Consent Agreement Annual Report
2009

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Overview

The goal of the Consent Agreement is 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 level of compliance with the Consent Agreement and the major accomplishments for 2009.

Compliance with Consent Agreement

The Consent Agreement mandates that the Hatchery net annual load be limited to a maximum of 175 lbs. per year. The corresponding maximum load for any consecutive three month period is 55 lbs. The net Hatchery annual loading for 2009 was 244.6 lbs. This is significantly above the Consent Agreement limit. The maximum load for any 3 month period of 55 lbs. was exceeded in March, April, September, October, November, and December of 2009. The average water use at the Hatchery was 7.57 mgd which is less than the Consent Agreement limit of 20 mgd.

The average volume-weighted total phosphorus concentration of Big Platte Lake was 7.87 mg/m^3 in 2009. The water quality goal of 8.0 mg/m^3 was achieved 59% of the time. This is not consistent with the goal of 95% attainment as stipulated in the Consent Agreement.

A total of 14,781 adult Coho and 138 adult Chinook salmon passed the Lower Weir in 2009. These numbers are in compliance with the Consent Agreement limits of 20,000 adult Coho and 1,000 adult Chinook salmon.

Major Accomplishments for 2009

- A phosphorus loading model for the Hatchery has been developed using the Wisconsin Fish Bioenergetics approach. The components of the model are the net load, fish food, fish production, pond loss, and trucked phosphorus from the sludge storage tank. Efforts should continue to improve the accuracy of the model.

- Brundage Creek and Brundage Spring input flow meters were calibrated.

- Use of the JN sampling equipment was discontinued at the Hatchery on June 30, 2009 and was replaced with Sigma samplers. Tests were completed in 2009 that clearly demonstrate that total phosphorus measurements from the JN and Sigma samplers are comparable when both technologies sample the same water.

- The research being conducted by Central Michigan University (CMU) to determine the bio-availability of various sources of phosphorus to Big Platte Lake was completed in July 2009.

- A long term phosphorus model has been developed for the water and sediments of Big Platte Lake. The results have been peer-reviewed and have been published in the Journal of Water Resources Planning and Management of the American Society of Civil Engineers. The model is based on historical as well as current water quality monitoring data. The model has been tested and has been shown to be reliable for a range of loading conditions. The model can be used with confidence to predict the annual average phosphorus concentration of the lake as a function of changes in flow conditions and phosphorus loading from the watershed. The model has been used to calculate phosphorus loading reductions necessary to attain the water quality goal of 8.0 mg/m^3 95% of the time.

- 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, Platte River Watershed, and Big Platte Lake. CMU invoices are now linked to the database.

Recommendations and Action Items

- Efforts should continue to improve the accuracy of the phosphorus mass balance calculations for the Hatchery.

- It is recommended that the Sigma sampling equipment be re-programmed to collect 2 composite samples per week each covering approximately 72 hours with change over for cleaning on Monday and Thursday morning. This schedule will generate more representative samples that can be used to characterize the weekly average incoming and discharge loads.

- More emphasis must be placed on accurate measurement of the amount of phosphorus removed from the Hatchery when the solids storage tank is cleaned. The tank should be thoroughly mixed during drawdown, and washed and cleaned at the end. 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 twice per year, preferably during early or mid-summer so that the surface water of the tank can be used for lawn irrigation and during late December.

- The phosphorus associated with harvested (shipped, planted, and mortalities) fish and fry tissue is a critical variable associated with understanding the fate of phosphorus that enters the Hatchery as food and subsequently transferred to harvested fish. It is recommended that fish tissue phosphorus samples be collected monthly and analyzed for total phosphorus content.

- It is recommended that phosphorus content of the fish feed as provided by the manufacturer be verified by independent monthly measurements of total phosphorus content.

- 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 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. It is recommended that a monitoring program be designed to collect data that can be used to verify bioenergetics model. This should involve the collection of data that better describes the growth of fish in the system, improved temperature and dissolved oxygen measurements, and the food and fish (both smolt and adult) tissue phosphorus content.

- It is recommended that operational data be collected to help improve the understanding and efficiency of the disk filters. The goal should be to provide data that will allow timely maintenance of the filters to maintain peak performance.

- It is recommended that random blank total phosphorus samples continue to be sent to CMU as a means to maintain and improve the accuracy of sample tracking to achieve high levels of quality assurance.

- It is recommended that plankton sampling be limited to 3 times per year in Big Platte Lake and that all sampling of Little Platte Lake be discontinued until budget constraints removed.

- It is recommended that the PLIA web site be expanded to include more timely lake water quality information. The web site does not necessarily need to have active database capabilities, but rather information on the web site should be updated approximately every two weeks in the summer.

Acknowledgements

The Implementation Coordinator would like to take this opportunity to again 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 2009 are contained in the Appendix A.

Jim Berridge (PLIA) deserves a gold star 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. The reliability of the data would suffer without his careful and conscientious efforts. 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 needs of Ray, Gary, and Wil and has cooperated with the Implementation Coordinator to measure the respiration rate of fish of various sizes.

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 the responsibility to collect, analyze, verify, and analyze 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: Mike Pattison has done a terrific job developing and maintaining the PLIA web site with the latest version of the database. Tom Inman has worked with the Hatchery staff on counting the Fall Salmon Runs, and Sally Casey has been making weekly open water Secchi Depth measurements for over 25 years.

Hatchery Operations

Antibiotic Use (Jan Sapak)

The antibiotic use at the Platte River State Fish Hatchery in 2009 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 200) was mixed in the feed at a rate 12,000 g per ton (2000 lbs.) 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 1 and May 20, 2009. Not all rearing units were fed on the same days, and the maximum treatment was 100.3 kg of treated feed per day. A total of 1,300 kg of treated feed were fed during the treatment period. The total amount of OTC in the feed in 2009 was 17.16 kg. In 2009, no OTC (TM 200) was fed for disease treatment purposes. The Hatchery discharge flow during the treatment period averaged 7.658 MGD (million gallons per day). No other antibiotics were used to treat fish during the 2009 calendar year.

Disinfectant Use (Jan Sapak)

Parasite-S was used in 2009 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). Formalin was used from October 2, 2009 through February 8, 2010 to treat fungus on salmon eggs. The treatment season was extended into February 2010 due to a small number of Atlantic salmon eggs that were being incubated for an experimental rearing project. During this period a total of 633 gallons of formalin was used. The maximum treatment was 9.15 gallons per day, during a 15 minute period. Hatchery flows averaged 7.743 MGD during the 2009 salmon incubation season.

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 for egg collection purposes 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.

