Michigan Department of Environmental Quality
Water Resources Division
June 2011

Total Phosphorus Total Maximum Daily Load for Goose Lake Marquette County, Michigan

INTRODUCTION

Section 303(d) of the federal Clean Water Act and the United States Environmental Protection Agency's (USEPA's) Water Quality Planning and Management Regulations (Title 40 of the Code of Federal Regulations, Part 130) requires states to develop Total Maximum Daily Loads (TMDLs) for water bodies that are not meeting water quality standards (WQS). The TMDL process establishes the allowable loadings of pollutants for a water body based on the relationship between pollution sources and in-stream water quality conditions. TMDLs provide states a basis for determining the pollutant reductions necessary to restore and maintain the quality of their water resources. This TMDL focuses on establishing a phosphorus load to Goose Lake to achieve WQS. All references to phosphorus in this document are assumed to mean "total phosphorus" unless otherwise specified.

PROBLEM STATEMENT

Goose Lake is on the 2010 Section 303(d) list (LeSage and Smith, 2010) as follows:

<u>2010 Listing</u>:
Goose Lake
AUID: 040301100107-02
Impaired Designated Uses: Other indigenous aquatic life and wildlife
Cause: Total Phosphorus
Size: 430 Acres

Goose Lake and its tributaries are located in Marquette County, Michigan, southeast of the city of Negaunee (Figure 1). Goose Lake has a mean depth of approximately 12 feet (3.6 meters) and a maximum depth of 15 feet (4.5 meters) (Figure 2). Lake temperature profiles collected between 2003 and 2007 indicate that Goose Lake is polymictic (completely mixing from top to bottom more than two times during the ice-free season). A history of nuisance algae blooms, fish kills, and odor problems led to Goose Lake being listed as hypereutrophic in the Integrated Report (LeSage and Smith, 2010). Goose Lake is not designated as a cold water lake and is not protected for the cold water fishery designated use. Goose Lake is not protected as a public water supply source.

Goose Lake is on the Section 303(d) list, as a Category 5 water body, for impairments to the fish consumption and the other indigenous aquatic life designated uses. The fish consumption designated use impairment is due to elevated polychlorinated biphenyl (PCB) concentrations in fish tissue. A PCB TMDL is scheduled for 2013. Total phosphorus is the only pollutant listed as the cause of Goose Lake's other indigenous aquatic life and wildlife designated use impairment. All other assessed designated uses in Goose Lake are meeting WQS.

Phosphorus and nitrogen are often considered to be the limiting nutrients for plant production in inland lakes (Horne and Goldman, 1994; Wetzel, 2001; Dodson, 2005). Sometimes the molar

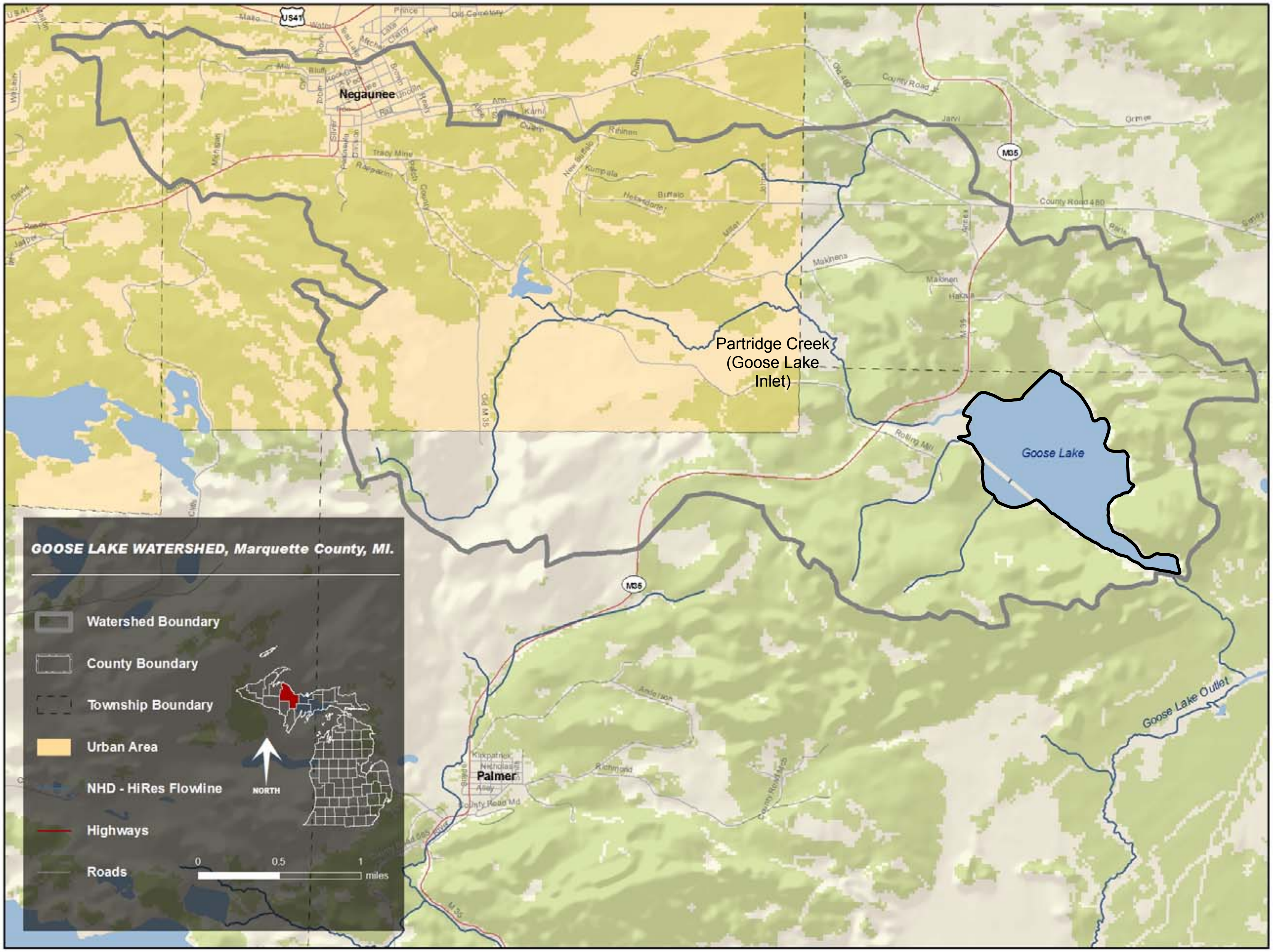

Figure 1. Goose Lake watershed.

ratio of nitrogen to phosphorus (N:P) can be used to determine which nutrient is more limiting (Downing and McCauley, 1992). Typically, an N:P ratio greater than 20 suggests that phosphorus may be the limiting nutrient, while a ratio less than 10 suggests nitrogen as the limiting nutrient (Wetzel, 2001). The summer N:P ratio in Goose Lake ranges from 12 to 15, which is in the range where it is not clear which nutrient is limiting. There is also some uncertainty in the scientific literature as to the scale that a single nutrient is limiting in lakes (Sterner, 2008).

