Consent Agreement Annual Report
2007

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Summary for the Year 2007

Overview

The goal of the Consent Agreement is to implement a long-term strategy to restore and preserve the water quality of Big Platte Lake. This goal is being advanced by minimizing the flow and phosphorus discharge from the Hatchery and by developing strategies to reduce non-point phosphorus loads from the watershed. Figure 1 summarizes the compliance with the Consent Agreement and the major accomplishments for 2007.

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 test period ended on June 30, 2007. The five year compliance period started on July 1, 2007. The net Hatchery annual loading for 2007 was 132.5 lbs. This is well within the requirement. The maximum load for any 3 month period was exceeded in October 2007 (70.9 lbs.) and November 2007 (62.9 lbs.). These loading violate the 55 lbs. limit. The average water use at the Hatchery was 6.98 mgd which is less than the Consent Agreement limit of 20 mgd.

The average volume-weighted total phosphorus concentration of Big Platte Lake was 7.34 mg/m^3 in 2007. The water quality goal of 8.0 mg/m^3 was achieved 63% of the time. This is not consistent with the goal of 95% attainment as stipulated in the Consent Agreement.

A total of 19,019 adult coho and 260 adult Chinook salmon passed the Lower Weir in 2007. 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 13,769 adult coho salmon were harvested for egg collection at the Upper Weir. This is 72% of the number of the coho salmon that were counted passing through the Lower Weir. A total of only 7 adult Chinook salmon were harvested at the Upper Weir. This is about 3% 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. The maximum estimated amount from this source assuming no fish were removed by anglers or other means was 158.6 pounds in 2007.

Major Accomplishments for 2007

- Annual phosphorus mass balance calculations have been completed for the Hatchery. (

- A model for Net Phosphorus loading from the Hatchery has been developed. The components of the model are net load, fish food, fish production, pond loss, and trucked phosphorus from the sludge storage tank.

- A bio-energetic fish growth and physical process model for the Hatchery has been developed. Validation is underway.

- Brundage Creek, Brundage Spring, and Platte River input flow meters have been calibrated using a volumetric (bucket) method. A rectangular weir has been installed to measure the outlet flow. There is good agreement between the measured sum of the influent flows and the measured outlet flows. Separate reports and Standard Operating Procedures (SOP) documents are included in Appendix A.

- A major effort has been completed to measure flow and phosphorus loading to Big Platte Lake. This work included measuring flow and phosphorus at four locations during several storm events. Stage-discharge relationships have been developed for several tributary sites in the watershed. These data have also been used to refine the calibration of the US EPA Better Assessment Science Integrating Point and Non-point Source watershed loading model (BASINS).

- Limno-Tech completed 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 Graphical User Interface (GUI). The GUI is linked to a one-coefficient model that predicts the annual average phosphorus concentration in Big Platte Lake. The model predicts 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.

- A study plan has been developed in cooperation with Central Michigan University (CMU) to determine the bio-availability various sources of phosphorus to Big Platte Lake. The plan involves algal assay procedures and a bio-availability model. Experiments are underway.

- A one-coefficient phosphorus model has been developed for Big Platte Lake. The model is based on extensive water quality monitoring data. The model has been tested and has been is shown to be reliable for a range of loading conditions. The model can be used with confidence to predict annual average phosphorus concentrations in the lake as a function of changes in flow conditions and phosphorus loading from the watershed.

- A comprehensive seasonal ecosystem model with several dependent variables and forcing functions is under development for Big Platte Lake. This model also has many coefficients that must be estimated using field measurements or through the process of model calibration. Although estimates of these model coefficients may not be highly reliable, the model that can be used in conjunction with the one-coefficient model to help refine understanding of water quality and food web dynamics in Big Platte Lake.

- The capabilities and functionality of the database are being expanded on an ongoing basis. Phosphorus and hydraulic mass balance reports have been created for the Hatchery, watershed, and Big Platte Lake. New reports have been created that provide a count of the number of samples completed by CMU during any time interval. This report is designed to help us verify the accuracy of CMU invoices. Another new report is designed to facilitate preparation of National Pollution Discharge Elimination System (NPDES) permit documents.

Recommendations and Action Items

- The phosphorus and turbidity data from the Jug & Needle and Sigma samplers remain inconsistent. It is desired by all to eliminate one of the methods, preferably the Jug & Needle 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. It is also recommended that permanent conduit replace tubing for the Sigma samplers and that a cleaning procedure be implemented to allow easy maintenance on a weekly basis for both samplers.

- It is imperative that continuing focused 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 track movement of various phosphorus pathways comes under significant question without such mass balance closure.

- 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. 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 triplicate samples be taken at the beginning, middle, and end of each individual truck load. It is suggested that the tank be cleaned at minimum one time per year, preferably as late in the year as permitted by weather conditions.

- 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 transferred from food to harvested fish. It is recommended that the current program with Lake Superior State University (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 and LSSU for phosphorus analysis to insure that the laboratory techniques are similar and results consistent.

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

- All SOP documents and equipment maintenance schedules should be reviewed and updated at minimum 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.

- It is recommended that total nitrogen be measured every two weeks from a surface composite sample from Big and Little Platte Lakes, and from a bottom composite sample of Big Platte Lake.

- The flow and water quality data (phosphorus, and turbidity) measurement program being conducted by Jerry Heiman should continue with focus on the North Branch of the Platte River and the Platte River at Stone Bridge during high flow periods.

- Studies of the bio-availability of Hatchery and non-Hatchery phosphorus sources should be completed.

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

- The Implementation Coordinator should continue efforts to calibrate and validate the fish 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.

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 2007 are contained in the Appendix B.

