Annual Report for the Year 2005

Consent Agreement Regarding the Operation of the Platte River Hatchery

Report Prepared by

Dr. Raymond P. Canale
Implementation Coordinator
Emeritus Professor, University of Michigan

Gary Whelan
Michigan Department of Natural Resources
Fisheries Division

And

Wilfred J. Swiecki
Platte Lake Improvement Association

July 2006

Table of Contents

Summary for the Year 2005

Overview

The goal of the Consent Agreement is to implement a long-term strategy to restore and preserve the water quality of Big Platte Lake. This goal is being advanced by minimizing the flow and phosphorus discharge from the Hatchery and by developing strategies to reduce non-point phosphorus loads from the watershed. Figure 1 summarizes the compliance with the Consent Agreement and the major accomplishments for 2005.

Compliance with Consent Agreement

The Consent Agreement mandates that the Hatchery net annual load be limited to a maximum of 250 lbs. during the construction period, 225 lbs. during a 3 year test period, and 175 lbs. thereafter. The corresponding maximum loads for any consecutive three month period are limited to 75 lbs., 70 lbs., and 55 lbs. The year 2005 is the second of three test years where the limits are 225 and 70 lbs. The net Hatchery annual loading for 2005 was 226.2 lbs. This is slightly above the requirement. The maximum load for any 3 month period exceeded the 70 lb limit by 8.3 lbs in October and 7.4 lbs in November of 2005. The average water use at the Hatchery was 8.03 mgd which is less than the Consent Agreement limit of 20 mgd.

The average volume-weighted total phosphorus concentration of Big Platte Lake was 8.2 mg/m^3 in 2005. The water quality goal of 8.0 mg/m^3 was achieved only 41% of the time. This is not consistent with the goal of 95% attainment as stipulated in the Consent Agreement.

A total of 14,571 adult Coho and 571adult Chinook salmon passed the Lower Weir in 2005. These numbers are in compliance with the Consent Agreement limits of 20,000 adult Coho and 1,000 adult Chinook salmon. Excess salmon that accumulated below the lower weir were harvested, counted, and removed from the watershed. A total of 11,478 adult Coho salmon were harvested for egg collection at the Upper Weir. This is 79% of the number of the Coho that were counted passing through the Lower Weir. A total of 84 adult Chinook salmon were harvested at the Upper Weir. This is about 15% of the number that were counted passing through the Lower Weir.

The difference between the biomass of fish that pass the lower weir and the biomass of fish actually harvested at the upper weir represents a potential source of phosphorus to the watershed. This amount was potentially as high as 28.3 pounds in 2005.

Major Accomplishments for 2005

- The capabilities and functionality of the database are being expanded on an ongoing basis. Essentially all available historical data have been added for the Hatchery, Big Platte Lake, and several tributaries. Phosphorus and hydraulic mass balance reports have been created for the Hatchery, watershed, and lake. These reports greatly facilitate comprehensive data analysis.

- Flow, phosphorus, and turbidity data were collected during 25 storm events at selected Platte River and Brundage Creek locations. These data will be used to refine the calibration of the BASINS watershed loading model.

- Stage-discharge relationships have been developed for all tributary sampling locations being monitoring for discharge. In addition, correlations have been developed that relate the flow at each sampling site with the flow at the USGS site at US-31. These data will be used to develop synthetic hydrographs to complete the calibration of the BASINS watershed model.

- Annual phosphorus mass balance calculations have been completed for the Hatchery. These can be displayed as a database reports.

- A preliminary bio-energetic fish growth and physical process model for the Hatchery has been completed using Visual Basic software.

- Several additions were made to the sampling program to enhance understanding of water quality processes in the watershed. New stations were added on Little Platte Lake and Featherstone Creek. The list of measurements was expanded to include nitrate, filtered phosphorus, and alkalinity.

- The sediment oxygen demand and phosphorus release rate studies have been completed.

- A one-coefficient phosphorus model has been developed for Big Platte Lake. This model can be used to predict phosphorus concentrations in the lake as a function of changes in phosphorus loading from the watershed.

- The BASINS model can be used to predict changes in the phosphorus loading from the watershed as a function of weather conditions and watershed development. A project is underway to complete the calibration of this model.

- A comprehensive seasonal ecosystem model has been developed. This model that can be used in conjunction with the one-coefficient model to help refine understanding of water quality dynamics in Big Platte Lake.

Recommendations and Action Items

- The phosphorus and turbidity data from the Jug & Needle and Sigma samplers are statistically dissimilar. It is desired by all to resolve these differences as soon as possible and eliminate one of the methods. However, we must understand why the two methods differ. It is recommended that CMU conduct controlled laboratory experiments to insure that no errors are introduced when phosphorus samples are collected and stored in either new or old polyethylene or glass bottles.

- Flow and water quality data (phosphorus, and turbidity) should be measured at least monthly at all tributary locations until the end of 2006. Emphasis should be placed on collecting samples during wet weather.

- All SOP documents and equipment maintenance schedules should be reviewed and updated annually. Certification letters regarding the accuracy of the numbers in the database should be sent to the Implementation Coordinator for inclusion in the Annual Report.

- The event sampling program should be continued until the end of 2006. The sampling locations should be reduced to Brundage Creek at the old residence and the Platte River at US-31 sites. Gage, total phosphorus, and turbidity measurements should also be taken at the Brundage Creek and Platte River automatic sampling sites during regular maintenance visits.

- Shoreline debris should be collected by PLIA members to allow the determination of the amount of phosphorus in this nutrient source. Wet and dry weight, density, and phosphorus content should be measured and entered into the database.

- Studies of the bio-availability of Hatchery and non-Hatchery phosphorus sources should be conducted as soon as possible.

- The BASINS model should be calibrated using wet weather stream data.

- The Implementation Coordinator should continue efforts to calibrate and validate the water quality models for the lake.

- The Implementation Coordinator should continue efforts to calibrate and validate the fish bio-energetic and Hatchery process model. Improvements in the current model should be implemented based on recommendations of the Hatchery staff.

- The Three Lakes Association and Steve Chapra from Tufts University are conducting a sampling program to study of the relationship between water clarity and calcium carbonate formation. The sampling data are being analyzed using a comprehensive water quality model developed by Steve Chapra called Lake 2K. Since we also need this information to properly understand the dynamics of Big Platte Lake, it is recommended that we cooperate with this effort by assisting with the design and implementation of the field study plan.

- The sampling program should be streamlined to remove unnecessary measurements to meet budget and personnel scheduling constraints. In addition, greater emphasis should be placed on Hatchery monitoring to support the validation of the Hatchery bio-energetic and process model. It is important to measure and calibrate all flow measurements in the Hatchery, particularly those in and out of the clarifier and sludge tanks.

Acknowledgements

The Implementation Coordinator would like to take this opportunity to thank Gary Whelan (MDNR Fisheries Division) and Wil Swiecki (PLIA) for their continuing contributions to this project. Gary has extraordinary leadership and management skills and has kept this project focused and moving forward. Wil has been tireless in his efforts to ensure the reliability of the data and has displayed incredible perseverance working toward the PLIA goal of preserving the water quality of the Lake. As a result, excellent coordination and communication has been maintained within our group as well as with many outside organizations and individuals. The minutes of our coordination meetings in 2005 are contained in the Appendix A.

Jim Berridge (PLIA) deserves a special medal for outstanding service to Platte Lake. He has contributed his talents and endless hours of his time to create an Access database for the laboratory and field data collected on this project. This daunting task is an ongoing process. All those interested in preserving the water of Big Platte Lake owe him their gratitude.

Aaron Switzer (MDNR Fisheries Division) has the major responsibility of collecting the field data and has done an absolutely outstanding job with this task. He has contributed not only through his perseverance and consistency but also through thoughtful analysis of procedures and data. He always stands ready to get “just a few more samples” to satisfy the whims of Ray, Gary, and Wil. The reliability of the data would suffer without his careful and conscientious efforts.

We also acknowledge and appreciate the support and assistance of Edward Eisch (MDNR Fisheries Division) for his overall management of the facility along with its personnel, ensuring the development of hatchery SOPs, and the design and implementation of the Hatchery flow measurement program. He has been instrumental in assuring that hatchery meets its commitments to the Consent Agreement.

Janice Sapak (MDNR Fisheries Division) has been helpful in collecting, verifying, and analyzing all aspects of the Hatchery production data. She also writes an annual report on fish production activities that has been incorporated into this report.

The authors would also like to thank and acknowledge the valuable contribution of many individuals from CMU. Jenny Estabrook and Scott McNaught have left no stone unturned in their efforts to evaluate and improve their laboratory methods. Scott McNaught has reviewed the historical plankton data, recommended much improved methods for sample collection, and added

biomass measurements. Michael Holmes and Scott McNaught conducted the study of sediment phosphorus release and oxygen demand in Big Platte Lake.

Finally, several additional individuals associated with the PLIA have made significant contributions to this project:

- Jerry Heiman has done a excellent job measuring the flow rates and water quality parameters of several tributaries.
- Mike Pattison has done a terrific job developing and maintaining the PLIA web site with the latest version of the database.
- Bill Berridge performed SCUBA diving and provided the use of his boat for the *Chara* study.
- Tom Inman has coordinated closely with the Hatchery staff on counting the 2005 Fall Salmon Run.
- Sally Casey has been making weekly Secchi Depth measurements for many years.
- Joe Francis has been measuring stream flow and pH of the North Branch of the Platte River and the Platte River at US-31and M-22.

Hatchery Operations

Renovation Program

The renovation of the Platte River State Fish Hatchery is now complete. The following items have been installed: headbox; covered outdoor raceways with automatic feeders and low head oxygen units; effluent management system including disc filters, clarifier and sludge storage; a partial recirculation system; a new water sampling and measurement system; and a liquid oxygen system (LOX). The new equipment and facilities have been tested and all are working within design parameters.

