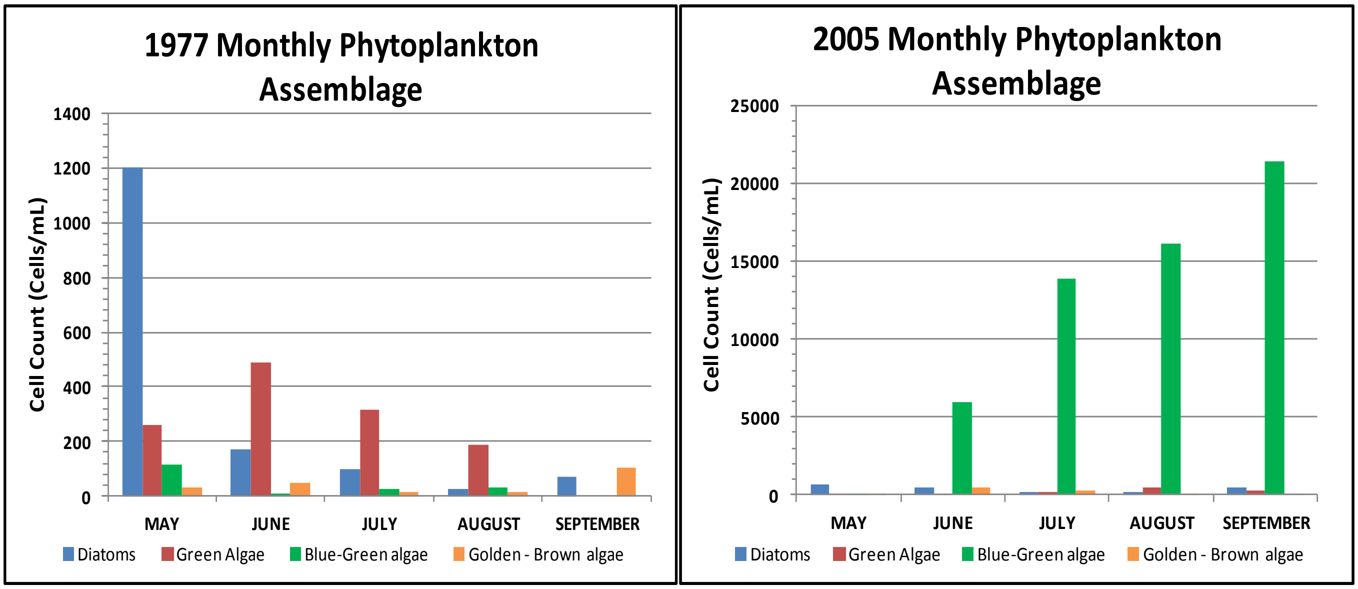


Figure 7-5: **Mussel and snail "rack" on eastern shore of Lake Attitash.**

As an example of the importance of these invertebrates to freshwater systems, filtration rates for freshwater mussels typically run between .5 and 1.25 gallons of water per hour.[3] A study of freshwater mussels in the New York Hudson River tidal area filtered approximately 5.3 million gallons of water per day. This was approximately equal to the total daily freshwater discharge of the Hudson River during the summer months.[4] Lake management is a balance of uses, or in many cases, more often a determination and selection of preferred uses. How this plays out on any lake is up to the resource managers and stakeholders of the lake to decide, with results that may have long term benefits or long term consequences.

7.2 Phytoplankton

Phytoplankton samples were collected through the yearlong study completed in 1977 by MADEQE. Samples were collected on a monthly basis from May through November with results showing that the largest concentration (cells/ml) occurred in May and was 74% dominated by diatoms, with a cell count of 1,202 cells/ml. This observation is supported by the sediment work, which shows bottom sediments being comprised almost entirely of silicate diatoms. Green algae dominated during the summer months of June, July, and August. The highest count for blue-green algae occurred in May and was 114 cells/mL. By the end of August, cell counts for blue-greens were down to less than thirty. In contrast, phytoplankton samples collected in 2005 by EPA showed diatoms again making up 74% of the phytoplankton cell counts in May, and the green algae averaged pretty much the same as in 1977. The blue-green algae however, was hyper-dominant through the summer months into September, averaging 11,500 cells/mL. The average 1977 blue-green counts during these months was 36 cells/mL. Based on the 1977


1977 Monthly Phytoplankton Assemblage

2005 Monthly Phytoplankton Assemblage

Figure 4-6: **Relative cell counts by assemblage through the summer months. Note the different scales; May diatoms are at similar concentrations in both years.**

survey year data, these values allude to the fact that in 1977 there did not appear to be a problem with elevated levels of blue-green algae in the lake, but there was at this time a significant problem with aquatic plants. By 2005, and possibly much earlier, blue-greens were becoming the dominant phytoplankton in the lake, transitioning it from an Oligotrophic-mesotrophic lake to a eutrophic-hypereutrophic system. In addition, it appears that the golden algae have also increased, yet the diatoms and green algae have remained essentially the same (Figure 7-6). Once the lake started to be monitored for cyanobacteria by the Massachusetts Department of Public Health in 2009, blooms 70,000 cells/mL (the World Health Organization's threshold criteria) and much greater were often detected. It is highly likely that bloom concentrations reached these levels in preceding years, it's just that they were never monitored.

