Annual Report for the Year 2006

Consent Agreement Regarding the Operation of the Platte River Hatchery

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Summary for the Year 2006

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 Platte River State Fish Hatchery (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 2006.

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 2006 is the third of three test years where the limits are 175 and 55 lbs. The net Hatchery annual loading for 2006 was 123.3 lbs. This is well within the requirement. The maximum load for any 3 month period was 45.8 lbs. This is less than the limit of 55 lbs. The average water use at the Hatchery was 6.9 mgd which is less than the Consent Agreement limit of 20 mgd.

The average volume-weighted total phosphorus concentration of Big Platte Lake was 8.0 mg/m^3 in 2006. The water quality goal of 8.0 mg/m^3 was achieved 47% of the time. This is not consistent with the goal of 95% attainment as stipulated in the Consent Agreement.

A total of 6,721 adult Coho and 433 adult Chinook salmon passed the Lower Weir in 2006. 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 4,376 adult Coho salmon were harvested for egg collection at the Upper Weir. This is 65% of the number of the Coho that were counted passing through the Lower Weir. A total of 109 adult Chinook salmon were harvested at the Upper Weir. This is about 25% 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 if not removed by anglers or other means. This maximum possible loading from this source without any angler harvest was estimated to be 98.6 pounds in 2006.

Major Accomplishments for 2006

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

- A bioenergetic fish growth and physical process model for the Hatchery has been developed and calibrated.

- Flow, phosphorus, and turbidity data were collected during 14 storm events at both the Platte River and Brundage Creek locations. These data have been used to refine the calibration of the BASINS watershed loading model.

- Stage-discharge relationships have been developed for several tributary sites in the watershed. 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 were used to calibrate the BASINS watershed model.

- A study plan has been developed with CMU to determine the bio-availability of likely phosphorus sources to Big Platte Lake.

- A one-coefficient phosphorus model has been developed and calibrated for Big Platte Lake using the extensive water quality monitoring data for the lake. The model can be used to predict annual average phosphorus concentrations in the lake as a function of changes in flow conditions and phosphorus loading from the watershed.

- Limno-Tech has submitted a report that contains the final calibration and validation of the BASINS watershed phosphorus loading model. The model can be used to predict changes in the phosphorus loading from the watershed as a function of weather conditions and watershed development. The model can be used to test various planning scenarios through a GUI (Graphical User Interface). The GUI also contains the one-coefficient model that predicts the annual average phosphorus concentration in Big Platte Lake as a function of watershed loading. Model outputs have estimated that 669 lbs/yr of non-point phosphorus loading must be removed from the watershed to insure that the phosphorus concentration of Big Platte Lake is less than 8 mg/m^3 95 % of the time for typical hydraulic loading conditions when the hatchery is operating at permit capacity. Typical hydraulic loading conditions were determined using the BASINS model following extensive analysis of flow and loading data between 1990 and 2005.

- A comprehensive but preliminary seasonal ecosystem model has been developed for Big Platte Lake. 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.

- 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 have greatly facilitated the comprehensive data analysis and the development of this report.

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 eliminate one of the methods, the Jug and Needle sampler, and move toward the Sigma sampler. However, we have no rational explanation for the differences. It is recommended we repeat earlier controlled tests with well water using both sampling methods.

- Ways must be sought to improve the accuracy of tracking sample bottles from the time they are taken in the field through laboratory analysis and reporting by CMU. The first step is to improve the design of the laboratory spreadsheets to minimize additional typing and cut and paste errors. It is recommended that this be a joint effort of the field staff, laboratory manager, database developer, and the implementation coordinator. If this fails to reduce the human errors associated with tracking samples to an acceptable level, then additional measures such as electronic marking or bar coding must be seriously considered.

- It is imperative that significant efforts be expended to accurately measure all the inputs and outputs of phosphorus from the Hatchery so that mass balance calculations can be verified each year. Our understanding of the operation of the Hatchery and our ability to measure movement of various phosphorus pathways comes under significant question without such mass balance closure. The next four bullet items are specific recommendations that relate to improving the accuracy of the Hatchery mass balance calculations.

- More attention must be given to accurate measurement of various Hatchery flow rates. It is recommend that the four pumps associated with the inlet flow be calibrated using a bucket procedure during the summer of 2007. Additionally, a weir should be installed at the Upper Discharge to measure flow from the entire system as a check on the data from the four inlet pumps. Finally, it is recommended that current efforts and procedures to measure the overflow from the clarifier and solids storage tanks be continued.

- More emphasis must be placed on accurate measurement of the amount of phosphorus removed from the Hatchery when the solids storage tank is cleaned. It is recommended that the hauling company be required to provide the Hatchery staff a three day notice prior to cleaning as part of any new contract with that vendor. Hatchery staff should place high priority on accurate measurement of the amount of phosphorus removed from the system when the solids tank is cleaned. The tank should be washed down and thoroughly cleaned. It is recommended that a single sample be taken at the beginning, middle, and end of each individual truck load. It is suggested that the tank be cleaned one time per year, preferably as late in the year as permitted by weather conditions and the MI Department of Environmental Quality (DEQ) Manure Exemption Permit language.

- The phosphorus associated with harvested (shipped, planted, and morts) fish and fry tissue is a critical variable associated with understanding the fate of phosphorus in the hatchery as it proceeds from food to harvested fish. It is recommended that the current program with LSSU be continued and that timely reporting of results be encouraged. Also it is recommended that liquefied fish tissues samples be split and sent to CMU for phosphorus analysis to insure the quality of the laboratory results.

- It is recommended that phosphorus content of the fish feed as provided by the manufacturer be verified by providing split samples to CMU and LSSU for analysis.

- It is recommended that an operational log be maintained by the Hatchery staff and distributed every two weeks or immediately after any significant changes or problems in hatchery operation.

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

- The BASINS report suggests that more emphasis should be placed on measurement of flow and water quality at the Stone Bridge site on the Platte River and on the North Branch of the Platte River. Therefore, it is recommended that the automatic sampling equipment be moved from the Brundage Creek location to the Stone Bridge location on the Platte River. Gauge height, turbidity, phosphorus, and nitrate should be measured at this site both as part of the regular bi-weekly monitoring program as well as during equipment maintenance visits.

- The storm event sampling program should be continued with locations reduced to the Stone Bridge site.

- A new regular sampling site should be added to the upper watershed of the North Branch of the Platte River near Hooker Road. A new gauge for this site should be installed and a stage-discharge relationship developed for this location.

- Samples from all regular stream sites should be taken for measurement of nitrate every two weeks.

- It is recommended that total nitrogen be measured in triplicate every two weeks from a 0 to 30 foot surface composite sample and a 45 to 90 foot bottom composite sample from Big Platte Lake. A single surface sample should be measured in triplicate for total nitrogen for Little Platte Lake.every two weeks

- The flow and water quality data (phosphorus, and turbidity) measurement program being conducted by Jerry Heiman should continue and focus on the North Branch of the Platte River (sites 41 and 47) and Stone Bridge (site 82). Emphasis should be placed on collecting samples at all sites during high flow periods.

