Case Study: Reduction of Total Phosphorus Loads to Big Platte Lake, MI Through Point Source Control and Watershed Management.

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ABSTRACT

The Platte River watershed is located in the northwest part of Michigan's Lower Peninsula. The watershed has a drainage area of approximately 495 km^2. The River has a mean annual flow of about 3.50 m^3/sec. Big Platte Lake is the largest lake in the system with a mean depth of 8.2 m and hydraulic retention time of 0.75 years. The lake is the receiving water body for roughly 95% of the drainage area before emptying into Lake Michigan at the Sleeping Bear Dunes National Lakeshore.

The Platte River and Big Platte Lake are under pressure from both point and non-point nutrient sources. The only point source in the watershed is a Coho and Chinook salmon hatchery operated by the Michigan Department of Natural Resources (MDNR). This source is highly regulated and currently represents a relatively small fraction of the total phosphorus loading to the lake. On the other hand, internal and non-point nutrient loads are expected to increase throughout the watershed because the area is one of the fastest growing regions in the State.

Several years ago the water quality of Big Platte Lake noticeably declined with an expansion of fish production and phosphorus loads from the hatchery. After a lengthy court case, the MDNR and the Platte Lake Improvement Association (PLIA) agreed on a program to reduce the hatchery phosphorus discharge. In addition, a phosphorus standard of 8 mg/m^3 was established for the lake. Consequently, the hatchery loading has declined and further reductions are expected with the completion of ongoing major renovations. These reductions have resulted in improvements in the water quality of Big Platte Lake. However, additional watershed scale efforts are needed to maintain the water quality of the lake over the long-term. Thus, the MDNR, PLIA, and the Benzie County Conservation District are working together to reduce non-point phosphorus loading to the lake through comprehensive watershed management.

This partnership currently conducts a comprehensive water quality monitoring program for the hatchery, lake, and several tributaries. The data generated by the program are critical to the development and preliminary validation of two system models, a watershed loading model (BASINS) and a lake water quality model. The reliability of the lake water quality model is being enhanced by conducting special laboratory and field studies that can be used to quantify the value of several model coefficients.

The two models will be used to assess seasonal and long-term improvements in lake water quality that result from reductions of point and non-point total phosphorus loading. In this manner, the models will facilitate local water resource protection efforts by providing quantitative tools for evaluating the impact of future changes in land-use, the effectiveness of local ordinances, and public outreach activities.

KEY WORDS

Big Platte Lake, watershed modeling, BASINS, lake water quality modeling, fish hatchery management.

INTRODUCTION AND BACKGROUND

The Platte River watershed is located in the northwestern part of Michigan's Lower Peninsula. It has a total drainage area of approximately 495 km^2 (see Figure 1). The watershed is unique in this region of Michigan because it is comprised of several connected lotic and lentic segments. The hydrology of the Platte River is relatively stable because the area has deep glacial outwash deposits and extensive groundwater resources. The USGS maintains a gauging station on the river as shown in Figure 1. The mean discharge of the river at the gauging station is 3.5 m^3/sec. Twenty percent of the flows exceed 4.1 m^3/sec, and 80% exceed 3.1 m^3/sec.

Big Platte Lake is the largest lake in the watershed. It has a volume of 83.5 million m^3, a mean depth of 8.2 m, a maximum depth of 28 m, and a mean hydraulic retention time of 0.75 years. The lake has a surface area of 10.2 km^2 and a drainage area of 471 km^2. The lake receives the drainage from roughly 95 % of the watershed before emptying into Lake Michigan at the Sleeping Bear Dunes National Lakeshore.

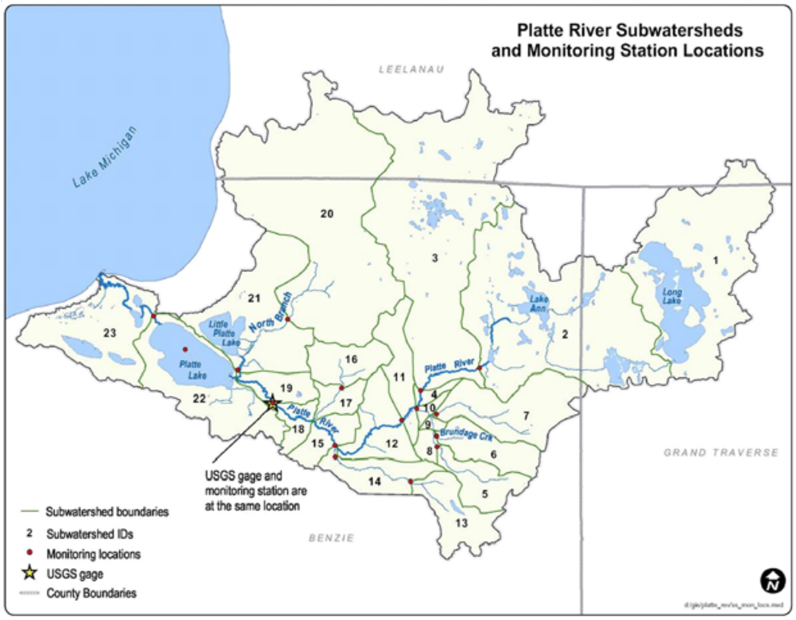

Figure 1. Platte River Watershed.

The Platte River State Fish Hatchery is the only point source in the watershed. The outflow from the hatchery discharges into the Platte River upstream of the village of Honor, Michigan. The hatchery is located 17.7 km upstream of Big Platte Lake and 29 km upstream from Lake Michigan.

Hatchery - Early History

The MDNR has operated a fish culture facility on the Platte River since 1928. The facility began as a trout rearing station and was expanded during the period from 1966 to 1972 to support the Department's Great Lakes salmon program. Figure 2 shows the history of the use of food at the hatchery. Approximately 16,000 kg of fish feed was used annually prior to facility expansion program. A maximum of about 250,000 kg of feed was needed in 1974 during the peak production period. Food use at the hatchery has gradually declined and is currently about one-third of the maximum mid-1970 levels.

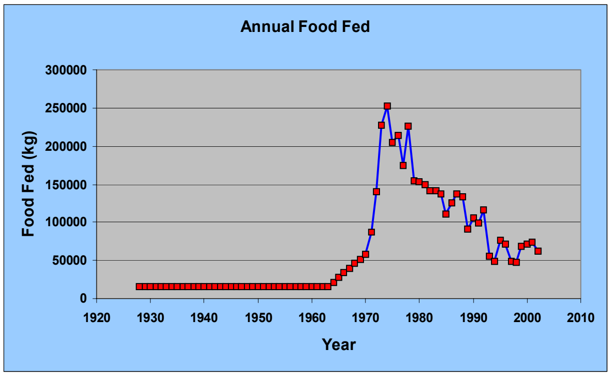

Figure 2. Historical Change in Food Used for Fish Production at the Hatchery.