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Web links

(http://www.dec.ny.gov/docs/water_pdf/ch6p3.pdf)

8.0 Timeline

The following timeline represents a compilation of events chronicling the historic path of water quality and land use in and around Lake Attitash through the years. This information was collected from previous water quality studies, historical documents, newspaper clippings, and personal conversations with longtime residents from the area. While some of this information is anecdotal in nature, the cumulative information assists in painting a picture of the changes that have occurred through the years in the watershed. Key events along the timeline highlight important milestones that have likely played a significant part in the decline of the ecological integrity and water quality of the lake. These milestones are components that likely represent "red flags" to impending water quality and ecological issues and are highlighted.

Year	Milestone
1712	**Birches Dam was constructed, elevating the lake approximately three feet to provide additional hydropower for industries in Amesbury.** *This represents the first record of hydrologic manipulations to the natural flow regime of the lake.*
1740	Pond Ridge was tunneled through with construction of a box culvert from Meadow Brook, forming Arch Brook that then discharges into the Powow River. Two barrels of rum as payment.
1891	"Lake Attitash a pleasant place for parties of all kinds"
1893	Strathmere Club founded.
1895	Circa - Lake name changed from Kimball Pond to Lake Attitash (Attitash - indian word meaning "blueberries all around")
1897	"Lake Attitash fast becoming one of the most famous resorts in vicinity" Amesbury notes.
1899	1st Illumination event and water carnival…drew large crowds.
1900	Second annual yacht race on Lake Attitash.
1900	**Sargent farm wetland area along Back River "ditched" for drainage, area used for haying (Circa?).** *"Ditching" was a common practice throughout the country during the early part of the century as a means to dewater wetland areas making more land available for farming. The downside was that it took away local wildlife habitat and critical stopover points for migratory waterfowl. The practice also eliminated critical wetland functions such as flood storage capacity in the drainages, and a natural filtration mechanism for water quality by reducing nutrient and sediment loads into adjacent water bodies.*
1900	Second Illumination on Attitash "thousands of lanterns…great throngs".
1901	Ice boating on the lake
1903	Boys camp opened on lake under Newburyport YMCA.
1904	30 acres of land sold for dance hall and pavillion on lake.
1904	Bowling lanes opened on lake.
1906	Ice harvesting interest at Attitash.
1908	Bonds sold for Ice Harvesting (Lake Attitash Ice & Transportation Co.)
1909	**Pinehurst Hotel opens on south side of lake.** *Another possible historical source of past nutrient loading to the lake from septic systems.*
1912	MADFW records state Lake Attitash as being "crowded" with vacation cottages.
1912	Dance hall and bowling alley burn down.
1912	MADFW records report that the lake is "crowded" with seasonal vacation cottages as early as 1912.
1912	MDFW report state plant growth in lake limited to North and West shores of lake (very typical for more aquatic plants in natural lakes to be located on the Northern shorelines due to sun exposure).
1920	**(Circa 1920) Merrimack Valley Power and Buildings Co. begin flow manipulation for hydropower on lake (water level fluctuations occurred frequently with level changes of over three feet until 1966, when the water rights were sold).** *The constant fluctuating water levels in Lake Attitash during these years most likely acted as a benefit to the waterbody; frequent drops in water elevation reduced the ability for aquatic plants to gain a foothold in the nearshore areas, and lower lake water elevations induced groundwater infiltration into the lake, helping to attenuate and flush out septic system effluent coming in to the lake from the surrounding summertime residences. This would have assisted in reducing nutrient levels that might have precipitated algal blooms.*
1922	Moonshine found near the dance hall.
1923	Electric lights available for Lake Attitash residents.