- 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 likely Hatchery and non-Hatchery phosphorus sources should proceed without delay.

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

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

- The sampling program should be streamlined to remove unnecessary measurements to meet budget and personnel scheduling constraints. It is recommended that single counts of phytoplankton be performed on three 0 to 30 foot and one 45 to 90 foot Big Platte Lake composite samples. It is also recommended that the LICOR light measurement program be discontinued.

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 2006 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, added

biomass measurements, and provided thoughtful analysis and insights on the plankton data results.

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 of the Platte River.
- 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 on Big Platte Lake.
- Tom Inman has coordinated closely with the Hatchery staff on counting the 2006 Fall Salmon Run at the Lower Platte Weir.
- Sally Casey has been making weekly Secchi Depth measurements on Big Platte Lake 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

Antibiotic Use (Ed Eisch)

The antibiotic use at the Platte River State Fish Hatchery (Hatchery) in 2006 was largely focused on the within label feeding of oxytetracycline (OTC) to Chinook salmon to produce a readable mark on the vertebra of Hatchery produced fish. The OTC was added to the feed during manufacturing and was obtained from BioOregon of Warrenton, Oregon. The OTC (TM 100) was mixed in the feed at a rate of 40 pounds per ton of feed. The medicated feed was fed to all rearing units of Chinook salmon at a rate of 2% of the body weight for four days, with one day off and then fed again for another 4 days. The treatment occurred between May 2 and May 29, 2006. Not all rearing units were fed on the same days, and the maximum treatment was 109.9 kg of treated feed per day. A total of 1,900 kg of treated feed were fed during the treatment period. The total amount of OTC in the feed in 2006 was 38.0 kg compared to 1.6 kg in 2005 when the medicated feed was used only for control of a bacterial infection. In 2006, no OTC (TM 100) was fed for disease treatment purposes. The hatchery discharge flow during the treatment period averaged 8.388 MGD (million gallons per day).

Yearlings of the Hinchinbrooke strain of Coho salmon were treated with erythromycin phosphate (Gallimycin) to control an outbreak of bacterial kidney disease (BKD) prior to plant out. The treatment, at a rate of 100 mg erythromycin per kg of fish, was delivered via a hatchery mixed top-dressed feed. A total of 3.91 kg of Gallimycin (391 grams per day) was administered over a ten day period, from February 28 through March 9, 2006. Hatchery flows averaged 6.512 MGD during this period.

Disinfectant Use (Ed Eisch)

Parasite-S was used in 2006 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 daily 15-minute flow-through treatment with formalin concentrations of 1 to 600 (1,667 ppm). During the 2006 incubation season, 492.3 gallons of Parasite-S were used to control fungus on salmon eggs between the dates of October 4, 2006 and January 8, 2007. In 2005 a total of 631.1 gallons were used, reflecting the greater number of eggs in incubation during that season. The maximum daily treatment was 6.8 gallons over a 15 minute period. Hatchery flows averaged 6.559 MGD during the 2006 incubation season.

Chloramine-T (CT) was used in various rearing units during the spring to combat an outbreak of bacterial gill disease (BGD) among Chinook salmon. One hour flow-through treatments at 12 ppm were conducted for three consecutive days. In several rearing units, the bacterial outbreak persisted and a second three day treatment at 15 ppm was conducted. A total of 15.123 kg of CT was used between March 22 and April 8, 2006. The maximum daily treatment was 2.292 kg of CT, which was administered over a one hour period. The average hatchery discharge during this period was 6.620 MGD.

Weir Operations (Jan Sapak)

The Consent Agreement with the Platte Lake Improvement Association allows 20,000 adult Coho salmon 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 salmon stocking program. The agreement also allows for passage of up to 1,000 adult Chinook salmon.

Weir Operation Procedure During the fall of 2006, both the Upper and Lower Platte River Weirs were operated in much the same fashion as in 2005, however the adult coho returns were down significantly. In contrast to this, the number of returning coho jacks was 5 times higher than in 2005. The Lower Weir grates were installed on August 15, 2006 and removed for the season on November 13, 2006. As fish collected below the weir in sufficient numbers, coho salmon were passed upstream for egg take purposes, and surplus Chinook, and coho salmon, were harvested and removed from the watershed. 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.

Lower Weir Summary. In 2006, 557 Chinook salmon, 9,014 coho salmon, 257 steelhead trout and 5 brown trout were passed upstream of the Lower Weir. In addition, a total of 2,691 Chinook and 2,547 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 the biological sampling of the season’s run.

Upper Weir Summary. All of the dam boards for the Upper Weir were in place by August 15, 2006, and any migrating salmon were directed to the maturation ponds after this time. Coho salmon egg take occurred between October 19 and October 26, 2006. Unlike previous years, there was no separate egg take for the Hinchinbrooke strain of coho in November, since this strain is being discontinued from hatchery rearing. After egg take all salmon were harvested. In

2006, a total of 148 Chinook and 6,985 coho salmon were harvested from the Upper Weir 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, 2006.

The total number of fish that were unaccounted for between the Lower and the Upper Platte River Weirs included 2,029 coho and 409 Chinook salmon. It is assumed that these fish were either caught by anglers, or spawned and died in the river prior to reaching the Upper Weir.

Egg Take and Egg Incubation (Jan Sapak)

The coho egg take operation occurred at the Platte River State Fish Hatchery between October 19 and October 26, 2006. A total of 4,301,124 coho eggs were taken and fertilized. This included 2,467,892 eggs (552 kg) for the Platte River State Fish Hatchery and 1,833,232 (410 kg) for other state agencies, including the Wolf Lake State Fish Hatchery and for state fish hatcheries in Indiana and Illinois. A total of 149,670 (33.5 kg) an additional coho salmon eggs were taken at the Boardman and Little Manistee Weirs to ensure sufficient eggs were available for the Coho salmon program and transferred to the Platte River State Fish Hatchery. These eggs were discarded in November 2006, as sufficient eggs were collected in the Platte River egg take.

Chinook salmon eggs were taken at the Little Manistee and Swan River Weirs and transferred to Platte River State Fish Hatchery in October 2006. A total of 3,770,820 eggs (925.5 kg) were incubated at the hatchery. During the course of incubation, 413.5 kg of coho and Chinook salmon egg mortalities were disposed of outside of the watershed, and 138.0 kg of newly, hatched eggs (fry) were fed to the yearling coho salmon as feed.

Incubation at the hatchery occurred during the months of October, November and December 2006. By early January 2007, all of the eggs had hatched and the fry were put into rearing units. In January 2007, 4,043,381 chinook and coho fry (1290 kg) were placed in the tanks for rearing.