The annual production of fish at the original rearing station was approximately 10,500 kg. This fish production is about two-thirds of the amount of food fed. Figure 3 shows historical changes in fish production at the facility as a function of time that generally follows the pattern of food usage.

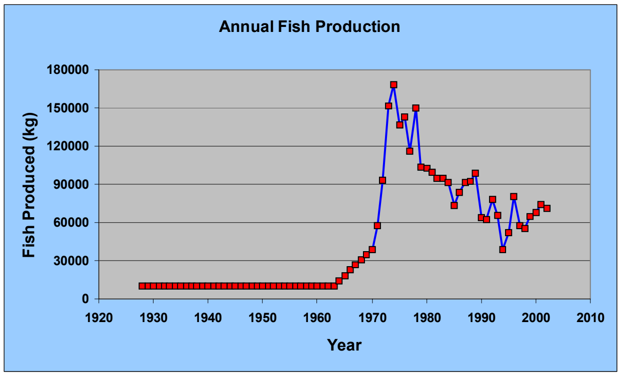

Figure 3. Historical Change in Annual Fish Production at the Hatchery.

The process water used to culture the fish becomes enriched with phosphorus from fish fecal pellets and unconsumed feed. The net phosphorus loading from the Hatchery is defined as the increase in the phosphorus concentration in the process water above background levels times the flow rate from the facility. During the period from 1928 to 1964 the phosphorus loading was relatively constant at about 74 kg/yr. This loading increased to a maximum of about 1960 kg/yr in 1974. The increase in loading was associated with increased food usage and fish production and accelerated by the fact that the phosphorus content of the feed increased because the composition changed from 66% waste slaughter house parts (0.24% P) and 33% fish meal (1.5% P) prior to the salmon program, to a nearly 100% diet of Oregon moist pellets that ranged from 2.0 to 3.5% P. Figure 4 shows data that define the history of changes in the phosphorus loading from the facility. Note that the current phosphorus loading is less than 5% of the maximum mid-1970 values.

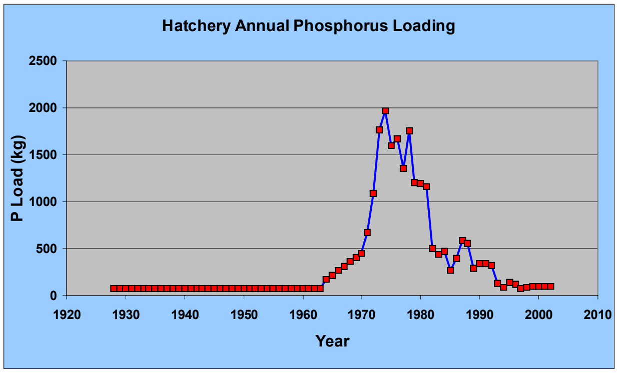

Figure 4. Historical Change in Hatchery Phosphorus Load.

Big Platte Lake Water Quality — 1940 to 1980

Big Platte Lake water quality conditions declined markedly in the late 1960's and early 1970's. The decline was first noticed as anecdotal observations and comparisons with historical photographs by local long-time permanent and seasonal residents. Such observers also noticed a marked deterioration of the rooted plant population in the deeper sections of the lake and most notably the complete disappearance of emergent round stem bull rushes. These rushes grew in water depths up to 4 m and were about 3 cm in diameter. The population density of rough fish such as brown bullhead, long nose gar, white sucker, carp, and bowfin also increased significantly. In addition, there was a marked reduction in the density of native clams and a near compete disappearance of a once abundant crayfish population and annual mayfly hatch. Historical data reported prior to the late 1960's and observations from the 1980's also document declines in Secchi Depth, increases in algal blooms, and decreases in bottom water dissolved oxygen concentrations. These changes are summarized in Table 1.

A paleontological study of fossil chironomids was conducted on Big Platte Lake sediments that confirmed anecdotal observations regarding the decline of water quality in the lake (Clerk, 2001). The sediment cores indicated minor chironomid impacts associated with the start up of the trout rearing station in 1928. Subsequent major changes related to oxygen depletions were observed that were consistent with the expansion of the program in 1966.

Parameter	1940	1980's	Reference
Minimum Secchi Depth	**3 m**	**1m**	**Brown & Funk (1940)** **MDNR (1990)**
Algal Blooms	**none**	**frequent**	**State of Mich. (1988)**
Minimum Dissolved Oxygen	**1.8 mg/L**	**0.1 mg/L**	**Brown & Funk (1940)** **MDNR (1990)**
Rough Fish	**11 per 300 m of net**	**306 per 300 m of net**	**MDNR (1981)** **Kenega & Evans (1982)**
Rooted Plants	**24 species**	**10 species**	**Brown & Funk (1940)** **State of Mich (1988)**
Crayfish	**abundant**	**sparse**	**State of Mich (1988)**
Mayfly	**abundant**	**sparse**	**State of Mich (1988)**

Table 1.Historical Water Quality Changes in Big Platte Lake.

Legal History

Long-time local and season residents were initially puzzled by the rapid decline in the water quality of Big Platte Lake. Individuals first began to share their concerns with the MDNR in 1974. Subsequently the Platte Lake Improvement Association (PLIA) was established in August of 1978 for the purpose of restoring and preserving the water quality of Big Platte Lake.

The MDNR applied for a NPDES permit for the Hatchery in 1979 and the PLIA presented a lengthy list of objections. In response, the MDNR commissioned additional water quality studies of the watershed with the PLIA providing the local match (Bostwick, et al. 1983). This study and others (Grant, 1979) have measured the hatchery phosphorus loading and defined baseline water quality conditions for the lake, river, and tributaries.

In the late 1970’s and early 1980’s, the PLIA again expressed concerns to the MDNR regarding the continuing decline of the water quality of the lake. Subsequent efforts to negotiate satisfactory responses failed, and as a consequence, the PLIA sued the MDNR in 1986 in Ingham County Circuit Court under the Michigan Environmental Protection Act (MEPA). The PLIA contended that a draft 1985 NPDES permit level of 636 kg P/yr was not adequate to protect the water quality of the lake and that salmon entering and subsequently dying in the lake should be considered by the permit. In 1988, the court agreed with the PLIA and ruled that the MDNR was polluting, impairing, and destroying Big Platte Lake. As a result, the MDNR was required to reduce phosphorus loadings from the facility to attain a volume-weighted annual average total phosphorus concentration of 8.0 mg/m^3 in the lake. In addition, the MDNR was required to use a low-phosphorus fish food (<1.0% P) and halt the migration of salmon at the lower weir. The migration part of the order was later modified to allow the passage of the first 20,000 fish then 1,000 fish per week from August 15 to December 15.