1929	Grand opening of lake Attitash Ballroom.
1931	Bauercrest converted over to jewish boys camp.
1933	Nude bathers discovered at Attitash.
1944	***(8/8/44)-article indicating Board of health took algal samples from the lake due to apparent algal blooms. "A green substance that has caused pronounced discoloration." Article stated that there had been intense heat during this summer. Complaints were received from some residents around the lake of the severe discoloration.** *This record alludes to the fact that there may likely have been plenty of nutrients available even back then for algal blooms to occur under the right conditions. It is likely that the hydromanipulations kept many potential blooms at bay except under conditions as stated above or during periods when the lake may have been at a constant pool level for an extended period.*
1944	*Algal growth is believed to be affecting water "green substance causing pronounced discoloration" present for several days on the Amesbury side before appearing on the Merrimac side - summer of very intense heat.
1945	Lanes Ten Acres opens.
1945	*Amesbury Electric Company stages for building new roadway bridge and culvert over the outlet brook at the Birches (26' wide roadway).
1950	***(6/27/1950) – Development of Birch Meadows Beach at "the Birches." 7.5 acres of land and 500 feet of lake frontage . Parking available for up to 1,000 cars. 30,000 yards of gravel brought in to fill in a swamp "of little use to anyone save mosquitos…" Huge quantities of beach sand was applied after the gravel. Proposed a commissary for food, ice cream and beverages, boat rentals, bathing suit rentals, proposed bathing pier and diving tower. Large bonfire on the shore.** *The filling in of this wetland eliminated its capabilities of filtering nutrients, runoff, and groundwater that eventually flowed to the lake.*
1950	* "Gus" Ouellette builds Birch Meadow Beach, "sufficient to accommodate 1,000 automobiles"*Birch Meadow Beach opens at the Birches, Lake Attitash (7.5 acres with commissary and boats and bathing suits to rent).
1954	Mrs. Clark shoots husband to death and dumps weighted body in Merrimack River
1955	**September 1955, Sandy Beach is created on east side of Attitash.** *This is another area adjoining the lake where a wetland has been altered, affecting its functional capabilities of flood storage and nutrient attenuation.*
1958	1958-1996 Claire Road construction (5 homes-dated by oldest construction date).
1958	*4th street out of town residents petition for hook up to town water line. Originally drew from Bauercrest but were shut off when Bauercrest connected to town water.
1959	***Richard Shute of Lake Attitash states at Amesbury town hearing that the lake has been maintained about two feet higher than it ever has been and has made it very difficult to control sewerage. Richard pointed out that before the town took jurisdiction of the water rights the utilities drew the water down allowing the ground to dry, and when freshets came there was room enough to take care of it. Shute said the water is now kept at a very high level the year round and "when a freshet or excessive rain comes, it floods the land so pipes for sewerage are immersed in water making the dry wells ineffective."** *This record appears to be the beginning of significant problems with septic systems around the entire lake (prior to sewer line connections completed in the late 80s early 90s) and corresponds to the time period that the lake was brought up to a permanently established pool level.*
1964	**Tile drain system constructed on Sargent farm (Circa?).** *Tile drains underlying agricultural fields are known to be significant sources of nutrients as they provide a direct conduit to surface waters. These systems are presently exempt from permitting under the Clean Water Act.*
1964	495 completed from Andover to Merrimac (Bostonroads.com).
1965	Amesbury water suppy installs surface intake on the Powow.
1965	* Amesbury drafts safety code for water skiing and high powered boats on lake.
1965	Hydroelectric company utilizing lake Attitash water sells the water rights to the town of Amesbury. It is purported that the town of Amesbury did not regulate the flow or create a permanent pool level for several years after acquiring these water use rights.
1966	**Use of lake for hydropower stops, Amesbury purchases flowage rights and lake levels cease fluctuating.** *This corresponds with increasing septic system failures around the lake and the beginning of documented algal blooms.*
1967	**Attitash had a permanent summer pool level established in 1967 (reports indicate that water levels were not well regulated at that time), the year after Town of Amesbury purchased the flowage rights. The 1977 Notini report states that at the time of the report the town of Amesbury "maintained the lake at a relatively low level." A copy of correspondence (Feb 4, 1980) with the Merrimac Conservation Commission included in this report states that "it is abundantly clear that no enforceable of viable management plan exists to systematically control the level of the lake." It is alleged that the Amesbury DPW manages lake water levels during this period based upon complaints from residents whose septic systems are flooded, or by receding shorelines during low flow and no precipitation periods.** *Another record indicative of the time period when establishment of a permanent pool level coincided with septic system failures.*
1969	Original boat ramp installed (Mass Dept. of Public Works, Division of Waterways, plans dated March 1969) .