During the fall of 2009, both the Upper and Lower Platte River Weirs were operated in much the same fashion as in 2008 however the adult coho salmon returns were up significantly. The return of adults in 2008 was the lowest on record, but the run in 2009 returned to more normal levels. This higher number of adults was expected due to the exceptionally high return of coho salmon jacks in the fall of 2008. A high return of jacks generally indicates a high return of adults the following year, and this relationship did hold true for the return of adults in the fall of 2009.

The Lower Weir grates were installed on August 17, 2009 and removed for the season on November 12, 2009. 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 of each 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 2009, 138 adult Chinook salmon, 9 jack Chinook salmon, 14,781 adult coho salmon, 3,471 jack coho salmon, 35 steelhead and 7 brown trout were passed upstream of the Lower Weir. In addition, a total of 1,012 adult Chinook salmon, 121 jack Chinook salmon, 991 adult coho and 199 jack coho salmon were harvested at the Lower Weir and shipped to American Canadian Fisheries, Inc. of Bear Lake, Michigan. All of these carcasses were removed from the Platte River Watershed. 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 27, 2009, and any migrating salmon were directed to the maturation ponds after this time. Coho salmon egg take occurred between October 15 and October 26, 2009. After the egg take, all fish were harvested and shipped to the contractor. All of these carcasses were removed from the Platte River Watershed. In 2009, a total of 9 adult Chinook salmon, 11 jack Chinook salmon, 12,381 adult coho salmon and 2,900 jack 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 November 23, 2009.

The total number of fish that were unaccounted for between the Lower and the Upper Platte River Weirs included 2,400 adult coho salmon, 571 jack coho salmon, and 129 adult 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 salmon egg take operation occurred at the Hatchery between October 15 and October 26, 2009. A total of 5,620,754 coho salmon eggs were taken and fertilized. This included 3,395,449 eggs for the Platte River State Fish Hatchery and 2,225,305 green eggs for other state agencies, including the Bodine State Fish Hatchery in Indiana and the Jake Wolf State Fish Hatchery in Illinois. The number of green eggs taken for the Hatchery was similar to the number taken in the fall of 2008 because the rearing assignment for coho salmon was expected to remain at full production of approximately 1.57 million yearlings for the spring of 2011.

Chinook salmon eggs were taken at the Little Manistee River Weir and transferred to the Hatchery in October 2009. A total of 3,845,835 Chinook salmon eggs were incubated at the Hatchery. Incubation took place from October to December, and the earliest hatching Chinook salmon were put in tanks at the beginning of January 2010.

Fish Production (Jan Sapak)

During the month of January 2009, 4,390,402 (1,423.46 kg) coho and Chinook salmon fry were placed in the rearing units. In October 2009, an additional 19,000 (194.27 kg) Atlantic salmon were added to the outside raceways as part of an experimental rearing project.

The Chinook and coho salmon were reared for production purposes, and during calendar year 2009, the Hatchery raised and stocked (planted) 633,227 (28,462.53 kg) coho salmon in the Platte River at the Hatchery. In addition, 2,274,383 (14,649.94 kg) fish were raised and shipped to other locations outside the Platte River watershed. This includes 2,046,466 (10,327.09 kg) spring fingerling Chinook salmon and 227,917 (4,322.85 kg) fall fingerling coho salmon.

During the course of the year, a total of 52,978 kg of feed was fed to the production lots of coho and Chinook salmon and the experimental lot of Atlantic salmon. This feed was predominantly (87.4%) BioOregon BioDry 1000 LP diet. Silver Cup Low Phosphorous Steelhead diet was also fed to coho salmon in a diet comparison study (8.7%), and both of these diets contained less than 0.9% phosphorous. A small amount of BioOregon BioVita Starter (less than 3.9% of the annual food fed) was fed to fry and this diet was approximately 1.5% phosphorous.

At the end of the calendar year there were 1,624,738 (40,252.91 kg) yearling coho and Atlantic salmon on hand. Also, there were approximately 4.4 million coho, Chinook and Atlantic salmon fry in incubation.

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.

In the early months of 2009, yearling coho salmon were located in B and C series. Four raceways in A series were used as a settling basin to help remove sediment before the water passed through B and C 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. This was done in small increments so as to avoid overflowing the clarifier directly to the settling pond. The sediment was then captured in the sludge tank. Operating the raceways in this fashion resulted in much improved water quality for the fish and additional sediment to the clarifier and sludge tank.

Fish waste was removed daily from the rearing units either by manual cleaning or automatic filtering of the wastewater by the disk filters. During the year the disk filter operation was modified on several occasions in an effort to improve efficiency. All filters were cleaned and equipped with 40 micron filter panels during the early summer when no fish were in the outside raceways. Additionally, the filters were periodically power washed in place during the year.

Filtered waste was directed to a clarifier to concentrate solids and the solids pumped from the clarifier to a sludge tank where it was stored. The sludge storage tank was pumped by BioTech Agronomics, Inc. on July 9, 2009 and a total of 109,500 gallons of sludge was removed. It was also pumped again on December 28 – 29, 2009, and a total of 142,500 gallons 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

The water used to culture fish becomes enriched with phosphorus as it passes through the Hatchery from fish excretion, egestion, and from unconsumed feed. The net phosphorus daily loading from the Hatchery is defined as the difference between the daily phosphorus loading that leaves the system (usually the Upper Discharge or any by-pass) and the daily phosphorus entering the system from the three possible water sources (Brundage Spring, Brundage Creek, and the Platte River). 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 are 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 were measured on samples collected using two methods during 2009. For several years, a composite sample has been taken using a jug equipped with a fine gauge needle that slowly allows air to escape from the jug at a theoretically set rate. Automated Sigma Samplers were installed in association with the Hatchery renovation program. This equipment collects 24-hour composite samples by pumping sub-samples at regular intervals. The 2009 Hatchery loading is calculated from Jug & Needle total phosphorus measurements through June 30, 2009. The Jug & Needle method was abandoned after this date and all subsequent samples were collected using the Sigma equipment. The net phosphorus load was 244.6 lbs. for 2009. Appendix B is a spreadsheet that shows the calculations in detail.

Figure 2 shows the history of total annual net phosphorus loads from the Hatchery from 1990 to 2009. Note that the loads since 2000 are about 25% of those in 1990. However, there is considerable variation with an increasing trend since 2004.

Figure 3 shows the 3-month net phosphorus loads for 2009. Note that the loads for March, April, September, October, November, and December violated the Settlement Agreement limit of 55 pounds. Figure 4 shows the concentration of total phosphorus in the Upper Discharge during 2009. Note that there are two distinct periods of high phosphorus concentrations. The first peak occurs approximately between Days 30 and 90. This corresponds to a period when water temperatures at the Hatchery are increasing and the Chinook and coho salmon from the proceeding year classes are reaching maximum size just before being planted. The low loading period between Days 100 and 225 occurs during periods of warm temperatures but the coho salmon from the proceeding year class and current year class of Chinook are gone and the size of the current year class coho salmon are still relatively small. Subsequent rapid growth and feeding of the coho salmon results in a high loading between Days 250 and 310. This peak subsequently declines to the end of the year due to decreasing water temperature.