On June 12, 1998 the Michigan Department of Environmental Quality (MDEQ) issued another permit to the MDNR that regulated the discharge of the fish rearing water. On August 7, 1998 the PLIA filed for a contested case hearing seeking to invalidate or modify the permit. After many months of intensive negotiations, the MDNR and PLIA signed and entered a March 10, 2000 Consent Judgment. The agreement allows for the phased installation of state-of-art effluent control equipment. Eventually the facility discharge will be limited to 79.5 kg P/yr and no more than 34.0 kg P in any 3 month period. Water use at the facility is limited to 0.88 m^3/sec. In addition, no more than 20,000 Coho salmon and 1,000 Chinook salmon are allowed to pass beyond the lower weir, and that all salmon harvested at the upper egg take weir shall be removed from the watershed. The agreement requires extensive hatchery monitoring (including antibiotics and antiseptics), compliance audits, oversight, and damage provisions.

Finally, it is noted that the Consent Judgment has brought the parties together and they are now working together to implement a comprehensive program to identify and control point as well as non-point sources of phosphorus within the watershed. This cooperative spirit is absolutely critical and is a major accomplishment of the Consent Judgment. This Consent Judgment provides the framework for the related monitoring and analysis issues presented in this paper.

Watershed Management Plan

Much of the Platte River watershed drains areas located in the northern half of Benzie County, MI. (see Figure 1). Although it is the smallest county in the State by land area, it is ranked as the third fastest growing. Population growth in critical areas important to water resource protection is projected to exceed 75% by 2025. In addition, the watershed is adversely affected by expanding development pressure from the adjacent urban center of Traverse City, MI. Thus, although significant measures to control point sources from the Platte River State Fish Hatchery are well underway, the Platte River and Big Platte Lake are under pressure from non-point nutrient and sediment loads.

Efforts to develop a comprehensive watershed management plan began in April 2000 in response to growing concerns over the declining water quality in several of the area lakes, tributaries, and reaches of the Platte River. During the initial phases of the effort, the growth of non-point sources of pollution was identified as a potential threat to ecological stability and recreational quality.

In response to these concerns, the Benzie Conservation District secured funding through the Clean Water Act, Section 319 program to develop a plan leading to the restoration and preservation of water resources in the Platte River basin. A 30-member watershed council representing all stakeholder groups in the watershed was formed to guide the watershed management planning effort. Key partnerships were formed with Federal and State agencies as well as with regional and local interests groups to insure the effectiveness of the effort. In 2002 the MDEQ formally approved the Platte River Watershed Management Plan. This plan is the culminating document of a two-year, multi-partner effort to identify water resource impairments and threats in watershed. The program is participating in the development of decision support models that will provide local planners quantitative information that is necessary to properly site and regulate land development. In July 2002, efforts began to undertake some of the pollution reduction tasks proposed in the plan such as non-structural improvements to road stream crossings and implementation of storm-water ordinances.

POINT SOURCE CONTROLS

Hatchery Current Operations

The Platte River State Fish Hatchery is currently the main Coho salmon egg take facility in the Great Lakes region and produces most of the Coho and Chinook salmon needed by the Michigan Department of Natural Resources’ Great Lakes fishery management program. The hatchery uses only surface waters from the Platte River, Brundage Creek, and Brundage Spring. The hatchery used an average of about 69,000 kg/yr of feed between 1999 and 2002 and produced about 69,000 kg/yr of Coho and Chinook salmon. Note that the current ratio of fish production to food-use has increased from historical levels of about 0.66 to 1.0. The current production targets for the facility are 1.5 million Coho salmon at 36 individuals/kg and 4 million Chinook salmon at 220 individuals/kg.

<u>Hatchery Pollution Abatement Activities</u>

The court ordered abatement measures have been instrumental in decreasing the hatchery annual phosphorus load from about 1750 kg in 1974 to current levels approximately 90 kg/yr. These reductions are attributable to improved solids handling and the use of low phosphorus foods with phosphorus concentrations below 1%. The pattern of declining loads is shown in Figure 4. Over this same time period, the lake total phosphorus concentration has decreased from about 12.0 to 7.5 mg/m^3 and the average Secchi Depth has increased from about 2 to 4 m. Figures 5 and 6 illustrate these trends.

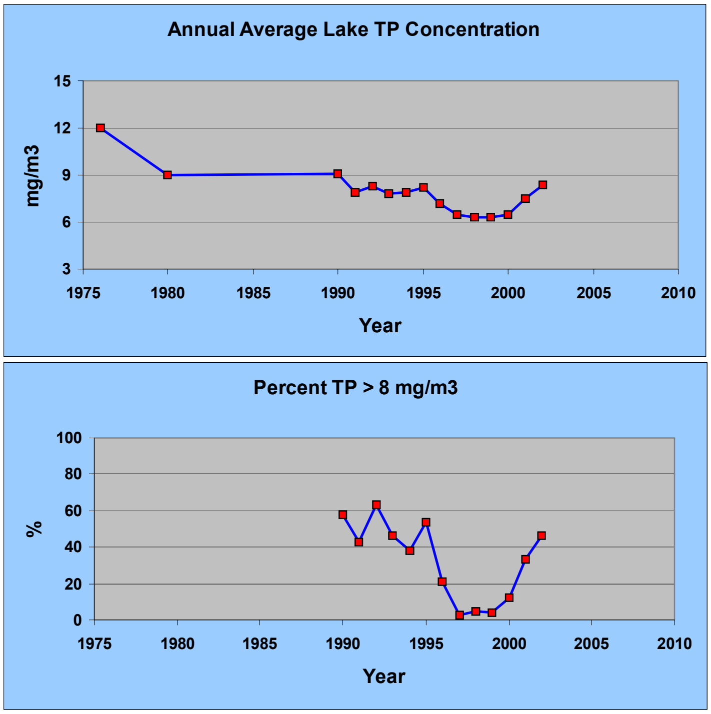

Figure 5. Lake Total Phosphorus Concentration and Percent Violation.

In addition, the Consent Judgment cleared the way for some major renovations of the facility that were completed in January 2004. Some of the main improvements included increasing from a 1.5 to a 3.5 pass system and screening all outdoor production water after each pass with 18-20 micron disk screens. Solids recovery was enhanced by screening all indoor production water; reconfiguring the outdoor raceways to force the movement of solids to the screens; adding a clarifier to settle solids; and adding a large sludge storage tank to effectively thicken and remove solids from the facility. Additionally, new water monitoring and sampling devices were installed to improve data collection abilities. Monitoring efforts are underway to determine the effectiveness of these technical improvements.