1972	Official state plans are drafted for the Lake Attitash boat ramp. Prior to this time an unpaved primitive boat ramp was in place, but use was limited to small watercraft due to fluctuating water levels (up until 1966) and limited accessibility. The concrete boat launch was constructed sometime between 1973 and 1975. This latter date is surmised based on the DEQE 1977 report that states motor boating had markedly increased over the two previous years and that the number and size of the boats now present on the lake (as large as 300 Hp reportedly) was a concern to lakeshore residents. Anecdotal reports recall boats and trailers lining both sides of the street leading from the main road to the boat ramp, a distance of approximately a third of a mile. The current boat launch is a single lane concrete ramp with a paved parking area and 22 trailer parking spaces and approximately eight to ten car top parking spaces. Although there are no established state criteria for the number of parking spaces installed for a lake and the only limitation appears to be available land space, a rule of thumb has been one parking space per ten acres of waterbody (personal communication, DCR). In Massachusetts, waterbodies such as Lake Attitash are considered “Great Ponds”, naturally occurring waterbodies that are over ten acres in size. These are considered owned by the general public and a town can apply a bylaw that establishes horsepower limitations on the lake. The bylaw must be reviewed by the MA environmental police and the attorney general.
1973	Current boat ramp constucted.
1975	Merrimac boat launch paved and parking spaces installed.
1976	*Lake Attitash residents offer proposal for cleaning up the shoreline around the lake. Article implies large amounts of debris, broken glass, and trash based on that it suggests that they propose using a contractor with heavy equipment. Article states that September is the routine time period for dropping lake levels for retaining wall work. Concern is expressed over lowering water and its effect on the town’s water supply.
1976	Proposal by lake residents to drop lake level to clean it of waterfront trash. Public works board members stated "September is the usual season for routine dropping of lake levels so residents can do work on walls".
1977	Over 250 seasonal and year round residences on 1st and 2nd tier of lake
1977	Anectdotal large increase in high powered boat traffic (300 Hp)
1977	**Tile drain system constructed on Sargent farm (Circa?).** *Tile drains underlying agricultural fields are known to be significant sources of nutrients as they provide a direct conduit to surface waters. These systems are presently exempt from permitting und*
1977	DEQE study on lake
1977	**MADEQE “Notini” report suggests winter drawdown as a lake management technique along with developing man made beaches for public and private use by trucking in sand. Conversations with locals state some folks trucked in beach sand during the winter and dumped in front of their cottages to be deposited once the lake ice melted (Buzzle, personal conversation).** *These management practices are not helpful at reducing aquatic plants or algal blooms within Lake Attitash.*
1977	More than 350 seasonal and year round homes around the lake (DEQE 1977 report). Transitioning to year round homes during this period.
1977	**All residences presently on septic systems.** *The 1977 report stated there were approximately 350 septic systems in the area at this time. Based on literature data collected by CDM (15 mg/l Phosphorus in septic tank effluent), CDM estimated a potential for as much as 3,000 lbs of phosphorus per year added to the lake from these systems. This does not take in to account any additional TP from lawn fertilizers, road runoff, or agricultural sources. (if the lake summer pool level was established in 1966, and the residences weren’t sewered until the early/mid 80’s, this would be at least fifteen years of TP added to the lake…over 45,000 pounds of phosphorus. During this time period as more year round residences are being established and the lake is at an established pool level summer influxes of TP are only increasing as the remaining seasonal residences are visiting the lake. Nutrients are likely being resuspended by heavy motorboat traffic.*
1977	First HABs seem to appear from reports of residents (with the exception of the 1944 newspaper article on severe lake “discoloration”).
1978	***Indian Head Beach closed due to bacterial contamination.** *With the lake now at a permanently established pool elevation and likely very little lake outflow if any during the summer months, effluent from failing septic systems would now be retained in the lake, possibly being a major contributor to beach closings.*
1978	Fish Kill occurs in August 1978 . Kill limited to Bluegills only and MDFW considered it a "normal" fish kill resulting from the prior heat wave.
1979	1st reported complaint on algal bloom .
1979	*Complaints of algal blooms come from lakeshore residents.
1980	*MADEQE report on Lake Attitash water quality comes out. Study began from water sampling in 1977. Article mentions numerous failures of septic systems around the lake, and based on associated report comments and correspondence (i.e. Amesbury BOH to MADEP) many of these failures occurred within months of the dwelling being converted from seasonal to year round residence. It should be noted that the occurrence of a septic system failure is a problem from the occupants point of view, but a failed system or a properly functioning system are both contributing nutrient loads to the water body.

1980	*Lake Attitash Watershed Association initiates program to eliminate excessive plant growth and siltation in the lake. Implies watershed association is newly formed. DEQE recommends dredging out of the silt and attacking the plant problem. Also mention increasing zoning lots to 1.5 acres. Board of health gives go ahead to test for leaking septic systems. IEP Inc. of Wayland is hired for $5,000 to conduct the study. Proposed to test for Bacteria, TP and TN.
1980	*** "Numerous failures of septic systems around the lake have been noted since 1977".** *This is a time period where many seasonal cottages were converted to permanent dwellings, increasing the demand on historic septic systems from a few weeks in the summer to year round use.*
1980	***Request to significantly drawdown lake water level in fall so owners could "attack the weeds along the shoreline." "members will talk with contractors about the feasibility of hiring heavy equipment to dredge out shorelines of silt.** *Aquatic plants now appear to be at nuisance levels ten years or so after the establishment of a permanent pool elevation in the lake and constant drawdowns ceased.*
1980	**First winter drawdown for plant management (based on personal conversation with Bill Stasiuk, former lake association member).** *This appears to have been an annual management strategy from here forward, adding to the organic loading to the lake and the release of plant bound nutrients into the waterbody.*
1981	*DPW hearing on sewer needs for around the lake. Acknowledgement that seasonal homes are quickly becoming year round residences.
1981	*Amesbury hearing held on need for sewer lines around the lake.
1987	1987-1988 68 Sewer permit applications within 1000' of lake.
1988	1988-1989 9 Sewer permit applications within 1000' of lake .
1989	1989-1990 5 Sewer permit applications within 1000' of lake.
1990	1990-1995 9 Sewer permit applications within 1000' of lake .
1993	Lake Attitash Association formed.
1993	Aquatic vegetation survey by ACT (Aug 24, 1993).
1993	Harmful algal bloom (from Aquatic Control Technologies data search).
1994	Lake Attitash Association water quality study.
1994	*1994- $10K state grant to Amesbury with required $10K match. Monthly monitoring program established and funding to provide for plant harvesting. State that nuisance “weeds” have always been a problem in the lake, but problem appears to be worsening.
1994	Harmful algal bloom (from Aquatic Control Technologies data search).
1994	Grant awarded to lake association for water monitoring, public outreach, and plant removal.
1995	(Circa 1995) Mid 1990’s- soil berm constructed at Sargeant’s farm to divert runoff from sloped fields into the millpond and away from the compost piles.
1995	1995-1996 First mechanical plant harvesting .
1997	1997-1998 Spindle Tree Lane development constructed (3 homes).
1998	CDM Watershed Management Study CDM.
1998	1998-1999 Lancewood Drive (3 homes).
1999	Watershed and Waterway Management Plan completed for Amesbury.
2001	2001-2002 Whitewood Circle development constructed (4 homes).
2003	Olde Tavern Lane development constructed (3 homes).
2005	**November 2005 MADEP issues a Beneficial Use Determination for Sargent Farm, allowing gelatin waste products from Kraft foods to be trucked in to Sargent farm for composting (it should be noted that "composting" operations started much earlier than when the Beneficial Use Determination , or BUD, was issued. Google earth historical photos from 1992 show extensive composting windrows very to the Back River, and personal conversations with long term residents claimed that intial operations began in the early 1980's).** *These compost piles appeared to be over the tile drain outlet from the fields, were not covered from the elements, and are directly adjacent to the major inflow to the lake. These types of sources are renown for their runoff impacts to surface waters and earlier work (see Sargent Farm Report, MADEP/EPA) identifies this as a historical or current likely source of nutrients.*
2006	USEPA National Lakes Assessment pilot utilizing the lake.
2006	Madison Way development begins off Bear Hill Road.
2007	2007- USEPA remote sensing flyover, vegetative mapping and analysis, sediment coring and dating, fish survey, detailed bathymetry mapping,
2009	9 week health advisory for cyanobacteria bloom.
2010	**Gelatin waste to Sargent Farm composting operation ceases.** *Total nitrogen and total phosphorus levels in this material was quite high. The seagull population on the lake went from hundreds to less than a handfull immediately after composting ceased.*
2011	USEPA year long monitoring of Attitash.
2011	HAB June 8 & June 20.