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 key in collecting, verifying, and analyzing all aspects of the Hatchery production data. She also writes an annual report on fish production activities that has been incorporated into this report.

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

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

- Jerry Heiman has done an excellent job measuring the flow rates and water quality parameters of several tributaries.
- Mike Pattison has done a terrific job developing and maintaining the PLIA web site with the latest version of the database.
- Tom Inman has coordinated closely with the Hatchery staff on counting the 2007 Fall Salmon Run.
- Sally Casey has been making weekly open water Secchi Depth measurements for over 25 years.
- Joe Francis has been measuring the pH of Big Platte Lake for many years.

Hatchery Operations

<u>Antibiotic Use</u> (Ed Eisch)

The antibiotic use at the Platte River State Fish Hatchery in 2007 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 12 and May 28, 2007. Not all rearing units were fed on the same days, and the maximum treatment was 65.1 kg of treated feed per day. A total of 1,210 kg of treated feed were fed during the treatment period. The total amount of OTC in the feed in 2007 was 24.2 kg compared to 38.0 kg in 2006 because fewer Chinook were produced, requiring less feed. In 2007 no OTC (TM 100) was fed for disease treatment purposes. The hatchery discharge flow during the treatment period averaged 6.51 million gallons per day (MGD).

Terramycin was used to treat a bacterial infection in the Chinook salmon fry. It was applied via a hatchery-mixed, top-dressed feed, at a rate of 3 grams TM per 100 lbs of fish from January 25 through February 3, 2007. The maximum treatment was 11 grams per day and a total treatment of 110 grams TM was applied to the feed over the 10 day period. The hatchery discharge flow during the treatment period averaged 6.49 MGD.

<u>Disinfectant Use</u> (Ed Eisch)

Parasite-S was used in 2007 to control fungus on fish eggs. Parasite-S is a trade name for formalin that consists of 37% formaldehyde by weight in water. The standard treatment used is a 15-minute flow-through with formalin at a concentration of 1 to 600 (1,667 ppm). During 2007, a small, experimental lot of steelhead eggs were treated from April 6 through May 11, 2007. The maximum daily treatment was 0.3 gallons of formalin during a 15 minute period, and a total of 16.6 gallons of formalin were used during the treatment period. The hatchery discharge flow during the treatment period averaged 6.63 MGD. Parasite-S was used again from October 3, 2007 through January 2, 2008 to treat fungus on salmon eggs. During this period a total of 310 gallons of formalin was used. The maximum treatment was 4.5 gallons per day, during a 15 minute period. Hatchery flows averaged 6.30 MGD during the 2007 salmon 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 15 ppm were conducted for three consecutive days. A total of 39.708 kg of CT was used between April 3 and May 11, 2007. The maximum daily treatment was 4.6 kg of CT, which was administered over a one hour period. The average hatchery discharge during this period was 6.62 MGD.

Another outbreak of BGD occurred during the summer in the coho salmon. Chloramine-T was again used for flow through treatments at a rate of 15 ppm. From August 23 through August 30, 2007, a total of 23.1 kg of CT were used with a maximum treatment of 1.539 kg over a one hour period. The average hatchery discharge during this period was 6.90 MGD.

Weir Operations (Jan Sapak)

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

During the fall of 2007, both the Upper and Lower Platte River Weirs were operated in much the same fashion as in 2006; however the adult coho returns were up significantly. The return of adults in 2006 was the lowest on record and the 2007 numbers were more in the normal range. The number of returning jacks was slightly lower than in 2006, indicating a potentially average run of adults in the fall of 2008.

The Lower Weir grates were installed on August 15, 2007 and removed for the season on November 14, 2007. As fish collected below the weir in sufficient numbers, coho salmon were passed upstream for egg take purposes, and surplus Chinook, and coho, were harvested and removed from the Platte River. Fish were passed upstream of the weir by raising the boat gate slightly and manually counting the number of fish, by species that swam upstream under the gate. For harvest operations the pumps were turned on and fish were allowed into the holding pond, where they were later removed. Members of the Platte Lake Improvement Association were contacted prior to passing fish upstream and were invited to observe the operation.

In 2007, 288 Chinook salmon, 21,214 coho salmon, 199 steelhead and 5 brown trout were passed upstream of the Lower Weir. In addition, a total of 2,536 Chinook, 15,060 coho salmon and 12 pink salmon (which were only listed in the comments of the weir database) were harvested at the Lower Weir and shipped to American Canadian Fisheries, Inc. of Bear Lake, Michigan. At the Bear Lake facility, MDNR staff conducted biological sampling of the season's run.

All of the dam boards for the Upper Weir were in place by August 29, 2007, and any migrating salmon were directed to the maturation ponds after this time. Coho egg take occurred between October 18 and October 24, 2007. There was no separate egg take for the Hinchinbrooke strain of coho in November, since this strain has been discontinued from the fish production program. After the egg take was completed, all salmon were harvested. In 2007, a total of 11 Chinook, 15,647 coho salmon, and 1 pink 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 14, 2007.

The total number of fish that were unaccounted for between the Lower and the Upper Platte River Weirs included 5,477 coho and 277 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 Hatchery between October 18 and October 24, 2007. A total of 3,493,365 coho eggs were taken and fertilized. This included 1,613,744 eggs for the Platte River State Fish Hatchery and 1,879,621 for other Michigan hatcheries and outside state agencies; including Wolf Lake State Fish Hatchery, and the States of Indiana and Illinois. After incubating eggs to the eye up stage, 133,210 surplus eggs were transferred from the Platte River Fish Hatchery to Bodine State Fish Hatchery in Indiana.