Antibiotic Use

In recent years, antibiotic use at the Platte River State Fish Hatchery has been focused on the within label feeding of oxytetracycline (OTC) to Chinook salmon to produce a readable mark on the vertebra of hatchery produced fish. This practice was not continued in 2005, but will be done again in 2006. OTC contained in medicated feed was used once for a ten day treatment to Hinchenbrooke strain of coho salmon to fight a systemic bacterial infection. The OTC is added to the feed during manufacturing and was obtained from Bio Oregon of Warrenton, Oregon. The OTC (TM100) was mixed in the feed at a rate of 40 pounds per ton of feed in 2004. A total of 80 kilograms (176 pounds) of medicated food was fed during the treatment process. The treatment was started on June 15 and ended on June 24, 2005. This compares to a total of 7,568 pounds fed during 2003 when OTC was used for marking purposes. The total amount of OTC in the feed in 2005 was 3.52 pounds which compares to 79.5 pounds in 2004. Hatchery discharge flow during that time period averaged 8.10 MGD (millions gallons per day).

Three Romet treatments were carried out during 2005. The Michigan strain of coho salmon were fed feed that had Romet 30 added during the Bio Oregon manufacturing process to treat for a systemic bacterial infection. A total of 31 kg (6.2 kg per day) of treated feed containing a total of 51.8 grams of Romet 30 was fed over the course of the five day treatment, beginning on June 15 and ending on June 19, 2005. Hatchery discharge flow during that time period averaged 7.93 MGD.

Another Romet treatment was administered to the Hinchenbrooke strain of coho salmon to treat a furunculosis outbreak. This treatment was done with Romet B which was mixed with the feed at the hatchery. The feed, obtained from Bio Oregon, was top dressed with vegetable oil used as the carrying agent. The five day treatment was started on July 14 and ended on July 19, 2005. A total of 95 grams of Romet B was fed out with 170 kg of feed. The daily dose administered was

19 grams of Romet B in 34 kg of feed. Hatchery discharge flow during that time period averaged 8.37 MGD.

The third Romet treatment was administered to the Michigan strain of coho salmon to control a furunculosis outbreak using Romet B mixed at the hatchery, as described above. The five day treatment ran from July 26 through July 30, 2005. A total of 812.5 grams of Romet B was fed with 227 kg of feed. The daily dose was 162.5 grams of Romet B mixed with 45.4 kg of feed. The feed was purchased from Bio Oregon. Average hatchery flow during the treatment period was 7.64 MGD.

Yearlings from the Hinchenbrooke strain of coho salmon were treated with erythromycin phosphate (Gallimycin) to control an outbreak of bacterial kidney disease (BKD). The treatment was delivered via a hatchery mixed top-dressed feed. A total of 4.586 kilograms of Gallimycin (458.6 grams per day) was delivered over the course of a ten day treatment. The treatment was started on March 8 and ended on March 17, 2005. Hatchery flows during this period averaged 8.40 MGD.

Disinfectant Use

Parasite-S is used to control fungus on fish eggs. Parasite-S is a trade name for formalin that consists of 37% formaldehyde by weight in water. The standard treatment used is a 15-minute flow through with formalin at a concentration of 1 to 600 (1,667 ppm). During the 2005 incubation season, 631.1 gallons of Parasite-S were used to control fungus on salmon eggs during the period October 5, 2005, to January 3, 2005. This compares to 817 gallons used during the 2004 incubation season. Maximum daily treatments were 9.8 gallons per day which is one 15 minute treatment. Hatchery flows during the period ranged from 5.47 MGD to 7.60 MGD as compared to a range of 8.69 MGD to 11.45 MGD during the 2004 incubation season. No monitoring for formaldehyde in the discharge was done in 2005 because of monitoring results that were obtained in 1999.

Chloramine-T (CT) was used on three different occasions to fight bacterial gill disease. Each treatment was a one hour flow through treatment at 12 ppm on three consecutive days. The first was delivered to the Little Manistee chinook salmon beginning on April 11, 2005. A total of 1.051 kg of CT was delivered each day for a total of 3.153 kg of CT used throughout the three day treatment. Hatchery discharge each of those days was 10.4 MGD.

The second CT treatment was administered to the Hinchenbrooke strain coho salmon beginning on May 18, 2005 using the same dosage as discussed above. The weight of chemical used during this course was 364 grams of CT during each of the three one hour treatments for a total of 1.074 kilograms. Hatchery discharge flow on these dates was 8.03 MGD.

The final CT treatment was administered to the Michigan strain coho salmon and commenced on May 27, 2005 using the same dosage as discussed above. The maximum weight of chemical used per hour during this course was 2.588 kilograms of CT during each of the three one hour treatments. The total amount of CT used was 11.118 kilograms. Hatchery discharge flow on these dates was 7.61 MGD.

Lower and Upper Weir Operations

The Consent Agreement with the Platte Lake Improvement Association allows 20,000 adult Coho to be passed upstream of the Lower Platte River Weir during the fall salmon run. This number ensures that sufficient eggs and milt can be obtained in order to maintain the MDNR Coho stocking program. The agreement also allows for passage of up to 1,000 adult Chinook salmon.

During the fall of 2005, both the Upper and Lower Platte River Weirs were operated.
The Lower Weir grates were installed on August 15, 2005 and removed for the season on November 14, 2005. As fish collected below the weir in sufficient numbers, coho salmon were passed upstream for egg take purposes, and surplus coho and chinook were harvested and removed from the river. Fish were passed upstream of the weir by raising the boat gate slightly and manually counting the number of fish, by species that swam upstream under the gate. For harvest operations the pumps were turned on and fish were allowed into the holding pond, where they were later removed. Members of the Platte Lake Improvement Association were contacted prior to passing fish upstream and were invited to observe the operation.

In 2005, 606 Chinook salmon, 15,314 coho salmon, 305 steelhead and 4 brown trout were passed upstream of the Lower Weir. In addition, a total of 3,471 chinook and 2,029 coho salmon were harvested at the Lower Weir and shipped to American Canadian Fisheries, Inc. of Bear Lake, Michigan. At the Bear Lake facility, MDNR staff conducted biological sampling of the season's run.

All of the dam boards for the Upper Weir were in place by August 23, 2005, and any migrating salmon were directed to the maturation ponds after this time. Coho egg take occurred between October 17 and November 9, 2005. After each egg take, all salmon were harvested. In 2005, a total of 95 chinook and 12,187 coho salmon were harvested and shipped to the contractor at the Bear Lake processing plant. The ponds were harvested for the final time, and weir operation was suspended for the season on December 15, 2005.

The total number of fish that were unaccounted for between the Lower and the Upper Platte River Weirs included 3,127 coho and 511 Chinook salmon. It is assumed that these fish were either harvested by anglers, or spawned and died in the river prior to reaching the Upper Weir.

Egg Take and Egg Incubation

The coho egg take operation occurred at the Platte River State Fish Hatchery between October 17 and November 9, 2005. A total of 6,928,930 coho eggs were taken and fertilized. This included 3,787,962 eggs (1,021.1 kg) for the Platte River State Fish Hatchery and 3,140,968 (867.8 kg) for other state fisheries agencies, including Indiana, Illinois and Wisconsin.

Chinook salmon eggs were taken at the Little Manistee and Swan River Weirs and transferred to Platte River State Fish Hatchery in October 2005. A total of 6,165,799 eggs (1,867.0 kg) were incubated at the hatchery. During the course of incubation, 1,279.1 kg of coho and chinook egg mortalities occurred and all of these dead eggs were disposed outside of the watershed.

Incubation at the hatchery occurred during the months of October, November and December. By early January, all of the eggs had hatched and the fry were put into rearing units.

Fish Production

During calendar year 2005, the Platte River State Fish Hatchery raised and stocked (planted) 792,405 (25,868 kg) yearling coho salmon in the Platte River. In addition, 746,776 (25,145 kg) yearling coho were raised and shipped out of the watershed. Also, 4,652,466 (17,852 kg) spring fingerling Chinook salmon were raised and shipped to other locations outside the Platte River watershed. Additionally, 582,791 (176.7 kg) coho and chinook eggs were shipped to other facilities out of the watershed and 258.0 kg of coho and Chinook salmon swim up fry were shipped as to facilities outside of the watershed A total of 930,043 (868.2 kg) Chinook and coho salmon died during rearing. These mortalities were removed from the hatchery and discarded at a certified landfill outside of the watershed.

At the end of the calendar year the inventory of fish on hand in the hatchery included 1,519,094 (39,663 kg) yearling coho salmon for stocking in 2006, and approximately 3.9 million (1,609 kg) Chinook and coho salmon eggs and sac fry in incubation.

During the course of the year a total of 56,025 kg of feed was fed to the production lots of coho and Chinook salmon. This feed was predominantly BioOregon BioDry 1000 LP and BioDiet Starter, and contained less than 1% phosphorous.

Waste Handling

Throughout the production cycle, all egg and fish mortalities were removed from the incubators and rearing units on a daily basis. Mortalities were weighed or counted and disposed of at a certified landfill, or in the case of egg mortalities during the egg take, to the salmon harvest contractor.

Fish waste was removed daily from the rearing units by manually cleaning the raceways. These cleaning wastes was then concentrated using disk filters. The filtered waste was directed to a clarifier for further concentration and finally set to a sludge tank for long-term storage. Twice during the year, the sludge storage tank was pumped by BioTech Agronomics, Inc. In June 2005, 280,000 gallons were removed. In December 2005, 60,000 gallons were removed. All sludge was land applied outside of the watershed per the Michigan Department of Environmental Quality's Manure, Paunch and Pen Waste Exemption guidelines.