2012	Chemical herbicide treatment of entire lake for aquatic plants
2012	June, July, August, and September HAB's
*(excerpts from Amesbury library newspaper clippings)	

Figure 8-1: **Timeline of events in and around Lake Attitash**

9.0 Summary & Recommendations

The previous timeline section, along with preceding chapters on the focused scientific components of this project, have painted a relatively vivid picture of the uses and abuses that Lake Attitash has been subjected to over the past hundred years or so. It also has revealed the environmental success stories over the years and alludes to the challenges that lie ahead in regards to lake restoration and watershed management.

Land use practices since the turn of the century have altered the hydrology of the watershed, from the trenching of wetlands that short circuit their natural function of filtration, water storage, and denitrification, to the filling in of wetland areas for beach or shore front developments with similar losses in wetland function or altered hydrologic regimes. Altering the “natural” pool elevation of the lake has also proven to have unintended consequences that sacrifice a certain set of uses for another set of preferred uses. The improvement of stormwater infrastructure has resulted in significant reductions in nutrient loads to the lake, yet impervious surfaces, lawn care practices, and private drainages are transporting water into the lake and out of the system much more quickly, eliminating natural infiltration processes that purify and provide more sustained lake baseflow contributions.

Storm water infrastructure BMP failures have been identified, stressing the importance of continual post BMP implementation monitoring and assessment. Even after BMPs have been purportedly “repaired,” it is apparent that in some cases fixes have been made that provide no improvement to structures or the water quality for which they were constructed in the first place.

Lake levels appear to respond relatively quickly to precipitation events, and just as quickly recede to pre-storm conditions. The small watershed size, percentage of impervious surfaces, truncation of wetland function, and open cropland quickly transport surface runoff in to the lake and then out of the watershed. The main surface water inflows have usually stopped flowing by mid-June. Groundwater withdrawals for public water supplies may also be playing a part in the reduction of inflows to the lake, but this was not investigated or determined through the course of this study.

Dry weather sampling showed tributary total phosphorus concentrations increasing during the summer months, although there was very minimal surface flow from these systems during this time period. These high concentrations represent solubilized phosphorus from wetland areas during summer anoxic conditions, and while high, do not represent significant loadings in to the lake. These concentration peaks also correspond well with precipitation events, demonstrating a nutrient “pulse- like” behavior from these sources when wet weather flows move them through the system.

Total phosphorus concentrations at the deep hole location of the lake revealed at times a five-fold increase in TP concentration emanating from the bottom hypo-limnetic layer of the lake compared to surface water concentrations. This is reflective of the anoxic conditions during the summer months and the dissolution of phosphorus from the sediments. Soluble reactive phosphorus in the hypolimnetic area of the lake also showed significant relative concentrations. This form is readily available to be taken up by phytoplankton and become a catalyst for harmful algal bloom formation. Internal loading to the lake is occurring.

Annual phosphorus budget estimates for the lake based on this study are considerably different than reported earlier and are partially a result of more complete flow information and water chemistry data. This report shows a net annual increase of total phosphorus to the lake rather than a net loss as indicated in earlier reports, in addition to internal phosphorus loading.

Nitrogen concentrations show an opposite trend to that of phosphorus, with higher concentrations in the spring and the fall when groundwater influence is usually greater, and the denitrifying capabilities of wetlands are less. Nitrogen levels were found to be high enough from the tributaries, as well as from the deep hole area of the lake, to be a stimulus to algal bloom formation. The ratios of nitrogen to phosphorus over the sampling period demonstrate that the lake is a phosphorus limited waterbody, indicating that phosphorus inputs are likely to be the main driver of algal production in the lake.