Fish Production (Jan Sapak)

During calendar year 2006, the Platte River State Fish Hatchery raised and stocked (planted) 830,322 (28,037 kg) coho salmon in the Platte River. In addition, 865,917 (26,437 kg) coho salmon were raised and shipped out of the watershed. Also, 2,524,510 (10,416 kg) spring fingerling Chinook salmon were raised and shipped to other locations outside the Platte River watershed. A total of 332,752 (622 kg) Chinook and coho salmon mortalities were removed from the hatchery and discarded at a certified landfill.

At the end of the calendar year the inventory of fish on hand at the Hatchery included 962,124 (35,212 kg) yearling coho salmon, and approximately 4.5 million (1,663 kg) Chinook and coho salmon eggs and sac fry in incubation.

During the course of the year a total of 55,189 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 (Jan Sapak)

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, to the salmon harvest contractor.

During the summer of 2006 (July 13-25), ,the outside raceways were set up in a two-pass system with coho salmon in B and C series in an effort to improve incoming water quality and reduce waste handling. Four raceways in the A series was used as a settling basin for inflow water and the A Filter Set was used as a pre-filter for the incoming water. Baffles were removed from the A Raceways and silt was allowed to settle out before the water passed through the disc filter. The sediment was periodically removed from the raceway. This resulted in much improved water quality and reduced waste for the clarifier and solids storage tank.

Fish waste was removed daily from the rearing units either by manual cleaning or automatic filtering of the wastewater. The filtered waste was directed to a clarifier and finally a solids storage tank where it was stored. The solids storage tank was pumped by BioTech Agronomics, Inc. on November 20-21, 2006 and a total of 212,500 gallons of solids storage was removed. All solids storage was land applied per the Michigan Department of Environmental Quality's Manure, Paunch and Pen Waste Exemption guidelines.

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 the net load on days when 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. The concentrations of total phosphorus and turbidity of the Hatchery inlet and outlet flows are currently measured on samples collected using two methods. Since the late 1980s, a composite sample has been taken using a jug equipped with a fine gauge needle that slowly allows water to enter the jug and is known as the Jug and Needle Sampler. Automated Sigma Samplers were installed in 2000 as part of the renovation program and are known as the Sigma Samplers. The Sigma Samplers obtain a 24 hour composite sample by pumping sub-samples at regular intervals. The official hatchery loading is calculated from Jug & Needle Sampler total phosphorus measurements as specified in the Consent Agreement. The net phosphorus load was 123.3 lbs. for 2006.

Hatchery Phosphorus Mass Balance

Figure 2 shows the total annual net phosphorus loading from the Hatchery from 1990 to 2006. Note that the loads since 2000 are about 25% of those in 1990. However, there is considerable variation with the 2006 load being about 100 pounds less than the load in 2005. The purpose of this section is to develop a rational analysis to understand the year to year variations. It is important to understand these variations so that steps can be taken to avoid Settlement Agreement limit violations if changes in fish production are desired or plant operations are altered.

The **Law of Mass Balance** is the primary tool that can be used to achieve these objectives. It states that the rate of accumulation of any conservative substance in a system is equal to the difference between the rates of input and output through the system boundaries (see Figure 3). It is important to recognize that the Law applies to any conservative substance such as water or total phosphorus for any closed boundary such as the Hatchery. The mass balance equation applies for both non-steady state conditions (also called time variable or dynamic) and steady state (also called non-time variable) cases.

Figure 4 shows the steady state application of the mass balance equation where the sum of inflows equals the outfalls. In this case, the accumulation is zero and the sum of the inputs is equal to the sum of the outputs. Steady state mass balance equation is used to determine the outflow from the Hatchery when the inputs are known.

Figure 5 shows a tank where water leaves faster than it enters. In this non-steady state case the water levels decrease in the tank and the level drops as a function of time. If the inflow and outflow are constant values with time given by Q_{in} and Q_{out} the mass balance equation becomes

$$DV/DT = Q_{in} - Q_{out} \qquad (1)$$

where V is the volume of water in the tank The volume of water in the tank as a function of time is given by the solution

$$V(T) = V_0 + (Q_{in} - Q_{out}) \times T \qquad (2)$$

Note that this equation can be used to calculate the flow rate if V(T) and T are measured. This equation also applies to the case where water entering the tank is greater than the leaving flow as shown in Figure 6. This equation can used to calculate flow if changes in depth are measured and the cross sectional area is known. This procedure is currently used to calculate the overflow flow rates from the clarifier and the solids storage tank. It can also be use to calibrate the flow meters using changes in the depth of water in the head box.

Figure 7 shows the Law of Mass Balance applied to the Hatchery on an annual basis. All terms in the mass balance equation must be expressed in units of pounds or kilograms of phosphorus per year. The first terms on the left refers to possible ways phosphorus can accumulate (may be positive or negative) in the Hatchery. There are two major accumulation terms.

1. Fish Tissue P. This term refers to the fish phosphorus present in the Hatchery. It is calculated by multiplying the whole wet weight biomass of the fish times the percent phosphorus in the fish tissue. If the Fish Tissue P is greater at the end of the year than the start of the year the accumulation term is positive. If the Fish Tissue P is less at the end of the year than the start of the year then this term is negative. Note that additions, transfers, or removals of fish from the system are not considered in the calculation because such factors are accommodated by other terms in the mass balance equation.

2. Tank P. This term refers to the amount of phosphorus in the solids storage tank. It is the average phosphorus concentration of the solids in the tank multiplied by the tank volume. This term can also have a positive or negative value depending on the amount of phosphorus in the tank at the start and end of the year. Phosphorus removed by truck is included in separate terms in the mass balance equation.

The second terms are the phosphorus inputs to the Hatchery.

1. Food P. This term is the amount of phosphorus that is fed to the fish in the Hatchery. Note that the term is “food actually fed” and not “feed that may have been purchased and stored at the facility”. It is calculated by multiplying the weight of the food fed times the phosphorus content of the feed. This term is always positive.

2. Source Water P. This is the annual loading of phosphorus contained in all of the Hatchery source water. The sources are Brundage Spring and Creek, the Platte River, and the Service water. The loading is determined by multiplying the flow rate times the phosphorus concentration. This term is always positive.

3. Fry Tissue P. This term refers to the phosphorus introduced to the system when fry are added into the fish inventory. It is calculated by multiplying the whole wet weight biomass of the fry times the percent phosphorus in the fry tissue. Note that this approach avoids the need to count or weigh the egg harvest and morts. Note that if all other terms in the mass balance equation were zero the input of fry tissue phosphorus would exactly equal the accumulation of phosphorus in the system. This term is always positive.

The third terms are the phosphorus outputs from the Hatchery.

1. Shipped, Planted, and Mort Fish Tissue P. This term refers to all the phosphorus that leaves the Hatchery in the form of fish tissue. Note that the mass balance equation does not care if the fish are shipped to another watershed, planted in the Platte River, or disposed as dead biomass. This term is calculated by multiplying the whole wet weight biomass of the fish times the percent phosphorus in the fish tissue. This term is always negative.