Water Use

Figure 2 shows the long-term changes in the annual average Hatchery effluent flow between 1990 and 2005. The long-term average flow is about 10.9 mgd. The minimum and maximum flows over this period are 7.5 and 13.0 mgd. The average flow or water use for 2005 is 8.02 mgd. This is less than the long-term average. Hatchery water use is about 10% of the total flow of the Platte River measured at the USGS Gage Station at Honor for 2005.

Net Total Phosphorus Load

Water used to culture fish becomes enriched with phosphorus as it passes through the hatchery from fish excretion and from unconsumed feed. The net phosphorus daily loading from the hatchery is defined as the difference between the phosphorus loading that leaves the system and the phosphorus entering the system from the three possible water sources (Brundage Spring, Brundage Creek, and the Platte River) on a given day. Negative net loads are set equal to zero for calculation purposes as specified in the Consent Agreement. The summation of daily net loads for the year gives the annual net phosphorus loading. Linear interpolation is used to determine loads on days where no measurements were taken. This may require the use of the last measurement of the proceeding year and the first measurement of the following year to complete the calculation. All samples are daily composites collected using the Jug & Needle method as specified in the Consent Agreement. Appendix B contains the details of the calculation of the net total phosphorus load for 2005.

Figure 3 shows the long-term trend in annual net phosphorus loading. Note that the 2005 loading of 226 lbs. is higher than the 175 lb limit that will be in effect starting in the year 2007. Figure 4 shows the cumulative loading for 2005 compared to the current limit of 225 lb and the 175 lb limit. Figure 5 shows a bar graph of the hatchery net loading for each month. Higher net loads usually occur in the late fall during the time when the hatchery accommodates the highest biomass of actively growing fish. The net load exceeded the 75 lb limit for the months of October and November, 2005. Note that if the 55 lb requirement was in effect, the Hatchery loading would have exceeded the limit six months during the year.

Sigma vs. Jug & Needle: The concentrations of total phosphorus and turbidity of the Hatchery inlet and outlet flows are currently measured on samples collected using two methods. For several years a composite sample has been taken using a jug equipped with a fine gauge needle that slowly allows water to enter the jug. Automated Sigma Samplers were installed in association with the renovation program. These samplers obtain a 24 hour composite sample by pumping sub-samples at regular intervals.

Figure 6 compares the phosphorus concentrations of the Brundage Creek intake water sampled with the Jug & Needle and Sigma methods. Note that although long-term average values of the two methods are nearly identical, the phosphorus spikes do not always occur on the same days for the two methods. This suggests that on some days different water samples are being taken by each method. Figure 7 compares turbidity data for the Brundage Creek intake. Note that the average turbidity of the samples taken with the Sigma equipment is significantly higher than that obtained with the Jug & Needle sampler. Figure 8 shows the total phosphorus concentration of the Upper Discharge of samples collected using the two methods. Figure 9 summarizes the annual average phosphorus and turbidity measurements for each hatchery sampling location 2005. Note that annual turbidity measured using the Sigma sampler is higher than the J & N values at each location. On the other hand, total phosphorus measurements are generally higher for the J & N samples. Because these differences are significant and the explanation elusive, it is recommended that samples continue to be taken using both methods and analyzed for phosphorus and turbidity. The official hatchery loading should be calculated from Jug & Needle total phosphorus measurements until sample values from both techniques are logically equivalent. In the meanwhile, it is recommended that CMU conduct a series of carefully controlled laboratory comparison measurements to uncover explanation for the observed differences.

Hatchery Phosphorus Mass Balance

Results: Figure 10 shows the calculated cumulative net hatchery phosphorus loading for 2004 and 2005. Figure 11 and 12 show the components of the overall phosphorus mass balance for the Platte River State Fish Hatchery in 2004 and 2005. The following are the major sources of phosphorus to the hatchery:

- Brundage Spring
- Brundage Creek
- Platte River
- Fish food
- Fish eggs
- Fish present in hatchery at beginning of the year

The following are the sinks or losses from the system and system accumulation:

- Waste sludge
- Upper discharge
- Losses to the pond sediments
- Fish planted into the Platte River
- Fish shipped from the Hatchery
- Fish mortality (morts)
- Fish remaining in the Hatchery at end of the year

Note that fish present in the system at the start of the year are a source of phosphorus, and that fish remaining in the system at the end of the year represents an accumulation of phosphorus. All of the major sources and sinks of phosphorus that enter or leave the hatchery and system accumulation are estimated and compared in the mass balance report. All terms are expressed as the phosphorus equivalent to facilitate comparison. These calculations assume that fish biomass is 0.4465 % phosphorus by wet weight and that fish eggs are 1.3 % phosphorus by wet weight. Linear interpolation is used to estimate the annual loss from the waste tank.

Analysis: The purpose of this section is to examine the annual variation of temperature, food use and fish production in an attempt to explain the large differences between the loads for 2004 and 2005. Figure 13 shows the annual variation of the monthly average hatchery raceway temperatures for 2004 and 2005. Monthly averages are based on measurements entered into the database twice per week. The small difference between the two years does not appear to be a major factor to account for the difference between the net hatchery load for 2004 and 2005. Figure 14 summarizes the mass balance for the two years. The difference between the total phosphorus that enters and leaves the system is only about 75 pounds. Note that in 2004, the hatchery used more food and imported more phosphorus through the eggs and source water. However, there was about three times more fish in the system at the beginning of 2005 compared to 2004. In 2005, significantly more fish biomass were planted in the Platte River or shipped outside of the watershed compared to 2004. This is the consequence of the large mortality that occurred in March 2004. All other components of the mass balance are approximately the same for 2004 and 2005. Figure 15 shows that there is little correlation between the net annual phosphorus load from the hatchery and food use for 2002 through 2005.

The net annual production of fish is defined as the phosphorus equivalent of the fish that leaves the hatchery as Morts, Shipped or Planted or as fish that contributes to an increase in the standing stock.

Net Production = Morts + Shipped + Planted + (End Fish – Start Fish) (1)

Each quantity in the above equation is expressed as phosphorus equivalents. This is equal to the wet weight times the percent phosphorus. Note that this definition appropriately accounts for either increases or decreases in the fish in the system. Figure 16 shows that there is little correlation between the net annual phosphorus load from the Hatchery and net annual production for 2002 through 2005.

Figure 17 shows that the 1017 pounds of phosphorus added to the system as feed in 2005 produced about 596 pounds of new fish biomass. The remaining 421 pounds escapes consumption or is subsequently excreted or egested by the fish after consumption. This unused or wasted phosphorus that does not eventually leave the system in the form of fish tissue is defined here as "Excess Food Phosphorus". This excess food can occur in either dissolved or particulate form. Excess phosphorus can be removed from the system by cleaning the sludge tank; settle and then be buried in the pond sediments; or leave the system as loading to the River. Note that measurements of the discharge include the phosphorus brought into the system through the source water from Brundage Creek and Brundage Creek. It is assumed here that the phosphorus in the source water is simply passed through the system and subtracted form the total discharge to determine the net discharge.

These considerations suggest that there should be a statistical relationship between the net loading from the Hatchery and excess food. Figure 18 shows that this linear model is 99%

accurate for years between 2002 and 2005. Although this relationship is highly significant, it has limited direct value as a tool to assist with the efficient operation of the hatchery. However, the strong correlation suggests that hatchery loading may be reduced by increasing the efficiency of food use by the fish or by enhancing the removal of phosphorus in the tank and pond. Such analyses require understanding of the bio-energetic mechanisms associated with fish metabolic activities and modeling of processes that occur in the physical components of the Hatchery. These concepts are further elaborated upon in Figures 19 and 20.

Monthly Data: Fish production data for 2005 are shown in Figure 21. These production data are estimated on a monthly basis by the hatchery staff. These data are reported and stored in the database and can be used to determine the annual contribution of phosphorus input to the Hatchery through the food supplied to the fish standing stock. This amount is calculated by multiplying the amount of food fed each month times the % phosphorus of the feed. The phosphorus content of each lot is independently tested and reported by the manufacturer. In 2005, this amount was approximately 1017 pounds. It is also possible to estimate the amount of phosphorus that leaves the Hatchery associated with fish tissue. Fish leave the Hatchery as: dead fish (Morts); fish planted in the Platte River; or are shipped out of the watershed. The amount of phosphorus is calculated by multiplying the quantity of each category times the percent phosphorus in the tissue. The phosphorus content of the fish biomass was measured by Aquatic Systems, 1983. The average phosphorus content of two adult males and two adult females was 0.4465% based on wet weight. The total measured amount of phosphorus leaving the system was 658 pounds in 2005, mostly as planted and shipped fish. Note however that about 9% (62 pounds) of the phosphorus exported via these mechanisms is the result of a decrease in the standing stock of fish in the system rather than new growth.

The hatchery produced a net of 59,478 kg of fish in 2005 using 57,419 kg of feed. The total mortality losses in 2005 were about 1.5% of the total production. The remaining production were either shipped outside of the watershed or planted in the Platte River. Note that the ratio of food fed to annual production is less than 1.0. This is part of an industry trend as reported by Hardy (2002) and reflects greatly improved food mixtures and feeding practices.

Figure 21 also shows monthly data for fish production and net growth rates for 2005. The percent net growth of fish over any month period is calculated according to Equation 2.

% Net Growth = 100*(Net Growth for the Month) / (Monthly Average Fish in System) (2) where the Net Growth equals the fish present in system at end of the month + mortalities + fish planted + fish shipped – fish present in the system at beginning of month. These calculations are illustrated for April and July 2005 at the bottom of Figure 21.   The maximum growth rate usually occurs in May or June, when temperatures are at optimal growth temperatures, and attains a maximum value of approximately 80% to 90% per month. Winter values decrease to about 10% per month because of cold water temperatures.