Dissolved oxygen concentrations decreased to zero at a depth of approximately three meters during the summer months, leaving a significant proportion of the lake volume to be uninhabitable to most biota. In-water temperatures also show a significant transition, with a change in the lake bottom temperature of over fourteen degrees over the course of the summer months. These warmer surface and bottom temperatures present optimal conditions for the proliferation of blue-green algae. Chlorophyll concentrations during the study period represented a eutrophic lake with borderline eutrophic conditions. These concentrations were not as high as those from the 1988 study. Secchi disk readings after the 1977 report all demonstrated poorer transparency than during that survey year. Readings taken the year after, in 1978, showed transparency values comparable to those taken two decades later, somewhat indicative that lake transparency has been poor for quite some time. Some loss of transparency can be attributed to fine dissolved organic materials within the lake, which is often a natural occurrence from lakes with adjoining wetland areas.

The single wet weather event survey demonstrated that the highest loadings of total phosphorus was from the Back River and the Southwest Inlet. TP loadings from the lake subbasin area revealed most discharge inlets to the lake to be comparatively much lower due to the lower flows associated with these catchment areas. Phosphorus concentrations from these areas however, were much higher as would be expected with more impervious surface contributions and associated land use characteristics. Results from the wet weather survey also demonstrated most infrastructure stormwater controls were doing a pretty good job at eliminating suspended solids from the lake and a reasonably good job at reducing nutrient inputs. A couple of the control structures need improvements to be made. The Bauercrest retention/detention pond needs to be cleaned out, reconfigured, and repaired to function properly, and the SD05 outlet could be improved upon to reduce loadings to the lake. Other outlets that could possibly have further reductions in loadings would be SD01 and SD04. Driveway drainages were not sampled, but should be looked at in the future as possible small contributors whose cumulative load may be notable.

Lake Attitash sediments portray a historical chronology of environmental successes through the years. Significant reductions in lead, historical pesticides such as DDT, and heavy metals like mercury are a direct result of environmental regulation and technological controls through the Federal Clean Air and Clean Water Act. It is no coincidence that there is now a prevalence of resident nesting American Bald Eagles in the immediate vicinity, and that many of the local fish are now fit for human and wildlife consumption based on reductions in fish tissue mercury levels. Lead exposure levels that at one time had significant human and wildlife health effects have been significantly reduced through this landmark legislation. Federal grants for development of municipal sewer and water infrastructure have also helped considerably. In contrast to these successes, the sediments also reveal the very significant and relatively recent increases in organic deposition within the lake and their accompanying loads of nutrients that are the catalysts for harmful algal bloom production, anoxia, and loss of aquatic habitat and function.

Fish within Lake Attitash show the success story of reduced mercury and pesticide levels in the environment and up the food chain, but also reflect the transference from these to other stressors. Nutrient enriched waters now limit fish habitat availability through development of anoxic zones, and significant thermal changes produce stressful conditions for many species accompanied by reduced oxygen levels and increased susceptibility to diseases. Many of the fish within the lake now show these stresses by their physiological conditions, including eroded fins, lesions, gill discolorations, and other anomalies. Proliferation of aquatic plants have also provided abundant refugia and allude to a possible burgeoning fish population. The lake population is depauperate in larger predatory fish that would assist in helping to balance the trophic levels, and was found to have an overabundance of smaller sized panfish that may be stripping the lake of important zooplankton that graze on the phytoplankton of the lake.

Aquatic macrophytes tell another story in the lake, and appear to have been around for quite some time based on historical anecdotal evidence. Their proliferation appears to have been tempered by the hydrologic manipulations through the years and only rose to nuisance levels after the lake went from a major source of hydropower to a use dominated by recreational activities, at which time a permanent pool elevation for the lake was established. With the current flushing rate of approximately twenty years during the summer months, in conjunction with the current practice of lake drawdown practices, the lake is set up for a constant feedback loop of nutrient cycling of internal in-lake nutrients, combined with an incremental annual increase in nutrients to the lake from the surrounding watershed. Aquatic plant management practices through herbicide treatments and winter drawdown practices will likely only exacerbate the problem. Evidence of nutrient enrichment and associated algal blooms seems to have been present as early as 1944, when the first known bloom was reported and investigated by the local board of health. Algal blooms were likely mitigated by the hydrologic manipulations of the time, much like the aquatic macrophytes. Although the same phytoplankton communities appear to presently exist as did in 1977, a major shift has occurred from a dominance of green algae, to that of a blue-green dominated system, with green algae abundances remaining relatively the same based on available data. Likely causes for this shift are the transition of the lake from an unstratified to a stratified lake system undergoing summertime anoxia with release of phosphorus from the sediments (internal loading) and the emergence of in-lake nitrate nitrogen concentrations.

A respectable understanding of the past is an important component in being able to appropriately plan for the future, and Lake Attitash has revealed an interesting and colorful history, with many insights into what has caused it to arrive at its current condition. With these points in mind, it should be noted that in general this lake at one time was much shallower than it is today, and current efforts are focused on management of a waterbody outside of its natural state. A balance of management practices will need to be found in order to provide the maximum number of beneficial uses, while still maintaining the ecological integrity of the system. Based on these findings the following steps are recommended.

9.1 Recommendations/Next Steps

The following recommendations and next steps outlined here may not be entirely inclusive of *ALL* available remedies (dependent on management goals), but it provides a starting point for entering discussions for improving the current condition of the lake. Lake management, as with other sciences, is continuously evolving and new technologies and approaches likely exist of which the author may not be aware. The author has made a good faith effort to be as inclusive as possible at presenting all potential management options at a cursory level, whether viable for this specific lake or not.