This TMDL proposes a phosphorus reduction goal in Goose Lake to eliminate the nuisance algae blooms, fish kills, and odor problems. It has been documented in a 30-plus year study in an experimental lake in Canada that eutrophication of lakes cannot be controlled by reducing nitrogen inputs (Schindler, et al., 2008; Carpenter, 2008). Even though phosphorus is not clearly the limiting nutrient in Goose Lake using N:P ratios, reducing phosphorus concentrations in the lake is the only way to reduce plant productivity and ensure that the “other indigenous aquatic life and wildlife” designated use is fully supported.

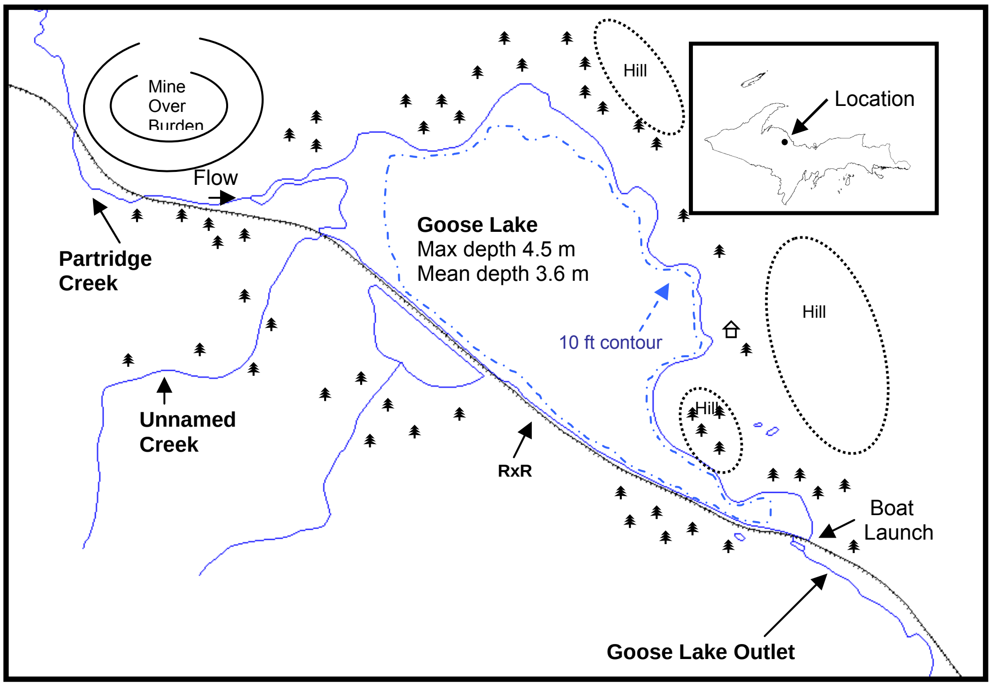

Figure 2. Goose Lake immediate vicinity.

NUMERIC TARGET

Rule 100 (R 323.1100) (Designated Uses) of the Part 4 rules, WQS, promulgated under Part 31, Water Resources Protection, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended, requires that Goose Lake be protected for warmwater fish, other indigenous aquatic life and wildlife, agriculture, navigation, industrial water supply, public water supply at the point of intake, partial body contact recreation, total body contact recreation from May 1 to October 31, and fish consumption. The impaired designated use for Goose Lake addressed by this TMDL is the “other indigenous aquatic life and wildlife” use (R 323.1100[1][e]), caused by nuisance blooms of algae (including *cyanobacteria*). Excess phosphorus can stimulate nuisance growths of algae and aquatic macrophytes that cause impairments to recreational uses such as swimming and boating (e.g., unsightly blooms from surface scum); that indirectly reduce oxygen concentrations to levels that cannot support a balanced fish or aquatic macroinvertebrate community (e.g., extreme day/night fluctuations in oxygen); and can shade out beneficial phytoplankton and aquatic macrophyte communities that are important food sources and habitat areas for fish and wildlife.

R 323.1060(2), Plant Nutrients, was developed to provide the authority to limit the addition of nutrients that are injurious to the designated uses listed above. Michigan does not have ambient numeric nutrient criteria for phosphorus within its WQS; however, the heavy blooms of algae are a violation of the narrative standard in subrule (2) of R 323.1060. Michigan's plant nutrient rule is as follows:

> R 323.1060 Plant nutrients.
> Rule 60. (1) Consistent with Great Lakes protection, phosphorus which is or may readily become available as a plant nutrient shall be controlled from point source discharges to achieve 1 milligram per liter of total phosphorus as a maximum monthly average effluent concentration unless other limits, either higher or lower, are deemed necessary and appropriate by the department.
> (2) In addition to the protection provided under subrule (1) of this rule, nutrients shall be limited to the extent necessary to prevent stimulation of growths of aquatic rooted, attached, suspended, and floating plants, fungi or bacteria which are or may become injurious to the designated uses of the surface waters of the state.

Nuisance algal blooms currently occur in Goose Lake during the summer period of July through September. Corresponding average summer phosphorus concentrations range from 0.076 to 0.113 milligrams per liter (mg/L) (averages are presented in Table 1 and raw data are included in Appendix A). Goose Lake has an average spring phosphorus concentration of 0.025 mg/L, which is very similar to the annual average inlet concentration from Partridge Creek (Goose Lake Inlet) of 0.027 mg/L. In the summer, Goose Lake total phosphorus concentrations average 0.089 mg/L.

Table 1. Goose Lake average phosphorus concentration by season and year. All units are mg/L. The average of all Goose Lake data is 0.06 mg/L. Cells without averages represent seasons and years when sampling did not occur. Data are averages of surface and bottom phosphorus concentrations on one date, except fall 2002, which is the average of two surface samples taken at two locations in the lake on one date.

	YEAR					
SEASON	2002	2003	2006	2007	2009	**Average**
Spring	--	0.037	0.016	0.024	--	**0.025**
Summer	--	0.076	0.081	0.113	0.086	**0.089**
Fall	0.049	--	--	--	--	**0.049**

A summer monthly average phosphorus numeric target concentration of 0.030 mg/L is recommended to meet WQS in Goose Lake. This target concentration will aid in reducing the sustained frequency and magnitude of nuisance algal blooms and reduce the chances of fish kills. Published literature has reported that the dominance of c*yanobacteria* in a lake tend to increase at phosphorus concentrations greater than 0.030 mg/L (Downing et al., 2001). In addition, 0.030 mg/L is considered a threshold between a more nutrient enriched eutrophic lake and a less nutrient enriched mesotrophic lake (Wetzel, 2001).

The numeric goal of 0.030 mg/L in Goose Lake was developed based on a weight-of-evidence approach that uses biological threshold information obtained from the literature and empirical modeling. The steps in this approach are: (1) determine a concentration target using a biological threshold and modeling framework; and (2) determine an allowable loading to meet the concentration target. The derivation and justification of the numeric targets for Goose Lake are described below.

