Alternatives Analysis
Mill Pond
Plymouth, Wisconsin

Prepared for:

City of Plymouth
128 Smith Street
Plymouth, WI 53073

Prepared by:

Earth Tech, Inc.
4135 Technology Parkway
Sheboygan, WI 53083

October 2007

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ATTACHMENTS

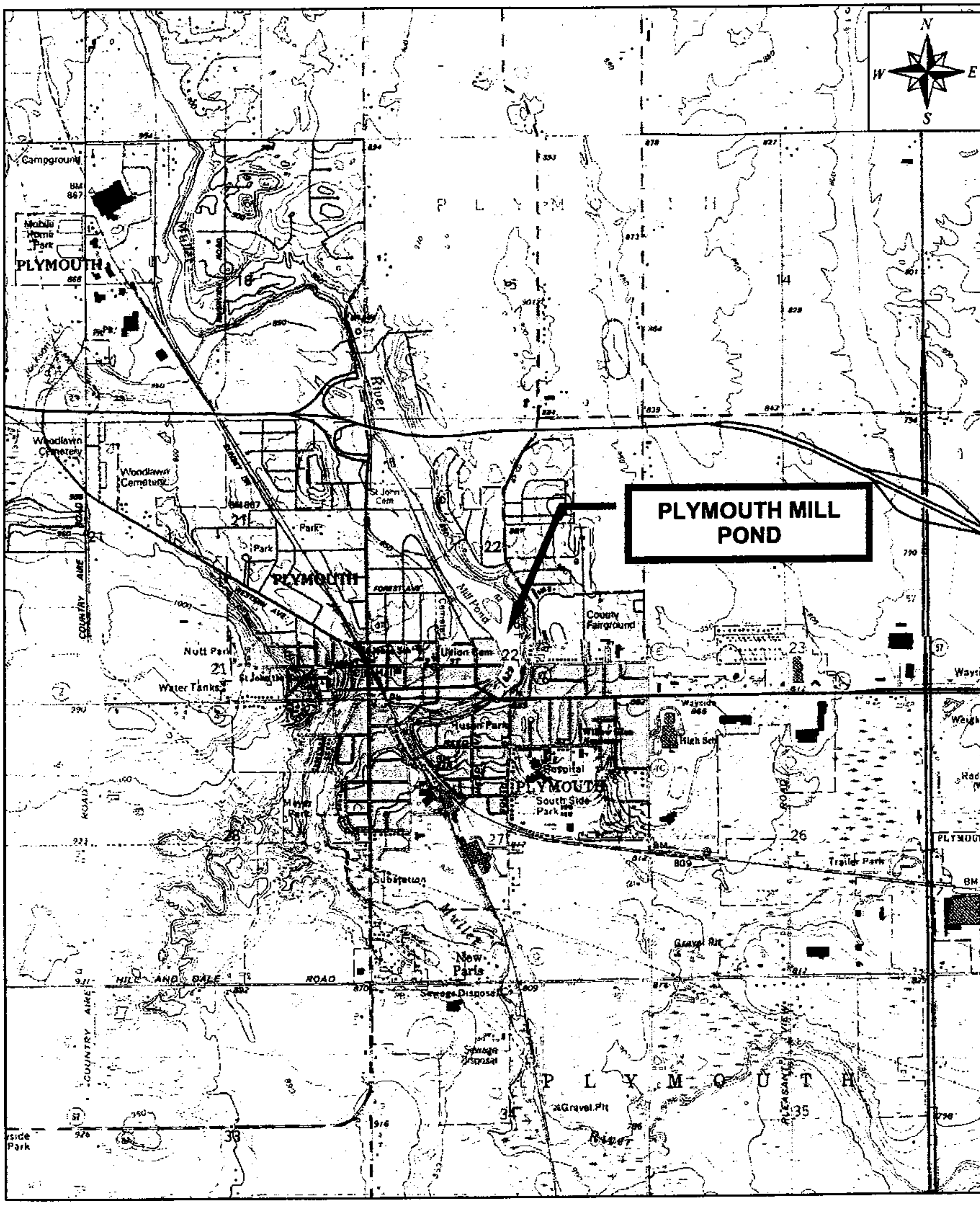
1.0 INTRODUCTION AND PURPOSE

The Plymouth Mill Pond has been an amenity to the City and local residents since the mid-1800s. However, in recent years, degraded water quality has lead to algal blooms and aquatic plant growth which have caused odor problems, impeded recreational use of the lake, and negatively impacted the aesthetics of the Mill Pond area. The City of Plymouth and their volunteer Mill Pond Committee have applied for and received grants from the Wisconsin Department of Natural Resources (WDNR) to determine the underlying cause of the degraded conditions and develop a comprehensive plan of action to improve the condition of the Mill Pond.

The Mill Pond is located in the heart of the downtown area of Plymouth in Sheboygan County, Wisconsin in Section 22, Township 15 North, Range 21 East (Figure 1). The Mill Pond is a 41-acre (including the island) lake created by the dam across the Mullet River and extends from the Plymouth dam north to State Trunk Highway (STH) 23. The City of Plymouth owns approximately 2 acres of property at the outlet of Mill Pond. There is approximately 1,000 feet of shoreline on City school property including a recreational trail along the northwest side of the lake and a pedestrian foot bridge across the northern portion of the lake. The Mill Pond is utilized for boating, fishing, and public ice skating. Prior to the recent infestation of aquatic macrophytes, the lake was navigable from the upper end of the lake to the dam. Restoration of the Mill Pond would lead to improved water quality, increased use of the lake as a recreational resource, improved civic pride, and would improve the look of the City to tourists and the local citizenry.

As indicated in the State of the Sheboygan River Basin (WDNR, October 21, 2001), the Mullet River is a high priority for the WDNR and one of the objectives of the WDNR is to work with the City of Plymouth to address safety and water quality issues associated with the Plymouth Mill Pond and its dam. It is anticipated that the WDNR will utilize the information gathered from this project and add it to their dataset for the Sheboygan River Basin and the management plan developed as part of this project will complement WDNR basin planning. There are three aquatic endangered resources that are known to occur in the Mullet River Watershed. Projects designed to protect or improve the water quality resource will benefit the protection of these listed resources.