Hatchery Process Model

Model Development

Process Water Flow Network: Water is used at the hatchery to incubate eggs and support fish growth in the starter, rearing, and raceway tanks. Brundage Spring water flows through sand filters by gravity in the winter and spring. It used for egg incubation. Water is pumped into the Head Tank from Brundage Creek, Brundage Spring, and when needed from the Platte River, currently a backup water supply that is rarely used, to support fish growth in the raceway tanks. The raceway system consists of a three series or sets of raceways. Each tank is equipped with aeration equipment, a low head oxygen unit, near the head and water discharged from the raceway is routed through a rotating continuous flow drum micro-screen to capture all possible solids. The flow in the tanks can be recycled although they are normally operated in series where the flow that leaves the A Raceway and Filter Building A flows to B Series and then C Series if needed. Following final filtering in C Building, the water enters a polishing pond before discharge to the Platte River. The blue lines in Figure 22 show a diagram of the major components of the Hatchery and the normal process water flow network.

Wastewater Flow Network: Water is used to backwash all three sets of screens to prevent excessive clogging. This water has a low volume and high total phosphorus concentration. The A and B Filter Buildings receive the effluent of the A and B raceways. Filter Building C accommodates the solids picked up by the vacuum pumps inside rearing tanks as well as the C raceway effluent. The backwater from all three screens enters the clarifier where solids are further separated and concentrated by gravity. The relatively clean overflow from the clarifier passes to the final polishing pond before discharge to the Platte River. Concentrated solids from the clarifier are pumped to the Sludge Tank where gravity concentration continues. The overflow from the sludge tank also passes to the final polishing pond before discharge. Solids from the Sludge Tank are removed once or twice a year and trucked to a disposal site. Note that this trucking and burial in the pond sediments are the only ways that phosphorus from unconsumed food or that is generated by fish excretion can be removed from the Hatchery effluent. The red lines in Figure 22 show the wastewater and combined flows in the system.

Food is fed into the starter tanks, the rearing tanks, and the three raceways and is converted into fish biomass. Water containing excess solids and phosphorus is passed to the screens, the clarifier, the sludge tank, and the effluent pond. The net loading from the system is affected by piping and recycle systems and the efficiencies of each system component. A comprehensive model of the hatchery would include a detailed bio-energetic model of fish consumption and growth as well as all the physical and chemical processes that occur in the system. Such a development would require a significant effort and more detailed data that are currently available that describe the response of the system. Such an effort will not be undertaken now. However, the strong relationship between excess food and net loading shown in Figure 18 suggests that a quantitative model for the system is both feasible and holds promise for significant practical application. The goal of the current modeling effort is to demonstrate the feasibility and application of a simplified model for the hatchery net loading.

First, a simplified model of the physical processes of the hatchery is needed. Figure 23 shows a heavy green box that encompasses the sand filter, the incubation trays, starter tanks, rearing tanks, three raceways, three screens, and the head box. Note that all water that enters the hatchery enters the green box, including both components of Brundage Spring. Also note that backwater from all 3 screens leaves the green box in a single flow. This suggests a simplified system representation of the hatchery shown in Figure 24. The three raceways and the Main Hatchery Building activities are represented as a single component. Incoming source water is combined into a single flow that is the sum of that from Brundage Spring, Brundage Creek, and the Platte River. Food is supplied to support fish growth and respiration needs. Starter feed for fry and feed for larger fish are combined into one model input variable. Fish are harvested from the system in the form of Morts, Shipped (to another watershed), or Planted (into the Platte River). These operations are replaced by a single raceway in the model to approximate the action of the actual system.

The effluent water from the three raceways is passed through screens before being passed to the pond. The screens split the flow into two fractions. Most of the flow passes directly into the pond with a reduced flow and phosphorus concentration as the result of particulate retention by the screen. Some of the water is used to backwash the screens to prevent excessive clogging. This backwash water has a relatively low flow and high concentration of phosphorus and is passed on to the clarifier tank. The clarifier essentially splits the flow further into two fractions. Solids are settled to the bottom of the clarifier tank. The clarifier overflow is sent to the finishing pond. The solids on the bottom of the clarifier are pumped to the sludge tank. The final split occurs in the sludge tank. The sludge tank overflow, which only occurs during clarifier pumping, empties into the pond. The concentrated sludge in the tank is removed on a periodic basis and transported outside of the watershed. This periodic cleaning is modeled as a time variable flow leaving from the bottom of the sludge tank and represents a true removal from the system rather than simply splitting and concentrating. The final component of the model is the effluent pond. The pond receives flow from the screens and the overflows from the clarifier and the sludge tank. Some phosphorus that enters the pond settles to the bottom and is buried. Some of the phosphorus is tied up with pond vegetation and either the vegetation is exported from the pond when it dies or it is deposited into the sediments. The final effluent leaves the system with a flow equal to the inflow minus an insignificant reduction when the sludge tank is cleaned. Figure 25 labels the flow and phosphorus concentrations at various locations in Hatchery. The model dependent variables include 12 phosphorus concentrations and 8 flow rates. Figures 26 through 32 describe the model and mass balance simulation equations in more detail.

Figure 26 shows bioenergetic and phosphorus processes that occur in the raceways. The bioenergetic processes can be simulated by the Wisconsin Model (Kitchell et al. 1977, Warren and Davis 1967). This model assumes that inputs, gains, and losses of energy are balanced. In the balanced energy equation, consumption is the energy input, growth is the net energy gain, and respiration and other processes represent losses. The balanced energy equation is represented by the following formula

$$C = G + R + S + F + U \qquad (3)$$

where, C = rate of energy consumption, G = somatic and reproductive tissue elaboration, R = standard metabolic rate, S = metabolic rate increase from specific dynamic action (heat increment), F = waste losses due to egestion (feces), and U = waste losses due to excretion (urine). Although this model is well-known and has detailed biochemical mechanisms, it has been criticized because it is complex and contains approximately 40 coefficients. Numerical values for these coefficients must be specified to apply the model and can be difficult to accurately parameterize. The uncertainty of the overall model can be large because the variance from all 40 coefficients propagates through the mathematical formulations. The model also has limited capability to simulate the effects of food availability and limitation on the consumption rate but if accurate data is available, it can be used in a wide range of applications.

To develop a first order approximation of hatchery bioenergetic processes, a simplified model will be used here that accounts for the energy intake through consumption, growth, and losses. The model simulates consumption as a function of temperature and food availability. The losses are modeled as a single temperature dependent loss term simply referred to here as respiration. The difference between consumption and the losses is the net growth. The model has only 6 coefficients and includes the effects of food availability. The model equations and behavior are described in Figures 33 and 34. The model coefficients shown in Figure 33 are based on PRSFH monthly measurements of net growth rate listed in Figure 21. Note that the model suggests that the most effective use of food occurs at temperatures between 10 and 11 degrees C where only about 14% of food is wasted through respiration. This is about one or two degrees less than the optimum consumption temperature of 12 degrees C. Note that at 19 degrees C about 68% of the food is lost through respiration and other losses. In the model, fish cannot survive long term exposures to temperatures greater than about 20 C based on bioenergetic considerations. The rate of consumption decreases as food availability decreases. The availability of food is modeled using the classic Monod half-saturation formulation as illustrated in Figure 34. This formulation is often used to describe food limitation and feeding mechanisms in plankton as well as larger animals. The overall behavior of the simplified model with the selected model coefficients is similar to the Wisconsin model.

The model uses daily average temperature data to simulate the annual variation of fish food consumption and growth. Monthly average temperature at the hatchery is illustrated in Figure 35. These data and the simplified bioenergetic model result in optimal fish growth during mid-October. Fish growth is clearly less efficient during warmest periods of the year. When food is in excess, growth rates greatly exceed those attainable when food is limited. Our model suggests that fish are growing at about 30 to 40 % of maximum due to food limitation and these data should be used in designing feeding strategies that maximize growth but minimize waste. This issue will be examined in more detain in a later section where some of the model simulations are compared to measurements.

Model Calibration

The measured flow and concentration of phosphorus of Brundage Creek and Spring are shown in Figure 36. Interpolation was used to determine daily values to provide input to the model. The cumulative total annual input was 258 pounds in 2005.

Figure 37 shows the calibrated model for 2005. The PRSFH records monthly measurements of food fed and the total harvest (sum of Morts, Shipped, and Planted). Daily values needed to drive the model were estimated using linear interpolation. Smoothing was used to facilitate the transition of numerical values from month to month. The model closely matches the measured fish in the system and the monthly growth rates. No direct measurements are available for the phosphorus concentration in the raceways. However, the model indicates that the water that leaves the raceways has an elevated phosphorus concentration due to fish excretion and egestion and unused food. The main variation of total phosphorus concentration leaving the raceways follows the seasonal patten of the dominant bioenergetic processes of the fish. Excess food (uneaten) also plays a role by increasing the raceway concentration around day 150 when the fish in the system have been depleted due to harvesting. Figures 38 through 40 show the model calculations for the annual average of flows, total phosphorus concentrations, and loadings for all components of the system. Note that sum of the inputs to each physical component of the system equals the sum of the outlets because the model is based on mass balance principles. Note that the calibrated model exactly replicates the 2005 net loading of 226 pounds. The model simulations indicate that 623 pounds of phosphorus were harvested, 683 pounds were released into the water from fish respiration, and 69 pounds remained in the form of unused food. The loading to the screens is 752 pounds (496 net). About 202 pounds of the phosphorus that enters the sludge tank is removed during two cleaning periods, 57 pounds remain in the tank, and 42 pounds are buried in the pond sediments. Note that screens and the clarifier tank do not directly remove phosphorus from the system. On the other hand, these processes concentrate the phosphorus concentration thereby facilitating and magnifying the removal during sludge tank cleaning. Also, the model predicted a tank cleaning loss of 201 pounds compared to a measured value of 333 pounds. It is recommended that additional measurements be taken to clarify the discrepancy.