Biological Thresholds and Modeling Framework

Numeric targets for nutrients can be developed for lakes by evaluating changes in biological responses (thresholds) along a nutrient gradient. These thresholds are levels above which major changes in lake biology occur due to a causal variable; in this case, phosphorus. Significant biological thresholds (e.g., secchi depth, chlorophyll *a* levels, phytoplankton/ zooplankton biomass, and fish community structure) have been found in lakes at phosphorus concentrations ranging from 0.008 to 0.06 mg/L (Soranno et al., 2008; Heiskary and Wilson, 2005). Thresholds from 0.008 to 0.021 mg/L can occur for water clarity and phytoplankton and zooplankton biomass. Thresholds from 0.03 to 0.06 mg/L can occur for severe algal blooms and the shift in a fishery to a rough fish dominated system (Downing et al., 2001; Heiskary and Wilson, 2005). These changes in specific biological responses can be used as surrogates for how biological integrity may change along a nutrient gradient (Soranno et al., 2008).

A biological thresholds and predictive modeling (BTPM) framework, developed by researchers from Michigan State University in consultation with the Department of Environmental Quality (DEQ), using input variables from a set of 374 Michigan lakes, was used by the DEQ to develop numeric targets for Goose Lake using the following steps:

1. Predict an expected natural phosphorus concentration for the lake.
2. Compare the expected natural phosphorus concentration to the biological thresholds and select an appropriate biological threshold.
3. Compare the selected biological threshold to current lake phosphorus concentrations. If current phosphorus concentrations exceed the threshold, establish the threshold as the concentration target.

The expected natural phosphorus concentration is determined using hydrogeomorphic land use features. For natural lakes (versus impoundments), mean depth (in meters), the proportion of geologic outwash, agriculture, and urban land use, as well as true color, are used in the model to predict the expected condition.

The equation to determine the expected natural phosphorus concentration is:

$$TP_N = [e^{(1.867 - 0.257(\ln a) - 0.202(b) + 0.344(\ln c))}] * (1.39)$$

Where:

TP_N = expected TP concentration for natural lakes in micrograms per liter
a = arithmetic mean lake depth in meters
b = proportion of outwash surficial geology within a 500 meter buffer around the lake
c = true color of lake in platinum - cobalt units measured as absorbance during the period July through September
ln = natural log
1.39 = level of allowance

The level of allowance represents model uncertainty in the prediction of the expected condition, and allows for some low or minimal level of human disturbance to the lake given present day land use patterns (Soranno et al., 2008).

The hydrogeomorphic land use features used for Goose Lake were as follows: mean depth (3.63 meters), proportion of geological outwash (0.0), and true color (70 platinum cobalt units). Based on these site-specific features, the expected natural phosphorus condition of Goose Lake is 0.028 mg/L.

The next step in the BTPM approach is to compare the expected natural phosphorus condition to biological thresholds and choose a threshold value. A threshold value is determined by choosing the first threshold along a phosphorus gradient that is greater than the expected natural phosphorus concentration (Soranno et al., 2008).

Given that the expected natural phosphorus concentration of the lake was estimated to be 0.028 mg/L, the threshold of importance to Goose Lake is 0.03 mg/L, since this is the first threshold greater than the expected natural phosphorus concentration (Figure 3). A concentration of 0.03 mg/L is a level above which severe summer blooms of cyanobacteria tend to occur. Choosing the next lowest threshold (0.018 mg/L) would not be appropriate since the natural expected condition for Goose Lake (0.028 mg/L) is greater, and the lake would not naturally be in this lower threshold range. Choosing a threshold value of 0.04 mg/L would allow the phosphorus concentration in the lake to increase to levels that might result in severe algal blooms during the summer.

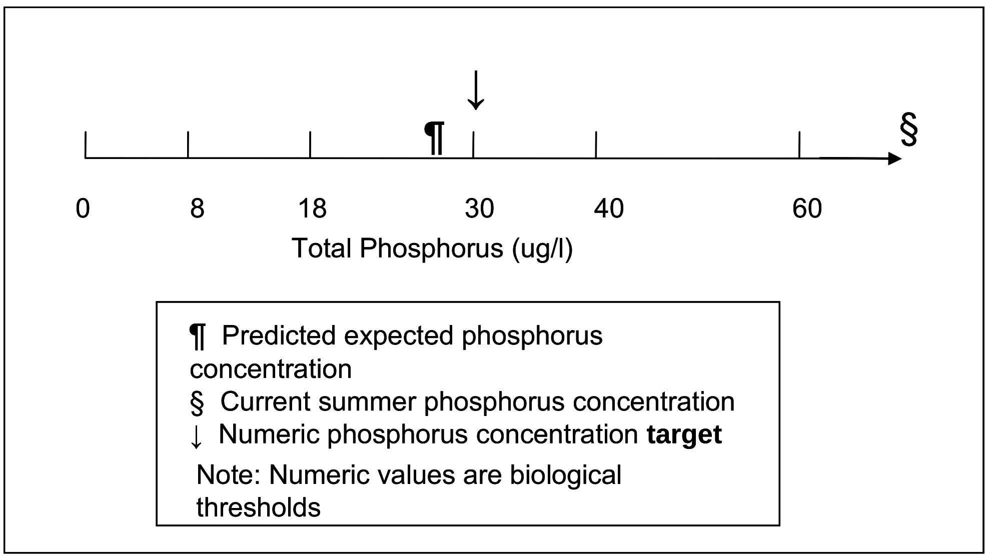

Figure 3. Determination of a phosphorus goal (arrow) for Goose Lake.

The final step in the BTPM approach is to compare the selected threshold with current lake phosphorus concentrations to select an appropriate target for the lake. Because the current concentrations are above the threshold, the threshold is the target. The DEQ used the thresholds in Figure 3 to determine a target phosphorus level for Goose Lake. Current concentrations of phosphorus in Goose Lake, using the data from the 2002, 2003, 2006, 2007, and 2009 sampling events, averaged 0.06 mg/L. The summer (samples collected in August and September) average phosphorus concentration in the lake is 0.089 mg/L. The annual average and summer phosphorus concentrations were calculated by averaging each concentration at all depths (Table 1). Since the existing phosphorus condition in Goose Lake is a summer average of 0.089 mg/L, which is greater than the threshold value of 0.03 mg/L, it was determined that existing phosphorus concentrations in the lake should be reduced to meet the numeric target level of 0.03 mg/L based on the BTPM approach. This value will ensure a restored biological integrity in Goose Lake.

This value is considered to be a level between a high-eutrophic (highly nutrient enriched) lake and a mesotrophic (moderately nutrient enriched) lake (Wetzel, 2001). Therefore, this numeric target is appropriate for restoring a balanced algal community to Goose Lake. The target of 0.03 mg/L will apply as a monthly average during the summer from July through September. The one fall sampling event in November showed the lake phosphorus concentration was 0.049 mg/L. It is expected that fall phosphorus concentrations will decrease to below the target value of 0.03 mg/L once the summer concentrations meet the TMDL goal. Therefore, the critical time period for making phosphorus reductions in Goose Lake is during the summer growing season when temperatures and algal growth are highest.