Although the City, the Mill Pond Committee, and the citizens of Plymouth have some ideas related to long-term management of the lake, there is little data related to the underlying problems related to the current degraded condition and there has been no formal evaluation of potential alternatives. An assessment of the feasibility and cost-benefit of various options is required for the City and the Mill Pond Committee to make sound decisions related to the management of the lake. This report contains an evaluation of the potential long-term management alternatives to solve the problems associated with poor water quality.



Note: Not to Scale
Source: USGS 7.5-Minute Topographic Quadrangle, Plymouth South (1974)

EarthTech
A Tyco International Ltd. Company

FIGURE 1
PROJECT LOCATION

PLYMOUTH MILL POND
PLYMOUTH, WISCONSIN

88073

L:\work\88073\ENG\ENV\Planning Grant\Figure 1- Project Location Map.doc

2.0 SUMMARY OF ALTERNATIVES

There were six alternatives assessed in this analysis. The alternatives studied during this analysis, with a brief description, follows.

Remove Mill Pond Dam

Removal of the Mill Pond Dam is noted in this report as an alternative, but since this alternative will not meet the goals of the Mill Pond Committee or the City of Plymouth, this alternative was not studied in detail in this analysis.

Dredge Pond

This alternative will involve dredging the existing sediments from the Mill Pond by either mechanical or hydraulic dredging techniques. Dredging the pond would remove the nutrients that are stored in the sediments from the pond system. If mechanical techniques are used, the pond may need to be drained before dredging could begin, depending on the type of dredging used. Hydraulic dredging could be done without draining the pond. Both techniques would require a nearby area to dry the sediments before disposing of them.

Vegetation Removal

This alternative would involve mechanically harvesting the vegetation in the pond. Harvesting the vegetation would remove the material from the pond and remove the nutrients associated with the vegetation breaking down over the winter months from the pond system.

Pond Drawdown

This alternative would involve drawing down the water in the pond. If the pond is drawn down, the sediments would compact and bind some of the nutrients from reentering the system when the water levels are brought back up to the normal elevation.