Figure 41 shows the 2005 calibrated model applied to the 2004 operation of the hatchery. The model simulates the 2004 conditions quite well. This ability to realistically Hatchery operations for various years strongly suggests that the model has the potential to assist with the management of the facility. Although the modeling results are considered quite promising, there are discrepancies and uncertainties that indicate that additional measurements made for various mass balance components to improve overall model accuracy and reliability. For example, the model calibrations were performed using a harvest multiplier factor of 0.95 for 2005 and 0.7 for 2004. This suggests that the average fish tissue concentration may be less than 0.4465%.

Model Sensitivity Analyses

The following are a few example calculations that examine the behavior and sensitivity of the calibrated model to various perturbations. The net annual phosphorus load is a function of temperature. A 10% increase in temperature increases the net load by 11 pounds. A 10% decrease in temperature reduces the load by 9 pounds. Reducing the food by 5% reduces the net loading by 14 pounds to 212. If the harvest is lowered by 20% and the food is reduced by

25% then the net load is reduced to 197 pounds. If cleanings are increased to 3 times per year the load is reduced to 209 pounds per year.

Another way to possible reduce the Hatchery net load would be to simply lower the production, although this may not be a viable fisheries management option. However, this decrease in production must be properly coordinated with a reduction of food use to produce the desired reduction in loading. For example, if production is reduced to 65% of the current amount with the same feeding rate, the net annual loading increases to 306 pounds. If both food and feeding are deducted to 65% the net load is reduced to 204 pounds, however the fish at end of the year is lower than the starting level. A sustainable standing stock of about 140 kg can be attained with a 35 % reduction in production and a 25% reduction in feeding rate. In this case, the net annual load is only 149 pounds. This can be further reduced to 134 pounds if the sludge tank is cleaned three times per year.

Note that harvest decreases fish to a minimum around day 150 which is near the temperature when food utilization is most efficient and food was boosted during May at a time when the fish were at a minimum. This caused excess food resulting in waste and increased loading. It may be possible to use the model to match food feeding rate to fish standing stock and temperature on a month-to-month basis to minimize loss and increase efficiency.

Simulations with the model for 2005 conditions show that decreasing the food fed by 5% from 1017 to 966 reduces the net load to 212 pounds. However, the fish on hand also drop from 180 to 167 kg. Thus, dropping food without regard to bioenergetic considerations simply drops production without much affect on net load. Most of the food reduction simply reduces production. A simulation was therefore performed where the food was dropped by 25% only from day 120 to day 180. This resulted in 44 pounds less food use, only 8 kg less fish at the end of the year, and a reduction of 16 pounds in the net load. Food reduction during this period has less impact on production and is more effective in reducing the net load.

Operational controls of the screens can have big impact. If the percent of the flow used for backwash is reduced from 1% to 0.5%, the net annual load is reduced by 36 pounds to 190. This is the result of concentrating solids so that clarifier and sludge tank concentrations are higher. This removes more phosphorus when the sludge tank is pumped and stores more when it is not pumped.

These are examples of how the model can be used to rationally manage fish production and feeding strategies consistent with a goal to maintain the Hatchery net loading to less than 175 pounds per year. The goal is to find optimum combination of food, harvest, and cleaning.

Model Improvements

The reliability and utility of the Hatchery Process Model can be increased by expanding the hatchery monitoring program, conducting experiments to verify model mechanisms, and refining the model mechanisms. These improvements are described in Figure 42. The increased monitoring essentially involves measuring fish and feed use two times per month and measuring water flow and phosphorus concentration more frequently at more locations. A bucket experiment should be designed with clarifier and sludge tank solids to estimate the settling rate of solids and the sediment release rates. The model can be improved by adding more detailed physical components. In addition, it is possible to add more realistic and refined formulations of fish bioenergetic and metabolic processes.

Tributary Flows and Water Quality

Flow Rates

Figure 43 shows the long-term trend of annual average flow of the Platte River measured at the USGS station at US 31. The average Platte River flow at the USGS station was 121.1 cfs in 2005. This flow is slightly lower than the long-term average flow of 126.5 cfs since 1990. Thus, 2005 can be characterized as a slightly drier than the average year. Figure 44 shows the daily hydrograph for the Platte River at the USGS gage station for 2005. Note that the hydrograph is relatively uniform. However, spring flows are about one-third greater than summer low flows. This shows the importance of snowmelt to the hydrology of this system. Several spikes in flow record during the spring, summer and fall correspond to significant rainfall events. Note that a high percentage of the wet weather high flow events were sampled in 2005.

Figure 45 shows instantaneous flows of the Platte River at Pioneer Road measured during 2004 and 2005 compared to the daily average flow at the USGS station. Figure 46 show similar data for the North Branch of the Platte River. These measurements and correlations with the USGS US-31 location can be used to develop synthetic hydrographs anywhere in the watershed. This capability is essential for the development of flow balances for the watershed and lake water quality models. The watershed flow balance for 2005 constructed in this manner is shown in Figure 47.

Phosphorus Concentrations

Figure 48 shows measured total phosphorus concentrations in the Platte River at the USGS station at US-31for 2005. Baseline concentrations in the spring were around 16 mg/m^3 and about 8 mg/m^3 in the summer. Figure 48 also shows measured phosphorus concentrations during 2005 storm events. In addition, total phosphorus concentrations were measured during several high flow periods. Maximum total phosphorus concentrations during these events are typically an order of magnitude higher than during base flow periods. Thus, non-point loads based on routine measurements alone may underestimate the actual non-point load because many spikes are missed. Furthermore, the magnitude of the phosphorus loads associated with just these events greatly exceed the annual phosphorus load from the hatchery. Thus, it is important that the tributary monitoring program and the BASINS modeling effort accurately evaluate the non-point total phosphorus loads in the system. These measurements will be used to determine the percentage of the overall phosphorus budget contributed by during storm events. It is recommended that sampling of storms event sites be continued during 2006.

Lake Water Quality

Big Platte Lake

Total Phosphorus: The annual variation of volume weighted total phosphorus in Big Platte Lake in 2005 is shown in Figure 49. The Consent Agreement mandates that the volume-weighted total phosphorus concentration of Big Platte Lake be maintained below 8.0 mg/m^3 95% of the time. The average annual volume-weighted total phosphorus concentration in 2005 was 8.2 mg/m^3. There were 217 days when the total phosphorus concentration exceeded the 8.0 mg/m^3 goal. This corresponds to about 41% attainment as compared to the 95% requirement. Figure 50 shows the total phosphorus concentration in the top, middle, and bottom layers of the lake. The bottom layer is approximately 3 mg/m^3 higher than the top. Figure 51 and 52 show that about 60% of the total phosphorus occurs in dissolved form in both the top thirty feet and bottom forty five feet of water. It is expected that most of this dissolved phosphorus is non-reactive although no direct measurements are available to confirm this supposition.

Dissolved Oxygen: Figure 53 shows that the annual variation of dissolved oxygen at eight depths in Big Platte Lake. The dissolved oxygen depletion in the hypolimnion of Big Platte Lake is closely related to temperature stratification and the onset of spring stratification. The concentration of dissolved oxygen dropped below 2 mg/L in waters deeper than 90 feet for 104 days in 2005. This is an important period because this is when it is expected that dissolved phosphorus will be released from the sediments. Shallower water experienced shorter periods low dissolved oxygen conditions as shown. These data are used to calculate the phosphorus release from the sediments. This internal loading of phosphorus can be compared to both non-point and point sources and used by the lake water quality model to simulate the annual dynamics of phosphorus in the lake. Ultimately, the magnitude of the internal source of phosphorus will be used to determine how quickly the lake will respond to changes in input phosphorus loadings.

Light attenuation: Secchi depth is a common and simple method used to measure water clarity. However, this measurement has a high amount of observer variation. Light attenuation and is an important indicator of water quality conditions in Big Platte Lake. The 2005 annual variation of Secchi depth in Big Platte Lake is shown in Figure 54. Note the distinct seasonal pattern. The low summer Secchi depths that occur around days 140 and 220 roughly correspond to elevated extinction coefficients as shown in Figure 55. These periods also correlate with high turbidity levels shown in Figure 56. The mid-summer clearing event occurs around day 180 and corresponds to high zooplankton numbers.

Marl lakes such as Big Platte Lake may precipitate calcium carbonate causing high turbidity and low Secchi depth. Such events are usually associated with high pH conditions that occur during periods of intense algal activity (see Figure 57). show the annual variation of turbidity and pH in Big Platte Lake during 2005. Thus, the seasonal variation of water transparency in this lake is a complex water quality modeling problem because it is affected by both chemical and biological processes. It is recommended that we coordinate the Three Lakes Association and Tufts University who are conducting studies of calcite formation.

Chlorophyll: The abundance and diversity of zooplankton and phytoplankton can provide insight and a more thorough understanding of nutrient and water clarity dynamics and long-term changes in the productivity of Big Platte Lake. The easiest way to estimate the quantity of phytoplankton in the lake is to measure chlorophyll a. Figure 58 shows the seasonal variation of chlorophyll a in the top 30 feet of water in Big Platte Lake. High chlorophyll a values were documented near day 140 and 215. Also observe that samples filtered at the Hatchery are about 25% higher than those filtered at the CMU laboratory. This is result of the deterioration of the samples between the time they are collected from the lake and the time the samples are filtered at the CMU laboratory. Figure 59 shows the bottom chlorophyll concentrations in Big Platte Lake during

2005. Note the strong correlation between surface chlorophyll and Secchi depth shown in Figure 54. The mid-summer decline in chlorophyll, the increase in water clarity, and the increase in zooplankton (see Figure 65 below) are particularly striking.