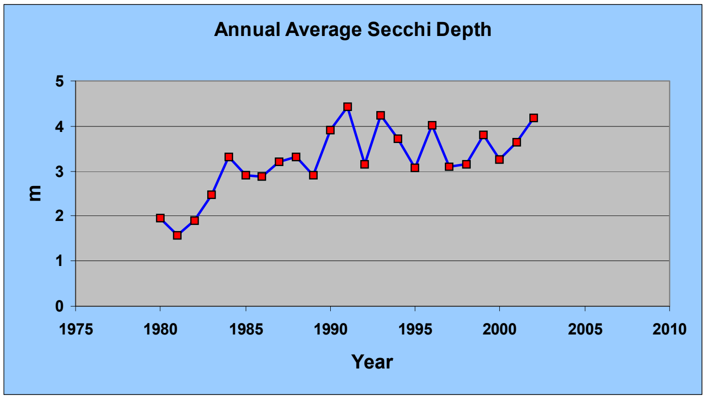

Figure 6. Historical Change Lake Secchi Depth.

While it is expected that these renovations may eventually result in further improvements in Big Platte Lake water quality, it is clear that rehabilitation takes time. Big Platte Lake total phosphorus concentrations were only reduced about 35% in spite of overall point source loading reductions of about 95% from the period of peak production. The limited response was likely the consequence of internal phosphorus recycling and non-point loading. With the current phosphorus loadings from the hatchery, it will become increasingly difficult to attain additional improvements in lake water quality from more aggressive effluent management at this facility. Therefore, further improvements in the water quality of Big Platte Lake will require control of non-point phosphorus sources from the watershed.

NON-POINT CONTROLS

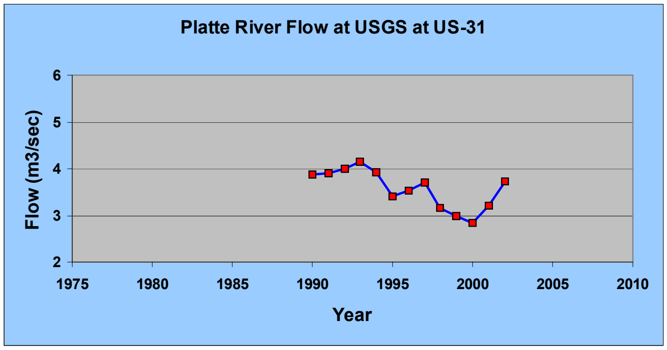

Figure 7. Historical Change in Total Annual Flow of Platte River.

The last section has shown that the point source of phosphorus from the hatchery has been reduced to near historic low levels. Yet, the phosphorus concentration in the lake has increased for the past two years, and the 8.0 mg/m^3 standard is being attained only about 60% of the time (see Figure 6). One reason for this trend may be that flows from the watershed that carry non-point sources of phosphorus have increased during the past 2 years (see Figure 7). However, it is not clear if the magnitude of such changes in flow is sufficient to cause the observed increase in lake phosphorus concentration. Such questions can only be answered through the use of reliable watershed loading and lake quality models that are based on extensive monitoring and laboratory data.

Non-point phosphorus loads from Platte River watershed are being analyzed using the Better Assessment Science Integrating Point and Non-point Sources (BASINS) approach. This is an integrated multipurpose environmental analysis tool developed by the U.S. Environmental Protection Agency's (EPA's) Office of Water. It comprises of a suite of interrelated components that perform various watershed analyses (USEPA, 2001). A powerful element of BASINS is the Hydrological Simulation Program – FORTRAN (HSPF). HSPF is a lumped parameter watershed and stream model that is well suited for modeling non-point phosphorus loads from the Platte River drainage basin.

BASINS can be used to simulate non-point pollutants coming off the land. It can also predict the consequences of future land use management scenarios by simulating the generation and movement of pollutants such as sediment and phosphorus from multiple sources in the watershed. These results can be used as inputs to a water quality model for the lake. In this way the BASINS and lake models can be used to help assess the impacts of both point sources from the hatchery and non-point sources such as agricultural operations, forests, and land developments. Figure 8 illustrates the overall approach.

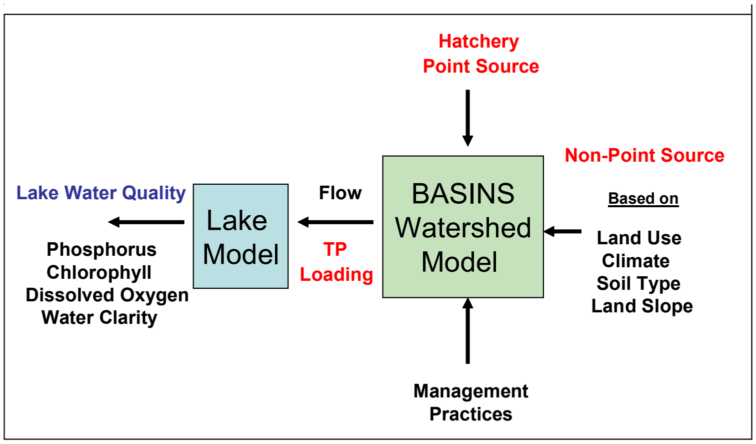

Figure 8. Components of BASINS and Lake Water Quality Model.

BASINS – Input Data

The BASINS model requires detailed data that describe various characteristics of the Platte River watershed. Geographic Information Systems (GIS) is being used to provide a convenient automated method to access and use these data. Data describing features such as land-use, stream networks, lakes, and soil characteristics are available in a GIS format. Other site-specific data, such as that collected from stream gauging sites and weather stations are also required to accurately simulate watershed response.

The Platte River watershed boundary was obtained from the MDEQ Land and Water Management Division, Hydrologic Studies Unit. This watershed boundary was published in 1998 and was created from USGS 7.5 minute Topographic Quadrangles, using MIRIS digital base maps as a control reference. The watershed boundary defines the study area and includes portions of three counties (see Figure 1). The stream network for the Platte River and its tributaries was obtained in GIS format from the state of Michigan. This information was supplemented with measurements of cross-section profiles of the Platte River and many of its tributaries. Continuous flow data were obtained from the USGS gauge located on the Platte River near Honor, MI (Gauge No. 04126740).

Land-use data were available in GIS format from the Benzie County Conservation District (Benzie County 1996 data and Grand Traverse County 2000 data) and from the Land Information Access Association (Leelanau County, 2000 data). Some manipulation of the data and reclassifications of land-use designations were needed to produce a coherent and consistent map of land-use within the watershed. The final land-use categories employed in the model are shown in Figure 9. The largest land-uses are forest (56.5%), pasture (16.1%), and cropland (8.6%). Currently, about two-thirds of the watershed remains undeveloped.