Chinook salmon eggs were taken at the Little Manistee and Swan River Weirs and transferred to Platte River Hatchery in October 2007. A total of 3,851,606 eggs were incubated at the hatchery. During the course of incubation, all Swan River Chinook eggs were discarded due to their poor quality, as well as other coho and Chinook egg mortalities. Incubation took place during the months of October, November and December, and the earliest hatching Chinook salmon were placed into early rearing tanks at the end of December.

<u>Fish Production</u> (Jan Sapak)

During the course of the year, 6,004,813 (1,723.24 kg) fry were placed in the rearing units. This includes 1,524.96 kg of Chinook and coho salmon fry added in January, 22.34 kg of steelhead fry added in June, and 175.94 kg of Chinook salmon fry added in December.

The Chinook and coho salmon were reared for production purposes, and during calendar year 2007, the Platte River State Fish Hatchery raised and stocked (planted) 802,467 (32,569 kg) coho salmon in the Platte River. In addition, 2,689,813 (21,265.9 kg) fish were raised and shipped to other locations outside the Platte River watershed. This includes 349,046 (10,454.9 kg) yearling and fall fingerling coho salmon and 2,340,767 (10,811 kg) spring fingerling Chinook salmon.

The steelhead was reared experimentally to test the capabilities of the hatchery for potential steelhead production. These fish did not respond well to the hatchery conditions, and were discarded in October and November 2007 as mortalities. A total of 652,864 (1454.9 kg) Chinook and coho salmon mortalities were removed from the hatchery in 2007 and disposed of in a certified landfill. A total of 88,984 (607.9 kg) steelhead fall fingerlings were buried on-site at a location away from the river.

During the course of the year a total of 53,689 kg of feed was fed to the production lots of coho and Chinook salmon, and the experimental lot of steelhead. This feed was predominantly BioOregon BioDry 1000 LP. Silver Cup Low Phosphorous Steelhead diet was also fed in small amounts, and both of these diets contained less than 1% phosphorous. A small amount of BioOregon BioVita Starter (less than 2.4% of the annual food fed) was fed to fry and this diet was approximately 1.5% phosphorus.

At the end of the calendar year the inventory of fish on hand in the hatchery included 1,233,392 (43,106 kg) yearling coho salmon, 1,737,081 (542 kg) Chinook salmon fry, and approximately 1.25 million coho and Chinook salmon fry in incubation.

<u>Waste Handling</u> (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.

In an effort to improve incoming water quality and reduce water use, the outside raceways were set up in a three-pass system, with coho salmon in A, B and C series. Only three raceways in A series contained fish. Three additional raceways in A series were used as a settling basin to help remove sediment before the water passed through B Series. 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 by pumping it directly to the line leading to the clarifier. The sediment was then captured in the sludge tank. In mid September, two raceways of coho salmon in A series were stocked out of the watershed and a fourth raceway was added as a settling tank. Operating the raceways in this fashion resulted in much improved water quality for the fish.

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 sludge tank where it was stored. The sludge storage tank was pumped by BioTech Agronomics, Inc. on November 16-17, 2007 and a total of 192,000 gallons of sludge was removed. All sludge was land applied per the Michigan Department of Environmental Quality's Manure, Paunch and Pen Waste Exemption guidelines at a site outside of the Platte River watershed.

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 on any day are set equal to zero for calculation purposes as specified in the Consent Agreement. 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 summation of daily net loads for the year gives the annual net phosphorus loading. The concentrations of total phosphorus and turbidity of the Hatchery inlet and outlet flows are currently measured on samples collected using two methods. For several years, a composite sample has been taken using a jug equipped with a fine gauge needle that slowly allows water to enter the jug. Automated Sigma Samplers were installed in association with the Hatchery renovation program. These samplers obtain 24-hour composite samples by pumping sub-samples at regular intervals. The official Hatchery loading is calculated from Jug & Needle total phosphorus measurements as specified in the Consent Agreement. The net phosphorus load was 132.5 lbs. for 2007.

Hatchery Phosphorus Mass Balance

Figure 2 shows the total annual net phosphorus loading from the Hatchery from 1990 to 2007. Note that the loads since 2000 are about 25% of those in 1990. However, there is considerable variation with the 2005 load being much higher than the loads in 2004, 2006, and 2007. 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 purpose of this section is to develop a rational analysis to understand the year to year variations.

The **Law of Mass Balance** is the primary tool that can be used to address 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. Note that the Law of Mass Balance is not an amorphous theoretical concept. Rather it is a dependable, practical, and exact tool that can be used to determine how well we have specified 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 measured the terms in the equation and not a condemnation of the Law itself.

Figure 4 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. This form of the equation is not particularly relevant because the fish inventory and the amount of phosphorus stored in the sludge tank can vary from the start to the end of the year.

Figure 5 shows the non-steady state Law of Mass Balance applied to the Hatchery on an annual basis. The last terms on the right refer 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 raceways. 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 input terms refer to phosphorus that enters the Hatchery, these terms include:

1. Food P. This term is the amount of phosphorus that is fed to the fish in the Hatchery starter building and raceways. 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 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 egg 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 output terms refer to phosphorus that leaves the Hatchery, these terms include:

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 mortalities. 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 system as flowing water. These flows include the Upper and Lower Discharges and the finishing pond by-pass. Currently, the Upper Discharge is only outlet flow. Note that this term is the gross loading 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 usually 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 is stored in the 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.