It is important to understand the cause of the violations and the dynamic patterns shown in Figure 2, 3, and 4 so that steps can be taken to avoid Settlement Agreement infractions. Some possible corrective actions could be lower feeding rates, decreasing the phosphorus content of the feed, decreasing fish production targets, or improving the phosphorus removal efficiencies of the Hatchery treatment equipment.

Figure 5 shows the cumulative net Hatchery loading for both 2008 and 2009. Note that the expected bi-annual loading peaks are manifested in both years. However, the load after about Day 240 is significantly larger in 2009 compared to a similar period in 2008. Figures 6 and 7 are tables that summarize fish production and feeding activities in 2008 as compared to 2009. Note that 52,978 kg of food was used in 2009 compared to 39,302 kg in 2008. The average phosphorus content of the feed for both years was 0.91%. As a result, approximately 250 more pounds of phosphorus entered the Hatchery via the feed in 2009 compared to 2008 (see calculations on bottom row in Figures 6 and 7).

Much of the phosphorus that enters the Hatchery in the feed is consumed by fish that are eventually removed from the system (shipped, planted, or mortalities) or by fish that increase the inventory. The phosphorus associated with these fish production components was calculated using a fish tissue phosphorus content of 0.44% of the gross wet weight. This value is consistent with recent CMU and LSSU measurements and with published results in the literature (Tipping and Shearer, 2007). However, it is recommended that measurements of fish tissue phosphorus concentrations (both smolt and adult) be continued to refine estimates of these values because of the critical role they play in the mass balance calculations.

The net production of fish biomass is the sum of mortalities, shipped, and planted plus any increase or decrease in the inventory minus the fry that enter the system (see further discussion is subsequent sections of this report). The difference between the amounts of phosphorus provided in the feed and the net production is defined here as "Excess Food" phosphorus. The Excess Food is the amount of phosphorus not utilized and incorporated into fish tissue. Note that this does not imply that the feeding rate can be lowered to exactly meet the fish tissue requirements because the fish growth is limited by energy needs and losses result from respiration, fecal matter, and excretion. The annual average calculations shown in Figures 6 and 7 indicate that the Excess Food phosphorus was approximately 112 lbs. higher in 2009 compared to 2008. This phosphorus is exported from the raceways and Hatchery Building and may be removed by the clarifier, settle to the bottom of the pond, or be released in the discharge flow.

Figure 8 shows the efficiency of the pond regarding phosphorus removal for 2009. The pond efficiency is defined as the phosphorus loading in the discharge divided by the sum of the input loading from the disk filter, clarifier, and sludge tank overflows. The pond efficiency is less than 1.0 when the pond discharge load is less than the sum on the input loads. If the pond discharge load is greater than the sum of the inputs then this ratio becomes greater than 1.0. Note that there were extended periods during 2009 when the ratio was greater than 1.0. This means that during these periods the pond outlet load was greater than the sum of the inputs. The overall result was that the pond contributed about 41.9 lbs of phosphorus to the discharge in 2009. By contrast, in 2008 the pond removed about 50.5 lbs from the discharge. This distinct change is a strong indication that capacity of the pond to remove phosphorus is deteriorating rapidly. Indeed, it has been about 20 years since the pond was last dredged and visual observations and sludge depth measurements support this conclusion. Thus, it is recommended that the pond be dredged as soon as practical to improve the pond phosphorus removal efficiency and storage capacity.

The above analyses suggest that the loading violations that occurred during 2009 were likely caused by a combination of increased excess phosphorus and the deterioration of the efficiency of the pond. Note however, these conclusions are based on annual average data for only 2 years. Furthermore, the analyses do not account inter-annual dynamics of feeding rates, temperature, and the day-today changes in the efficiency of removal of the pond and clarifier/sludge tank. Thus, it is recommended that efforts be continued to understand energy and phosphorus sources and losses using bioenergetics and the performance of various removal processes using mass balance principles as described in the next sections.

Phosphorus Mass Balance

The **Law of Mass Balance** can be used to help understand and develop a model for changes in the net load from the Hatchery as a function of production activities and facilities operation. The Law of Mass Balance 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 9). The Law applies to any conservative substance such as water or total phosphorus for any closed boundary such as the Hatchery. The mass balance formulation (see Equation 1) applies for both non-steady state conditions (also called time variable or dynamic) and steady state (also called non-time variable) cases. The Law of Mass Balance 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.

The mass balance equation simply requires that the accumulation of phosphorus in the system (in the case the Hatchery) is equal to the difference between the amount of phosphorus that enters the system (Inputs) and the amount leaving the system (Outputs).

Accumulation of P in the Hatchery = Sum on Inputs – Sum of Outputs (1)

The input terms refer to any phosphorus that enters the Hatchery, these terms include:

1. Food P. This term is the amount of phosphorus associated with the food 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. The phosphorus value of this term is calculated by multiplying the weight of the food fed times the phosphorus content of the feed.

2. Source Water P. This is the amount of phosphorus contained in all of the Hatchery source water. The sources are Brundage Spring and Creek, the Platte River (only used rarely), and Service water. The phosphorus value of the input amount is determined by multiplying the flow rate times the phosphorus concentration.

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 wet weight biomass of the fry times the measured 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.

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. It is not relevant to the mass balance equation if the fish are shipped to another watershed, planted in the Platte River, or disposed as mortalities. The phosphorus value of this term is calculated by multiplying the whole wet weight biomass of the fish times the measured percent phosphorus in the fish tissue.

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 the phosphorus value of this term is calculated by multiplying the discharge flow rate times the phosphorus concentration. The Net Discharge is the difference between the phosphorus measured Gross Discharge and the sum of the measured phosphorus inputs, and is used for NPDES and Settlement Agreement purposes.

3. Trucked P. This term refers to the amount phosphorus that is trucked away from the Hatchery usually as a result of emptying and cleaning the solids storage tank. The phosphorus value of this term is calculated by multiplying the measured number of gallons of liquid trucked away times the average measured phosphorus concentration of the liquid.

The accumulation terms are calculated by subtracting the outlets from the inputs. Accumulation can be positive or negative. There are three major accumulation terms.

1. Fish Tissue P. This term refers to the phosphorus present in fish in the Hatchery Building and raceways. The phosphorus value of this term is calculated by multiplying the whole wet weight biomass of the fish times the measured 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. The phosphorus value of term 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.