Soils data are used to estimate model parameters related to infiltration, water storage, and susceptibility to erosion. The USDA STATSGO soil data for the watershed were used for the Platte River watershed.

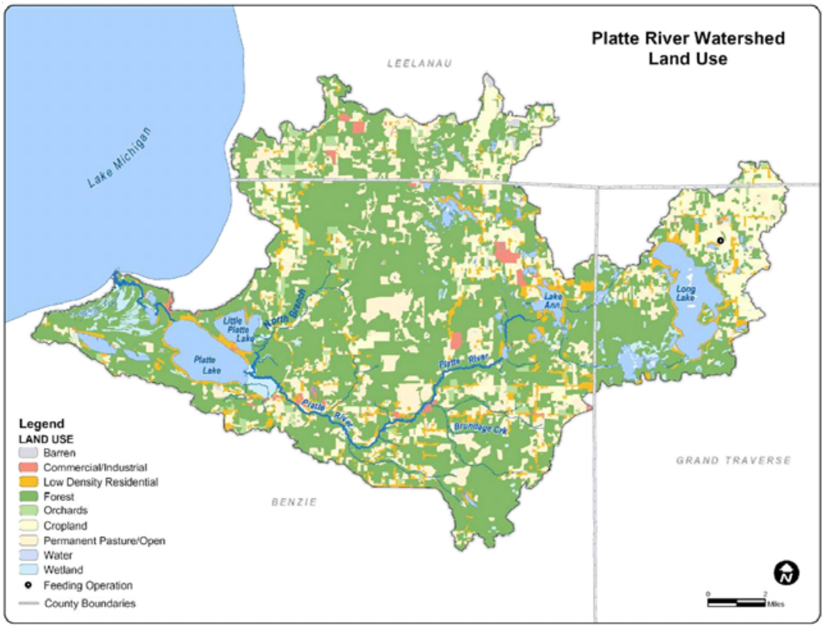

Figure 9. Current Land Use in the Platte River Watershed.

Climatological data are used as forcing functions to simulate the hydrologic cycle. Precipitation and evaporation data, along with soil properties, are used to predict the relationships between rainfall and runoff in the model. Runoff generated by precipitation or snowmelt may cause erosion and transport pollutants to Platte Lake. Air temperature, dew-point temperature, evaporation, and solar radiation data are used to predict snowmelt, stream water temperature, and evaporation. The climatological data required by the model were obtained from the National Climatic Data Center (NCDC) and the International Atmospheric Data Network.

BASINS - Model Calibration

Calibration of the BASINS watershed model is proceeding using a phased approach. The first phase consists of a baseline calibration for flow and total phosphorus. The flow calibration starts in March 1990 to coincide with the installation of the USGS flow gauge. The calibration ends in September 2000 because at the time this work was initiated, the meteorological data used to estimate evaporation were only available through 2000.

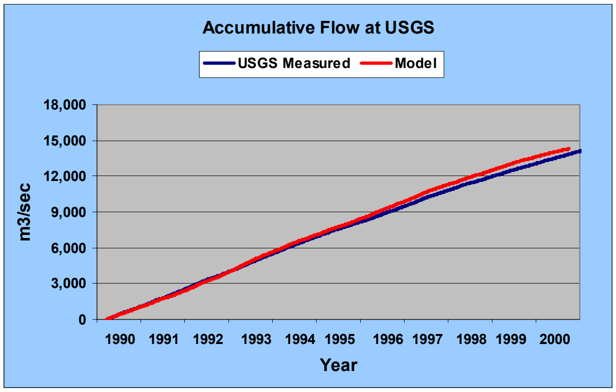

Figure 10. USGS and Model Accumulative Flow (1900 – 2000).

The baseline total phosphorus calibration begins in November 1989 and ends in September 2002. This period corresponds to the available data record. The total phosphorus calibration is considered preliminary because sufficient suspended sediment and wet weather event data are not available for the baseline calibration period. Suspended sediment data will improve the phosphorus calibration because phosphorus binds to sediment. Therefore, watershed erosion and scoured sediment are potential sources of in-stream phosphorus. Concurrent in-stream suspended sediment and phosphorus data will be collected in 2004 to facilitate the calibration of the model. Local rain and snowfall data will also be collected along with wet-weather event stream data that will better define site-specific event mean concentrations (EMC) and other in-stream responses to non-point source loadings.

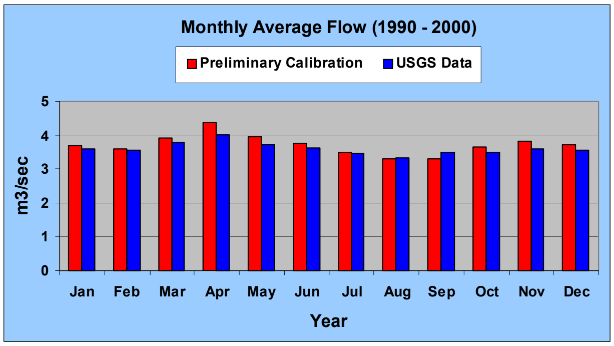

Figure 11. USGS and Model Monthly Average Flow (1900 – 2000).

The flow calibration focused on comparisons between model results and observed flows at the USGS gauge. Figure 10 compares the model predicted cumulative volumetric flow at the USGS gauge with observed values. This result indicates that over the ten-year calibration period the model does not exhibit significant bias for prediction of flow.

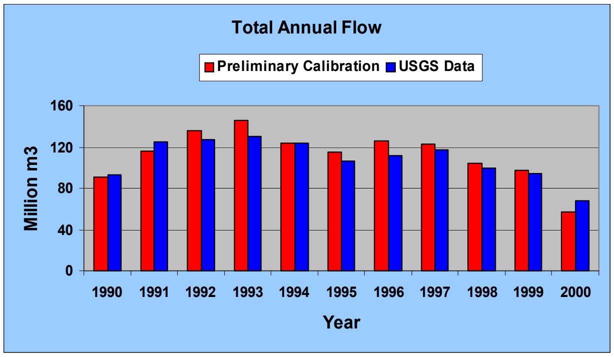

Figure 12. USGS and Model Total Annual Flow (1900 – 2000).

Figure 11 compares observed and predicted average monthly flows at the USGS gauge for the ten-year calibration period. This figure shows that the model reproduces the seasonal hydrologic response of the watershed. Figure 12 shows favorable comparisons between the simulated and observed annual volume at the USGS gauge.