Allowable Loading Development

Empirical modeling was used to determine the allowable loading rate of phosphorus to Goose Lake given a target of 0.03 mg/L (Reckhow, 1978). The following steps outline how the model was used to develop the relationship between annual phosphorus loading and in-lake phosphorus concentrations, and how the target loading rate of phosphorus to Goose Lake was developed.

Step 1: Choosing the Model

Numerous lake models exist that describe the relationship between phosphorus loads and phosphorus concentrations, each with its own advantages, disadvantages, and limitations. The DEQ reviewed several lake models before choosing one to characterize the conditions in Goose Lake.

The Reckhow Anoxic lake model was chosen as the most appropriate model for predicting the phosphorus load necessary to meet the numeric target. There are no known significant biases associated with using this model. The model was considered to be a good fit, since Goose Lake becomes anoxic at intervals throughout the summer (Appendix A) and the water quality characteristics of the lake meet the model constraints. The Anoxic model is based on data from 21 northern temperate lakes. The known constraints (i.e., requirements) for this model include an average in-lake phosphorus concentration between 0.017 and 0.610 mg/L and an average influent phosphorus concentration between 0.024 and 0.621 mg/L. The average in-lake concentration for Goose Lake is 0.06 mg/L and the average influent concentration is 0.027 mg/L, both of which meet the model constraints.

Step 2: Calculating Target Loading

The following equation represents the Reckhow Anoxic model followed by site-specific variables of mean lake depth (meters) and hydraulic detention time (years):

$$P = \frac{Pa}{.17\ D_m + 1.13\ D_m/DT}$$

Where:

P = target in-lake phosphorus concentration (mg/L) = 0.03 mg/L
Pa = annual phosphorus loading (g/m^2/year)
DT = hydraulic detention time (years) = 0.65 years
D_m = mean lake depth (meters) = 3.63 meters

Rearranging the model allows one to predict the annual phosphorus load at a given in-lake phosphorus concentration. The annual load is the mass critical to attaining WQS, since for many lakes, the long-term inputs of phosphorus, rather than short-term inputs, are what contribute to overall lake productivity. The following equation represents the Reckhow Anoxic model followed by site-specific variables used to predict the target annual load at an in-lake numeric target concentration of 0.030 mg/L.

$$P_a = (P)(.17\ D_m + 1.13\ D_m/DT)$$

Where:

P = in-lake phosphorus concentration (mg/L) = 0.030 mg/L
P_a = annual phosphorus loading (g/m^2/year)
DT = hydraulic detention time (years) = 0.65 years
D_m = mean lake depth (meters) = 3.63 meters

The model predicts the goal of 0.030 mg/L can be obtained with a maximum annual phosphorus load of 0.208 g/m^2/year from all sources. Converting this load to pounds per year equates to an annual target load of 798 pounds per year. This is the load that is necessary to attain an in-lake phosphorus concentration of 0.03 mg/L during the summer in Goose Lake and attain designated uses.

DATA DISCUSSION

A fish kill and many reports of odor problems and algal blooms initiated the collection of data from Goose Lake and Partridge Creek (Goose Lake Inlet) in the fall of 2002. The 2002 sampling showed that Partridge Creek did not contribute a high load of phosphorus to the lake (Villa, 2003). In 2003, a more intensive sampling program sampled the two tributaries and the outlet twice per month and conducted two lake sampling events (spring and summer) (White Water Associates, 2004). The lake, inlet, and outlet were sampled in spring and summer in 2006 and 2007 and in summer in 2009.

Goose Lake phosphorus concentrations are low in the spring and much higher in the summer, averaging 0.025 and 0.089 mg/L, respectively (Table 1 and Figure 4). Along with the high total

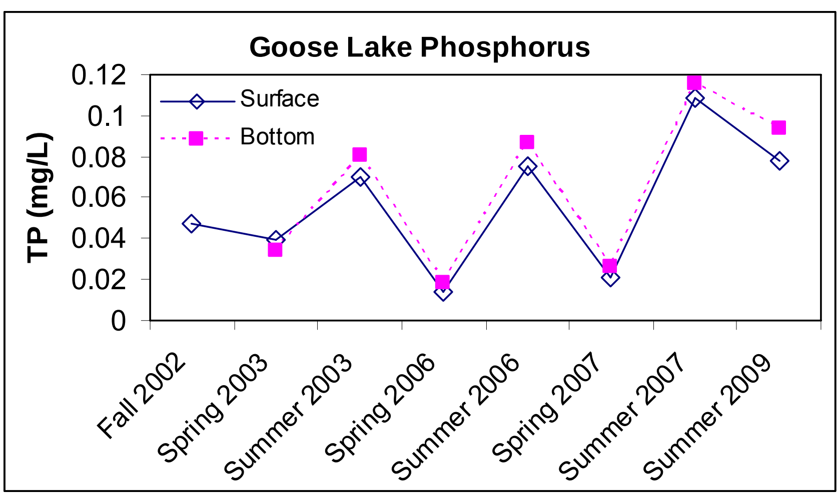

Figure 4. Goose Lake Phosphorus concentrations at the surface and bottom.

phosphorus concentrations, there are other indicators of nutrient-rich conditions. Chlorophyll *a* levels in the summer get up to 0.078 mg/L and average 0.045 mg/L, which is well above the average concentration of 0.014 mg/L often used to characterize eutrophic lakes (Wetzel, 2001). Summer secchi depths get as shallow as 1.9 feet, which is less than the average of 8 feet associated with eutrophic lakes (Wetzel, 2001).

Although the lake does not show evidence of having a strong thermal stratification during the summer, the bottom of the lake is often anoxic (all summer data from 2003, 2006, and 2007 show dissolved oxygen was below 2 mg/L). When the lake is not mixing, oxygen is depleted at the bottom of the lake and phosphorus releases from bottom sediments. Frequent mixing due to strong winds or storms then resuspends this phosphorus in the water column and adds nutrients for algal production. The phosphorus concentrations at the surface and bottom of the lake are typically similar (Figure 4), which also indicates that the lake mixes frequently.

Similar to Goose Lake, Partridge Creek and Goose Lake Outlet also have low concentrations of phosphorus in the spring, 0.02 and 0.027 mg/L, respectively (Table 2 and Appendix B). In the summer the phosphorus concentrations in Partridge Creek remain relatively low (averaging 0.034 mg/L), while the concentrations are much higher in Goose Lake Outlet (averaging 0.190 mg/L). The difference between the summer phosphorus concentrations in Partridge Creek and both Goose Lake Outlet (range from 0.065 to 0.53 mg/L) and Goose Lake indicates that there is a significant release of phosphorus from the sediments in Goose Lake.

Table 2. Goose Lake Inlet (Partridge Creek) and Goose Lake Outlet phosphorus concentrations by season and year. All units are mg/L. Except for 2003, each data point is based on one sample. In 2003, the data are averages of 2 to 6 samples. The average of all Partridge Creek data is 0.027 mg/L and the average of all Goose Lake Outlet data is 0.113 mg/L. Seasons are defined as: spring = May and June; summer = July, August, and September; fall = October and November.