3. Pond P. This term refers to the amount phosphorus that settles and is stored in the bottom of the pond. Phosphorus that settles to the bottom is prevented from leaving the by the pond clay liner. The phosphorus value of this term can be measured directly, but is usually 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.

The non-steady state form of the Mass Balance equation can be applied to the Hatchery on an annual basis and expressed in terms of regulatory, fish production, and facilities operation as shown on the bottom of Figure 9 and Equation 2.

$$\text{Net P Load} = \text{Food} - \text{Production} - \text{Tank Retention} - \text{Pond Retention} \quad (2)$$

The Net P Load is simply the difference between the measured Gross Discharge Loading and the summation of the loadings from the various source waters. All the input terms are routinely measured. Food In 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 phosphorus equivalent of the fish that leaves the Hatchery as Morts, Shipped or Planted or contributes to an increase in the fish inventory in the raceways. Increases or decreases in inventory and the transferred fish are offset by the amount of fry that annually enter the system. The remaining terms are losses or retentions of phosphorus 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 retention term is negative and contributes to the Net Load.

Hatchery Mass Balance for 2009

Figure 10 shows Hatchery mass balance terms for 2009. The phosphorus associated with the source water and discharge was measured using the Sigma sampling method. The fish production terms were calculated using a fish tissue phosphorus content of 0.44% of the gross wet weight, a value that is consistent with recent measurements as discussed above. There was a net increase of 157 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. The solids storage tank began operation collecting and thickening the underflow from the clarifier on September 9, 2003 and has been emptied and cleaned 8 times as of the end of 2009. In 2009, the measurements indicate that the trucked loss was approximately 113 lbs. The amount of phosphorus being removed by the clarifier and sludge tank has generally declined since 2005. This suggests that the effectiveness of the disk filters or the clarifier/sludge tank collection efficiency has slowly become less effective. The retention of phosphorus in the pond is determined by adding the inputs from the screens, clarifier, and tank overflows and subtracting the outputs measured at the Upper

Discharge. The JN measurements in 2009 resulted in a pond loss of 38 lbs. Overall, the measured input of phosphorus to the Hatchery was 1,606.8 lbs. compared to only 1,396.0 lbs. that can be accounted for from known losses.

Figure 11 shows Hatchery phosphorus mass balance summary calculations for other years using both the Sigma and Jug & Needle equipment. The measured sum of input phosphorus is usually higher than the sum of outputs except for JN 2004 and JN 2005. Typically, the measured net load is 100 to 200 pounds lower than what is expected based on fish production levels and the amount removed by trucking from the sludge tank. 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 0.42%.
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. The most likely the reason for the discrepancy is the use of twice weekly 24 hour composite samples to measure phosphorus rather than composites that cover the entire week. The 2010 sampling program has corrected this possible source of error.

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 problematic without this understanding of fundamental processes. For example, one uncontrolled variable is temperature which affects all parts of this living system. As we improve our understanding of the bioenergetics of the system, we expect to make significant gains in improving the accuracy of the mass balance calculations and make predictions regarding how the net load of the Hatchery will change with changes production, feed rates, and treatment facility operation.

MDNR Fish Production Model

The Hatchery staff is faced with the responsibility to operate the facility so the discharge is compliant with the Consent Agreement annual and 3-month phosphorus loading limits. This task is arduous because the temperature of the water in the raceways varies, both daily and seasonally, and the need to rapidly increase the size of the fish to meet fish management requirements. The challenge is to use the disk filters in conjunction with: ferric chloride; appropriate operation of the clarifier and sludge storage tank; and the properly operating finishing pond to remove phosphorus from the discharge consistent with the excess amount of phosphorus introduced into the system due to fish production. Alternatively, food use and fish production might be lowered to reduce the discharge.

Currently, the Hatchery staff use a simple production model that employs a feed conversion factor to assist them to determine feeding rates. This approach is implemented by counting the mortalities and multiplying by the average weight of an individual fish to obtain the weight of mortalities. The new weight is then the old weight minus the mortalities plus any new increase in weight as a result of feeding. The new weight produced from feeding is simply the weight of the feed divided by a feed conversion factor. The feed conversion factor is an empirical number based on staff observations over many production cycles. As a result, the model often does a reasonable job of predicting the new weight of fish. Unfortunately, this model is often not robust enough to quantitatively respond to the complex management issues involved in operating the Hatchery in a manner that is consistent with the restraints of the Consent Agreement and production goals. The model does not address the amount or fate of phosphorus losses that are an inevitable consequence of normal feeding schedules and does not have a quantitative way to adjust the feed conversion factor if the energy or phosphorus content of the feed changes. In addition, the model does not have a quantitative way to adjust the feed conversion factor if the temperature changes. Finally, the model fails to account for the maximum consumption rate of the fish. The consumption rate must eventually become larger and larger as the feeding level increases.

The Hatchery staff need an improved quantitative approach that can guide production activities and facilities operation because violations (or near violations) of the Consent Agreement still occur. The next two sections of this report discuss progress to date regarding the development of such a tool to assist management of the Hatchery.

Bioenergetics Approach for Fish Production Model

Fish growth and food energy consumption can be simulated by the Wisconsin Fish Bioenergetics Model (Kitchell et al. 1977, Warren and Davis 1967). This model assumes that the energy associated with the growth of new fish biomass is equal to the energy gained through feeding minus the energy associated with respiration, excretion, and egestion. The balanced energy equation is represented by the following formula:

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

Where: C = rate of energy consumption; G = somatic and reproductive tissue elaboration; R = standard metabolic rate; S = metabolic rate increase from specific dynamic action; F = waste losses due to egestion (feces); and U = waste losses due to excretion (urine). Note that C and R are primarily functions of temperature and the size of the fish. U and F are either constants or temperature variable fractions of C. This model is well-known and has documented biochemical mechanisms which have been used in a wide range of applications. The model has limited capability to simulate the effects of food availability and its limitation on the consumption rate, and does not directly handle diurnally fluctuating temperatures.

A preliminary approach to this model has been described in previous Annual Reports. It is recommended that efforts continue to: 1) refine the mass balance calculations for the Hatchery; 2) incorporate bio-energetic restraints to the consumption and loss components of the model; and 3) refine the mechanisms in the model that contribute to losses of energy and phosphorus. It is recommended that the model be calibrated and verified at the Hatchery by increasing the frequency of measurements of fish growth and mortality losses. The ultimate purpose of this development is to give the Hatchery staff a potentially real-time quantitative tool that can be used to optimize fish production and food utilization as well as to meet the phosphorus discharge limits.