Inorganic Nitrogen: Figure 60 shows the seasonal variation of surface and bottom water nitrite and nitrate concentrations in Big Platte Lake during 2005. The concentration during spring and early summer is about 250 to 300 $mg/m^{3.}$ This is similar to the concentration measured in rainwater during 2005. The concentrations decrease with the onset of summer algal growth. Note that the surface concentration reaches a minimum of about 15 mg/m^3 around day 235. The bottom water concentration also decreases with time reaching a short-lived minimum around day 280. The low summer concentrations are approaching but are not likely rate-limiting for algal growth, although some competitive advantage may be present for nitrogen-fixing blue-green species. This observation leads to the recommendation that nitrate and nitrite be measured in Big and Little Platte Lakes during 2006.

Plankton Food Web: Phosphorus is the primary limiting nutrient that drives the simplified food web for Big Platte Lake shown in Figure 61. The phytoplankton and zooplankton cells are collected and counted to enumerate the density of the populations. The number of each organism is then multiplied by an organism-specific cell weight to determine biomass. It is important to characterize the phytoplankton populations because they have a number of water quality implications. They reflect mixing conditions in the lake, nutrient availability, and have an impact on color, foam, water transparency, and other visible signs of nutrient enrichment. Zooplankton are important because their feeding activities are implicated with mid-summer clearing events in the lake. In addition, zooplankton are the conduits that transfer energy to the upper food chain fish in the lake. The fish population of the lake can affect water quality through top to bottom mechanisms. For example, heavy fish predation on zooplankton can relieve pressure on the phytoplankton. An increase in phytoplankton can result in a decrease in water transparency. These important and complex interactions are described in more detail in Appendix C authored by Dr. Scott McNaught from Central Michigan University.

Little Platte Lake

Little Platte Lake is located about one-half miles north of the north-shore of Big Platte Lake (see Figure 87). It has a surface area of about 805 acres or about 35% of that of Big Platte Lake. The maximum depth is about 8 feet, compared to 95 feet for Big Platte Lake. Approximately 12,000 feet of the shoreline of Little Platte Lake is State of Michigan owned wetland. About one-half of the flow of the North Branch of the Platte River passes through Little Platte Lake. This flow rejoins the other half of the North Branch flow before entering the Platte River just upstream of the outfall into Big Platte Lake. The North Branch is the 2nd largest tributary to Big Platte Lake having a flow of about 20% of that of the main branch of the Platte River. Thus, the water quality of Little Platte Lake has an impact on the water quality of Big Platte Lake. A water sampling program was initiated on Little Platte Lake in 2005 to help characterize these impacts.

Figures 62 through 71 compare the surface concentration of several water quality variables in Big and Little Platte Lakes in 2005. The measurements in Figure 62 indicate that the surface water of Little Platte Lake is 8 to 10 degrees warmer than that of Big Platte Lake during the winter; perhaps attributable to large groundwater inflows. The data in Figure 63 show that the total phosphorus of Little Platte Lake is about double that of Big Platte Lake. The dissolved phosphorus of Little Platte Lake is about 2 mg/m^3 greater than that of Big Platte Lake (see Figure 64). Figures 65 and 66 indicate that the chlorophyll and turbidity of Little Platte Lake are higher than Big Platte Lake as expected because of the higher phosphorus concentrations. Figure 67 compares the nitrite and nitrite concentrations in the two lakes. Note that nitrite and nitrite concentrations decline rapidly in Little Platte Lake and decrease to algal growth rate limiting levels during the spring, and remain low for the remainder of the year. This low level of inorganic nitrogen is expected to promote the growth of nitrogen-fixing blue-green algae such as *Anabaena* as shown in Figure 68. Phytoplankton samples were collected in Little Platte Lake in 2005 and are currently being analyzed. These data will be compared to Big Platte Lake and reported at a latter time. It is also noted that the pH of Little Platte Lake is higher than that of Big Platte Lake, while the alkalinity is lower (see Figures 69 and 70) reflecting higher levels of algal activity in Little Platte Lake as a result of higher phosphorus concentrations. Finally, the dissolved oxygen concentrations of the surface water of both lakes are at or near saturation (see Figure 71). It is recommended that sampling of Little Platte Lake be continued during 2006.

Water Quality Modeling

The ability to quantitatively and reliably predict the effects of Hatchery and non-point total phosphorus loads from the watershed is an important part of the planning process to protect the water quality of Big Platte Lake. Such capability is best attained using modeling tools based on comprehensive water quality monitoring programs. The goal of this section is to describe ongoing efforts to develop these important tools.

Watershed Loading Model

Non-point phosphorus loads from Platte River watershed are being measured and analyzed using the US EPA Better Assessment Science Integrating Point and Non-point Sources (BASINS) approach. BASINS can be used to simulate input of non-point pollutants from the watershed to the Platte River and ultimately Big Platte Lake for various rainfall conditions. It can also predict the consequences of future land use management scenarios in the Platte River watershed by simulating the generation and movement of pollutants such as sediment and phosphorus from multiple sources in the watershed. These results will next be used as inputs to a water quality model for the Big Platte Lake. In this way, the BASINS and lake models can be used to help assess the impacts of both point sources such as the hatchery and non-point sources such as agricultural operations, forests, and land developments. Figure 72 illustrates the overall approach.

The BASINS model has been calibrated for baseline conditions by LimnoTech. A project has been approved and efforts are underway to extend the calibration using recent 2005 storm event and tributary measurements that will greatly improve the utility of this model. A model interface is in development that will allow users such as the PLIA to calculate changes in phosphorus loading to Big Platte Lake as a function of changes in land use and nutrient abatement projects.

Lake Water Quality Model

It is important to recognize that the reliability of any lake water quality model is a function of model complexity. The complexity of a model depends on spatial resolution, time-scale, the number of dependent variables, and the number of model coefficients that define the physical, chemical, and biological rate processes. Each model forcing function and coefficient must be specified before the model can be used to calculate the system response. These model inputs can be constant or time-variable. They can be in the form of a mathematical function or as a series of measurements. These model inputs are not usually known with exact certainty. The overall reliability of the model decreases as the number of model inputs and their uncertainty increases unless large amounts of data are collected to support it. Thus, it is usually better to keep the models simple and avoid unnecessary complications. At the other end of the spectrum, a lake model that is too simplistic is easy to operate and maintain but cannot realistically simulate ecosystem processes. The model having optimum utility lies between these extremes as shown in Figure 73.

Two separate Big Platte Lake water quality models are being developed to accommodate these considerations. A one-coefficient model has simple model mechanisms and is easy to apply and defend, yet this model does not provide much insight into the chemical and biological dynamics of the lake. A more complex ecosystem model is being developed to provide these insights but requires explicit numerical values for many model coefficients and forcing functions which are often difficult to specify without introducing uncertainty. The key to our approach is to capture most of the variation in the system with a minimum of effort.

One-Coefficient Model Development: A one-coefficient model for total phosphorus in Big Platte Lake is illustrated in Figure 74. The model assumes the lake is completely mixed in both the horizontal and vertical directions. It includes point, non-point, and internal loading and discharge through the outlet. The only model coefficient is the apparent settling velocity that results in a net loss of phosphorus to the sediments. This is the simplest deterministic, yet realistic model for total phosphorus and is widely used in various forms. The annual average total phosphorus concentration is given in Equation 4 where various terms are defined in Figure 74.

$$p = W / (Q + v_s A) \qquad (4)$$

The first step in the development of the one coefficient model is to create annual average balances for water and phosphorus for the lake and watershed. Figures 75 and 76 show water balances for 2004 and 2005 in terms of average flow rate from various sources in units of cfs. The non-point and tributary flows are based on flow measurements and correlations discussed in an earlier section. Figures 77 and 78 illustrate watershed mass balances for phosphorus in terms of lbs/yr for 2004 and 2005. Figure 79 shows calculations for estimating the phosphorus associated with fish lost between the lower and upper weirs for 2005. The phosphorus lost is the difference between the fish passing the lower weir and those that are collected at the upper weir times the percent phosphorus in the fish flesh (0.4465%). This is the maximum possible value because some fish are taken by anglers. This figure also shows the estimated atmospheric phosphorus loading calculated by multiplying the annual rainfall for 2005 times the surface area of the lake times the average of measured rainfall phosphorus concentrations. The macrophyte load consists of fall senesce plus continuous sloughing and excretion. Senesce is calculated as the product of the macrophyte biomass times the measured percent phosphorus of 1.3%. A first-cut approximation of the sloughing and excretion component is the measured biomass divided by two, times a 90 day growing period, times an excretion rate of 0.05 per day as obtained from the literature (Bowie, et al, 1985). Figure 79 also shows calculations of phosphorus release from the sediments. The release rate is taken directly from the Holmes measurements and the duration of the period when the dissolved oxygen is less than 2 mg/L is from direct measurements for various lake depths. Lake residents observed higher than usual of pollen on the surface of the lake in 2005. This contribution to the total phosphorus mass balance was estimated using data collected by Banks and Nighswander (1999) for Hemlock forested areas in Ontario, Canada. The estimated a gross flux of phosphorus on the surface of their lakes of 26.3 mg/m^2/yr, which is approximately 392 pounds during 2005 for Platte Lake.

These inputs and data for the annual average total phosphorus concentration in the lake provide a way to calculate the apparent settling velocity (see Figures 77 and 78) using Equation 4. Sediment retention can also be determined by subtracting the lake outlet phosphorus from the total inputs. The apparent settling velocity and the retention of about 60% are consistent with other oligotrophic lakes (Chapra, 1997).