		YEAR				
Location	**Season**	2002	2003	2006	2007	**Average**
Partridge Creek (Goose Lake Inlet)	Spring	--	0.021	0.019	0.016	0.020
	Summer	0.033	0.035	0.022	0.040	0.034
	Fall	0.014	0.025	--	--	0.021
Goose Lake Outlet	Spring	--	0.030	0.014	0.024	0.027
	Summer	--	0.224	0.073	0.102	0.190
	Fall	0.051	0.098	--	--	0.082

The Goose Lake Outlet samples were collected just downstream of the lake and should represent the phosphorus concentration in the lake. On the seven times when lake and outlet samples were collected on the same date, the two concentrations are very similar (Figure 5). These data indicate that the average 2003 summer phosphorus concentration in the lake may have been closer to 0.19 mg/L (which is the average of the 6 samples taken in July, August, and September), versus the 0.076 mg/L based on one lake sampling event in August.

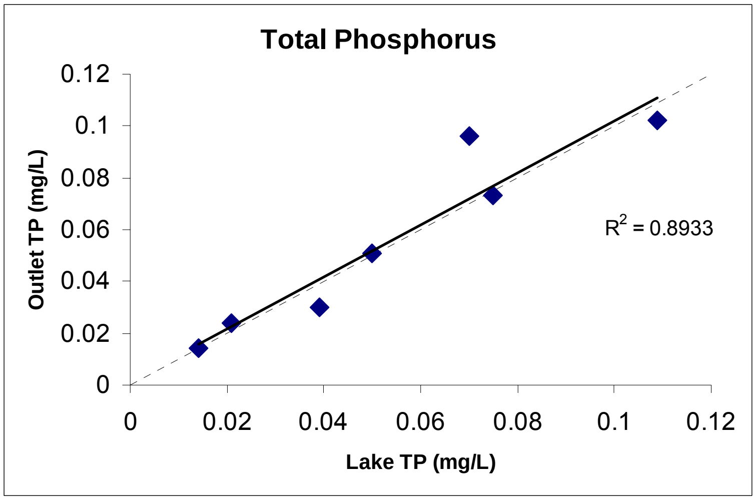

Figure 5. Goose Lake and Goose Lake Outlet phosphorus concentrations from the following sample dates: November 8, 2002; May 22, 2003; August 20, 2003; May 16, 2006; August 23, 2006; May 22, 2007; and August 29, 2007. The dashed line is a 1:1 line and the solid line is a trendline based on the paired data.

SOURCE ASSESSMENT

The Goose Lake watershed is approximately 9,384 acres. The geology includes rock outcrops and bedrock-controlled moraines. Soils are loamy and silty over either gravelly and sandy till or bedrock. The majority, 77 percent, of the watershed has natural land cover (forest and wetland) (Table 3 and Figure 6). There is a large amount (approximately 15 percent) of barren land in the watershed, mostly related to mining operations. The remaining land cover is made up of a small amount of agricultural use (0.5 percent) and urban uses (8 percent).

Table 3. Land use/cover in the Goose Lake watershed. Land use/cover layer: United States Geological Survey (USGS), 2000.

Percentage of Total	Landuse Category	Landuse Type	acres	Percentage of Total
76.8%	Natural	Deciduous Forest	3900.1	41.6%
		Evergreen Forest	194.2	2.1%
		Mixed Forest	1363.4	14.5%
		Scrub/Shrub	22.8	0.2%
		Grassland Herbaceous	113.7	1.2%
		Open Water	551.1	5.9%
		Woody Wetlands	1035.1	11.0%
		Emergent Herbaceous Wetlands	29.8	0.3%
14.6%	Barren	Barren Land	1369.1	14.6%
8.0%	Urban	Developed Open Space	380.9	4.1%
		Developed Low Intensity	195.7	2.1%
		Developed Medium Intensity	134.1	1.4%
		Developed High Intensity	44.5	0.5%
0.5%	Agricultural	Pasture/Hay	0.0	0.0%
		Cultivated Crops	49.1	0.5%
100%		**TOTAL**	**9383.6**	**100%**

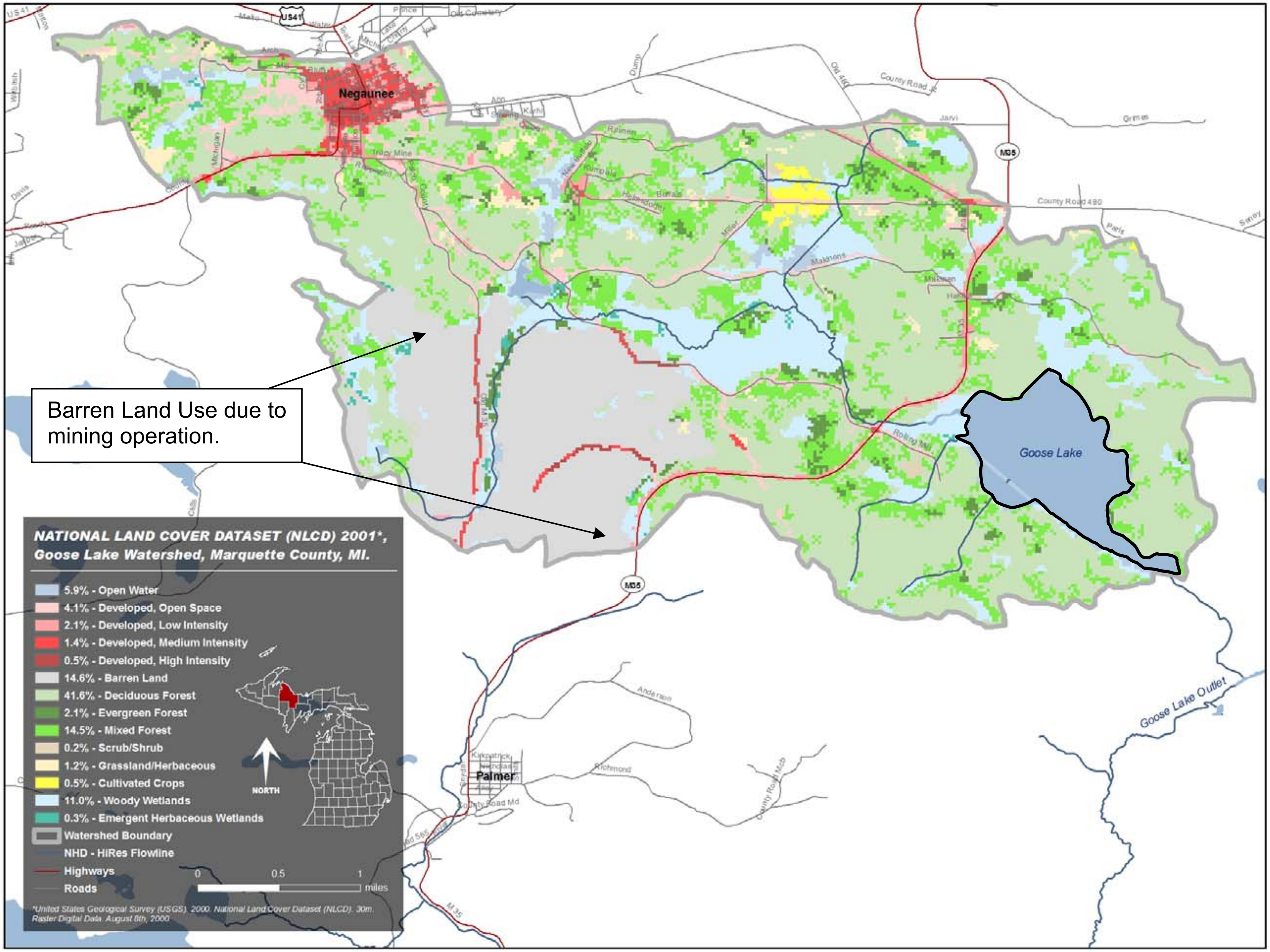

Figure 6. Land use in the Goose Lake watershed.