2. Discharge P. This term refers to the gross loading of phosphorus that leaves the Hatchery as flowing water. Possible flows include the Upper and Lower discharges and the construction By-pass. Currently the Upper discharge is only outlet flow. Note that this term is the gross loading as determined by multiplying the flow rate times the phosphorus concentration. This term is always negative. The Net Load is the difference between the gross discharge loading and the sum of the input loading and is used for NPDES and Settlement Agreement purposes.

3. Trucked P. This term refers to phosphorus that is trucked away from the Hatchery as a result of emptying and cleaning the solids storage tank. This term is calculated by multiplying the gallons of liquid trucked away times the phosphorus concentration of the liquid. This term is always negative.

4. Pond P. This term refers to the amount phosphorus that settles and stays at the bottom of pond. It is an average value for the year and does not include short-term variations due to wind or other temporary disturbances. This term cannot be measured directly. Instead it is calculated by subtracting all the inputs of phosphorus to the pond from the outlets. Normally, the inputs are greater than the outlets. Other terms in the mass balance would need to be added to cover the case where the pond is drained and bottom materials removed.

Note that the Law of Mass Balance is not an amorphous theoretical concept. Rather it is a practical and exact tool that can be used to determine how well we have stated and measured the terms in the equation. If the mass balance equation does not seem to work very well it is a reflection of how accurately we have accounted for and measured the terms in the equation and not a condemnation of the Law itself. Figure 8 shows the annual phosphorus mass balance equation or model for the Hatchery for the special case when the accumulation terms are zero and the sum of the inputs equals the sum of the outputs.

Figures 9 and 10 display the mass balance equation expressed in regulatory, aquaculture, and facility operations terminology. The net load on the left and side of the equation is simply the difference between the gross output load and the summation of the loading from the various source waters. Food is a positive term that represents the phosphorus in the food fed to the fish. The Production term is the annual amount of phosphorus associated the net growth of new fish biomass. The net annual production of fish is defined as the net 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 as described by Equation 3.

$$\text{Net Production} = \text{Morts} + \text{Shipped} + \text{Planted} + (\text{End Fish} - \text{Start Fish}) - \text{Fry In} \quad (3)$$

New fish grown in the system can remain in the Hatchery and measured as an increase in the standing stock. In addition new growth of fish biomass and associated phosphorus can leave the Hatchery as shipped or planted product or as morts. Note that the term Harvest in Figure 9 is simply the fish that leave the system. Finally, the increase or decrease in standing stock and the transferred fish is offset by the amount of fry that enters the system. The remaining terms are losses due to cleaning and trucking tank phosphorus, phosphorus that settles to the bottom of the pond, or storage of phosphorus in the tank. If the amount of phosphorus in the tank is less at the end of the year compared to the start, the Tank Increase term is negative.

Mass Balance Application

The purpose of this section is to apply the model (that is, the mass balance equations) to actual Hatchery data. This will be accomplished by examining the 2004 through 2006 data in significant detail. Hatchery production data and calculations for 2004 are shown in Figure 11. The fish production terms were calculated assuming that the fish tissue phosphorus content was constant over the year and had a value of 0.4% of the gross wet weight. This assumed constant value is consistent with the range of available estimates, and will no doubt vary with the time of year when more data are available from the current sampling program.

The fish in the system at the end of the year were about double the amount at the start of the year. This means that some of new fish biomass produced was used to increase the stock of fish in the system rather than being shipped or planted.

The solids storage tank began operation collecting and thickening the underflow from the clarifier on September 9, 2003 as shown in Figure 12. The tank has been emptied and cleaned 3 times as of the end of 2006. A small amount of phosphorus was also removed during November 2005 and is not shown. Linear interpolation was used to estimate the amount of phosphorus in the tank at the start and end of each year. This analysis shows that some of the phosphorus supplied to the system during 2004 remained in the solids storage tank. The final term in the mass balance equation is the annual amount of phosphorus that accumulates in the bottom of the pond. This amount is calculated by subtracting the amount exported by the outlets from the pond from the amount provided to the pond by the various inputs.

Figure 13 shows similar mass balance terms for 2005. In this case the fish at the end of the year were less than the start, illustrating a case where some of the fish that were shipped or planted came from stock depletion rather than new growth. Again, the fish production terms were calculated assuming that the fish tissue phosphorus content was 0.4% of the gross wet weight. Tank trucked and stored amounts were determined using Figure 12. The agreement and consistency with mass balance are excellent for 2004 and 2005.

Figure 14 shows the measured mass balance terms for 2006 calculated using the same methods as for the years 2004 and 2005. The measured losses are approximately 177 lbs. less than the inputs. Measured inputs were either too high or measured outputs are too small. In 2006, the measurements of the trucked loss were incomplete and that some phosphorus was no doubt removed when Raceway A was used as a clarifier to remove sediments from the source water. Figure 15 shows application of the mass balance concept to the hatchery for the years 2001 through 2006. Note that for all years except 2004 and 2005 that the measured phosphorus inputs to the hatchery are considerably larger than the measured outputs. These results suggest the following possible explanations:

1. The phosphorus in the food is actually lower than that reported by the supplier.
2. The biomass of the fish leaving the system is larger than that reported.
3. The phosphorus associated with fish tissue is much greater than 0.4%.
4. The actual pond losses are greater than those being measured.
5. The net loading is actually larger than that being reported.
6. The actual discharge flows are larger than measured values.

It is imperative that significant efforts be expended to accurately measure all the inputs and outputs of phosphorus from the system so that mass balance calculations can be verified each year. Our understanding of the operation of the hatchery and our ability to measure movement of various phosphorus pathways comes under significant question without such mass balance closure.

Hatchery Process 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. In the winter and spring, Brundage Spring water flows through sand filters in the Main Hatchery Building by gravity and is used for egg incubation, early rearing and some production rearing. Water to support fish growth in the outdoor raceway tanks 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. The outdoor raceway system consists of three sets of raceways. Each raceway set is equipped with aeration equipment near the head and water discharged from the raceways is routed through a rotating continuous flow drum micro-screens to capture solids. The flow in the tanks can be recycled although they are normally operated in series where the flow that leaves the A Raceway flows to B Series and then C Series if needed. Following final filtering in C Screening Building, the water enters a polishing pond before discharge to the Platte River. The blue lines in Figure 16 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 from a Service well. 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, respectively. Filter Building C accommodates the solids picked up by the vacuum pumps at the end of the raceways in the Main Hatchery Building 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 solids storage tank where gravity concentration continues. The overflow from the solids storage tank also passes to the final polishing pond before discharge. Solids from the storage tank are removed once or twice a year and trucked to a disposal site. Trucking and burial in the pond sediments are the only ways that phosphorus from unconsumed food or fish excretions can be removed from the Hatchery effluent. The red lines in Figure 16 show the wastewater 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 solids storage tank, and the effluent pond. The net loading from the Hatchery is affected by piping and recycle systems and the efficiencies of each system component. A comprehensive model of the Hatchery would include a detailed bioenergetic 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 describe the response of the Hatchery than are available currently. Such an effort will not be undertaken now. 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 17 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 18. 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 phosphorus concentration as the result of particulate retention by the screen. Service 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 further splits the flow into two fractions. Solids are settled to the bottom of the clarifier tank and the overflow is sent to the finishing pond. The solids on the bottom of the clarifier are pumped to the solids storage tank. The final split occurs in the solids storage tank. The solids storage tank overflow, which only occurs during clarifier pumping, empties into the pond. The concentrated solids in the tank are 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 solids storage 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 solids storage tank. Some phosphorus that enters the pond settles to the bottom and is buried in the sediments. Some of the phosphorus is tied up with pond vegetation and either the vegetation is exported from the pond when it dies or senesced material is deposited into the sediments. The final effluent leaves the system with a flow equal to the inflow minus an insignificant reduction when the solids storage tank is cleaned. Figure 19 labels the flow and phosphorus concentrations at various locations in Hatchery.