1. In order to understand changes in lake conditions, see responses to best management practices, and appropriately plan for future management efforts, lake monitoring is imperative. This effort can be somewhat selective in nature depending on the circumstances, but should have a core set of monitoring parameters and locations that are consistently sampled from here forward. Inconsistent temporal and spatial sampling efforts can lead to much conjecture on probable causes of impairments as well as be misleading for the best direction for future management efforts. As a minimum, the following parameters should be collected, analyzed, and organized in a consistent structured format (i.e. database/spreadsheet). Optimal locations would be at the major inflows, Birches Dam outlet, and the deep hole location of the lake. At a minimum the following should be implemented.
    1. Minimum- Weekly deep hole secchi readings.
    2. Minimum- Monthly deep hole epilimnetic integrated chlorophyll samples.
    3. Minimum- Monthly deep hole Total Phosphorus.

    4. Minimum- Continuous monitoring of stage height for discharge interpolation.
    5. Optional- Twice monthly phycocyanin (and filtrate for correction) or monthly phytoplankton ID.
    6. Optional- Minimum twice monthly deep hole physical chemistry profile (dissolved oxygen, pH, temperature, conductivity).

2. Efforts should be undertaken to better understand the hydrology of the system from a groundwater perspective. This could involve simple initiatives such as the monitoring of well levels to understand the groundwater gradient and flow directions, surface water level monitoring around groundwater well fields hydraulically connected to the lake, and the placement of seepage meters within the lake to better understand the groundwater contributions to the lake. These efforts would help in developing a sound hydrologic management program for the lake. Areas where wetlands have been short circuited, such as at Bisson Lane and Sandy Beach, should be looked at to determine if groundwater seepage from the wetland is migrating in to the lake or if that function has been lost.
3. A continuous monitoring of stage height/discharge should be initiated. The optimal location would be at the Birches Dam, as long as accurate records of flashboard removal and placement were maintained. Other locations would also be helpful, such as the Back River and possibly the Southwest Inlet. Water levels can easily be recorded using simple inexpensive level loggers that will record levels at predetermined intervals over long time periods. Accurate stage/discharge is critical for making accurate assessments of nutrient loads leaving the lake and understanding the hydrology of the system. Improvements could be made to the management of discharge from the lake in relation to flashboard manipulations.
4. BMPs that are implemented within the watershed need to be monitored in order to ensure that they are constructed properly and functioning as intended. It is also critical that these controls are being maintained in order to receive the most benefit from these often large investments. Historically this has been one of the biggest problems under 319 and similar grant programs; once construction approval is given, these structures are often forgotten or neglected. Some of these current structures could be altered to improve retention time and promote more infiltration to groundwater.
5. More improvements to drainage conveyances could be made with emphasis on private driveway drainages that directly convey runoff into the lake. Efforts should be made to focus on green infrastructure improvements such as pervious driveway surfaces, or conveyances that move water into retention/detention structures that will “pre-treat” prior to entering the lake and slow the migration of water out of the system while maximizing infiltration.
6. SD01, the concrete storm drain in front of “Kurt’s” house, just east of the public boat ramp, needs to be improved upon. In addition to the construction of a proposed rain garden, a catch basin or forebay area prior to the rain garden would significantly help in keeping suspended solids and adsorbed nutrients from entering the lake. There should also be public outreach in this area about lawn fertilizers, pet waste, etc. as the Nitrate levels were relatively high in this area.

7. From a management perspective, the watershed should be looked at as a whole, as the most beneficial lake management efforts at reducing external nutrient loads usually work from the shoreline out away from the lake rather that from the shoreline in to the lake. Partnerships with local conservation commissions and public works officials can help ensure that homeowner and public works practices along the lake front implement consistent and current best management practices, from natural shoreline protection measures and bioengineering practices that not only enhance the aesthetics of the lake and waterfront and improve property values, but provide natural nutrient attenuation and restore natural lake edge function and processes. Old boilerplate standards such as typical retaining wall structures, impervious driveways, and the like should be discouraged. New developments or individual construction should mandate BMPs that eliminate or minimize any runoff from the site and optimize infiltration.
8. Equally as important to lake ecological health and water quality as management of the external nutrient loading from the surrounding watershed, is addressing any nutrient sources that are coming from within the lake itself. Internal nutrient loading of phosphorus and nitrogen due at least in part to anoxic conditions is occurring in Lake Attitash and is a major factor in the production of summertime cyanobacteria blooms. Both components of nutrient loading (external and internal) need to be addressed in order for progress to be made in mitigating water quality issues in Lake Attitash.
9. Natural wetland function should be restored wherever possible. Wetlands provide natural nutrient attenuation and filtration, provide flood and storm water storage, and provide critical habitat to many forms of wildlife. Many programs currently exist such as the Massachusetts Department of Ecological Restoration (mass.gov) and the Natural Resource Conservation Service (NRCS) that have programs designed to assist stakeholders as well as agricultural operations in restoring these critical resource functions and enhancing wildlife habitat (nrcs.usda.gov).