Shoreline Preservation and Urban Stormwater Management

This alternative involves educating the public and municipal employees on how to employ proper shoreline preservation techniques and fertilizer and sediment management throughout the City.

No Action

This alternative will involve making no changes to the Mill Pond system.

3.0 DISCUSSION OF EACH ALTERNATIVE

Each of the six alternatives are discussed in detail in this section.

3.1 REMOVE MILL POND DAM

As previously stated, removing the Mill Pond Dam is not in the interest of the Mill Pond Committee or the City of Plymouth. Since this alternative would result in the loss of the Mill Pond altogether, no further consideration of this alternative will be made in this Alternatives Analysis. An estimated cost for the removal and restoration of the Mill Pond area is $80,000, based on other dam removals done in the state. There is a WDNR dam removal grant program that would cover half of this cost.

3.2 DREDGE POND

The results of the 2005 bathymetric survey showed that there is approximately 180,000 cubic yards of soft sediment accumulated on the bottom of the Mill Pond. The depth of these sediments range up to 6.8 feet deep with an average depth of 1.8 feet. One management alternative is to remove these sediments by dredging. The sediment analysis conducted for this project estimated that sediment being carried into the Mill Pond by the Mullet River could be accumulating at a rate of 0.3 or 1.2 inches per year over the pond bottom, depending on the calculation method used (see Attachment 1). The table below shows the time it would take to refill areas that are dredged based on these accumulation rates. The time varies considerably depending on the accumulation rate used. The attached sediment analysis indicates that the method used to calculate the 1.2 inches/year accumulation rate is better suited to the Mill Pond than the other method.

Sediment Accumulation Rate	Time to Fill 1.8 Feet of Depth	Time to Fill 6.8 Feet of Depth
0.3 inches/year	72 years	272 years
1.2 inches/year	18 years	68 years

There are two different methods of dredging that can be done at the Mill Pond: mechanical and hydraulic. For the mechanical dredging method, the water in the pond can either be drained or left in place, depending on which method is used. One method involves draining the pond and entering the basin with an excavator. The other method involves floating a barge with an excavator and dredging from the barge. Once the sediment is excavated, the sediment will then be transported by truck to a drying area where the sediment will be allowed to dry prior to finally trucking to a disposal site. The excavation equipment, likely a track hoe or a dragline, will need to be able to deposit the material into a dump truck, which will transport the material to the drying site. In order to do this, either access to the pond edge will need to be gained from multiple points or the dump trucks will need to enter the bed of the Mill Pond. For the trucks to enter the bed of Mill Pond, a gravel road would need to be constructed in the bed of the pond to accommodate the trucks. This gravel bed would be removed after dredging is completed. Since the pond is primarily surrounded by private property and the gravel road in the pond bed would add additional impact to the pond and total cost to the project, mechanical dredging was not considered to be a cost effective option for dredging.

For hydraulic dredging, a barge holding the hydraulic pumps will need to enter the pond. The pumps will remove the sediments from the pond bottom through suction and pump the sediment to either trucks, to transport the material to the drying area, or directly to the drying area if possible. Benefits to this method over the mechanical method are that the pond does not have to be drained for the hydraulic method and that the material can be pumped up to 2 miles to a drying area instead of having to transport it by truck, which will be a large cost savings. Once the material has sufficiently dried, it will need to be deposited at either a landfill or in an area agreed to by the Wisconsin Department of Natural Resources. The cost to dredge the entire 180,000 cubic yards of soft sediment in the Mill Pond by hydraulic methods has been estimated to be between $3.5 and $5.2 million not including disposal costs, which could be as much as $3.2 to $5.4 million if the material needs to be disposed in a landfill.