Phosphorus loadings to Goose Lake likely originate from external and internal sources; however, a large historic external load is still adding a large internal load of phosphorus to Goose Lake. In the early 20th century, the untreated sewage from the city of Negaunee was routed to Goose Lake through Partridge Creek. The DEQ has estimated that 20,000 pounds of total phosphorus entered the lake annually until the Negaunee Wastewater Treatment Facility was constructed in 1953 and the treated discharge was rerouted outside the Goose Lake watershed. Current external loadings are limited to natural land uses, urban land uses, storm water permits for state roads and closed mining operations, and one mine dewatering and storm water permit.

External Phosphorus Sources

The Long-Term Hydrologic Impact Assessment (L-THIA) Web-based software created and maintained by Purdue University and the USEPA (Purdue University and USEPA, 2001) was used to estimate phosphorus loads from the various land use types based on annual average runoff volumes. The L-THIA model uses the event mean concentration and curve number procedures to calculate annual pollutant loads based on land use, soil type, and meteorological data. There was a small discrepancy between watershed boundaries in L-THIA and the watershed boundary used by the DEQ (Lesmez, 2010), which accounted for less than 4 percent of the watershed area. The land use acreages from the 2000 USGS National Land Cover Dataset for the watershed delineated by the DEQ were manually entered into L-THIA to correct for this error in the watershed boundary.

National Pollutant Discharge Elimination System (NPDES) Permitted Sources

A review of Michigan's NPDES Management System (NMS, 2010) found four NPDES-permitted sources within the Goose Lake watershed. Two of the permits are individual permits: the Michigan Department of Transportation (MDOT) statewide Municipal Separate Storm Sewer System (MS4) - NPDES Permit No. MI00557364; and one outfall (outfall 003) from the Empire Iron Mining Partnership facility - NPDES Permit No. MI0000094. There are also two Certificates of Coverage (COCs) under the Industrial Storm Water General Permit (MIS210038 and MIS310524). There are no facilities covered under the Confined Animal Feeding Operation General Permit in the Goose Lake watershed.

The MDOT permit addresses less than 1 percent (approximately 59 acres) of the 9,384-acre Goose Lake watershed. A detailed estimation of the phosphorus load contribution from this source, which is assumed to be part of the residential land use category, can be found in the Loading Capacity (LC) section. The Empire Iron Mine is permitted to discharge a maximum of 17.3 million gallons per day (MGD) of treated mine dewatering water and an unspecified amount of storm water to Goose Lake Inlet (also referred to as Partridge Creek in this document), but based on available data from May 2003 to September 2010 the annual average flows range from 1 to 1.7 MGD.

Internal Loading

Internal loading estimates are difficult to quantify. For the development of this TMDL, we have determined that internal loading plays a significant role in the nuisance conditions of Goose Lake. Wind-induced mixing throughout the summer plays a role both (1) mixing phosphorus released from sediments during short-term anoxic periods (Nurnberg, 1984), and (2) in sediment resuspension of phosphorus to the water column from oxygenated sediments in shallow areas of the lake (Twinch and Peters, 1984).

LINKAGE ANALYSIS

Phosphorus can exist in dissolved and particulate forms. When dissolved, some of the phosphorus is available for use by aquatic plants and increased growth in rooted plants and floating algae can result. Phosphorus in the particulate form, such as that sorbed to eroding soil, can be released as dissolved phosphorus under certain conditions, contributing to increased plant growth. A reduction in phosphorus loadings to Goose Lake is expected to directly address the cause of designated use nonattainment, which is listed on the Section 303(d) list as total phosphorus and is expressed in nuisance algae blooms.

LC

The LC represents the maximum load of a pollutant (phosphorus in this case) that can be discharged to a water body and allow the water body to support the designated use and therefore meet WQS. The LC is the sum of individual point source waste load allocations (WLAs), including individual and general NPDES permitted facilities as well as load allocations (LAs), made up of the combined nonpoint source (NPS) and background sources. Uncertainty in the relationship between pollutant load and receiving water quality is accounted for by including a margin of safety (MOS) in the TMDL, either explicitly incorporated in the allocation calculations or implicitly integrated into other target areas. The equation representative of the LC is:

$$LC = \sum^{WLA} + \sum^{LA} + MOS$$

As described in the Numeric Target section, the LC for this TMDL is 798 pounds per year (2.18 pounds per day) based on a target goal of 0.03 mg/L (Table 4).

LA

The LA component of the TMDL defines the fraction of the LC originating from NPS. Estimates of all land use-related loads of total phosphorus to the Goose Lake watershed were estimated using the L-THIA model (Purdue University and USEPA, 2001). The L-THIA model has been developed as a straightforward analysis tool that provides estimates of changes in runoff, recharge, and NPS pollution resulting from past or proposed land use changes. It gives long-term average annual runoff for a land use configuration, based on actual long-term climate data for that area. By using many years of climate data in the analysis, L-THIA focuses on the average impact, rather than an extreme year or storm. L-THIA results do not predict what will happen in a specific year. As a quick and easy approach, L-THIA results are intended to provide insight into the relative hydrologic impacts of different land use scenarios. The results can be used to generate community awareness of potential long-term problems and to support physical planning aimed at minimizing disturbance of critical areas. It is a tool to assist in the evaluation of potential effects of land use change and to identify the best location of a particular land use for minimum impact on the natural environment of the area. Concern over urban sprawl has focused on several land use change issues, including the failure to account for hydrologic aspects of land use change that can result in flooding, stream degradation, erosion, and loss of groundwater supply. The L-THIA was developed to provide a quick, accessible tool to use in assessing the long-term impacts of land use change. This site suitability analysis tool makes use only of information that is readily available from municipal databases (Purdue University and USEPA, 2001).

Using the Midwest calibrated model, the L-THIA annual phosphorus loads estimated for natural land covers (forest, wetland, and grass/pasture) was 8 pounds (Table 4). An additional source of phosphorus to the lake includes the contribution from precipitation directly to Goose Lake.