This indicates that the model is adequately simulating the long-term hydrologic response within the watershed and the variations in flow volume between dry and wet years. It also indicates that the available meteorological data are adequate for long term-simulations, although more site-specific meteorological information is required for future event calibration efforts. Figure 13 presents both modeled and observed percent of average daily flows that exceed a given flow at the USGS gauge. The similarity between the two curves indicates that the flows predicted by the model are within a similar range and occur with similar frequency as those observed at the gauge. Note that the shape of the frequency of exceedance curve confirms geological evidence that flows in the Platte River are supplemented by groundwater sources (Seelbach, 1997). Overall, it is concluded that the annual and seasonal flow trends and patterns observed at the USGS are well represented by the model.

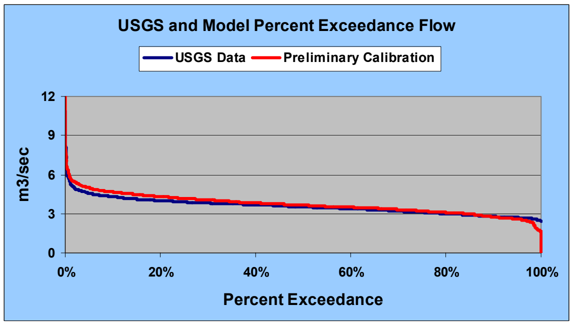

Figure 13. Percent Exceedance of Daily Average Flow (1990 - 2000).

Land use	Simulated Event Mean Concentration (mg/m3)	Event Mean Concentrations from Literature (mg/m3)
Commercial/Industrial	153	280-330
Low Density Residential	48	520-570
Grassland	8	10 –1300
Cropland	21	370 – 1300
Orchard	21	370 –1300
Feeding Operations	718	370 – 1300
Forest	9	10 - 110
Barren	20	80
Wetlands	8	120

Table 2. Simulated and Literature Event Mean Phosphorus Concentrations.

The preliminary phosphorus model calibration focused on comparisons with measured concentrations and loads at five stations using data collected between March 1990 and September 2000. The total phosphorus calibration proceeded in a two-step iterative process. The event mean concentrations for each land-use were estimated using the HSPF model and compared with literature values (see Table 2).

Next, the diffuse loadings generated by the model were adjusted (within the range cited in the literature) to match observed measurements at the USGS gauge (see Figure 14).

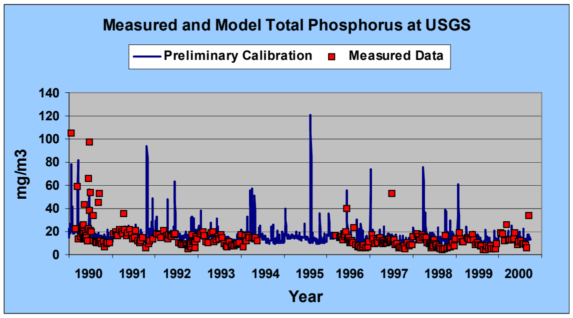

Figure 14. Measured and Model Total Phosphorus at USGS Station.

This preliminary total phosphorus calibration will be expanded when data become available for in-stream sediment and storm event concentrations of sediment and phosphorus.

BIG PLATTE LAKE WATER QUALITY

Lake Sampling Program

Big Platte Lake is sampled at 8 depths at the deepest location near the center of the lake every two weeks all year except when ice conditions restrict access. These discrete samples are analyzed for total phosphorus, turbidity, and alkalinity. In addition, a 10 m vertical tube sampler is used to obtain composite samples. These composite samples are analyzed for total phosphorus, chlorophyll, turbidity, alkalinity, phytoplankton, total dissolved solids, and calcium. Vertical net hauls are used to collect zooplankton. Other field measurements include Secchi Depth, dissolved oxygen, temperature, pH, oxidation-reduction potential, and light penetration.

Total Phosphorus

Figure 5 shows the measured volume-weighted average total phosphorus concentration in Big Platte Lake and the percent of the time that the concentrations exceed the 8 mg/m^3 standard. The concentration of total phosphorus declined from about 12.0 mg/m^3 in 1976 to a minimum of about 6.3 mg/m^3 in 1998 and 1999. This change coincided with major reductions in the phosphorus loading from the hatchery, increased development of the watershed, and the change to phosphorus-free detergents. However, the concentration increased to about 8.3 mg/m^3 in 2002 reversing the long-term downward trend. Note from Figure 7 that the USGS flow of the Platte River is higher in 2001 and 2002 compared to the past two or three years. The higher total phosphorus levels in the lake and more violations of the 8 mg/m^3 goal may be related to the higher than average flow of the River. However, there also was an accidental release of raw domestic sewage into Platte River during the winter of 2002 that may have contributed to increases in the lake concentration. Finally, an unauthorized landfill containing domestic sewage sludge and fruit processing wastes has been recently discovered that may have contaminated the groundwater and a small tributary that enters the lake below the USGS gauge station. A reliable water quality model of the lake is needed to properly evaluate the relative significance of these trends and events. Such a model must be based on an accurate assessment of the point and non-point loads and the physical, chemical, and biological mechanisms operative in the lake. Without such a model it is impossible to quantify the impact of various factors on the total phosphorus concentration of the lake.

Dissolved Oxygen

Figure 15 shows the changes in the concentration dissolved oxygen in the bottom waters of Big Platte Lake over past few years.

Note that the concentration of dissolved oxygen drops below 2 mg/L for about 100 days each year. This is an important period because this is when anaerobic conditions exist in the sediments and dissolved phosphorus is released into the hypolimnion. Note that the period of low dissolved oxygen was much shorter in 2002 compared to other years due to differences in lake temperature.

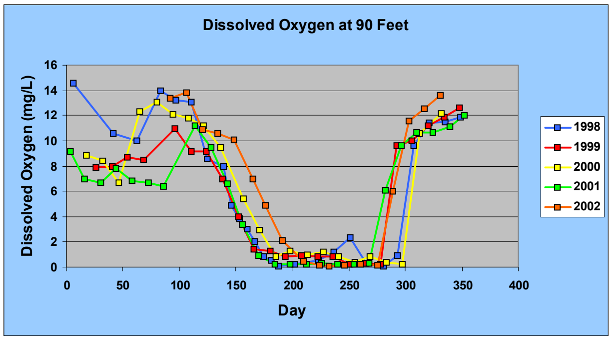

Figure 15. Dissolved Oxygen Concentration in Bottom Waters of Big Platte Lake.

Lake Water Quality Model

A comprehensive model of the lake is needed that can predict the impact of the hatchery and non-point total phosphorus loads from the watershed on water quality of Big Platte Lake. It is also important that the model accurately simulate light attenuation (extinction coefficient or Secchi Depth) and the internal loading of phosphorus from the sediments that are associated with low bottom water dissolved oxygen concentrations. The model must also be able to account for variable atmospheric temperature, rainfall, and wind patterns that impact the magnitude of the phosphorus loads and mixing conditions in the lake.