Fish Growth Bioenergetic Sub-Model: Figure 20 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

$$C = G + R + S + F + U \qquad (4)$$

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 species 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 21 and 22. The model coefficients shown in Figure 21 are based on Hatchery monthly measurements of net growth rate. Note that the model suggests that the most effective use of food occurs at a temperature of 10 degrees C where only about 14% of food is wasted through respiration. 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 23. 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 Fish Bioenergetics Model. Figure 24 shows the mass balance equations for the water, food and fish tissue phosphorus in the growth tank.

Waste Treatment Component Sub-Models: The waste treatment components at the PRSFH are: the screens; a clarifier; a solids storage tank; and final effluent polishing pond.

The screens simply remove solids from the raceway and Main Hatchery Building water after fish use without changing the inflow or outflow rates because the wash water (Q3) originates from a separate source. The screen operations are described by Equations 5 and 6.

$$P_2 = P_1 (1- f) \qquad (5)$$

$$P_3 = Q_1 P_1 f / Q_3 \qquad (6)$$

The fraction of the incoming phosphorus concentration removed by the screens is given by f, and the flow and phosphorus concentrations are defined in Figure 25.

Each of the other three treatment components of the Hatchery can be considered as special cases of the general reactor as shown in Figure 26. The general reactor has two mixed layers. The flow into the top layer of the reactor is split into a surface overflow and a bottom underflow to simulate solids collection and removal. Solids settle from the top to the bottom layer at a rate of v_s. Diffusive and dispersive exchange between the layers is represented by E. Solids from the bottom layer can also be buried and lost at a rate of v_b.

The behavior of the general reactor is described by the following linear differential equations.

$$V_1\, dP_1 / dt = Q_0\ P_0 - Q_1 P_1 - Q_2 P_1 - v_s A P_1 + E (P_2 - P_1) \qquad (7)$$

$$V_2\, dP_2 / dt = Q_2 P_1 - Q_2 P_2 + v_s A P_1 - E (P_2 - P_1) - v_b A P_2 \qquad (8)$$

In Equation (7) and (8) V is the volume, A is the area between the top and bottom layers, Q are flow rates, P are total phosphorus concentrations, and 1 and 2 refer to the top and bottom layers respectfully. The steady state solution is readily obtained and the dynamic solutions can be derived analytically or can be approximated using numerical methods.

The clarifier has a residence time of less than 1 day, therefore it is modeled as a steady state reactor with vb =0. Essentially the clarifier splits the backwash flow from the screens into two fractions. The overflow passes to the pond, while the underflow is directed to the solids storage tank. The solids storage tank is treated as a non-steady reactor to simulate the yearly buildup of solids in tank. The solids storage tank has no underflow and vb=0. Cleaning and emptying solids storage tank are simulated by setting the tank concentrations to zero on the day the tank is cleaned. The pond is also treated as a non-steady state reactor with no underflow. However, vb is not zero because phosphorus is permanently lost to the pond sediments.

<u>Model Calibration</u>

The model has four forcing functions: the flow and concentration of phosphorus of Brundage Creek and Spring; water temperature; the food fed; and the total harvest (sum of Morts, Shipped, and Planted). These time variable functions for 2005 are shown in Figure 27. Interpolation and smoothing were used to determine daily values to provide input to the model and facilitate numerical solution of the system differential equations.

The model closely matches the measured fish in the system and the monthly growth rates for 2004 through 2006 as shown in Figure 28. 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 egestion and excretion and unused food. The main variation of total phosphorus concentration leaving the raceways follows the seasonal pattern of the dominant bioenergetic processes of the fish, much of this is driven by water temperature. Excess uneaten food also plays a role by increasing the raceway concentration around day 150 when the fish in the system have been depleted due to harvesting. Figure 29 shows the model calculated phosphorus concentrations for 2005 at the outlet of the growth tank, screens, clarifier, and pond. Figures 30 through 32 show the model calculations for the 2005 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. The model simulations indicate that 582 pounds of phosphorus were harvested and that the loading to the screens is 724 pounds. About 269 pounds of the phosphorus that enters the solids storage tank is removed during two cleaning periods, and 4 pounds are buried in the pond sediments. The screens and the clarifier tank do not directly remove phosphorus from the system but concentrate the phosphorus concentration thereby facilitating and magnifying the removal during solids storage tank cleaning. Note that the calibrated model closely matches the 2005 net loading of 226 pounds.

Figures 33 and 34 show the 2005 calibrated model applied to the 2004 and 2006 operations of the hatchery. The model simulates the 2004 conditions quite well. Figure 35 shows the model coefficients for each year. Note that consistent values were used for the bioenergetic coefficients for all three years. The mass transfer coefficients varied somewhat from year to year to reflect changes in Hatchery operations or water temperature (weather conditions). The ability of the model 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.

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 formulation of model mechanisms. These improvements are described in Figure 36. The increased monitoring essentially involves measuring fish weight 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 solids storage tank solids to estimate the settling rate of solids and the sediment release rates. The model can be improved by adding more detail regarding the physical components such as the raceway recycle flows. In addition, it is possible to add more realistic and refined formulations of fish bioenergetic and metabolic processes such as modeling each age class of fish as a separate model component rather than treating the population as a whole.

Tributary Flows and Water Quality

Flow Rates

Figure 37 shows the long-term trend of annual average flow of the Platte River measured at the USGS station (at US 31 (Gage Number 04126740). The average Platte River flow at the USGS station was 119.1 cfs in 2006. This flow is slightly lower than the long-term average flow of 125.8 cfs since 1990. Thus, 2006 can be characterized as a slightly drier than the average year. Figure 38 shows the daily hydrograph determined by USGS for the Platte River at the USGS gage station for 2006 as well as PLIA measurements. Note that the hydrograph is relatively uniform. Several spikes in flow were recorded during the spring, summer, and fall that correspond to significant rainfall events.