   Note: The Nitrogen/Phosphorus relationship should be looked at carefully and fully understood prior to Implementation, because there has been relatively current research on some lakes that shows in-lake nitrogen concentrations can act as inhibitors to phosphorus release under anoxic conditions[1].
10. The high concentration of nitrates emanating into the Back River directly adjacent the Sargent farm croplands, tile drain outlet, and composting area are likely the result of agricultural fertilizers and manures leaching out of the groundwater from underneath these fields. This could be a major source of nutrient problems in Lake Attitash, but can be easily remedied or largely mitigated through the use of wetland restoration practices in this segment of the Back River. Wetland areas can be large contributors to denitrification by reducing nitrate through anaerobic bacteria common to wetland environments. The very low oxygen levels and abundance of organic carbon make these areas ideal for denitrification. The Sargent Farm wetland area should be returned to a more natural condition, where the Back River regains its lost sinuosity, being restored from the historical trenching practices and helping in the denitrifying process.
11. Winter drawdown efforts should be discontinued, or at most approved only under very extenuating circumstances. Although this is a convenient practice for ease of making

repairs to retaining walls and the taking out of docks in the fall, it is not a healthy practice for this lake and is exacerbating the nutrient cycling problem in the lake. This practice is working in a reverse direction of natural hydrologic processes and is creating a nutrient feedback loop within the lake. Continued current practices will likely result in greater impacts that will require more costly mitigation efforts that will only be temporary in nature.

12. The Amesbury Watershed and Waterway Management Plan should be reviewed. Efforts should be made to attempt to bring the lake hydrology back to more “normal” natural conditions. This will require more of a balance of uses that may not be palatable to every stakeholder at all times, but will provide a benefit to all stakeholders over the long term. For instance, redevelopment of some residential wells may need to take place in conjunction with alternate drawdown strategies in order to divert the more expensive costs of water treatment and filtration technologies for mitigating blue-green algae and associated cyanotoxins from public drinking water supplies. Periodic “natural” drawdowns during the summer months preceding wet weather events or on a routine basis may reduce or eliminate the occurrence of harmful algal blooms and promote cooling groundwater inflows, yet limit boating recreation for a period of time on the lake. The establishment of a definitive pool level and its associated timeline for the lake may not be in the best interest of the resource or its users.
13. Efforts should be made to work collaboratively with agricultural operations in the watershed to eliminate nutrient inflows into the lake. These operations are still a source of some nutrients to the lake and resources are available to agricultural operators from the NRCS and others that provide opportunities for improving water quality and ecological integrity.
14. Focused efforts should also be directed towards small hobby farms and horse paddocks to ensure that these entities do not contribute to water quality issues in the lake or to public water supplies. Such practices were identified in the watershed and were contributing nutrients to the surface water tributaries.
15. *Chemical treatments: Utilizing aluminum and more recently lanthanum for sequestering in-lake phosphorus/nutrient concentrations due to internal loadings has shown promise. Treaments often improve water clarity, which may result in more light penetration and the potential for additional aquatic macrophyte growth. Depending on the waterbody, treatment benefits may last from eight to twenty years. Discussions should be initiated for this treatment option based on management objectives, cost, logistics & permitting, longevity of treatment, etc.
16. *Hypolimnetic withdrawals: Removal of anoxic nutrient laden bottom waters has proven to be an effective management strategy for improving the water quality of some stratified eutrophic lakes. Discussions should be initiated for this treatment option based on management objectives, cost, logistics & permitting, longevity of treatment, etc.
17. *Hypolimnetic aeration: Aeration of anoxic waters utilizing compressed air or pure oxygen has shown to be effective in mitigating anoxia, algal production, and phosphorus accumulation. This strategy provides increased habitat for fish and other aquatic life with oxygenated waters, but may also transport nutrients to the surface which may stimulate

algal blooms. Discussions should be initiated for this treatment option based on management objectives, cost, logistics & permitting, longevity of treatment, etc.

18. *Dredging: The removal of in-lake nutrient rich organic sediments has been proven as an effective management tool at mitigating the source of anoxia and associated nutrients. Many types of dredging are possible such as dry dredging (draining the lake and then dredging), wet excavation, pneumatic dredging, suction dredging, and reverse layering techniques. These are often costly endeavors even at a small scale, but deserve to be discussed, as the approach can provide long term benefit. Discussions should be initiated for this treatment option based on management objectives, cost, logistics & permitting, longevity of treatment, etc.

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* The asterisked management options listed above should be considered as potential options, and not recommendations based on the findings of this study. They are presented here for informative purposes and as a starting point from which to enter discussions on further efforts that may be needed to determine their viability as an appropriate management strategy. As stated earlier, this is not an all-inclusive list, but presents some of the current strategies utilized in improving lake water quality and ecological integrity with potential applicability to most surface water bodies. It is imperative that lake management objectives be decided upon and clearly stated, as some management strategies that are effective for one objective may prove counter-productive for another. Such an example would be managing for mitigating algal blooms with resulting improved water clarity, but having the effect of exacerbating the proliferation of aquatic macrophytes.

References

1. Hemond F., Lin K., Nitrate Suppresses Internal Phosphorus Loading in an Eutrophic Lake., Water Research 44 (2010) 3645-3650. R.M. Parsons Laboratory, Department of Civil and Environmental Engineering, Cambridge, MA

Web Links

1. http://www.mass.gov/eea/agencies/dfg/der/
2. http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/