Lake Water Quality

Big Platte Lake

Total Phosphorus: The annual variation of volume-weighted total phosphorus in Big Platte Lake for 2009 is shown in Figure 12. The average annual volume-weighted total phosphorus concentration in 2009 was 7.87 mg/m^3. There were 149 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 59% attainment as compared to the 95% requirement.

Secchi Depth: Secchi depth is a common and simple method used to measure water clarity and an important indicator of water quality. Consistent measurements of Secchi depth have made in Big Platte Lake since 1990. The 2009 seasonal variation of Secchi depth in Big Platte Lake is shown in Figure 13. This variation is a complex function of calcite precipitation and the concentrations plankton and phosphorus in the Lake. These relationships have been recently described by mathematical models developed by Homa and Chapra (2011) for nearby Torch Lake. Such models can be used to calculate increases in water clarity as a function of decreases in Hatchery and watershed phosphorus loading. Readers should note that as phosphorus concentrations in the Lake decrease, corresponding increases in water clarity may be less than expected due to the precipitation of calcite (marl). It is recommended that a similar modeling approach be applied to Big Platte Lake.

Dissolved Oxygen: Figure 14 shows the annual variation of dissolved oxygen concentrations 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 81 days in 2009. This is an important period because dissolved phosphorus will be released from the sediments during this anoxic period which reduces pH values that mobilize phosphorus from the sediments. Shallower water depths of 75, 60, and 45 feet experience shorter periods of low dissolved oxygen conditions as shown at the top of Figure 14. In addition, note that a single measurement during the winter showed significant oxygen depletion under ice cover. These data are used to calculate the phosphorus release from the sediments. This internal loading of phosphorus can be compared to both non-point and point sources and can be used to calculate the annual dynamics of phosphorus in the lake. Ultimately, the magnitude of the internal sources of phosphorus determines how quickly the lake will respond to changes in input phosphorus loadings. Quantitative models have been developed to predict the magnitude of these changes as discussed in subsequent sections of this report.

Plankton: Phytoplankton populations have a number of water quality implications. They reflect mixing conditions in the lake, nutrient availability, and have an effect on color, foam, water transparency, and are a visible sign of nutrient enrichment. Zooplankton are important because their phytoplankton foraging activities are implicated with mid-summer clearing events in the lake. In addition, zooplankton transfers primary production energy to other invertebrate predators and fish in the lake. The fish community 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 Appendices C and D authored by Dr. Scott McNaught from Central Michigan University.

Watershed Flow and Phosphorus Balances

Watershed Flow Balance

Figure 15 shows the long-term trend of mean annual flow of the Platte River as measured at the USGS station at US 31. The mean annual Platte River flow at the U.S. Geological Survey (USGS) Gauging Station at Honor, MI (Station ID 04126740) was 118.2 cfs in 2009. This flow is lower than the long-term average flow of 124.0 cfs since 1990. Thus, 2009 can be characterized as a drier than the average year. Figure 16 shows the daily hydrograph as well as the days sampled. Note that 5 samples were taken during high flow events, while the remainders were for baseline flow conditions. Figure 17 shows an annual average flow balance for the lower watershed starting at Fewins Road and extending to the outlet of Big Platte Lake. The flow balance also includes the tributary water diversion and discharge 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 USGS location is about 2.2 times the flow at Fewins Road, and the Lake outlet is about 2.7 times that of the flow at Fewins Road. Figure 17 shows that there were approximately 23 storms events at the USGS site in 2009 where flow flows rapidly increased and then receded over a one or two day period. The majority of these events occurred during the spring time as expected. Daily hydrograph data from the Platte River at the USGS gauging station were compartmentalized into base flow and wet weather event flows. The average flow during the storm events was 140.9 cfs. The daily average flow during dry or baseline conditions was 116.7 cfs. The storm flows occurred only about 6.3% of the time during 2009, but accounted for about 7.5% of the total amount of water that entered Platte Lake through tributaries. Baseflows are generally associated groundwater inputs and accounted for the remainder of the flow or 92.5% of the hydrologic inputs.

Watershed Phosphorus Balance

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. The Platte River was sampled for total phosphorus concentration during 5 of these storm events in 2009 from a total of 23 (see Figure 16). Thus, estimates of the total phosphorus loading into Big Platte Lake based on the 26 routine measurements are not expected to accurately estimate the loading because of the inaccurate representation of storm events. Unfortunately, it is impractical to measure flow and phosphorus concentration during every storm event at all key locations in the watershed every year.

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 Gauging Station at Honor, MI sites on the Platte River using continuous water sampling equipment. The average event total phosphorus concentrations at these locations were 72.6, 28.7, and 50.95 mg/m^3, respectfully. The storm event concentrations at the Fewins site and North Branch sites were assumed to be identical to those measured at the Stone Bridge site. The measured storm event total phosphorus concentrations measured at the Old Residence site on Brundage Creek were also used to characterize storm events for the Stanley, Carter, and Collision Creek sites. The total phosphorus concentrations during baseflow conditions were averaged for all years for Stanley, Carter, and Collision Creeks because limited measurements are available for these sites and they are no longer included in the regular monitoring program. These data (as shown in Figure 18), along with the regular monitoring data for 2009, were used to determine the total phosphorus loads into Big Platte Lake as shown in Figure 19.

The baseline total phosphorus loads were determined for each site according to Equation 4.

Baseline TP Load = Annual Average Baseline TP Concentration * Annual Average Baseflow * Percent of the time the flow is at Baseline conditions (4)

The storm event or wet conditions total phosphorus loads were determined for each site according to Equation 5.

Storm Event TP Load = Annual Average Storm Event TP Concentration * Annual Average Storm Event Flow * Percent of the time the flow is at Storm Event conditions (5)

These estimates along with measured flows and phosphorus concentrations entering and leaving the Hatchery were used to complete the phosphorus balance for the watershed as shown in Figure 19.

The annual phosphorus at the USGS Gauging Station at Honor, MI site based on Equations 4 and 5 was 3,972 pounds. Note that storm events contributed 22.4% of total phosphorus load compared to only 7.5% of the flows. The total phosphorus concentration at the USGS Gauging Station at Honor, MI site was measured 26 times during 2009. The average total phosphorus concentration was 14.3 mg/m^3 and the annual average flow was 118.3 cfs. This is equivalent to an annual phosphorus load of 3,331 lbs., an amount that is about 16% lower than the annual load calculated using Equations 4 and 5. The average daily phosphorus load estimated from 26 individual measurements was 9.4 pounds or 3,431 pounds for the entire year, an amount that is about 14% lower than the annual load calculated using Equations 4 and 5. Difference is the result of both storm event flows and total phosphorus concentrations being disproportionate to corresponding dry weather or baseflow conditions.