Phosphorus Concentrations

Figures 39 and 40 shows measured total phosphorus concentrations in the Platte River at the USGS station at US-31 and Brundage Creek at the old residence for 2006. The GPS locations for these and all other sites in this report are included in the Site Maintenance section of the project database. Baseline concentrations were around 18 mg/m^3 in the spring and about 8 mg/m^3 in the summer. These figures also show measured phosphorus concentrations during several 2006 storm events. Maximum total phosphorus concentrations during these events are typically an order of magnitude higher than during base flow periods. It is apparent that non-point loads based on routine dry weather measurements alone will underestimate the actual non-point load because many spikes are missed. The calibrated BASINS model was used to estimate that between 28 and 45% of the overall phosphorus loading from the watershed is contributed by storm events (see Table 8 in the Appendix C BASINS report). 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. Therefore, it is recommended that sampling of storm events at the Stone Bridge site be continued during 2007.

Figure 41 shows total phosphorus measurements in the North Branch of the Platte River in 2006. Note that maximum total phosphorus concentrations of about 20 mg/m^3 occur during the spring and early summer. This annual pattern is distinctly different than the variation at the USGS site. Storm event spikes are not observed because of the attenuating influence of Little Platte Lake. The BASINS modeling project has demonstrated that the phosphorus export from the North Branch watershed is higher than would be expected based on land use and soil conditions alone. This report has recommended that more emphasis be placed on measuring the loading of the North Branch by adding a new upstream station near Hooker road to the regular monitoring program.

Lake Water Quality

<u>Big Platte Lake</u>

<u>Total Phosphorus:</u> The annual variation of volume weighted total phosphorus in Big Platte Lake ranged from 5.5 mg/ m^3 to 12.6 mg/m^3 in 2006(Figure 42). 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 2006 was 8.0 mg/m^3. There were 192 days when the total phosphorus concentration exceeded the 8.0 mg/m^3 goal. This corresponds to about 47% attainment as compared to the 95% requirement. Figure 43 shows the total phosphorus concentration in the top, middle, and bottom layers of the lake. The bottom layer is approximately 4 mg/m^3 higher than the top because particulate phosphorus settles form the surface layers and phosphorus may be released from the bottom sediments during periods of low dissolved oxygen. Figure 44 and 45 show that about two-thirds of the total phosphorus occurs in dissolved form in both the top thirty feet and bottom forty five feet of water. It is likely that most of this dissolved phosphorus is in a non-reactive form although no direct measurements are available to confirm this supposition.

<u>Dissolved Oxygen:</u> Figure 46 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 112 days in 2006. This is an important period because this is when it is expected that dissolved phosphorus will be released from the sediments because of reducing conditions in the sediments. Shallower water experienced shorter periods low dissolved oxygen conditions as shown. These data are used to calculate the depth and area weighted 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.

Secchi Depth: Water clarity is an important indicator of water quality conditions in Big Platte Lake. Secchi depth is a common and simple method used to measure water clarity. Although, this measurement has a high amount of observer variation, a single individual volunteer from the PLIA has measured the Secchi Depth of Big Platte Lake for over 20 continuous years. . The 2005 and 2006 annual variations of Secchi depth in Big Platte Lake are shown in Figure 47. Note that 2005 has a distinct clearing event around day 180 where the Secchi depth increases to about 20 feet for a period of about one month. Otherwise, the Secchi depth variations are similar in 2005 and 2006. Figure 48 shows that the 2005 clearing event was associated with a significant spike in zooplankton biomass. In 2006 the zooplankton were more evenly distributed throughout the year and no prominent clearing event was observed (see Figure 49). The differences between the zooplankton distribution in 2005 compared to 2006 also have a significant affect on the phytoplankton biomass as illustrated in Figure 50. Note that the phytoplankton biomass around day 180 in 2005 was about one-half that in 2006 during the same time period. Thus, it appears that high zooplankton biomass in 2005 reduced phytoplankton levels and increased water clarity. In 2006, the zooplankton biomass was lower and no summer clearing event was observed

Chlorophyll: Figure 51 shows the annual variation of chlorophyll during 2005 and 2006.. Note that the measured chlorophyll around day 180 is lower in 2005 compared to 2006. This is consistent with the phytoplankton biomass data shown in Figure 50.

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. Thus, the seasonal variation of water transparency in Big Platte Lake is a complex water quality modeling problem because it is affected by both chemical and biological processes. It is recommended coordinating our efforts with those of the Three Lakes

Association and Tufts University who are conducting advanced research studies on Torch Lake (Antrim County, MI) of the links between calcite formation and water clarity.

Inorganic Nitrogen: Figures 52 and 53 show the seasonal variation of surface and bottom water nitrite and nitrate concentrations in Big Platte Lake for 2005 and 2006. The concentration during spring and early summer is about 250 $mg/m^{3.}$ This is similar to the maximum concentrations measured in rainwater during 2006. The lake concentrations decrease with the onset of summer algal growth. Note that the surface concentration reached a minimum of about 1.0 mg/m^3 around day 235 during 2006. The bottom water concentration also decrease with time reaching a short-lived minimum of about 15 mg/m^3 around day 275 for both 2005 and 2006. The low summer concentrations are approaching and sometimes below rate-limiting values for algal growth (approximately 5.0 mg/m^3). Thus, 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 Platte Lakes during 2006.

Plankton Food Web: Phosphorus is the primary limiting nutrient that drives the simplified food web for Big Platte Lake (Figure 54). The sampling program for both Big and Little Platte Lakes includes the collection of phytoplankton and zooplankton samples that are enumerated to develop density estimates for each population. 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 on phytoplankton are likely related to 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 also affect water quality through top down predation mechanisms. For example, heavy fish predation on zooplankton can relieve pressure on the phytoplankton which can lead to an increase in phytoplankton. This results in a decrease in water transparency. These important and complex interactions are described in more detail in Appendix B authored by Dr. Scott McNaught from Central Michigan University.

Little Platte Lake

Little Platte Lake is located about one-half mile north of the north-shore of Big Platte Lake. 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 and was a large shallow wetland complex flooded by its water control structure. Approximately 12,000 feet, or about 57% 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 its confluence with Big Platte Lake. The North Branch is the 2^{nd} 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 55 through 63 compare the surface concentration of several water quality variables in Big and Little Platte Lakes in 2006. The measurements in Figure 55 indicate that the surface water of Little Platte Lake is 2 to 4 degrees warmer than that of Big Platte Lake during the winter; perhaps attributable to a larger percentage of the inflow from groundwater sources. The summer surface temperatures of the lakes are similar but Little Platte Lake does not stratify because of its shallow nature.

The total phosphorus concentrations in Little Platte Lake are about 50% or 6 mg/m^3 greater than that of Big Platte Lake (Figure 56). The dissolved phosphorus of Little Platte Lake is about 2 mg/m^3 greater than that of Big Platte Lake (Figure 57). Figures 58 and 59 indicate that the chlorophyll and turbidity of Little Platte Lake are slightly higher than Big Platte Lake. This is expected because of the higher phosphorus concentrations.