Figure 6 displays the mass balance equation expressed in regulatory, aquaculture, and facility operations terminology. The net load on the right side of the equation is simply the difference between the Gross Discharge Loading and the summation of the loadings 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 1.

$$\text{Net Production} = \text{Morts} + \text{Shipped} + \text{Planted} + (\text{End Fish} - \text{Start Fish}) - \text{Fry In} \qquad (1)$$

New fish grown in the system can remain in the Hatchery and are 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. The term “Harvest” in Figure 5 is simply the fish that leave the system, regardless of how. Increases or decreases in standing stock and the transferred fish are offset by the amount of fry that annually enter the system. The remaining terms are losses due to cleaning and trucking tank phosphorus, phosphorus settling to the bottom of the pond, or storage of phosphorus in the sludge tank. If the amount of phosphorus in the tank is less at the end of the year compared to the start, then the Tank Increase term is negative and contributes to the Net Load.

Mass Balance Application

The purpose of this section is to apply the model (that is, the mass balance equations) to actual values for the Hatchery. Figure 7 shows the measured water chemistry data using the Jug and Needle method for 2007. Figure 8 shows similar water chemistry data measured using the Sigma Sampler method for 2007.

The fish production terms were calculated assuming that the fish tissue phosphorus content was 0.4% of the gross wet weight. This assumed value is consistent with available estimates, but will change with the 2008 report as new data become available from the current sampling program. This will be discussed in a later section of this report. There were about an additional 75 lbs. of phosphorus associated with fish resident in the system at the end of the year when compared to values 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 9. The tank has been emptied and cleaned 4 times as of the end of 2007. A small amount of phosphorus was also removed during November 2005 that is not shown. Linear interpolation is used to estimate the amount of phosphorus in the tank at the start and end of each year. The 2006 measurements of the trucked loss were adjusted to account for phosphorus removed when Raceway A was used as a clarifier to remove sediments from the source water.

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 outlets from the pond from the inputs.

Figure 10 shows similar mass balance terms for 2001 through 2007 measuring using both Jug and Needle and Sigma sampling methods. The fish production terms for each year were calculated assuming that the fish tissue phosphorus content was 0.4% of the gross wet weight, which will be updated using actual data in future reports. Figure 11 shows, that except for 2001, the phosphorus contained in the food and the phosphorus associated with fish tissue are closely related. The calculations in Figure 12 show that about 50 to 60 % of the phosphorus contained in the food is incorporated into fish tissue.

Figures 12 and 13 show that phosphorus input from fish feed to the Hatchery has been about 1000 lbs. per year for 2004 through 2007. In addition, roughly 250 lbs. of phosphorus enters the system through the source water. About 550 lbs. of this phosphorus is incorporated into fish tissue that either leaves the system or is used to replenish fish inventory at the hatchery. This leaves about 700 lbs. that is either: discharged into the Platte River; is retained in the sludge tank; or lost to the bottom of the pond. If there were no pond or no sludge tank the expected net loading from the system would be about 450 lbs. per year (700 – 250 = 450). In order to comply with the Consent Agreement, the pond and the sludge tank must together remove about 275 lbs. per year (450 – 275 = 175). According to the measurements, this has only been achieved twice since 2004. The JN measurements in 2003 resulted in a pond loss of 99 lbs. that combined with a tank retention of 214 lbs. gives a theoretical net loading of 134 lbs. The Sigma measurements in 2007 resulted in a pond loss of 285 lbs. that combined with a tank retention of 63 lbs. gives a theoretical net loading of 115 lbs. Measured net loads are normally lower than the theoretical net loadings except for the 2004 and 2005 JN measurements.

The measured sum of input phosphorus is higher than the sum of outputs except for JN 2004 and JN 2005. This means that the measured inputs are too high or that the measured outputs are too small. These results suggest the following possible explanations:

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

The first three items above are related to measurements of flow and phosphorus associated with the source water, the input to the pond, and the upper discharge. Significant efforts have been made to measure, calibrate, and verify that flow rates associated with these components are accurate. Therefore, it is assumed that any errors with these terms in the mass balance equations are associated with measurement of total phosphorus rather than flow rate. Twenty-four hour composite phosphorus and turbidity samples are taken 2 times per week and are measured in triplicate. Samples are collected with both the JN and Sigma equipment. The data for 2007 are shown in Figures 14 through 21. Note that the JN method generally has higher average total phosphorus and turbidity compared to the Sigma. However, there are exceptions. For example, Figure 17 for Brundage Creek shows that the JN turbidity is significantly less than the Sigma turbidity despite the fact that the JN phosphorus concentration is slightly higher than the Sigma phosphorus (Figure 16). Similar trends are also seen in Figures 18 and 19. Large differences in phosphorus and turbidity are displayed for the JN and Sigma equipment in Figures 20 and 21. The equipment at this location measures the input to the pond following screening. These differences have a large impact on calculation for the pond loss term in the mass balance equations.

On the other hand, the data are tantalizing. It is also clear that these data have the correct trends because the seasonal pattern of the discharge phosphorus concentration (Figure 18) closely follows the fish feeding rate shown in Figure 22.

There are some clear analysis issues with fish food and tissue phosphorus concentrations that must be resolved before fully accepting the results of the mass balance model. Figure 23 shows the phosphorus content of the fish food provided by the supplier and CMU phosphorus measurements for the same fish food. The significant differences in fish food phosphorus have profound effects on the mass balance computations for the Hatchery. It is not clear if the extraction procedures used by CMU are less efficient than those used by the supplier, or if the sub-samples used by CMU are not representative of the entire lot. In either event, these issues must be resolved prior to determination of accurate mass balance computations.

Figure 24 shows fish tissue measurements by LSSU and CMU. Again, it is possible that the extraction procedures used by CMU are less efficient than those employed by LSSU. The differences have a large influence on mass balance computations and must be resolved. Also note that the LSSU data indicate a large increase in phosphorus content of the fish from summer through fall. More data are needed to determine if this trend is real and consistent.