It is our opinion that the above calculations using Equations 4 and 5 are good representations of the hydrologic and phosphorus watershed balances despite the assumptions and approximations used in the analyses. Practical alternatives to this approach 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 are not likely to represent the actual non-point loads because many storm event spikes are missed. Thus, the monitoring program needed to compile a more accurate phosphorus balance for the total watershed is monumental and outside of the current budget for this program. 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: 1) the input of accurate data to characterize the local rainfall patterns throughout the watershed; 2) real-time atmospheric weather conditions; and 3) knowledge of hydraulic conditions in prior years. Thus, preparing the inputs for BASINS to simulate a given year is a significant and costly task, and not necessarily more accurate than the above approach. Given the difficulties and limitations of both direct monitoring and BASINS modeling, the current approach is considered the best alternative and a reliable screening tool that can be reliably used for planning applications. In addition, it would be useful to explore applications of intermediate level complexity models to predict stream flow such as those proposed by Limbrunner et al. (2005). However, if watershed planning issues arise in the future that involve large expenditures or significantly influence watershed land use, it is recommended that the full dry and wet weather monitoring program be resumed and that the BASINS or other models be re-calibrated.

Watershed Management

The goal of the Platte River Watershed Phosphorus 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. 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 protect the water quality of the lake and develop these important tools.

Tamarack Creek

Tamarack Creek has two branches that converge near Platte Road before entering the southeast corner of Big Platte Lake. The western arm of Tamarack Creek is affected by a fruit waste land disposal site that has been the subject of extensive legal action. The east arm of Tamarack Creek is affected by the runoff from active cattle pastures. The two branches converge just north of Platte Road. The MDNR measured various parameters during 2009 and 2010 to characterize water quality conditions. The average values of various parameters are shown in Figure 20 along with a single measurement of total iron in 2008. The PLIA sampled these branches as well as the converged Tamarack Creek to determine the affect on the water quality of Big Platte Lake. Nearby and unaffected Bixler Creek was measured as a control. The average of measurements about nine flow measurements taken between 2003 and 2009 as well as about fifty measurements of TP and turbidity are also shown.

The affects of the landfill and barnyard sites on the water quality of Big Platte Lake are relatively small because their flow is much less than the Platte River and because the concentrations of phosphorus and inorganic nitrogen are similar to nearby control streams. The load from the landfill site is about 1% of the total non-point load to the lake. The barnyard site is about 2% of the total non-point load.

The landfill site has higher turbidity and about double the organic carbon content of non-affected streams. The average value of MDNR measurements for the five-day Biological Oxygen Demand (BOD5) was about 20 mg/L. The lake temperature and dissolved oxygen model were used to test the impact of this discharge on Big Platte Lake. If all the discharge is mixed directly into the hypolimnion of Big Platte Lake, the models indicates that the decrease in the hypolimnion dissolved oxygen concentration would be negligible.

The high turbidity of the landfill site can be attributed to common Iron bacteria such *Thiobacillus* and *Leptospirillu.* These bacteria derive the energy they need to live and multiply by oxidizing dissolved ferrous iron (or less frequently manganese and aluminum). The resulting ferric oxide is insoluble, and is visible as brown gelatinous slime (see Figure 21). These bacteria can grow and proliferate in waters containing as low as 0.1mg/l of iron, and the single iron measurement of 5.5 mg/L is well in excess of this minimum requirement. Aerobic conditions are needed to carry out oxidation. Therefore, iron bacteria frequently colonize the transition zone where de-oxygenated water from an anaerobic environment such as the fruit disposal site flows into an aerobic environment such as Tamarack Creek. Microorganisms feeding on dissolved organic material such as fruit waste de-oxygenate the when the concentration of organic material exceeds the concentration of dissolved oxygen required for complete oxidation. The microbial populations have specialized enzymes that can reduce insoluble ferric oxide in aquifer soils to soluble ferrous hydroxide and use the oxygen released by that change to oxidize some of the remaining organic material (1)

Water + ferric oxide → ferrous hydroxide + oxygen (6)

When the de-oxygenated water reaches a source of oxygen, iron bacteria use that oxygen to convert the soluble ferrous iron back into an insoluble reddish precipitate of ferric iron (Snoeyink and Jenkins, 1980)

Ferrous hydroxide + oxygen → water + ferric oxide (7)

Thus, the likely underlying cause of the iron bacteria population in the creek is the anaerobic groundwater that has been depleted by the fruit waste. The dramatic effects of iron bacteria are seen in surface waters as brown slimy masses on stream bottoms and lakeshores or as an oily sheen upon the water as shown in Figure 21. Other anthropogenic sources like landfill seepage, septic drain fields, or leakage of light petroleum fuels like gasoline are other possible sources of organic materials allowing soil microbes to de-oxygenate groundwater. It is recommended that chemical analyses of Tamarack Creek be discontinued. Instead, it is suggested that photographs similar to Figure 21 be taken 3 times per year to track the progress of the restoration of the creek.

BASINS Watershed Phosphorus Loading 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. The BASINS model is a U.S. Environmental Protection Agency (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 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 from the PLIA and the Benzie Conservation District. Funding to the District originated with grants from the MDEQ and USEPA. The project produced a Graphical User Interface (GUI) that allows users such as the PLIA to calculate changes in the lake phosphorus concentration as a function of changes in the Hatchery or watershed phosphorus input loadings.

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.

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, both of which have error components associated with them. 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 to 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 realistically simulate ecosystem processes.

Three separate Big Platte Lake water quality models are being simultaneously developed to accommodate these considerations. A one-coefficient steady state model has simple model mechanisms and is easy to apply and defend, however this model does not provide detailed insights into the chemical and biological dynamics of the lake and cannot predict changes in water quality as a function of time. A non-steady state dynamic model with an intermediate level of complexity has been completed for bottom water concentrations of dissolved oxygen and lake and sediment concentrations of total phosphorus. This model has five coefficients that have numerical values determine by calibration using extensive data collected over a period of many years. The model can predict time-variable changes in phosphorus in the lake that result from sediment release as sediment concentrations in the sediment change in response to changes in external loading conditions. A more complex ecosystem model is being developed to provide more insights into the detailed chemical and biological components of the lake ecosystem. This model requires explicit numerical values for many coefficients and forcing functions that are difficult to quantify without introducing significant uncertainty. Our approach is to rely primarily on the one-and five coefficient models for watershed planning applications. The ecosystem model will be used with caution in conjunction with the other models to provide in-depth understanding of the lake water quality dynamics when appropriate.

One-Coefficient Model Development

The one-coefficient model for total phosphorus in Big Platte Lake 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 (v_s) 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 8.

$$p = W / (Q + v_s A) \tag{8}$$

In Equation (8), p is the annual average volume weighted total phosphorus concentration of the lake, W is the annual total point and non-point phosphorus load into the lake, Q is the annual average hydrologic flow rate into the lake, v_s is the apparent settling velocity, and A is the area where settling occurs.