In both 2005 and 2006, 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 both years (Figures 60 and 61). This low level of inorganic nitrogen creates conditions that favor the growth of nitrogen-fixing blue-green algae such as *Anabaena*. Phytoplankton samples collected in Little Platte Lake in 2006 contain *Anabaena* and other blue-green algae and are described and discussed more thoroughly in Appendix C. It is also noted that the pH of Little Platte Lake is higher than that of Big Platte Lake, while the alkalinity is lower (Figures 62 and 63) reflecting higher levels of algal activity in Little Platte Lake as a result of higher phosphorus concentrations. It is recommended that sampling of Little Platte Lake be continued during 2007 so that the cause of high phosphorus in the Little Platte watershed can be better understood.

Watershed Management

The goal of the Platte River Watershed Management Program is to control and minimize the input of point and non-point phosphorus loads to Big Platte Lake. The control of the phosphorus loads will protect the water quality of Big Platte Lake. In order to be effective, the program must be accurate, reliable and have scientific credibility. Such quantitative capability must be grounded by a comprehensive water quality monitoring program and the resultant data must be analyzed and synthesized using well designed watershed loading and lake water quality models. The goal of this section is to describe ongoing efforts to develop these important tools.

BASINS 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 are then 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 64 illustrates the overall approach.

The BASINS model has been calibrated using extensive flow and water quality data for the Platte River watershed collected by Hatchery staff and PLIA members between 1990 and 2005 as well as historical data from Kenega and Evans (1982). The water quality monitoring program included measurement of river and tributary flows, total phosphorus, and suspended solids during numerous storm events. The BASINS modeling effort was conducted by LimnoTech, Inc. through a separate contracted funded by PLIA. LimnoTech, Inc. has produced a graphical user interface (GUI) for BASINS that allows users such as the PLIA to calculate changes in phosphorus loadings to Big Platte Lake as a function of changes in land use and nutrient abatement projects. These changes in loading can be used to calculate the annual average phosphorus concentration of the lake itself and provide insights into lake productivity and water transparency. An application of the BASINS model and the GUI follows and the complete LimnoTech report is included as Appendix C.

Lake Water Quality Modeling

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. Most 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 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 65.

Two separate Big Platte Lake water quality models are being simultaneously developed to accommodate modeling considerations. A one-coefficient model has simple model mechanisms which are easy to apply and defend, however this model does not provide detailed insight into the chemical and biological dynamics of the lake. It can provide at least first order estimates of the lake's status. A more complex ecosystem model is being developed to provide these insights but this model requires explicit numerical values for many coefficients and forcing functions that are difficult to quantify without introducing additional uncertainty.

Our approach will be to rely primarily on the one-coefficient model for watershed planning applications. The ecosystem model will be used in conjunction with the one-coefficient model to provide in-depth understanding of the lake water quality dynamics when appropriate.

One-Coefficient Model Development: A one-coefficient model for total phosphorus in Big Platte Lake is illustrated in Figure 66. 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 9 and the various terms are defined in Figure 66.

$$p = W / (Q + v_s A) \qquad (9)$$

The first step in the development of the one coefficient model is to construct annual average balances for water and phosphorus for the lake and watershed. These balances are best constructed for the Platte watershed using the BASINS model along with field measurements. This is because the model has been validated for the entire watershed using data from the field sampling program. The model is not directly dependent on the measurement frequency and location which varies from year to year.

These water and phosphorus balances for 1990 through 2005 are shown in Figure 67. The flows are based on USGS measurements that are extrapolated on a drainage area basis to include the entire watershed using the BASINS model and calibrated using field measurements throughout the watershed. The Hatchery load is based on direct measurements. The direct phosphorus loads and those at the USGS US-31 and North Branch of the Platte River sites are based on the verified BASINS model. Figure 67 also shows calculations for the phosphorus associated with fish lost between the Lower and Upper Platte River Weirs. 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 which is assumed to be 0.4%. The amount estimated in Figure 67 is the maximum possible loading from salmon not harvested at the weirs because some fish are taken by anglers. The estimated atmospheric phosphorus loading was calculated by multiplying the annual rainfall times the surface area of the lake times the average of measured rainfall phosphorus concentrations. The macrophyte phosphorus loading 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%. The initial approximation of the sloughing and excretion component uses the measured biomass (divided by two), the growing period (times the 90 day period), and the excretion rate (times 0.05 per day) as obtained from the literature (Bowie, et al, 1985). The phosphorus release rate from the sediments is taken directly from the Holmes measurements (Figure 67). The release period is length of time when the dissolved oxygen is less than 2 mg/L as determined from direct measurements of dissolved oxygen at selected lake depths.

These inputs and data for the annual average volume weighted total phosphorus concentration in the lake was used to calculate the apparent settling velocity using Equation 9. The average apparent settling velocity over the period 1990 and 2005 is 20.3 m/yr. This estimate is quite close to the average values determined by five independent investigators using sub-sets of the data and similar modeling approaches (Figure 67). This consistency prompts the conclusion that the estimate of 20.3 m/yr for the apparent settling velocity can be used with considerable confidence in the one coefficient model for watershed management applications. The apparent settling velocity of 20.3 m/yr and the associated phosphorus retention of about 55% are consistent with other oligotrophic lakes (Chapra, 1997).

BASINS and Lake Model Applications: The model calculates 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 68 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. A linear regression model using these data estimates that an annual average concentration of 6.4 mg/m^3 will insure that Big Platte Lake total phosphorus will be less than 8 mg/m^3 95 % of the time.

The one coefficient model to predict phosphorus concentrations in Big Platte Lake is driven by the outflow discharge and the phosphorus loading (Figure 69). The Upstream, Hatchery, Lower Platte River Watershed, North Branch of the Platte River, and Direct Platte Lake loads are generated as output of the BASINS model. The Lost Fish from Salmon plantings and adult salmon results, Sediment, Macrophytes, and Atmospheric phosphorus loads are based on site specific measurements. The model results in Figure 69 Column B are based on an apparent settling velocity of 20.3 m/yr. The calculations show that a load of 4997 lbs/yr results in a lake concentration of total phosphorus of 6.4 mg/m^3 and that the lake will be less than 8 mg/m^3 95 % of the time for typical hydraulic loading conditions that occurred in 2004 (see Appendix C for through discussion).

The next step is determining the loading to the Big Platte Lake for different loading and hydraulic conditions and comparing these loads to the goal of 4997 lbs/yr. This best approach is to use the BASINS model and GUI developed by LimnoTech. The modeling indicated that typical loading conditions occurred in 2004 (Figure 69 Column C). In 2004, the Platte River discharge from Big Platte Lake was 161 cfs and the total phosphorus load to the lake was 5,666 lbs/yr assuming that the Hatchery was at the permit limit of 175 lbs/yr. The model calculated the mean lake phosphorus concentration at 7.3 mg/m^3 and phosphorus concentrations exceeded the Consent Agreement goal 18% of the time under current loading and typical hydraulic conditions. A total of 669 lbs/yr of phosphorus would need to be removed to meet the lake water quality goals for these modeled conditions (Figure 70).