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 track movement of various phosphorus pathways comes under significant question without such mass balance closure. Rational management of the Hatchery is problematical without this understanding of fundamental processes, and reliable predictions cannot be made regarding how the net load of the Hatchery will change with changes production, feed rates, and treatment facility operation.

Lake Water Quality

Big Platte Lake

Total Phosphorus: The annual variation of volume-weighted total phosphorus in Big Platte Lake for 2007 is shown in Figure 25. The average annual volume-weighted total phosphorus concentration in 2007 was 7.34 mg/m^3. There were 134 days when the total phosphorus concentration exceeded the 8.0 mg/m^3 goal. 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. This corresponds to about 63% attainment as compared to the 95% requirement.

Dissolved Oxygen: Figure 26 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 109 days in 2007. This is an important period because dissolved phosphorus will be released from the sediments during this anoxic period. Shallower water experienced shorter periods low dissolved oxygen conditions (Figure 26). These data can used to calculate the phosphorus release from the sediments. This internal loading of phosphorus can be compared to both non-point and point sources and is 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: Secchi depth is a common and simple method used to measure water clarity and an important indicator of water quality conditions in Big Platte Lake. The 2007 annual variation of Secchi depth in Big Platte Lake is shown in Figure 27. Note the distinct seasonal pattern. The low summer Secchi depths that occur around day 225 roughly correspond to high phytoplankton counts as shown in Figure 28. Similarly as expected, high Secchi depth values are associated with low phytoplankton counts.

Inorganic Nitrogen: Figure 29 shows seasonal variation of surface and bottom water nitrite and nitrate concentrations in Big Platte Lake for 2007. The concentration during spring and early summer is about 225 mg/m^3 in both the surface and bottom layers of the lake. This is similar to the maximum concentrations measured in rainwater. The lake concentrations decrease with the onset of summer algal growth. Note that the surface concentration reaches a minimum of about 10 mg/m^3 around day 250. The bottom water concentration also decreases with time reaching a short-lived minimum around day 280. The low summer nitrite and nitrate concentrations may be growth rate-limiting for some algae and a competitive advantage may be present for nitrogen-fixing blue-green species (Bowie et al, 1985). It is noted that little data are available for the concentrations of ammonia or organic nitrogen in Big and Little Platte Lakes. It is recommended that nitrate and nitrite continue be measured in Big and Little Platte Lakes, and that measurements of ammonia and filtered and non-filtered total nitrogen be added to the sampling program during 2008 and2009.

Plankton Food Web: Phytoplankton populations have a number of water quality implications. They reflect mixing conditions in the lake, nutrient availability, and have an impact on color, foam, water transparency, and other visible signs of nutrient enrichment. Zooplankton are important because their feeding activities are implicated with mid-summer clearing events in the lake. In addition, zooplankton can transfer energy to the upper food chain fish in the lake. The fish population of the lake can affect water quality through top to bottom down mechanisms. For example, heavy fish predation on zooplankton can relieve pressure on the phytoplankton. An increase in phytoplankton can result in a decrease in water transparency. These important and complex interactions are described in more detail in Appendix C authored by Dr. Scott McNaught from Central Michigan University.

Little Platte Lake

Little Platte Lake is located about one-half 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 only about 8 feet, compared to 95 feet for Big Platte Lake. Approximately 12,000 feet, or more than 60% of the shoreline of Little Platte Lake is State of Michigan owned wetland. About one-half of the flow from the upper part of the North Branch of the Platte River watershed passes through Little Platte Lake. This flow, along with local drainage into Little Platte Lake, rejoins the other half of the North Branch flow before entering the Platte River just upstream of the outfall into Big Platte Lake. The North Branch is the 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.

Figures 30 through 32 compare the surface concentration of three water quality variables in Big and Little Platte Lakes in 2007. The data in Figure 30 show that the total phosphorus of Little Platte Lake is about 6 mg/m^3 greater than that of Big Platte Lake. Figure 31 shows that the chlorophyll in Little Platte Lake is about 2 mg/m^3 greater than in Big Platte Lake. This is consistent with the differences in total phosphorus. Figure 32 compares the nitrite and nitrite concentrations in the two lakes for 2007. Both nitrite and nitrite concentrations are low in winter in Little Platte Lake and decrease to algal growth rate limiting levels during the spring then remain low for the remainder of the year. This low level of inorganic nitrogen is expected to promote the growth of nitrogen-fixing blue-green algae such as *Anabaena*. Phytoplankton samples were collected in Little Platte Lake in 2007 and are discussed in a separate report by CMU. It is recommended that sampling of Little Platte Lake be continued during 2008 so that the cause of high phosphorus can be better understood.

Watershed Flow and Phosphorus Balances

Watershed Flow Balance

Figure 33 shows the long-term trend of annual average flow of the Platte River measured at the USGS station at US 31. The average Platte River flow at the USGS station was 109.4 cfs in 2007. This flow is lower than the long-term average flow of 124.9 cfs since 1990. Thus, 2007 can be characterized as a drier than the average year. Figure 34 shows a flow balance for the watershed stating at Fewins Road and extending to the outlet of Big Platte Lake. The flow balance also includes water withdrawals and discharges by the hatchery. Tributary and non-point flows and flows at intermediate locations on the Platte River are based on correlations with the USGS measured flows at US-31. These correlations were developed over a three-year period using flow measurements at intermediate locations in the watershed. Flow at the outlet of Platte Lake is about 2.7 times that of the flow at Fewins Road site in the upper Platte River watershed.