After validation, such a model can be used to estimate the effectiveness of various remedial control measures designed to promote compliance with the water quality goals of the lake.

Water quality models for Big Platte Lake have been developed by in the past by Chapra (1996), Walker (1998), and Lung (2000). Unfortunately, these models do not adequately address exchange processes between the water and the sediments and do not include dissolved oxygen or Secchi Depth as model variables. Therefore a custom model was developed for the system that includes these features. Figure 16 shows the physical layout of a three-layer horizontally mixed dynamic model for Big Platte Lake.

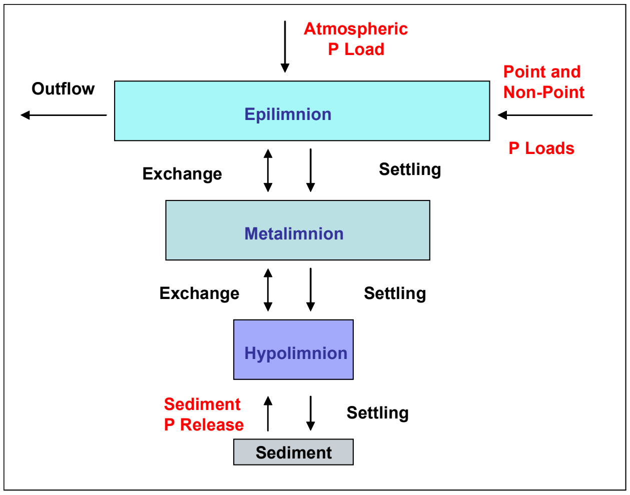

Figure 16. Components of Lake Water Quality Model.

The components of the model include tributary flow and loading, outflow, settling, exchange between adjacent layers, and sediment phosphorus release. This framework will allow simulations of the history of the water quality of the lake and permit predictions of long-term recovery and responses to remedial activities.

Figure 17 shows the major kinetic components of the model. The lake model variables are soluble and particulate phosphorus, phytoplankton and zooplankton density, dissolved oxygen, and Secchi Depth. The lake model includes mechanisms that describe the release of phosphorus from the bottom sediments under low oxygen conditions and the recycling of phosphorus by rooted macrophytes. The model mechanisms were chosen to allow accurate modeling of phosphorus, water clarity, and dissolved oxygen with minimum model complexity. This model requires the solution of 30 linked time-variable nonlinear differential equations.

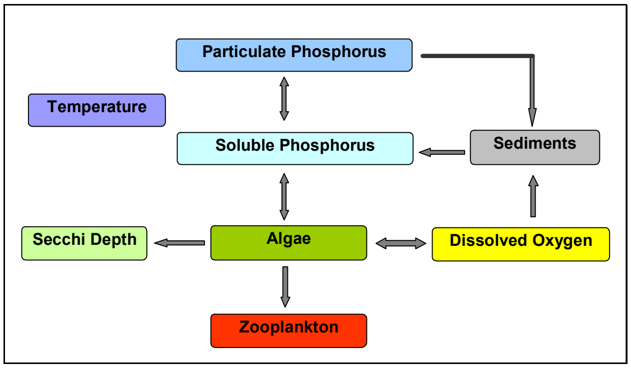

Figure 17. shows the major Kinetic Components of the model.

Figure 18 shows the preliminary model calibration for dissolved oxygen. This calibration uses measured temperatures to determine the vertical exchange coefficients.

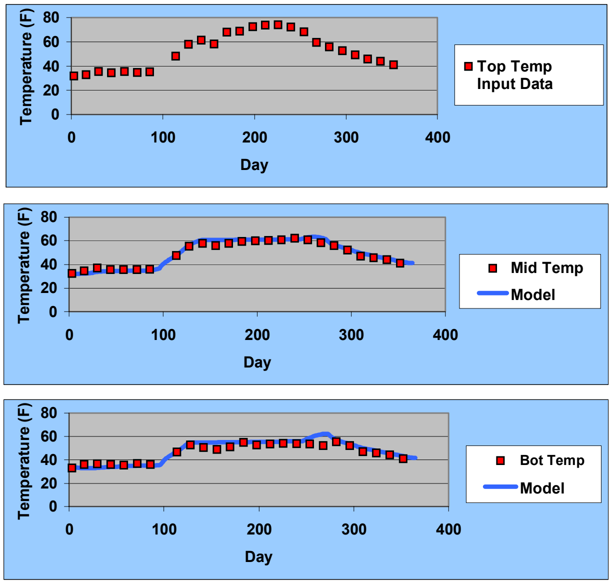

Figure 18. Measured Dissolved Oxygen and Model Predictions for 2000.

Note that the model does an excellent job of simulating dissolved oxygen for both winter and summer conditions. The model also adequately predicts spring and fall turnover and the rate of hypolimnetic oxygen decline. Figure 19 shows preliminary model calculations and measured 2000 concentrations of total phosphorus and chlorophyll and Secchi Depth.

The model fits the spring and fall increases in phosphorus as well as the minimum in the summer. The model also simulates a long spring phytoplankton bloom as well a short early fall increase with summer clearing in between. The model fails to predict a late fall bloom, and does not replicate the Secchi Depth very well, especially during the important summer minimum period. Because of these shortcomings, it is planned to refine the model coefficients and mechanisms as more monitoring data become available and several special studies are completed as described below.

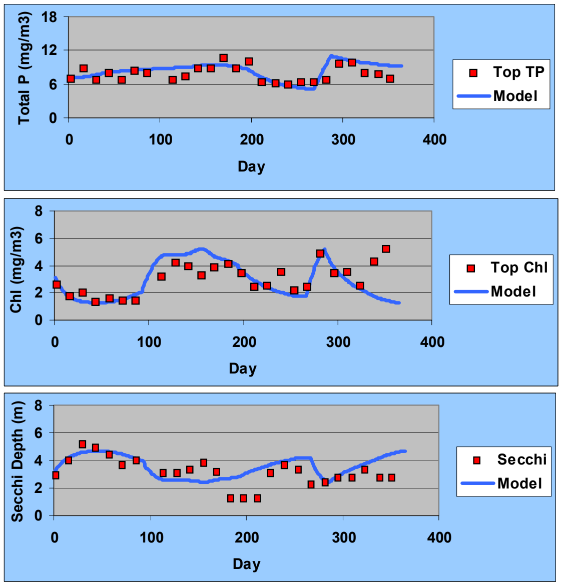

Figure 19. Measured Data and Model Predictions for 2000.