The direct inputs from precipitation were estimated to be 22 pounds per year based on an annual precipitation of 31.9 inches (Michigan Department of Agriculture [MDA], 1989) falling directly onto the 430-acre lake surface at a concentration of 0.007 mg/L. The estimate of the concentration of phosphorus in precipitation was based on findings from a study in northern Wisconsin (Rose, 1993). No reductions from the forest, grass/pasture and wetland land covers, or precipitation loads are proposed for the LA.

Approximately 351 pounds of phosphorus per year are attributed to urban and agricultural land use/cover areas (Table 4). To achieve the numeric target of 0.03 mg/L in Goose Lake as a summer concentration, the LA from these sources is 236 pounds of phosphorus per year, which is approximately a 33 percent reduction in load. This reduction is expected to be attainable through the implementation of best management practices.

Table 4. Current annual and LC total phosphorus loads to Goose Lake.

Source	Current TP Load lbs P/year 2,438	Loading Capacity lbs P/year 798
WLA		
NPDES Individual Permits		
Industrial Wastewater		
MDOT Statewide MS4	24	16
Empire Iron Mining Partnership (MI0000094)	183	183
NPDES General Permits		
Industrial Storm Water Only	15	10
Lucy Mine-Negaunee (MIS310524)		
Tracy Mine-Negaunee (MIS210038)		
WLA Subtotal	**222**	**209**
LA		
Nonpoint Source Load		
Water/Wetlands	0	0
Commercial	203	136
Agricultural	25	17
High Density Residential	71	48
Low Density Residential	52	35
Grass/Pasture	0	0
Forest	8	8
Precipitation	22	22
Internal Load (Goose Lake sediments)	1835	243
LA Subtotal	**2,216**	**509**
MARGIN OF SAFETY		**80**

The primary source of phosphorus to Goose Lake is from the internal recycling of phosphorus from the sediment. The current internal load was estimated by calculating the difference between the Goose Lake Inlet and Goose Lake Outlet phosphorus concentrations and using the annual discharge rate from Goose Lake Outlet (10.96 cubic feet per second), which resulted in a current load of 1,835 pounds of phosphorus [[[[0.113 mg/L (average outlet concentration) – 0.027 mg/L (average inlet concentration)] * 10.96 ft^3/sec * 28.31685 L/ft^3 * 31,557,600 sec/yr] / 453592.4 mg/lbs (mg to lb conversion)] – 22 lbs (current precipitation loading) = 1,835 lbs TP/yr.] To meet the summer goal of 0.03 mg/L in Goose Lake, the internal load needs to be drastically reduced to 243 pounds per year. Because there is no longer a large external load to Goose Lake, the mass of available phosphorus currently stored in the sediments is gradually going down over time and the internal LA is expected to be achievable. However, this may take a very long time to occur naturally, possibly centuries.

WLA

The four NPDES permits in the Goose Lake watershed contribute loads of phosphorus to Goose Lake even though they do not have phosphorus monitoring or limitations in their permits. The current phosphorus load from the two industrial storm water COCs in the Goose Lake watershed is 15 pounds. These calculations were made using a geographic proportion of the mining land associated with these facilities compared to the total area of mining land use in the watershed. The WLA for the COCs was determined by reducing the existing load by approximately 33 percent (Table 4).

The existing annual load of phosphorus from the Empire Iron Mine is estimated to be 183 pounds based on discharge data from the outfall and corroborated with L-THIA modeled loads from the watershed. Although the facility is permitted to discharge a relatively high volume of water to Goose Lake Inlet (Partridge Creek), the long-term annual average discharge is much lower (ranging between 1 and 1.7 MGD from 2003 to 2010) and mining dewatering water is expected to have very low (between 0.01 and 0.02 mg/L) concentrations of phosphorus (NMS, 2010; DEQ, 2010). The current load from the Empire Iron Mine permit to Goose Lake was determined using conservative estimates of flow (3.0 MGD) and phosphorus concentration (0.02 mg/L). The WLA for the Empire Iron Mining Partnership is 183 pounds (Table 4).

Precipitation runoff from transportation areas is covered under the statewide MDOT MS4 permit. The MDOT owns and operates approximately 59 acres of transportation right-of-way in the Goose Lake watershed. This includes a 50-foot right-of-way on either side of the centerline of the road. A conservative estimate of the phosphorus load from this source is assumed to be 24 pounds (Table 4). This load is estimated assuming that half of the volume of precipitation that falls on the land area under the jurisdiction of the MS4 permit will run off to an impaired water body and have an average phosphorus concentration of 0.22 mg/L (Waschbusch et al., 1999). The state roads were included in the L-THIA modeled LA, so 24 pounds of phosphorus were taken away from the LA and allocated to the MDOT permit. The WLA for the MDOT MS4 permit is 16 pounds and was determined by reducing the current load by approximately 33 percent.

MOS

The MOS in a TMDL is used, in part, to account for variability in source inputs to the system, or lack of knowledge concerning the relationship between pollutant loading and water quality. The MOS can be either implicit (i.e., incorporated into the TMDL analysis through conservative assumptions) or explicit (i.e., expressed in the TMDL as a portion of the loadings). In this TMDL, an implicit MOS was used in developing the target loads for attaining WQS. The estimates of current watershed-based phosphorus loads, and the following LAs based on those estimates, were derived from the L-THIA model, which may overestimate nutrient loading. The nutrient loading aspects of the model use curve numbers that have been calibrated for small watersheds in the Midwest, but the specific area within the Midwest (Indiana) naturally has more enriched soil and therefore higher phosphorus loads than occur in Marquette County, Michigan. Also, loadings for larger watersheds (larger than a few square miles) may be overestimated in L-THIA because the curve numbers were developed using data from small (less than a few square miles) watersheds. However, because we do not know the scale of the overestimation of watershed-based phosphorus loading, we have also set aside 10 percent of the LC, equivalent to 80 pounds, within the MOS to ensure that the allocations in this TMDL are protective of Goose Lake.

SEASONALITY AND CRITICAL CONDITIONS

Concurrent with the selection of numeric targets, development of the LC requires identification of the critical conditions. The "critical condition" is the set of environmental conditions (e.g., flow) used in developing the TMDL that result in attaining WQS and has acceptable low frequency of occurrence. The critical conditions for Goose Lake are the elevated summer temperatures and nutrient loadings, which promote nuisance aquatic plant growth. The target goal of 0.03 mg/L phosphorus in this TMDL will apply during the months of July, August, and September. The concentration target, if achieved, is expected to restore designated uses by reducing the frequency and magnitude of nuisance algal blooms and fish kills and eliminate odor problems.

MONITORING

Occasional future monitoring of the Goose Lake Outlet will be conducted to assess whether conditions within the lake are improving. Summer monitoring of nutrient concentrations at the outlet of Goose Lake may be more feasible than open lake monitoring and show very similar phosphorus concentration compared to lake data. Because of the difficulty at reducing the current internal load to Goose Lake, frequent monitoring of the lake is likely not needed since improvements will be long-term. If any lake management activities are conducted on the lake (e.g., alum treatments or dredging), monitoring should be conducted on Goose Lake to document both the short-term and long-term in-lake response.