Watershed Phosphorus Balance

Figure 35 shows a watershed phosphorus loading balance for 2007. The development of an accurate annual phosphorus balance for the watershed is not a simple task because the Platte River and tributary loadings are highly affected by flow spikes that occur during several storm events throughout the year. It is impractical to measure flow and phosphorus concentration during every storm event at all key locations in the watershed every year. However, extensive storm event measurements were taken from 2004 to 2006 at the Old Residence location on

Brundage Creek, and at the Stone Bridge and USGS sites on the Platte River. The average event total phosphorus concentrations at these locations were 71.5, 28.7, and 48.5 mg/m^3, respectfully. The regular monitoring data were used to characterize the dry weather concentrations for 2007.

Daily hydrograph data from the Platte River at USGS for 2007 were compartmentalized into base flow and wet weather event flows. The event and base flow total phosphorus concentrations were used along with the compartmentalized flows to synthesize a loading curve for each site in 2007. Measured flows and phosphorus concentrations entering and leaving the Hatchery are also used to complete the phosphorus balance for the watershed. Finally, the other key inputs were: measured dissolved oxygen concentrations in Big Platte Lake that estimated the sediment release during anaerobic periods; weir data that estimated the potential loading from lost fish; and rainfall data that estimated the atmospheric loadings. These inputs allow calculation of the annual average settling velocity of 16.5 m/yr and a corresponding phosphorus retention of 58.5%. These values are consistent with estimates determined for other years when more extensive data were available and with those observed in other lakes (Chapra, 1997). All these computations are performed by the database.

It is the authors' opinion that the above phosphorus watershed balance is quite reasonable but should be considered only an estimate because of the many assumptions involved in calculation. However, practical alternatives are problematic. Maximum total phosphorus concentrations during storm events are typically an order of magnitude higher than during base flow periods. Thus, load estimates based on routine measurements alone likely underestimate actual non-point loads because many storm event spikes are missed. Thus, the monitoring program needed to compile an accurate phosphorus balance for the total watershed is monumental. The BASINS model (discussed below) can also be used to estimate the phosphorus balance for the watershed. This model takes into account daily weather data and hydrographs for each site in the watershed. However this model requires: the input of accurate data to characterize the local rainfall patterns throughout the watershed; real-time atmospheric weather conditions; and knowledge of hydraulic conditions in prior years. Thus, preparing the inputs for BASINS to simulate a given year is a significant and costly task. Given the difficulties of both direct monitoring and BASINS modeling, the current approach is considered a useful alternative that can be used as a preliminary screening tool. However, watershed planning issues arise in the future that involve large expenditures or significantly influence watershed residents it is recommended that consideration be given to using the BASINS model and to resume the direct event monitoring program.

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 thereby protecting its water quality. In order to be effective however, such a program must be accurate and 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. Figure 36 illustrates the overall approach.

BASINS Model

Non-point phosphorus loads from Platte River watershed have been measured and analyzed using the Better Assessment Science Integrating Point and Non-point Sources (BASINS) approach. BASINS is an EPA supported watershed model and simulation tool. Hydraulic transport modeling within BASINS is based on the *Hydrologic Simulation Program* (HSP). The BASINS framework also includes models that simulate stream total phosphorus and suspended solids concentrations. BASINS model calculations for flow and water quality are dependent primarily on weather conditions, local soil type, and land use within the watershed. The BASINS model has been calibrated so that it can reliably simulate input of non-point pollutants from the watershed to the Platte River and ultimately to 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 the watershed depending on the land use. These results can be used as inputs to a water quality model for the Big Platte Lake. In this way, the BASINS and lake models work together to help assess the effects of both point sources such as the Hatchery and non-point sources such as agricultural operations, forests, and land developments on water quality in Big Platte Lake.

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. This program included the measurement of flow, total phosphorus, and suspended solids during numerous storm events. The BASINS modeling effort was conducted by LimnoTech, Inc. through contracts funded by the PLIA and the Benzie Conservation District. The project produced a GUI that allows users such as the PLIA to calculate changes in phosphorus loading to Big Platte Lake as a function of changes in land use and nutrient abatement projects. These changes in loadings can be used to calculate the annual average phosphorus concentration of the lake itself when coupled with a lake phosphorus model. An application of the BASINS model and the GUI will be given below. The complete LimnoTech report is included as Appendix C in the 2006 Annual Report.

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. These model inputs are not usually known with exact certainty. The overall reliability of the model decreases as the number of model inputs and their uncertainty increases unless large amounts of data are collected to support it. Thus, it is usually better to keep models simple and avoid unnecessary complications and assumptions. At the other end of the spectrum, a lake model that is too simplistic may be easy to operate and maintain but may not be able to realistically simulate ecosystem processes. A model between these extremes has the optimum utility (Figure 37).