3.3 AQUATIC VEGETATION REMOVAL

This alternative involves removing the aquatic vegetation by mechanical means, such as raking or cutting. This alternative would remove the existing vegetation in the pond, thereby removing the nutrients tied up in the vegetation. Plants would either be cut with a floating harvester or raked from the pond bottom including the roots and deposited outside of the pond. This alternative may need to be done annually or more often because the plants will continue to grow after they have been cut or raked from the pond. To be an effective alternative, this method would need to be done regularly, as many as three times per year, at a cost of approximately $125,000 per time. Permits from the WDNR would need to be obtained to harvest the plants and a trucking and a disposal site would need to be identified to dispose of the vegetative material at an additional cost. In addition, there are shallow areas of the Mill Pond (the average depth is 1.2 feet) which would not be accessible to a floating harvester. While this alternative would keep parts of the pond free of floating vegetation, aquatic vegetation removal is not an effective long-term solution to controlling the nutrients in the Mill Pond; however it is a temporary solution and would need to be done regularly.

3.4 POND DRAWDOWN

This alternative will involve drawing the water level of the Mill Pond down to baseline flow of the Mullet River. Drawing the water in the pond down will allow the sediments in the pond to settle and compact. This may prevent some of the sediments from becoming resuspended in the water column and perhaps contributing to the nutrients in the water column. The lake modeling analysis done for the project (see Attachment 2) indicates that the sediments are probably not a large source of nutrients to the water column, although they would promote rooted aquatic plants growth. A second benefit of this method is that it would create more water depth in the pond. The average percent solids by weight of the sediment samples collected in the Plymouth Mill Pond on June 18, 1999 was 34 percent. This translates to 21 percent solids by volume if one assumes the dry density of the sediment is 120 pounds/cubic foot. Assuming that the sediments after drawdown achieve 60 percent solids by volume, then the average sediment depth of 1.8 feet would compact by 39 percent to 1.1 feet deep and the maximum sediment depth of 6.8 feet would compact to 4.1 feet deep.

While the cost for this alternative is minimal (approximately $500 for permitting), there will be some impact to the community, because the resource that the Mill Pond supplies to the community will not be available for several months. Although, when water starts to refill the Mill Pond basin, the sediments may re-suspend in the water column, reversing the desired effects of pond drawdown. Since the nutrients in the pond will also be available to rooted vegetation, the long-term effectiveness of this alternative is mostly unknown.

3.5 SHORELINE PRESERVATION AND URBAN STORMWATER MANAGEMENT

This alternative will involve educating the public and the City of Plymouth on better methods to manage the shoreline of the Mill Pond and proper erosion control and stormwater management within the City. The Water Quality assessment completed in 2006 indicated that nutrients and sediments coming into the Mill Pond from the immediate drainage area may have a disproportionate water quality impact to the Mill Pond compared to the drainage area upstream of the pond. Therefore, improvements to the shoreline and the immediate urban drainage area may have the potential to most directly improve the Mill Pond water quality.

The education should stress the importance of establishing an unmowed buffer strip along the shoreline of the pond. Education also needs to include the proper methods and rates of fertilizer application of lawn on private and public property as well as keeping street gutters clear of grass clippings and other organic material. The City and the Mill Pond Committee could consider hosting educational meetings for the public and utilizing the County Extension office or the WDNR for support. The costs to the City and the Mill Pond Committee for this alternative would be minimal.

Urban stormwater management activities that the City can promote includes such activities as: vigorously enforcing construction site erosion control ordinances, street sweeping, catch basin cleaning, and implementing stormwater treatment systems such as detention ponds and sediment traps as required. The cost of these activities could be carried out as part of the normal operating budget of the City as well as costs incidental to new construction.

The Sheboygan County Fairgrounds was assessed for a potential source of stormwater pollution to the Mill Pond. Historically, runoff from the race track and the barn area did flow to the Mill Pond relatively untreated. Several treatment practices were constructed in 2004 with coordination between the County and WDNR. These include a sediment trap under the grandstand, a french drain in the infield and the west side of the racetrack, and sanitary sewer connections for the wash drains by the barn area. These practices provide a reasonable level of treatment for the stormwater runoff from the Fairgrounds and no further improvements are recommended.

3.6 NO ACTION

For this alternative, no action would be taken by the Mill Pond Committee or the City of Plymouth. The Mill Pond would be left as it is with no modifications to the pond or the watershed. There would be no cost for this alternative.