Figure 80 shows long-term trend data (1990 through 2005) for lake total phosphorus, Secchi depth, and flow of the Platte River. The total phosphorus concentration of the lake increased between 2004 and 2005 (from 7.1 to 8.2 mg/m^3) and the discharge from the Hatchery increased from 157.4 to 226.2 pounds (see Figure 10) while the flow of the Platte River also decreased. The annual variation of volume weighted total phosphorus in Big Platte Lake in 2004 and 2005 is shown in Figure 81. Similar data for other years provides an excellent opportunity to estimate the apparent settling coefficient for a number of years. Figure 82 shows watershed loads and model-calculated values for the apparent settling velocity for 2002 through 2005 using various ways and refinements to estimate the total load into the lake. Values of the apparent settling velocity are directly and positively related to the estimates of total loading. For example, in 2005 a low value of 9.0 m/yr is calculated if only dry weather data (dip only) are used to calculate the loading. This value increases to 18.0 m/yr when wet weather data are added and 20.1 m/yr when pollen is also included. It is assumed for the subsequent application that the most representative value for the apparent settling velocity is 21.0 m/yr.

One-Coefficient Model Application: The model will now be used to calculate the allowable non-point source watershed phosphorus loading that is consistent with the goal of maintaining the total phosphorus concentration of Big Platte Lake below 8 mg/m^3 95% of the time.

Figure 83 shows a plot of the percent of the time Big Platte Lake exceeds 8 mg/m^3 as a function of the annual average volume-weighted total phosphorus concentration based on approximately 7,000 individual measurements collected over a period of 16 years. The correlation estimates that an annual average concentration of 6.44 mg/m^3 will insure that the Lake total phosphorus will be less than 8 mg/m^3 95 % of the time.

The next step is to specify the flow leaving the lake. This can be estimated from extensive historical USGS flow records at US-31 and measurements at the outlet at M-22. Annual average values are shown in Figure 84.

These inputs and Equation 4 can be used to estimate an allowable total phosphorus load into the lake of 5043 lbs/yr that is consistent with the goal of less than 8 mg/m^3 95 % of the time. The allowable non-point load for the system is 4868 lbs/yr after subtracting the Hatchery permit load of 175 lbs/yr. The current non-point load is about 5768 lbs/yr which is about 900 lbs/yr above the goal. A reduction of the current non-point load by 15.6% will likely meet the Big Platte Lake goal.

Note that the model describes conditions for an average flow year which really does not exist. The watershed loading must be known to apply the model for other flow conditions. This is the task of the BASINS watershed loading model currently being completed.

Ecosystem Model: More complex water quality models have been developed for Big Platte Lake in the past by Canale et al. (1991), Chapra (1996), Lung (2000), and Walker (1998). Unfortunately, even these models do not adequately address exchange processes between the water and the sediments and do not include algal productivity, dissolved oxygen, or Secchi Depth as model variables. A more comprehensive water quality model for the lake will eventually be needed that can predict algal blooms, light attenuation (extinction coefficient or Secchi Depth), and the internal loading of phosphorus from the sediments associated with low bottom water dissolved oxygen concentrations.

The development of such a water quality model for the lake is proceeding in stages. Figure 85 shows the current model kinetic components. The model mechanisms were chosen to allow accurate modeling of phosphorus, water clarity, and dissolved oxygen with a minimum of model complexity. It is planned to make additional improvements to this model framework as more monitoring data becomes available and the special studies are completed. Figure 86 compares the one-coefficient and ecosystem models and summarizes the advantages and disadvantages of each approach.

Monitoring Program

Objectives

The overall purpose of the monitoring program is to facilitate and support the goals of the Consent Agreement. The sampling program has the following specific objectives.

- To quantify the total phosphorus loading from the Platte River State Fish Hatchery as required by the NPDES permit for the facility and the Consent Agreement.
- To determine the volume-weighted total phosphorus concentration of Big Platte Lake to insure compliance with water quality standards as stated in the Consent Agreement.
- To support trend analyses of the water quality of Big Platte Lake and its tributary streams so that long-term changes can be identified, quantified and corrected if necessary.
- To construct mass balances for water and total phosphorus for the hatchery, lake, and watershed to support the development of water quality models for the system.
- To support the development, calibration, and validation of the BASINS model for watershed total phosphorus loading as a function of land-use, soil type, and weather conditions to allow the full implementation of this watershed planning tool.
- To determine total phosphorus and suspended solids loads from sub-watershed basins during storm events to allow the proper calibration of the BASINS model and to determine potential high priority remediation locations.
- To support the development, calibration, and validation of water quality models for Big Platte Lake to support the overall watershed planning efforts.
- To evaluate and document changes in water quality following possible future remedial activities within the watershed.

2005 Sampling Plan

The sampling plan for 2005 involves collecting data from the hatchery, watershed streams, and Big and Little Platte Lakes. The sampling stations are shown in Figures 87, 88, and 89.

The net hatchery total phosphorus load to the system is evaluated by subtracting the inlet load from the total outlet loading. Measurements of flow, total phosphorus concentration, and turbidity are currently taken at four locations two times per week using both the Jug & Needle and Sigma samplers. It is recommended to maintain this regular schedule in 2006.

The tributary sampling program is designed to calculate the non-point phosphorus loading into Big and Little Platte Lakes. Measurements of flow, phosphorus, and turbidity are taken on a regular basis and during wet weather flow events. These data will allow a detailed evaluation of water quality for various hydrologic conditions, provide sub-watershed loading estimates, assist in defining high priority remediation areas, and support the calibration and validation of the BASINS watershed model. The regular and special monitoring schedule implemented in 2005 should be continued through 2006.

Big and Little Platte Lakes are sampled every two weeks during the year. A Yellow Springs Instruments (YSI) meter is used to measure dissolved oxygen, temperature, pH, conductivity, and ORP. Discrete depth and tube samples are analyzed for total and dissolved phosphorus, nitrite and nitrate, turbidity, phytoplankton, alkalinity, chlorophyll, total dissolved solids, and calcium. Zooplankton is sampled using a vertical net haul. Light penetration is measured with a Licor meter. Secchi depths are measured with a standard Secchi disk. This program should be continued in 2006.

A summary of the sampling frequency and the measured parameters for each station is listed in Figure 90 and compared with the current contract with CMU. It is seen that it is recommended that more samples be taken for alkalinity, calcium, phytoplankton, and nitrate compared to the CMU contract. However, these are more than offset by decreases in total phosphorus, zooplankton, chlorophyll, water content, and solids phosphorus. The current plan and contract can accommodate additional measurements of alkalinity in some of the streams and some calcium measurements in Torch Lake to help calibrate the calcite model being developed by Dr. Chapra. In addition, the plan can accommodate an expanded measurement program for the Hatchery clarifier and tank overflows to increase the reliability and credibility of the hatchery process model.

In addition to the regular sampling program, the following are recommended for 2006:

- It is proposed investigate the feasibility of using the Gran procedure to titrate alkalinity in the field or at the Platte River State Fish Hatchery laboratory instead of sending samples to CMU for analysis. This procedure is preferred when performed in the field within one hour after sampling.

- It is proposed to measure the dissolved calcium in Big and Little Platte Lakes and Torch Lake to support model development for calcium carbonate formation and light attenuation in these lakes by Dr. Chapra. Coordination will allow us to benefit from this study without having to perform all the development work.

- It is proposed to continue to measure density and tissue phosphorus content of debris on the shoreline of Big Platte Lake to assess the amount of phosphorus that could be potentially removed from the lake via this effort.

- The phosphorus mass balance for the Platte River State Fish Hatchery is sensitive to the amount of phosphorus contained in fish in the Hatchery, planted fish, fish stocked outside of the Platte River Basin, and in fish eggs. It is proposed that these quantities be measured and recorded on at minimum a monthly basis.

- It is possible that a low-volume high-phosphorus flow enters the pond from the routine clarifier and sludge tank overflows. It is recommended that all the flows into and out of these tanks be sampled for flow, phosphorus, and turbidity every two weeks.

<u>Quality Assurance and Control</u>

Extensive efforts are made to insure the accuracy of the various field and laboratory procedures. Appendix D contains a maintenance schedule for all equipment as well as SOP documents for Fish Culture, Hatchery Flows, Net Total Phosphorus Load, and Water Sampling. Appendix E contains Certification Letters that specify that all data have been accurately entered into the database. In addition to the SOP specified QA/QC measures, the following is a list of key QA/QC activities and recommendations for 2006:

- CMU regularly measures the phosphorus concentration of purchased standards that have concentrations of 5 and 10 mg/m^3. The average concentration of 38 measurements of the 5 mg/m^3 purchased standard solution was 5.003 mg/m^3 with a standard deviation of 0.006 mg/m^3. The average concentration of 38 measurements of the 10 mg/m^3 purchased standard solution was 10.0002 mg/m^3 with a standard deviation of 0.006 mg/m^3. These results are extraordinarily accurate and precise and provide strong confidence regarding the reliability of the CMU phosphorus measurements. These efforts should be continued indefinitely to insure overall quality control.

- CMU measures the 10 mg/m^3 in-house standard solution that is used to develop the correlation curves that relate total phosphorus concentration to absorbance. The re-run of 52 samples increases in concentration by an average of about 0.33 mg/m^3 with a standard deviation of 0.33 mg/m^3. These increases are caused by the extra handling required to re-run the samples. CMU has changed the handling procedures to significantly reduce the re-run errors and these should be continued in 2006.

- The YSI pH meter is calibrated with pH = 7.0 buffer solution just prior to each lake sampling. Possible drift of the instruments is measured after every use. The YSI meter should be sent to the manufacturer for annual during periods when ice conditions do not permit regular sampling.

- Procedures were developed to calibrate the YSI meter dissolved oxygen meter before every use. This is accomplished using air saturated refrigerated and room temperature distilled water to simulate conditions on the bottom and surface of the lake. The dissolved oxygen concentration of these waters is measured with the air-calibrated YSI meter. The measured concentrations are compared to known values to verify the accuracy of the meter readings. This procedure has worked well and should be continued in 2006.

Special Studies

Overview

The development, calibration, and final validation of the BASINS watershed loading model and the water quality model for Big Platte Lake will be based on the hatchery, tributary, and lake monitoring data described above. However, it is also important to enhance the model reliability by conducting special studies that will provide direct estimates of some of the model coefficients that are independent of the regular monitoring data. These special studies are described below.