Two separate Big Platte Lake water quality models are being simultaneously developed to accommodate these considerations. A one-coefficient model has simple model mechanisms and is easy to apply and defend, however this model does not provide detailed insight into the chemical and biological dynamics of the lake. 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 uncertainty. Our approach is 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 38. 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 (Chapra, 1997). The annual average total phosphorus concentration is given in Equation 2 where various terms are defined in Figure 38.

$$p = W / (Q + v_s A) \qquad (2)$$

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 River watershed using the BASINS model as well as direct phosphorus measurements. This is because the model has been validated using the actual data and is not dependent on the measurement frequency and location which varies from year to year. These balances for 1990 through 2005 are shown in Figure 39. The flows are based on USGS measurements extrapolated to include the entire watershed using the BASINS model. The Hatchery load is based on direct measurements of phosphorus. The phosphorus loads from the watershed area that flows directly into the lake and those at the USGS and North Branch sites are based on the verified BASINS model. Figure 39 shows calculations for the phosphorus associated with fish lost between the lower and upper 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 (assumed as 0.4%). This is the maximum possible value because some fish are taken by anglers. This figure also shows the estimated atmospheric phosphorus loading calculated by multiplying the annual rainfall times the surface area of the lake times the average of measured rainfall phosphorus concentrations. The macrophyte load consists of fall senesce plus continuous sloughing and excretion. Senesce is calculated as the product of the macrophyte biomass times the measured percent phosphorus of 1.3%. A first-cut approximation of the sloughing and excretion component is the measured biomass divided by two, times a 90 day growing period, times an excretion rate of 0.05 per day (Canale and Auer, 1982). Figure 39 also shows calculations of phosphorus release from the sediments. The release rate is taken directly from measured values in Big Platte Lake. The duration of the period when the dissolved oxygen is less than 2 mg/L was determined from direct dissolved oxygen measurements at various lake depths.

These inputs and data for the annual average volume-weighted total phosphorus concentration in the lake can be used to calculate the apparent settling velocity using Equation 2. 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 39). 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 and mesothophic lakes (Chapra, 1997).

BASINS and Lake Model Applications

The one-coefficient model will now be used to calculate the allowable non-point source watershed phosphorus loading that is consistent with the goal of maintaining the total phosphorus concentration of Big Platte Lake below 8 mg/m^3 95% of the time. Figure 40 shows a plot of the percent of the time Big Platte Lake exceeds 8 mg/m^3 as a function of the annual average volume-weighted total phosphorus concentration based on approximately 7,000 individual measurements collected over a period of 16 years. The correlation indicates that an annual average concentration of 6.4 mg/m^3 is required to insure that the Lake total phosphorus will be less than 8 mg/m^3 95 % of the time.

Figure 41 presents the necessary input and output information to apply the one-coefficient model to predict the phosphorus concentration of Platte Lake. The inputs are the flow rate of water leaving the lake and the phosphorus loading. The Upstream, Hatchery, Lower Watershed, North Branch, and Direct loads are generated as output of the BASINS model. The Lost Fish, Sediment, Macrophytes, and Atmospheric loads are based on site specific measurements. All model results in Figure 41 are based on an apparent settling velocity of 20.3 m/yr.

The calculations shown in Figure 41 (b) indicate 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. This is the overall total loading goal for the watershed consistent with Platte Lake water quality objectives.

It is critical to determine the loading to Platte Lake for different loading and hydraulic conditions and compare these loads to the goal of 4997 lbs/yr. This was done using the BASINS model and GUI developed by LimnoTech. Typical loading conditions occurred in 2004 as shown in Figure 41 (c). The flow rate leaving the 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 Platte Lake phosphorus concentration was 7.3 mg/m^3. The Platte Lake phosphorus concentration exceeds the goal 18% of the time under current loading and typical hydraulic conditions. Thus the models indicate that a total of 669 lbs/yr of phosphorus must be removed to meet the lake water quality goals for these typical conditions as illustrated in Figure 42.

It was determined that low loading conditions occurred in 2000 as shown in Figure 41 (d). The flow rate leaving the 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. The lake phosphorus concentration under these low conditions is less than the goal.

It was determined that high loading conditions occurred in 1992 as shown in Figure 41 (e). The flow rate leaving Big Platte Lake was 170 cfs and the total phosphorus load to the Big Platte 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. The lake phosphorus concentration under high conditions exceeds the goal 81% of the time. A total of 2,401 lbs/yr of phosphorus must be removed to meet the Big Platte Lake water quality goals for high conditions.

These models can be applied to a wide array of watershed management planning scenarios. This is accomplished using the GUI. Figure 43 shows the lower North Branch sub-watershed editor as an EXCEL worksheet. This worksheet 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 1000 acres of forested area to low density residential and commercial development. The sheet also allows the user to implement BMP (Best Management Practice) treatment options and add or subtract point loads (in this case a new point load of 175 lbs is added). Similar adjustments can be performed for each of 19 different sub-watersheds. The loads from the entire watershed are summarized in Figure 44 after the user has specified conditions in all 19 watersheds. The specified scenario flow and loading can then be used to calculate the Big Platte Lake phosphorus concentration as show in column (a) of Figure 41.

Ecosystem Model

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

The development of such a water quality model for the lake is proceeding in stages. Figure 45 shows the current model kinetic components. The model mechanisms were chosen to allow accurate modeling of phosphorus, water clarity, and dissolved oxygen with a minimum of model complexity. It is planned to make additional improvements to this model framework as more monitoring data becomes available and the special studies are completed. Figure 46 compares the one-coefficient and ecosystem models and summarizes the advantages and disadvantages of each approach.

Special Studies

Overview

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

Phosphorus Bio-availability

Laboratory tests are being performed to determine the bioavailability of different point and non-point sources of phosphorus. These include the Hatchery effluent, the upper Platte River, major tributaries within the watershed, Platte River water at the inflow to Big Platte Lake, and small local drainages that discharge directly to the lake. The detailed experimental and laboratory program was developed following a comprehensive literature review by CMU.

Phosphorus bio-availability experiments are being performed using the green alga *Scenedesmus.* This alga is abundant the whole year in the Big Platte Lake. The alga is being grown in batch culture in flasks as shown in Figure 47. The effective light that the alga receives is a function of the algal density and Beer's Law. The proposed phosphorus bio-availability model is shown in Figure 48. The model components are unavailable phosphorus, available phosphorus, and phosphorus associated with algal tissue. The kinetic mechanisms that describe the transfer rates among the three phosphorus states are illustrated in Figures 48 and 52. Figure 49 shows how the light intensity received by the algal population varies as a function of density measured as chlorophyll a. Figure 50 shows standard Monod curves that relate the algal growth rates and the concentration of available phosphorus and light intensity.