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 can be developed for the Platte River watershed using the BASINS model or through direct flow and phosphorus measurements as discussed above. Figure 19 shows the phosphorus loading calculations based on measurements conducted in 2009. The mass balance includes: phosphorus associated with fish lost between the lower and upper weirs; atmospheric phosphorus loading; and phosphorus release from the sediments. These inputs and data for the annual average loading and volume-weighted total phosphorus concentration in the lake can be used to calculate the apparent settling velocity using Equation 8. The calibrated value for the apparent settling velocity for 2009 is 17.7 m/yr. This coefficient is a collective characterization of the net removal of phosphorus from the water column and corresponds to the permanent retention of 58.3% of the incoming phosphorus into the sediments. This value compares well to the long-term average value of 19.9 m/yr (Standard Deviation = 3.9 m/yr) since 1990 and with those observed in other lakes (Chapra, 1997). All these computations are automatically performed by the project database.

Five-Coefficient Water and Sediment Model Development

State and local planning agencies may be obligated to determine allowable phosphorus loads and devise recovery strategies for lakes that do not meet water quality goals as part of the Total Maximum Daily Load (TMDL) process. A paper has been written and published (Canale, et al. 2010) that presents the modeling results that are a critical component of any TMDL process for Big Platte Lake and the Platte River watershed (see Figure 22). The calibrated BASINS model is used to simulate total phosphorus loads from the watershed. A non-steady state five-coefficient model was developed and applied to determine total phosphorus concentrations in the lake water and sediments. Temperature and dissolved oxygen models were used to predict the number of days that the hypolimnion is anoxic to facilitate calculation the internal phosphorus loading due to sediment release. The water and sediment dynamic 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. This goal can be achieved if the annual average lake concentration is 6.4 mg/m^3 as determined by correlation analysis using extensive measurements of total phosphorus in the lake over a period of many years. The calibrated models can also be used to determine allowable phosphorus loads for Big

Platte Lake for various hydrologic and non-point phosphorus loading conditions. Model development and subsequent planning applications are expedited in this case because of the availability laboratory measurements of sediment phosphorus release rates and an extraordinarily comprehensive database of current and historical lake and tributary water quality measurements.

Figure 22 illustrates the five-coefficient total phosphorus model for Big Platte Lake and the bottom sediments. The model has single water and sediment layers that are assumed to be completely mixed in both the horizontal and vertical directions. The phosphorus model mechanisms include: point and non-point external loads; discharge through the outlet; settling losses to the bottom sediments; internal loading due to release from the sediments; and sediment burial. The non-steady state mass balance equations are similar to those used by Chapra and Canale (1991) and Canale and Seo (1999) and are given by:

$$V_w \frac{dP_w}{dt} = W - QP_w - v_s A_s P_w + v_r A_r P_s \qquad (9)$$

$$V_s \frac{dP_s}{dt} = v_s A_s P_w - v_r A_r P_s - v_b A_r P_s \qquad (10)$$

where: A_r = Phosphorus Release Area (m^2); A_s = Settling Area (m^2); P_s = Sediment Total Phosphorus Concentration (mg/m^3); P_w = Water Total Phosphorus Concentration (mg/m^3); Q = Hydraulic Flow Rate (m^3/yr); t = Time (yr); v_b = Sediment Burial Rate Velocity (m/yr); v_r = Phosphorus Release Rate Velocity (m/yr); v_s = Settling Rate Velocity (m/yr); V_s = Volume of Lake Sediments (m^3); V_w = Volume of Lake Water (m^3); and W = Total Annual Phosphorus Loading (kg/yr).

Significant phosphorus release from the sediments of Big Platte Lake occurs only when the sediments are anaerobic. These conditions occur when the average concentration of dissolved oxygen in the hypolimnion is less than about 2 mg/L. Thus, it is necessary to have a model that predicts the seasonal variation of the hypolimnetic dissolved oxygen concentrations to permit calculation of the fraction of the year when significant sediment release occurs. Equation 11 is a differential equation that is the basis of the dissolved oxygen component of the Lake model.

$$V_h \frac{dDO_h}{dt} = v_e A_e (DO_e - DO_h) - A_r (HOD) \qquad (11)$$

where A_e = Area of the Thermocline (m2); DO_e = Epilimnion Dissolved Oxygen Concentration (mg/L); DO_h = Hypolimnion Dissolved Oxygen Concentration (mg/L); HOD = Hypolimnetic Oxygen Demand Rate (mg/m^2/d); v_e = Exchange Rate Velocity between Epilimnion and Hypolimnion (m/yr); and V_h = Volume of Hypolimnion (m^3). The hypolimnetic dissolved oxygen model mechanisms include hydraulic exchange between the epilimnion and hypolimnion and the hypolimnetic oxygen demand rate. Equations 9 through 11 represent a simple yet robust non-steady state model that can simulate long-term changes in lake water and sediment total phosphorus. Similar models have been successfully used in a wide variety of applications (for example, Lung and Canale 1977; Seo and Canale 1996).

Figure 23 shows model projections for the annual average total phosphorus concentration in Big Platte Lake as a function of watershed flow conditions. The model calculated lake phosphorus concentration for high flow conditions was 9.7 mg/m^3 assuming that the Hatchery was at the permit limit of 175 lbs/yr. The lake phosphorus concentration under these high conditions exceeds the goal. The model calculated lake phosphorus concentration for low flow conditions was 6.0 mg/m^3 assuming that the Hatchery was at the permit limit of 175 lbs/yr. The lake phosphorus concentration under these low conditions is less than the goal. The model calculated lake phosphorus concentration for typical flow conditions was 7.6 mg/m^3 assuming that no actions are taken to reduce the non-point phosphorus load and that the Hatchery was at the permit limit of 175 lbs/yr. The lake phosphorus concentration under these low conditions exceeds the 6.4 mg/m^3 the goal.