SPECIAL STUDIES

The development and calibration of the water quality model for Big Platte Lake will be based on the hatchery, tributary, and lake monitoring data described above. This model may be used to support or reject alternative measures to control nutrient inputs to the lake. It is imperative that the model have high reliability because such measures may be costly and disruptive to individual property rights. The reliability of the model can be enhanced by conducting special laboratory and field studies that will provide direct estimates of some model coefficients that are independent of the regular monitoring data. Several special studies are described below.

Water Clarity

Water clarity, as characterized by measurements of Secchi Depth, is an important indicator of water quality conditions in Big Platte Lake. However, Secchi Depth measurements lack precision and are often inconsistent. Therefore light attenuation is also being measured using a LICOR submersible light meter. These are direct and more precise measurements of light attenuation as a function of depth that can be used to calculate extinction coefficients. These measurements are expected to enhance the understanding of the relationships among Secchi Depth, chlorophyll concentrations (or phytoplankton and zooplankton counts), and turbidity. Light attenuation may also be a function of pH that is affected by algal activities, and perhaps the input of acid rain.

Figure 19 shows changes in measured Secchi Depth in 2000 as well as a preliminary model calculation that involves the chlorophyll concentration and the calcium carbonate Saturation Index. The model is reasonably consistent with the data for most parts of the year, but it does not predict the mid-summer minimum that is associated with calcium carbonate precipitation. Note that the model fails during the time of the year most important in terms of water quality impacts. Therefore it is desirable that additional analyses be performed with the hope of improving the understanding of the relationships among Secchi Depth, chlorophyll, turbidity, particulate fractions, and other limnological parameters.

Sediment Flux Rates

The magnitude of the internal source of phosphorus from the sediments of Big Platte Lake is directly related to the phosphorus content of the sediments and area of the bottom that experiences anoxic conditions. It has been estimated that 77 kg/yr of phosphorus is contributed to Big Platte Lake through this mechanism (Canale et al. 2002). This is about 80 % of the current point load from the hatchery. It is noted that with the reduction of the hatchery point source of phosphorus, the internal and watershed loading become more significant. Therefore, it is important to be able to accurately estimate the flux rate of phosphorus from the sediments and the sediment oxygen demand.

Phosphorus release rates are dependent on the sediment physical and chemical properties. Measurement of these parameters will be used to develop correlation relationships between sediment flux rates and various sediment properties. Nurnberg (1988) performed a similar study and showed that a significant correlation existed between phosphorus release rate and sediment total phosphorus content. The phosphorus release rate experiments will be conducted on undisturbed sediment cores using methods proposed by Kamp-Nielson (1974) and Penn et al. (2000).

The sediment oxygen demand will be measured using techniques proposed by Gardiner (1984). Water overlying a sediment core will be saturated with oxygen, and the decrease in concentration will be recorded. Sediment oxygen demand is expected to show a positive correlation with the chemical oxygen demand (COD) and may serve as a convenient surrogate parameter for estimation of sediment oxygen demand (Gardiner 1984).

Others

The major loss mechanism of phosphorus in Big Platte Lake is the settling of particulate matter to the sediments. The settling velocity of these particles is also an important model coefficient. The value of the settling coefficient is usually estimated through model calibration by fitting the model output to measured data. However, it is preferable to measure the settling velocity directly. This is accomplished by placing collection chambers in the lake and measuring the accumulated solids as a function of time. The settling velocity can be then calculated from these data.

Most of the macrophytes in Big Platte Lake obtain phosphorus for metabolic activities through their root system rather through their leaves. Phosphorus absorbed from the sediments is stored in the tissue of the macrophytes in a pool that increases in size with the growth and expansion of the population. This tissue phosphorus is recycled into the water in the fall. Landers (1982) found that senescing macrophytes contributed 18% of the annual phosphorus budget in an Indiana reservoir. Both periphyton and phytoplankton increased in surrounding waters subsequent to the release. It has been estimated that macrophytes contribute 45 kg/yr of phosphorus to Big Platte Lake through these mechanisms (Canale et al. 2002). This is almost half of the current point load from the hatchery. This again illustrates that internal and watershed loads are becoming larger components of the overall phosphorus budget for the lake. A macrophyte survey has been conducted to more accurately determine the type, density, area, and phosphorus content of the plants. These data can be used to make first-cut approximation of the amount of phosphorus absorbed from the sediments during the growing season and subsequently released during the fall die-off period. This information can be used to determine the significance of macrophyte activity on phosphorus concentrations and dynamics in Big Platte Lake.

Laboratory tests are planned to determine the bio-availability of different point and non-point sources of phosphorus. These sources include the hatchery effluent, the upper Platte River, major tributaries within the watershed, and small local drainages that discharge directly to the lake. The tests should measure the growth rate of a test algal species to determine the growth potential of various sources of phosphorus.

The filter-feeding activities of zebra mussels can reduce phytoplankton concentrations and consequently increase Secchi Depth (Canale and Chapra, 2002). The respiration of zebra mussels can also be a significant oxygen demand. Lake residents have observed numerous small zebra mussels during the summer of 2002. A survey is planned to estimate the area, density, and size-distribution of resident mussels.

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Several individuals on the hatchery staff have been helpful. Ed Eisch and Bob Humphrey have made this project one of their top priorities and have provided valuable insights. The tough job of day to day sample collection through hot and cold, and sometimes on the ice, has been handled by Bob Kerry, Brian Haffner, Bob Eggleston, and most recently Aaron Switzer. The reliability of the data would suffer without their careful and conscientious efforts. Bob Haas from the Mt. Clemens Research Station and Jim Breck from the Institute of Fishery Research in Ann Arbor, Michigan are working on macrophyte sampling techniques. Doyle Brunsen from the MDEQ helped procure, install, and provided training for the automated stream sampling equipment.

Several individuals associated with the PLIA have made significant contributions to this project in addition to co-author and PLIA President Wilfred Swiecki. Jim Berridge has developed a comprehensive database for the system that serves as a storehouse for the data. The database program also generates reports that analyze and display the data. Dr. Jerry Heiman has worked on a Watershed Planning Grant and related water sampling. Tom Inman has coordinated closely with the Hatchery staff on counting the fall salmon run. Sally Casey has been making weekly Secchi Depth measurements for many years. Joe Francis and Al Amstutz have been measuring stream flow of the North Branch of the Platte River and the Platte River at US-31and M-22. Dr. Mike Pattison and Dr. John Spencer review the data and have provided historical background and anecdotal observations.

Russell Minnerick and his staff at the U.S. Geological Survey – Grayling Office have been involved in measuring flows at the hatchery, calibrating equipment, and providing guidance and training to hatchery staff on how to properly collect stream flow measurements.

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