4.0 ANALYSIS OF ALTERNATIVES

Of the six alternatives considered, removal of the dam was disregarded because neither the City nor the Mill Pond Committee is interested in permanently draining Mill Pond.

Dredging the pond sediments is a viable alternative, but according to the results of the sediment modeling completed by Earth Tech in 2007 (Attachment 1), the pond may retain up to 1.2 inches of new sediment per year. While dredging the pond may eventually be necessary to restore water depth, this method is not likely to keep the Mill Pond from becoming infested with algae because there will still be nutrients entering the pond system from other sources. Dredging may limit the extent of rooted aquatic vegetation because these plants cannot grow in depths where sunlight cannot penetrate (the maximum measured water clarity was 1.07 meters) but they would persist in the shallower areas. In addition, this alternative is the most costly, with total costs possibly being as high as $7 million and would cause additional environmental impacts to the area surrounding Mill Pond.

Removal of the aquatic vegetation is another short term remedy for the Mill Pond. Removing the vegetation would only be a temporary solution because there will still be seeds located in the sediments with a surplus of nutrients in the pond. According to the lake eutrophication model completed by Earth Tech in 2007 (Attachment 2), the input of nutrients into the Mill Pond will still occur from runoff from adjacent properties and the watershed. Desirable plants would also be removed with the unwanted species. For vegetation removal to be an effective remedy it would have to be done three or more times a year. At a cost of up to $125,000 per time, this alternative is not cost effective.

Pond drawdown would also not be a good solution by itself. While it may bind some of the nutrients in the sediment, it will not remove the sources of nutrients or keep them from entering the pond. This alternative may be a good solution in conjunction with another alternative that would work to remove the source of nutrients in the pond system. In addition, this alternative would be an inexpensive way to increase water depth in the pond.

Shoreline management and urban stormwater management is the most effective alternative for reducing the nutrient inputs in the Mill Pond. This alternative, in conjunction with drawdown of the pond for a winter season, would reduce the nutrients in the pond system at a reasonable cost to the City and Mill Pond Committee. The County Extension Office and the local WDNR staff could hold public educational meetings, hosted by the City, to inform the public and the City employees on how to better protect the watershed of the Mill Creek from nutrient runoff and erosion.

No action is another possible alternative. While this alternative will not improve the Mill Pond nutrient problem, the last few seasons may have been an aberration from normal conditions in the Mill Pond. The Mill Pond Committee and the City may decide to wait and see what happens in the Mill Pond over the next few seasons and then decide if further management of the Mill Pond system is necessary.

Below is an alternatives matrix summarizing some of the important aspects of each alternative. Short-term and long-term effectiveness relates to how well the alternative would reduce aquatic plant and algae growth. Implementability relates to how easily the alternative could physically be implemented.

Alternatives Analysis Matrix

Alternative	Short-Term Effectiveness	Long-Term Effectiveness	Implementability	Public Acceptability	Cost
Dam Removal	high	high	high	low	$80,000
Dredging	high	medium	medium	high	$7,000,000
Aquatic Vegetation Removal	medium	medium	medium	medium	$125,000/yr X 3
Pond Drawdown	medium	medium	high	medium	$500
Shoreline and Stormwater Management	medium	medium	medium	medium	unknown
No Action	low	low	high	medium	$0

5.0 SUMMARY

Earth Tech completed an alternatives analysis to evaluate six different alternatives to improve the water quality of the Mill Pond in Plymouth, Wisconsin. The alternatives evaluated included removal of the Mill Pond Dam, dredging the pond, pond vegetation removal, drawdown of the pond, shoreline management and urban stormwater management, and no action. The analysis of the alternatives showed that the best means to improve the Mill Pond were to institute a process with the assistance off the County Extension and the local WDNR offices to educate the public and City employees on how to better manage the nutrients and sediments entering the pond in the immediate watershed of the Mill Pond. This process should be done in conjunction with a drawdown of the pond over the winter months to compact the sediments in the pond to increase water depth in the pond and potentially bind some of the nutrients in the compacted sediment. This solution would be the least costly, with the exception of no action, and can be implemented relatively quickly.