The model calculations indicate that 825 pounds of phosphorus must be removed from non-point sources to achieve the goal; therefore an action plan is needed to attain the required phosphorus loading reductions. This requires an analysis of the effectiveness of various watershed management practices intended to reduce the non-point phosphorus loading. A local ordinance requires lakeside residents to construct retention basins to collect the runoff from all impervious surfaces to allow percolation into the groundwater. The calibrated BASINS model for the Platte River watershed estimates that the event mean concentration of this runoff has a total phosphorus concentration of approximately 250 mg/m^3 and that local groundwater has a concentration of about 6 mg/m^3. A maximum potential phosphorus reduction of about 86 kg/yr could be attained if all 500 lakeside residents complied with the ordinance. This is equivalent to about 23% of the needed reduction in phosphorus loading to meet water quality goals under “Typical” conditions. Buffer zone ordinances are being considered to reduce the non-point phosphorus loads to the Lake. Although buffer zone vegetation reduces erosion, it is not considered effective for the removal of phosphorus over the long-term because phosphorus retained by plants in the spring and summer is released with plant senesce in the fall. Therefore, lakeside residents are being encouraged circumvent this recycling by collecting beach debris and cutting, harvesting, and removing excess buffer zone vegetation 2 to 3 times per year. Measurements indicate that typical shoreline debris material has a water content of about 75% and contains about 0.25% phosphorus by dry weight. Therefore, a total phosphorus loading reduction of about 70 kg/yr could be attained if each lakeside property owner removed approximately 225 kg of vegetative litter and beach debris (wet weight) from their property per year. A typical 9 kg bag of lawn and garden fertilizer used in the area contains 10% phosphorus, or 0.9 kg per bag. Lakeside residents are being encouraged to only use phosphorus-free fertilizers. Detailed fertilizer sales volume and application rate data are not available for the local area; however, if 50% of the 500 lakeside residents currently use one bag of fertilizer per year, then a potential reduction of 227 kg of phosphorus could be attained with the use of phosphorus-free fertilizers. A summary of these calculations is shown in Figure 24.

It is important to note that the reductions in phosphorus loading estimated for the actions described above are a maximum because even without the remedial measures, some phosphorus would naturally percolate into the groundwater. It is not possible to quantitatively evaluate the actual phosphorus reduction achieved in practice compared to the potential reductions described in the previous paragraphs. In addition, note that the model calculations presented above do not account for increases in the non-point phosphorus loads that result from the future growth of population and commercial activities. Therefore, a long-term monitoring program should be implemented to both verify the effectiveness of the corrective efforts and detect long-term trends in watershed development.

Special Studies

Phosphorus Bio-availability

It is generally assumed that bio-available phosphorus rather than total phosphorus is the direct cause of algal growth in Big Platte Lake. Non-point nutrient sources such as groundwater, storm runoff, and atmospheric inputs are usually considered poor sources of bio-available phosphorus compared to point sources such as those associated with the fish wastes in the Hatchery wastewater. The Hatchery wastewater has fish fecal matter and undigested food particles that may contain readily available phosphorus and other nutrients that may stimulate algal growth. In addition, the Hatchery discharge wastewater may contain high populations of decomposing bacteria and alkaline phosphatase that may accelerate the rate of transfer of total unavailable phosphorus to available phosphorus forms.

The rationale of the above hypothesis was evaluated using bioassay techniques and the test green alga *Selenastrum capricornutum*. Experiments measured the growth of the alga in fish Hatchery discharge water, non-point source water, and mixtures water of Hatchery and non-point source water. It was determined that algal growth in various mixtures of non-point and Hatchery discharge waters was greater than the growth in non-point phosphorus waters alone for conditions where both had nearly identical initial starting total phosphorus concentrations. These results indicate that the bio-availability phosphorus from non-point sources was enhanced when mixed with Hatchery discharge water. This effect is shown in Figure 25 taken from Qian, (2009).

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 net phosphorus loading from the Platte River State Fish Hatchery as required by the NPDES permit 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 mass balance and bio-energetic models for the phosphorus discharge from the Hatchery as a function of fish production activities and the efficiency of the filters, clarifier, and final finishing pond.
- 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 can be 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 2010 involves collecting data from the Hatchery, watershed streams, and Big Platte Lake. The proposed lake and watershed sampling program for 2010 includes no sampling of Little Platte Lake; no nitrogen or total dissolved phosphorus samples; and only three samples for phytoplankton and zooplankton. The sampling program for the Hatchery has been downsized because of the abandonment of the sludge tank sampling site and the consolidation of the three backwash flow sampling sites.

Hatchery

The net Hatchery total phosphorus load is evaluated by subtracting the inlet load from the total outlet loading. It is recommended that measurements of flow, total phosphorus concentration, and turbidity be taken at six locations using the Sigma samplers. The Sigma equipment should collect 3.5 day composite samples twice each week. . In addition, all flow rates should be calibrated annually. The overflow rate of the clarifier should be based on pump capacity and the measured running times of the pumps.

It is recommended that measurements be made of the fish food and fish tissue for phosphorus as well as protein, lipid, and carbohydrate content to facilitate more accurate mass balance calculations for the Hatchery.

Watershed

The tributary sampling program is designed to calculate the non-point phosphorus loading into Big Platte Lake. 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 recommended the regular monitoring program for 2010 contain three sites on the Platte River – one just upstream of the Hatchery, another at the USGS Station on US31, and the last below Big Platte Lake on M-22. One sample should be taken of the North Branch of the Platte River at Deadstream Road.

It is recommended that Big Platte Lake be sampled every two weeks during the year, whenever it is safe to do so. A calibrated 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 phosphorus, turbidity, alkalinity, chlorophyll, total dissolved solids, and calcium. Vertical net hauls should be taken for zooplankton one time during the spring, summer, and fall. A surface composite (tube sampler) and grab bottom sample should be taken during these same periods for phytoplankton. Secchi depths should be measured with a standard Secchi disk. It is recommended that four more upstream tributary sites be added and samples be taken for nitrate and TN when current budget restraints are lifted.

Cost

A summary of the sampling frequency and the measured parameters for each station is listed in Figure 26. Separate cost estimates are provided for the Hatchery and watershed sampling programs using CMU unit costs.

Quality Assurance and Control

Extensive efforts were made to insure the accuracy of the various field and laboratory procedures. CMU regularly measures the phosphorus concentration of purchased standards that have concentrations of 5 and 10 mg/m^3. The average concentration of 14 measurements of the 5 mg/m^3 purchased standard solution for 2009 was 5.018 mg/m^3 with a standard deviation of 0.012 mg/m^3. The average concentration of 14 measurements of the 10 mg/m^3 purchased standard solution for 2009 was 10.02 mg/m^3 with a standard deviation of 0.024 mg/m^3. These results are extraordinarily accurate and precise and provide strong confidence regarding the reliability of the CMU phosphorus measurements.

On the other hand, sample handling and tracking of sample bottles has caused some difficulties. Therefore, bottles containing distilled water are randomly included with regular samples scheduled for measurement of phosphorus. This is done to insure that bottle and sample identification information are properly tracked through the measurement and laboratory handling process. Appendix E contains a detailed discussion of the results of this effort to improve the integrity of sample tracking. These efforts should be continued indefinitely to insure overall quality control.

Appendix F contains up to date SOP documents and 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.

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. 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 reliable application of the data. It is recommended that documentation of the database organization and computer code be completed and then kept current.

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