REASONABLE ASSURANCE ACTIVITIES

Because this TMDL does not require large reductions to the WLA or external load component of the LA, there are very few reasonable assurance activities that can be conducted in the Goose Lake watershed that will produce measurable improvements in lake water quality. Reducing the internal load of phosphorus to Goose Lake is not very practical. Dredging the lake might be successful in removing a mass of phosphorus from the lake sediment and therefore reducing internal loading, but it is costly and logistically difficult. Alum treatments are another option, but beyond cost, which is estimated at $400,000 per treatment, may not be successful in Goose Lake because it is so shallow and mixes frequently. The lack of riparian homes and land owners or a watershed association also makes any lake management practices unlikely in Goose Lake.

All of the NPDES permits contain TMDL-related language. The language in the Empire Iron Mining permit and the storm water general permit states that "the Stormwater Pollution Prevention Plan shall identify the level of control for those materials necessary to comply with the TMDL, and an estimate of the current annual load of those materials." The MDOT MS4 permit states that “[t]he permittee shall develop, implement and enforce storm water management programs designed to reduce the discharge of pollutants from the MDOT drainage systems in the state of Michigan to the Maximum Extent Practicable (MEP),” and that the MEP shall include “the development, implementation and enforcement of storm water controls designed to meet the permittee’s responsibilities established by the TMDL.” It is assumed that the implementation of currently available Best Management Practices will allow these facilities to meet their WLAs.

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APPENDIX A

Goose Lake water chemistry data. All data are in mg/L unless otherwise noted.

Year	Season	Date	Total Phosphorus	Total Kjeldahl Nitrogen	Nitrate + Nitrite	Total Nitrogen	TN:TP	Chlorphyll *a* (ug/L)	Secchi (ft)	Dissolved Oxygen	Depth
2002	Fall	11/8/2002	0.05	0.84	1.07	1.91	38		15		Surface
2002	Fall	11/8/2002	0.047	0.81	1.06	1.87	40		14		Surface
2003	Spring	5/22/2003	0.039	0.66	1	1.66	43	35	9		Surface
2003	Spring	5/22/2003	0.034	0.59	1	1.59	47			4.4	Bottom
2003	Summer	8/20/2003	0.07	0.95	0	0.95	14	20	3.9		Surface
2003	Summer	8/20/2003	0.081	1.05	0	1.05	13			0.1	Bottom
2006	Spring	5/16/2006	0.014	0.39	0.91	1.3	93				Surface
2006	Spring	5/16/2006	0.018	0.44	0.91	1.35	75			5.99	Bottom
2006	Summer	8/23/2006	0.075	1.15	0.001	1.151	15	63	1.9		Surface
2006	Summer	8/23/2006	0.087	1.26	0	1.26	14			0.5	Bottom
2007	Spring	5/22/2007	0.021	0.39	0.001	0.391	19	12			Surface
2007	Spring	5/22/2007	0.026	0.43	0.003	0.433	17			1.4	Bottom
2007	Summer	8/29/2007	0.109	1.42	0	1.42	13	78			Surface
2007	Summer	8/29/2007	0.116	1.45	0	1.45	13			1.6	Bottom
2009	Summer	9/1/2009	0.078	0.96	0	0.96	12	19			Surface
2009	Summer	9/1/2009	0.094	1.11	0.03	1.14	12				Bottom

APPENDIX B

Goose Lake Inlet (Partridge Creek) and Goose Lake Outlet water chemistry data. All data are in mg/L unless otherwise noted.

Date	Season	Location	Total Phosphorus	Total Kjeldahl Nitrogen	Nitrate + Nitrite	Total Nitrogen
9/1/2002	Summer	Goose Lake Inlet - Partridge Creek	0.033	0.576	7.13	7.706
11/8/2002	Fall	Goose Lake Inlet - Partridge Creek	0.014	0.45	6.5	6.95
5/21/2003	Spring	Goose Lake Inlet - Partridge Creek	0.013	--	--	3.05
5/29/2003	Spring	Goose Lake Inlet - Partridge Creek	0.026	--	--	3.71
6/9/2003	Spring	Goose Lake Inlet - Partridge Creek	0.018	--	--	3.6
6/24/2003	Spring	Goose Lake Inlet - Partridge Creek	0.026	--	--	4.86
7/8/2003	Summer	Goose Lake Inlet - Partridge Creek	0.032	--	--	4.84
7/24/2003	Summer	Goose Lake Inlet - Partridge Creek	0.031	--	--	4.32
8/6/2003	Summer	Goose Lake Inlet - Partridge Creek	0.029	--	--	5.9
8/20/2003	Summer	Goose Lake Inlet - Partridge Creek	0.03	--	--	4.94
9/2/2003	Summer	Goose Lake Inlet - Partridge Creek	0.061	--	--	5.06
9/23/2003	Summer	Goose Lake Inlet - Partridge Creek	0.029	--	--	3.62
10/8/2003	Fall	Goose Lake Inlet - Partridge Creek	0.021	--	--	4.5
10/31/2003	Fall	Goose Lake Inlet - Partridge Creek	0.029	--	--	4.43
5/16/2006	Spring	Goose Lake Inlet - Partridge Creek	0.019	0.53	2.3	2.83
8/23/2006	Summer	Goose Lake Inlet - Partridge Creek	0.022	0.45	2.2	2.65
5/22/2007	Spring	Goose Lake Inlet - Partridge Creek	0.016	0.37	1.94	2.31
8/29/2007	Summer	Goose Lake Inlet - Partridge Creek	0.04	0.74	2	2.74
11/8/2002	Fall	Goose Lake Outlet	0.051	0.88	1	1.88
5/21/2003	Spring	Goose Lake Outlet	0.03	--	--	1.71
5/29/2003	Spring	Goose Lake Outlet	0.024	--	--	1.46
6/9/2003	Spring	Goose Lake Outlet	0.021	--	--	1.34
6/24/2003	Spring	Goose Lake Outlet	0.046	--	--	1.3
7/8/2003	Summer	Goose Lake Outlet	0.065	--	--	0.8
7/24/2003	Summer	Goose Lake Outlet	0.24	--	--	2.7
8/6/2003	Summer	Goose Lake Outlet	0.27	--	--	3
8/20/2003	Summer	Goose Lake Outlet	0.096	--	--	1.42
9/2/2003	Summer	Goose Lake Outlet	0.53	--	--	6.2
9/23/2003	Summer	Goose Lake Outlet	0.144	--	--	2.02
10/8/2003	Fall	Goose Lake Outlet	0.065	--	--	0.98
10/31/2003	Fall	Goose Lake Outlet	0.131	--	--	0.79
5/16/2006	Spring	Goose Lake Outlet	0.014	0.41	0.84	1.25
8/23/2006	Summer	Goose Lake Outlet	0.073	1.34	0.003	1.343
5/22/2007	Spring	Goose Lake Outlet	0.024	0.4	0.001	0.401
8/29/2007	Summer	Goose Lake Outlet	0.102	0.39	0.77	1.16