Macrophytes and *Chara*

Hass (2003) mapped the distribution of biomass and density of common macrophytes in Big Platte Lake. However, the study did not include measurements of *Chara.* A limited survey was conducted on July 27, 2005 to estimate the area, density, and tissue phosphorus content of *Chara* in Big Platte Lake. The *Chara* generally occurred at depth between 5 and 12 feet. This corresponds to an area of approximately 1.73 million square meters. The density was estimated by drying and weighing all the plant material in a hoop collected by a SCUBA diver. The average density of the *Chara* was about 191 gm DW/m^2. The average tissue phosphorus of *Chara* in Big Platte Lake was about 0.0208 %. This low value is near a critical limit and indicates *Chara* growth rate is limited by phosphorus availability in the water column. Although Chara is attached to the lake bottom, the root structure of the plant is for structural support only and receives no nutrition from the sediments. Approximately 151 pounds of phosphorus are estimated to be bound up in Big Platte Lake *Chara*. This phosphorus is removed from the water column and rendered unavailable to phytoplankton during the summer. The tissue phosphorus is released and returned to the water column with fall Chara senesce. These estimates of the impact of this species on phosphorus dynamics increase our understanding of the phosphorus processing in this lake.

<u>Sediment Studies</u>

Michael Holmes and Scott McNaught from CMU have completed a study of sediment oxygen demand and phosphorus release dynamics of Big Platte Lake (see Appendix F). The overall objective was: 1) to measure and characterize phosphorus release and oxygen uptake in the sediment from different locations and times of the year; and 2) determine the influence of different sediment types. Measured sediment parameters included chemical oxygen demand (COD), total organic carbon (TOC), volatile solids (VS), grain size (GS), and total sediment phosphorus (total phosphorus). Sediment cores were taken at several sites and stored on ice prior to conducting phosphorus release and oxygen uptake experiments. All sediment cores were incubated in the dark at temperatures similar to the current hypolimnion.

The SOD (sediment oxygen demand) was determined by measuring the decrease in dissolved oxygen concentration as a function in water overlying undisturbed sediment in the laboratory. The SOD of Platte Lake sediments typically range between 1.0 and 1.5 gm O_2/m^2/day. These are values consistent with data from other lakes similar to Big Platte Lake Gardiner (1984).

The phosphorus release experiments were handled similarly to studies done by Kamp-Nielson (1974) and Penn et al. (2000). Phosphorus release was monitored under both oxic and anoxic conditions. Preliminary phosphorus release rates measured in Big Platte Lake vary with location in the lake and time of year. Maximum values occur in the late summer and fall and typically range from about 0.2 to 1.5 mg P $/m^2$/day. These values are somewhat lower than values for similar lakes (Penn et al, 2000). The low release rates may be a function of the high marl content of the sediment that may chemically bind soluble phosphorus, although such interactions have not been formally documented in the scientific literature.

The sediment studies are completed. A Master's Thesis is being prepared and will be submitted sometime during 2006. Upon completion of the thesis, it will be possible to refine the estimates of the significance of sediment release on the overall phosphorus budget for the lake.

Bioavailability

Laboratory tests should be performed to determine the bioavailability of different point and non-point sources of phosphorus. These include the hatchery effluent, the upper Platte River, major tributaries within the watershed, Platte River water at the inflow to Big Platte Lake, and small local drainage 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 detailed experimental and laboratory will program will be finalized following a comprehensive literature review by CMU.

Calcium Carbonate

Calcium carbonate formation can affect water clarity in marl lakes such as Big Platte Lake. This chemical precipitation is a function of temperature and pH. The pH can be elevated during periods of intense algal productivity that result from stimulation by biologically active phosphorus concentrations. It has been a long-term goal of this project to understand these processes in Big Platte Lake. Dr. Steven Chapra and Betsy Homa (PhD student) from Tufts University (Medford, MA) are developing a comprehensive state-of-art model of these complex processes in Torch Lake in cooperation with The Three Lakes Association. We have the opportunity learn from this study through sharing data and analyzing samples from both Torch and Big Platte Lakes. It is recommended that we participate in this effort.

Settling Velocity

The settling velocity of particulate phosphorus is an important input to both the one-coefficient and the ecosystem models. In the past, it has been recommended that we undertake the effort to measure this variable in Big Platte Lake. This was not accomplished because of the difficulties of deploying a permanent buoy station in Big Platte Lake. Fortunately, the Three Lakes Association has successfully measured this parameter in Torch Lake. These data are available to us and should be used in the Big Platte Lake models.

Data Management

An ACCESS database has been developed that accommodates the current sampling at the hatchery, in tributary streams, at lake stations, and the Hatchery weather station, and USGS. The database contains all the 2005 data except phytoplankton.

The Platte Lake Watershed Sampling Database consists of three components: Field; Data Manager; and Data Viewer (Figure 91). The field component is used to enter various measurements taken in the field or hatchery laboratory analyses. Field measurements, bottle numbers, and measurement instructions are sent to the Data Manager and CMU. Laboratory results for various bottle numbers are sent to the Data Manager in the form of EXCEL spreadsheets using email. The Data Manager imports the laboratory results and matches this information with the bottle numbers obtained from the Field component. At this point, conflicts such as inconsistent bottle numbers and missing data are resolved. The Data Manager updates the Data Viewer and distributes new data files through email. The reports examined through the Data Viewer are used to track progress on the Hatchery loading and lake water quality and produce graphs and tables for the Annual Report.

Figure 92 shows the expanding list of reports that can be examined using the Data Viewer. Figure 93 shows a new report that incorporates data on the Trophic State Index (TSI) for several lakes in the State of Michigan. It is seen that Big Platte Lake is in the middle of the range with lakes such as Houghton Lake having poorer water quality, and lakes such as Crystal and Long Lake having superior water quality.

Despite the database and EXCEL programs developed to accommodate all data management tasks, significant communication and coordination is required among the four components to insure that all data are correctly entered and displayed. These efforts should be continued in 2006.

References

Bowie, G. L. et al. 1985. Rates, Constants, and Kinetic Formulations in Surface Water Quality Modeling, 2nd Edition, EPA/600/3-85/040, Environmental Research Laboratory, U.S.E.P.A.

Canale, R.P. and S.C. Chapra. 2002. "Modeling Zebra Mussel Impacts on Water Quality of the Seneca River, NY". J. of Env. Engr. Div. ASCE, Vol. 128, (12), pp. 1158-1168.

Canale, R.P., W.J. Swiecki and S.C. Chapra. 1991. Fish Hatchery Impacts on High Water Quality Lakes. Report Prepared for PLIA, 25 pages.

Chapra, S.C. 1997. Surface Water-Quality Modeling. McGraw-Hill, New York, New York, USA.

Chapra, S.C. 1996. Data Analysis and Preliminary Modeling of Platte Lake, Michiga*n*. Report prepared for MDNR and PLIA.

Chapra, S.C. and R.P. Canale. 1998. Numerical Methods for Engineers. 3rd Edition. McGraw-Hill, New York, New York, USA.

Clevenger, J. A. Jr. 2004. Summary of the Chinook and Coho Salmon Harvest From Michigan Weirs on Tributaries of Lakes Michigan and Huron, Michigan Department of Natural Resources Fisheries Division.

Gardiner, R.D. 1984. Sediment oxygen demand and related surficial sediment characteristics in Green Bay (Lake Michigan*)*. Master's Thesis, Department of Civil Engineering, Michigan Technological University, Houghton, Michigan, USA.

Hardy, R.W., Gatlin, D. 2002. Nutritional strategies to reduce nutrient losses in intensive aquaculture. In: Cruz-Suárez, L. E., Ricque-Marie, D., Tapia-Salazar, M., Gaxiola-Cortés, M. G., Simoes, N. (Eds.). Avances en Nutrición Acuícola VI. Memorias del VI Simposium Internacional de Nutrición Acuícola. 3 al 6 de Septiembre del 2002. Cancún, Quintana Roo, México.

Kenaga, D. and E.D. Evans. 1982. The Effect of the Platte River Anadromous Fish Hatchery on Fish, Benthic Macroinvertbrates and Nutrients in Platte Lake. Water quality Division, Michigan DNR, 41 pages.

Kitchell, J.F., D.J. Stewart, and D. Weininger. 1977. Applications of a bioenergetics model to perch (Perca flavescens) and walleye (Stizostedion vitreum). Journal of The Fisheries Research Board of Canada 34:1922-1935.

Lung, W. 2000. Modeling Total Phosphorus and Dissolved Oxygen in Platte Lake. Report prepared for 30th Circuit Court, state of Michigan.

Nurnberg, G.K. 1986. Prediction of Phosphorus Release Rates from Total and Reductant-Soluble Phosphorus in Anoxic Lake Sediments. Canadian Journal of Fisheries and Aquatic Science 45: 453-462.

Penn, M.R., M.T. Auer, S.M. Doerr, C.T. Driscoll, C.M. Brooks, and S.W. Effler. 2000. Seasonality in phosphorus release rates from the sediments of a hypereutrophic lake under a matrix of pH and redox conditions. Canadian Journal of Fisheries and Aquatic Science 57: 1033-1041.

Walker, W. W. 1998. Analysis of Monitoring Data from Platte Lake, Michigan. Report prepared for Michigan Department of Natural Resources.

Hugh H. Banks and James E. Nighswander. 1999. Relative Contribution of Hemlock Pollen to the Phosphorus Loading of the Clear Lake Ecosystem Near Minden, Ontario.Proceedings: Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America GTR-NE-2

Appendices

A. 2005 Coordination Meetings Minutes

B. Hatchery 2005 Load Calculations

C. Plankton Report

D. SOP Reports

E. Certification Letters: flows, loading, weir, production

F. 2005 Sediment Report