Low phosphorus loading conditions occurred in 2000 (Figure 69 Column D). The Platte River discharge from Big Platte Lake was 115 cfs and the total phosphorus load to the lake was 4,169 lbs/yr assuming that the Hatchery was at the permit limit of 175 lbs/yr. The model calculated lake phosphorus concentration was 6.1 mg/m^3 and the lake phosphorus concentration was below the stated Consent Agreement goal.

High loading conditions occurred in 1992 (Figure 69 Column E). The Platte River discharge from Big Platte Lake was 170 cfs and the total phosphorus load to the lake was 7,398 lbs/yr assuming that the Hatchery was at the permit limit of 175 lbs/yr. The model calculated lake phosphorus concentration was 9.3 mg/m^3 and the lake phosphorus concentration under high conditions exceeds the goal 81% of the time. A total of 2,401 lbs/yr of phosphorus would need to removed to meet the Consent Agreement lake water quality goals for high loading conditions.

The models can be applied to a wide array of watershed management planning scenarios using the GUI. Figure 71 shows the lower North Branch of Platte River sub-watershed editor as an EXCEL model. This worksheet model allows the user to select baseline hydraulic conditions that result in relatively low, typical, or high phosphorus loads. Once the hydraulic condition is specified the user can change land use in the sub-watershed. For example, sub-watershed development can be represented by converting a specified number of forested acres to low density residential and commercial development. The model also allows the user to implement BMP (Best Management Practice) treatment options and add or subtract point loads for each of 19 different sub-watersheds. The loads from the entire watershed are summarized after the user has specified conditions in all 19 watersheds (Figure 72). The specified scenario flow and loading can then be used to calculate the lake phosphorus concentration (Figure 69 Column A).

Ecosystem Model: More complex water quality models have been developed for Big Platte Lake 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 is being developed to 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 and uses a number of kinetic components (Figure 73). The model mechanisms were chosen to allow a more detailed 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 if warranted by more monitoring data and the special studies are completed. These improvements might be nitrogen limitation on algal growth rates and the bio-availability of various phosphorus sources.

Figure 74 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 construct mass balances for water and total phosphorus for the Hatchery, Big Platte Lake, and the Platte River 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 Platte River 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 Platte River Watershed.

2007 Sampling Plan

The sampling plan for 2007 involves collecting data from the Hatchery, Platte River Watershed streams, and Big and Little Platte Lakes (Figures 75, 76, and 77).

The net Hatchery total phosphorus load is evaluated by subtracting the inlet load from the total outlet loading. Measurements of discharge, 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 2007.

The Platte River tributary sampling program is designed to calculate the non-point phosphorus loading into Big and Little Platte Lakes. Measurements of discharge, phosphorus, and turbidity should continue to be taken every two weeks and during wet weather flow events. These data will allow a detailed evaluation of water quality for various hydrologic conditions, provide Platte River sub-watershed phosphorus loading estimates, assist in defining high priority remediation areas, and support the calibration and validation of the BASINS watershed model for the Platte River. The regular monitoring schedule should contain three sites on the Platte River (Stone Bridge, USGS, and M-22), two sites on the North Branch (Deadstream and Hooker Roads), and Featherstone Creek. Measurement at these sites should be continued through 2007.

Big and Little Platte Lakes are currently sampled every two weeks during the year. A Yellow Springs Instruments (YSI) meter is used to measure dissolved oxygen, temperature, pH, conductivity, and Oxidation-Reduction Potential. Discrete depth and tube samples are currently analyzed for total and dissolved phosphorus, nitrite and nitrate, turbidity, phytoplankton, alkalinity, chlorophyll, total dissolved solids, and calcium. Zooplankton are currently sampled using a vertical net haul. Light penetration, as measured with the Licor meter, no longer needs to be collected because the sensivity of the instrumentation and variability of the data limit the usefulness effort. Secchi depths are currently measured with a standard Secchi disk.

A summary of the sampling frequency and the measured parameters for each station is listed in Figure 78 and compared with the current contract with CMU. It is recommended that more samples be taken for nitrate and TN than compared to the CMU contract because it is possible that the algae in Platte Lake are rate-limited by nitrogen. . However, the costs for these samples are more than offset by decreases in zooplankton, chlorophyll, and phytoplankton. It is judged these reductions can be made to conform to budget limitations without compromising the integrity or continuity of the sampling program. The current plan and contract can accommodate additional measurements of nitrate in some of the streams to accommodate better understanding of the role of nitrogen limitation in Big Platte Lake.. In addition, the sampling and analytical plan and budget has the flexibility to address unanticipated Hatchery data needs such as measurement of the clarifier and tank overflows and to increase the reliability and credibility of the Hatchery Process Model.

Quality Assurance and Control

Extensive efforts are made to ensure 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 2007:

- 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 5.004 mg/m^3 with a standard deviation of 0.009 mg/m^3. The average concentration of 38 measurements of the 10 mg/m^3 purchased standard solution was 10.008 mg/m^3 with a standard deviation of 0.013 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.

- 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 2007.

Special Studies

<u>Overview</u>

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, Platte River tributary, and Big and Little Platte Lake monitoring data described above. Special studies should be conducted to enhance the model reliability by providing direct estimates of some of the model coefficients that are independent of the regular monitoring data. In particular, a study of the bioavailability of the various sources of phosphorus should be conducted.

<u>Phosphorus Bioavailability Studies</u>

Laboratory tests to determine the bioavailability of different point and non-point sources of phosphorus should be conducted. These include the Hatchery effluent, the upper Platte River, major tributaries within the Platte River Watershed, Platte River water at the confluence with Big

Platte Lake, and small local drainages that discharge directly to the Big Platte Lake. The tests should measure the growth rate of selected algal species to determine the growth potential of the various sources of phosphorus. These data will allow managers in the Watershed to better target available rehabilitation funds to address loadings that have higher bioavailability and the potential to cause water quality effects in Big Platte Lake. The detailed experimental and laboratory will program should be finalized following a comprehensive literature review by CMU.

Data Management

The ACCESS database accommodates the current sampling at the Hatchery, in Platte River tributary streams, at Big Platte Lake stations, the Hatchery weather station, and USGS gaging station at US-31 (USGS Gage Number). The Platte Lake Watershed Sampling Database consists of three components: Field; Data Manager; and Data Viewer (Figure 79). 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 Big Platte Lake water quality and produce graphs and tables for the Annual Report.

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. In addition, as the size of the database grows, data handling and display becomes less efficient and the current structure will eventually become prohibitive for practical use. Therefore enhancements are being identified and implemented to promote the utility of the database. These efforts should be continued in 2007.

References

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.

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.

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

Appendices

A. 2005 Coordination Meetings Minutes

B. Plankton Report

C. BASINS Report

D. SOP Reports

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