ATTACHMENT 1

SEDIMENT LOADING ANALYSIS

EarthTech
A tyco International Ltd. Company

Memo

1210 Fourier Drive	P 608.836.9800
Suite 100	F 608.836.9767
Madison, WI 53717	www.earthtech.com

10/4/2007

To: Steve Grumann, Earth Tech

Copy: Bernie Michaud, Earth Tech

From: Theran Jacobson, Earth Tech

Subject: Plymouth Mill Pond Sediment Loading Analysis, Project No. 100540

This memorandum summarizes the results of the sediment loading analysis for the tributary area of the mill pond located in Plymouth, WI and the sediment removal efficiency methods evaluated for the mill pond.

Methodology

The average annual inflow to the Plymouth Mill Pond was determined by the evaluation of the Mullet River at the Greenbush, WI gauging station (U.S. Geological Survey (USGS) gauge station #04085746) that recorded flow data for the Mullet River for a five (5) year period from 2001 through 2005.

The unit-area sediment loading values were determined from the Onion River, an adjacent watershed with similar land use. The unit-area loading values from the Onion River were determined from a USGS study (USGS Fact Sheet FS-195-97).

The sediment trapping rate for the Plymouth Mill Pond was calculated using two different empirically derived methods; the Brune's curve and Churchill's curve methods. The methods determine the sediment removal rates for small to large reservoirs using a variety of input parameters. Brune's curve method uses the following input data: reservoir capacity and annual inflow. Churchill's curve method uses the following input data: reservoir capacity and length, and average daily inflow.

Results

The flow data for the Plymouth Mill Pond was calculated from a watershed area ratio from the flows recorded at the Greenbush, WI gauging station. The watershed area for the Mullet River at the Greenbush, WI gauging station is approximately 24.3 square miles (sq. mi.). The watershed area for the Plymouth Mill Pond downstream is approximately 62.2 sq. mi. The recorded flows from the Mullet River at Greenbush, WI were multiplied by the watershed area ratio (62.2 / 24.3 = 2.56) to determine the discharge rate into Mill Pond. The calculated average daily inflow to the Plymouth Mill Pond is approximately 26.7 cubic feet per second (cfs).

The average annual sediment loading to the Plymouth Mill Pond was calculated from a watershed area ratio from the unit-area loading results for the Onion River. The watershed area for the Onion River is approximately 91.8 sq. mi. The average unit-area loading of total suspended solids for the Onion River is approximately 84 tons per sq. mi. (U.S. Dept. of the Interior, FS-195-97) based on two years of monitoring data. The average unit-area loads from the Onion River were multiplied by the watershed area ratio (62.2 / 91.8 = 0.68) to determine the unit-area loads to Mill Pond. The average sediment loading into the Mill Pond is estimated to be 3,540 tons TSS per year (tons-TSS/yr).

The sediment trapping rate of the Plymouth Mill Pond as estimated by the Brune's and Churchill's curve methods is 10% and 63% respectively. These are significantly different results. The following comparison of the two methods was found in a U.S. Bureau of Reclamation document; "As a guideline Brune's curve method should be used for large storage or normal ponded reservoirs and Churchill's curve method should be used for settling basins, small reservoirs, flood retarding structures, semi-dry reservoirs, or reservoirs that are continuously sluiced." (U.S. Dept of the Interior, 2006). This does not appear to provide clear cut guidance for which method to use in this situation. Several factors seem to favor the Churchill's curve method; the Plymouth Mill Pond is a smaller reservoir, the Churchill's method takes into account reservoir length (the mill pond is long and narrow), and it provides a more conservative result (higher trapping rate). At best these methods provide an approximation of what is happening in the mill pond and should be used as a guidance and the results of the two methods could be used as bracketing values.

To translate the amount of sediment trapped by weight to a depth of sediment, the density of the sediment must be known. The average bulk density of the sediment samples collected in the Plymouth Millpond on June 18, 1999 was 0.34 tons per cubic yard. The calculated depth of sediment deposited over the entire surface area of the Plymouth Mill Pond on an average annual basis is then estimated to be 0.3 inches for Brune's method and 1.2 inches for Churchill's method.