Figure 51 (a) shows the initial test data set and preliminary model calibration. The model simulates the growth of the algal population measured as either chlorophyll a or individual cell counts. The model captures an initial lag phase, exponential growth, and a stationary plateau phase. Figure 51 (b) shows the uptake of total dissolved phosphorus separated into available and un-available components. Un-available phosphorus accumulates over time as a result of algal respiration. Figure 51 (c) shows rate limitation factors for both light and phosphorus concentration. The model indicates that light limits growth in this experiment because the starting phosphorus concentration was quite high (over 500 mg/m^3) and remains high (about 200 mg/m^3) until the end of the test. Experiments conducted with Hatchery and Platte River watershed samples will have much lower phosphorus concentrations where both nutrients and light may limit growth. The model coefficients for the test data are shown in Figure 52.

Figure 53 describes the next three phases of the work, where algae will be grown in water from watershed and Hatchery sources as well as various mixtures. The tests will measure the growth rate of the test algal species as well as other kinetic and stoichiometric coefficients to determine the bio-availability of various sources of phosphorus.

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 goals as stated in the Consent Agreement.
- To construct mass balances for water and total phosphorus for the Hatchery, Big Platte Lake, and watershed.
- To support the continued calibration, validation, and application 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 support the development, calibration, validation, and application of water quality models for Big Platte Lake that are used to assist overall watershed planning efforts.

- To evaluate and document changes in water quality following possible future remedial activities within the watershed.

The sampling plan for 2008 involves collecting data from the hatchery, watershed streams, and Big and Little Platte Lakes. The sampling stations are shown in Figures 54, 55, and 56.

Quality Assurance and Control

Extensive efforts were made to insure the accuracy of the various field and laboratory procedures. Appendix A contains a maintenance schedule for all equipment as well as SOP documents for the Hatchery, Lake, and Platte River watershed water quality sampling program. Appendix D contains a report that describes extensive calibration of the Brundage Creek, Brundage Spring, and Platte River intake pumps using bucket tests. Appendix E describes the installation of a rectangular weir at the Hatchery discharge location that is being used to verify the input flows to the Hatchery. Appendix F shows the flows at the outlet when the settling pond is bypassed. Appendix G contains Certification Letters that specify that all data have been accurately entered into the database, checked and verified by responsible Hatchery staff members.

CMU regularly measures the phosphorus concentration of purchased standards that have concentrations of 5 and 10 mg/m^3. The average concentration of 35 measurements of the 5 mg/m^3 purchased standard solution was 5.006 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 10.005 mg/m^3 with a standard deviation of 0.011 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.

Hatchery

The net Hatchery total phosphorus load is evaluated by subtracting the inlet load from the total outlet loading. Measurements of flow, total phosphorus concentration, and turbidity are currently taken at four or five locations two times per week using both the Jug & Needle and Sigma samplers. It is recommended to maintain this regular schedule in 2008. In addition, the overflow rate of the clarifier and the time required to re-fill the clarifier are measured daily. The re-fill rate is used to calculate the overflow rate of the sludge tank. The phosphorus concentration of the clarifier and sludge tank overflow are measured approximately weekly.

The phosphorus content of each lot of fish food is measured on split composite sample provided by the supplier. This split sample is further split and sent to both CMU and LSSU for analysis. Fish are collected approximately monthly for tissue phosphorus analysis by both CMU and LSSU.

Watershed

The tributary sampling program is designed to calculate the non-point phosphorus loading into Big and Little Platte Lakes. Measurements of flow, phosphorus, and turbidity are taken on a regular basis independent of flow conditions. These data allow evaluation of water quality for various hydrologic conditions, provide sub-watershed loading estimates, assist in defining high priority remediation areas, and support the calibration, validation, and application of the BASINS watershed model. The current regular monitoring schedule contains six sites and should be continued through 2008.

Big and Little Platte Lakes are sampled every two weeks during the year. A Yellow Springs Instruments (YSI) meter is used to measure dissolved oxygen, temperature, pH, conductivity, and ORP. Discrete depth and tube samples are analyzed for total and dissolved phosphorus, nitrite and nitrate, turbidity, phytoplankton, alkalinity, chlorophyll, total dissolved solids, and calcium. Zooplankton is sampled using a vertical net haul. Secchi depths are measured with a standard Secchi disk. It is recommended that more samples be taken for nitrate and TN if budget restraints are not exceeded.

Cost

A summary of the sampling frequency and the measured parameters for each station is listed in Figure 57. Separate cost estimates are provided for the Hatchery and watershed sampling programs using CMU unit costs.

Data Management

The ACCESS database organizes and stores data from the current sampling program for the Hatchery, tributary streams, Big and Little Platte Lake stations, the Hatchery weather station, and USGS sampling location at US 31. The Platte Lake Watershed Sampling Database consists of three components: Field; Data Manager; and Data Viewer (Figure 58). 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 on an ongoing basis to insure that all data are correctly entered and displayed. These efforts should be continued into the future to promote the application of the data.

Efforts are underway to document the organization and computer code associated with the database. These efforts should continue until completed and then kept current.

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Appendices

A. **SOP Reports**
B. **2007 Coordination Meetings Minutes**
C. **Plankton Report**
D. **Flow Calibration Report**
E. **Outlet Weir Report**
F. **Pond Bypass Report**
G. **Certification Letters**