Table 1: Sediment Removal Results for Brune's and Churchill's Curve Methods

Method	Sediment Loading (tons TSS / yr)	Average Daily Flow (cfs)	Pond Area (acres)	Reservoir Capacity (acre-feet)	Sediment Removal (%)	Weight Sediment Removed by Pond (tons / yr)	Sediment Deposited (inches/yr)
Brune's	3,540	26.7	39.6	48.1	10	354	0.3
Churchill's	3,540	26.7	39.6	48.1	63	2,230	1.2

References

U.S. Department of the Interior, Bureau of Reclamation, "Erosion and Sedimentation Manual", November 2006.

U.S. Department of the Interior, U.S. Geological Survey, "Unit-Area Loads of Suspended Sediment, Suspended Solids, and Total Phosphorus from Small Watersheds in Wisconsin" Fact Sheet Number: FS-195-97.

ATTACHMENT 2

LAKE MODELING ANALYSIS

EarthTech
A tyco International Ltd. Company

Memo

1210 Fourier Drive	P 608.836.9800
Suite 100	F 608.836.9767
Madison, WI 53717	www.earthtech.com

10/4/2007

To: Steve Grumann, Earth Tech

Copy: Theran Jacobson, Earth Tech

From: Bernie Michaud Earth Tech

Subject: Plymouth Mill Pond Lake Modeling, Project No. 100540

This memorandum summarizes the results of the lake water quality modeling of the Plymouth Mill Pond in Plymouth, Wisconsin.

Methodology

The Plymouth Mill Pond was modeled with the lake water quality model **Wisconsin Lake Modeling Suite** (WiLMS). The model estimated phosphorus concentrations in the pond based on physical attributes of the watershed, estimated river flows, and lake morphometry. The watershed area and watershed characteristics were assessed during Part 1 of this project. Additionally, river flow information was interpolated from available United State Geological Survey (USGS) river gaging station information from the nearest appropriate gaging location (see below). The bathymetric mapping created in 2005 was also used in the modeling.

The model was calibrated using the actual pond phosphorus concentrations measured as part of this project. The in-lake phosphorus cycling rate was also assessed using the model.

Hydrologic and Morphometric Data

The average annual inflow to the Plymouth Mill Pond was determined by the evaluation of the Mullet River at the Greenbush, WI gauging station (U.S. Geological Survey (USGS) gauge station #04085746) that recorded flow data for the Mullet River for a five (5) year period from 2001 through 2005. The watershed area for the Plymouth Mill Pond downstream is approximately 62.2 sq. mi. The recorded flows from the Mullet River at Greenbush, WI were multiplied by the watershed area ratio (62.2 / 24.3 = 2.56) to determine the discharge rate into the Plymouth Mill Pond. The calculated average daily inflow to the Plymouth Mill Pond is approximately 26.7 cubic feet per second (cfs) or 5.8 inches of runoff from the watershed.

The Plymouth Mill Pond is approximately 39.6 acres is area with a volume of approximately 48.1 acre-feet. The Mill Pond is shallow with a mean depth of 1.2 feet. The pond volume is small in relation to the inflow so the average pond flushing rate is 400 times per year.

The unit-area sediment loading values were determined from the Onion River, an adjacent watershed with similar land use. The unit-area loading values from the Onion River were determined from a USGS study (USGS Fact Sheet FS-195-97).

Non-point Source Pollution Source Data

Non-point source pollution from stormwater runoff is the largest source of phosphorus to the Plymouth Mill Pond. There are no known point sources of pollution of note. WiLMS estimates non-point phosphorus loading based on land uses in the watershed. The watershed land usage was estimated using USGS mapping and results of the windshield survey conducted in 2006. These results are shown in the table below. WiLMS estimated that the "most likely" loading of phosphorus from non-point source runoff is 19,477 pounds per year.

Land Use	acres	%
Agricultural	25,333	63.6%
Forest	8,768	22.0%
Wetlands	3,710	9.3%
Rural Residential	1,536	3.9%
Medium Density Urban	393	1.0%
High Density Urban	28	0.1%
Pond Surface	40	0.1%
Total	**39,808**	**100%**

The average annual phosphorus loading to the Plymouth Mill Pond was also calculated using the unit-area loading results for Silver Creek near Ripon. The watershed area for Silver Creek is approximately 36.2 sq. mi. The average unit-area loading of total phosphorus for Silver Creek is approximately 283 pounds per sq. mi. (U.S. Dept. of the Interior, FS-195-97) based on nine years of monitoring data. This average unit-area load was multiplied by the Plymouth Mill Pond watershed area (62.2 sq. mi.) to arrive at an estimated average total phosphorus loading of 17,603 pounds per year. This correlates well with the loading calculated by the WiLMS model.

In Pond Phosphorus Prediction

The WiLMS model predicts in lake total phosphorus concentrations using 13 empirical regression equations. Each regression equation is derived from data from many lakes. The model identifies those equations which best fit the lake being modeled. In this analysis it was determined that the "Canfield-Bachmann Artificial Lake Model" and the "Reckhow, 1977 Lakes with qs>50 m/yr Model" best fit the parameter range values for the Plymouth Mill Pond.

These two empirical equations predict the Growing Season Mean (GSM) total phosphorus concentration (the mean for the months June, July, and August). The GSM total phosphorus concentration actually measured in the Plymouth Mill Pond in 2006 was **98 micrograms/liter (ug/l)**. The model predictions are statistically derived and have a level of uncertainty in the results. The initial results are below.

Initial Phosphorus Concentration Predictions

Equation	Low (ug/l)	Most Likely (ug/l)	High (ug/l)
Canfield-Bachmann	124	283	452
Reckhow qs>50m/yr	119	300	522

Model Calibration

The model results above are well above the actual measured total phosphorus concentrations. The WiLMS model has a feature that back calculates what the total phosphorus loading from the watershed should be to arrive at the observed in lake total phosphorus concentration. This back calculation indicated the incoming phosphorus loading would be approximately 6,107 pounds per year. This is 69% less than the loading estimated by the WiLMS non-point source pollution estimator.

The WiLMS non-point source pollution estimator was adjusted to reduce the annual phosphorus loading by 69 %. This may be justified by the fact that the drainage ways and stream banks in the watershed appeared to be well buffered from surrounding land uses by woods, wetlands or other well vegetated areas during the 2006 windshield survey. In addition, the Mullet River at points upstream showed a high degree of clarity. Settling in the upstream Glenbeulah Mill Pond may also reduce the phosphorus load. The calibrated results are below.

Calibrated Phosphorus Concentration Predictions

Equation	Low (ug/l)	Most Likely (ug/l)	High (ug/l)
Canfield-Bachmann	42	100	166
Reckhow qs>50m/yr	37	93	163

Internal Phosphorus Cycling

Bottom sediments were assessed for being a potential source of phosphorus to the pond. WDNR sediment sampling from June 18, 1999 showed phosphorus concentrations in the sediment ranging from 523 to 622 mg/kg. Phosphorus in bottom sediments can be cycled back into the water column under the right conditions. The internal cycling occurs most frequently when the bottom lake water is stratified and anoxic. Phosphorus becomes soluble under anoxic conditions. The Plymouth Mill Pond does not stratify and become anoxic due to its shallow depth (it remains well mixed vertically). The WiLMS model was used to predict the internal phosphorus load from the sediments. It predicted that there is a net loss of phosphorus to the sediment of 374 pound per year due to settling.

Discussion

The WiLMS modeling showed that the loading of phosphorus to the Plymouth Mill Pond from watershed runoff is less than what is typically expected but nonetheless is the central reason why the Mill Pond exhibits eutrophic conditions. This is accentuated by the large amount of flow that is cycled through the Mill Pond.

Bottom sediments may not be releasing phosphorus back into the water column in significant amounts. However it would still be available to promote growth of rooted aquatic plants.

References

U.S. Department of the Interior, U.S. Geological Survey, "Unit-Area Loads of Suspended Sediment, Suspended Solids, and Total Phosphorus from Small Watersheds in Wisconsin" Fact Sheet Number: FS-195-97.

L:\WORK\projects\100540\Admin\Reports\LakeModeling_2007-10-04.doc