Michigan Department of Environmental Quality
Water Bureau
August 2008

Total Phosphorus Total Maximum Daily Load for Morrison Lake Ionia 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) require 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 from point and nonpoint sources (NPS) to restore and maintain the quality of their water resources. This TMDL focuses on establishing reductions in external total phosphorus loads to Morrison Lake to achieve WQS. All references to phosphorus in the document are assumed to mean "total phosphorus" unless otherwise specified.

PROBLEM STATEMENT

Morrison Lake is on the 2006 and 2008 Section 303(d) lists (Edly and Wuycheck, 2006; LeSage and Smith, 2008) as follows:

2006 Listing:
Morrison Lake
WBID#: 082810Q
NHD RCH_Code: 04050006002395
Problem Summary: Nuisance algal blooms, phosphorus.
Size: 330 Acres
Location: South of US 96, due south of Saranac.
County: IONIA

2008 Listing:
Morrison Lake
AUID: 040500060311-03
Impaired Designated Uses: Warm water fish, other indigenous aquatic life and wildlife
Cause: Excess algal growth, elevated phosphorus
Size: 294 Acres

The area of Morrison Lake ranges from 294 acres (NHD, 2008) to 336 acres (MSU, 2005). For purposes of this TMDL, load estimates and allocations are based on 336 acres derived from a digitized, enlarged aerial photograph of Morrison Lake (MSU, 2005).

The molar ratio of nitrogen to phosphorus can be used to estimate the potential for phosphorus to limit primary productivity during the summer period (Downing and McCauley, 1992; Smith, 1982). Generally, a nitrogen to phosphorus (N:P) ratio greater than 15 to 20 suggests that phosphorus may be the limiting nutrient, while a ratio less than 15 suggests total nitrogen as the limiting nutrient (Wetzel, 1983). Phosphorus is the limiting nutrient requiring reduction in Morrison Lake based on N:P ratios of greater than 20 and as high as 75 during both the 1984-1985 and/or the 2006 nutrient budget studies (Wuycheck, 1987; Wuycheck, 2008 - *in preparation*).

BACKGROUND

Morrison Lake and its tributaries are located in portions of Boston, Campbell, and Berlin Townships, Ionia County and are designated as warm water fisheries (MDNR, 1997). The lake's mean depth is 12.8 feet (3.9 meters) with a maximum depth of 35 feet (10.7 meters) in the east basin (Table 1). The lake's central basin maximum depth is 15 to 20 feet (4.57 to 6.1 meters), which lessens to a maximum depth of 15 feet (4.57 meters) in the west basin (Figure 1). Morrison Lake has established legal lake levels, maintained with an outlet control structure, of 806 feet above sea level for the period November 1 through May 14 and 807 feet for the period May 15 through October 31 (Ionia County Circuit Court, 1961). Lake temperature profiles collected between 1974 and 1984 indicated that the east basin of the lake is dimictic (completely mixes from top to bottom during the spring and fall) and is normally thermally stratified during the summer and possibly winter (Wuycheck, 1987).

Morrison Lake has a 6,637-acre watershed dominated by 3,428 acres (52 percent) of agricultural-related land use (Table 2) (Purdue University, 2001). For purposes of developing the TMDL, agricultural land use includes such sources as golf course use, turf grass, and traditional farming practices in the Morrison Lake watershed. These activities are grouped together since it is assumed that they use fertilizers at similar rates and may share similar runoff characteristics. Grass/pasture, forest, and open water/wetland areas comprise 46 percent of the land use in the watershed with commercial and residential land uses comprising approximately 2 percent of the remaining watershed area. The residential and commercial facilities are serviced by a lake-wide sanitary sewer collection system installed in 1980 that directs wastewater away from the lake to the Clarksville Wastewater Sewage Lagoon (WWSL) facility located outside the lake watershed. The WWSL discharges treated wastewater to Lake Creek about one mile downstream of its origin at Morrison Lake.

Five tributaries drain into Morrison Lake from the surrounding watersheds. Two prominent tributaries are Leary Drain that enters the lake from the east, and Stuart Green Drain that enters from the south central shoreline (Figure 3). A 97-acre (0.4 square kilometers) public golf course is located about 1,800 feet upstream from the confluence of Leary Drain and Morrison Lake, immediately west of Leary Drain and southwest of the intersection of Portland and Jackson Roads. The Stuart Green Drain flows north through a turf farm in its upper reaches, in the vicinity of Clarksville Road, thence through a wetland complex to Morrison Lake. One of the three remaining, unnamed, minor tributaries enters the lake on the east end just south of the Leary Drain confluence and the other two enter near the southwest corner of the lake. Lake Creek, a Michigan Department of Natural Resources (MDNR) (1997) designated cold water stream, originates at the Morrison lake outlet near the northeast end of the lake. The stream flows north about six miles to the Grand River near the community of Saranac.

Chemical treatments have been implemented for years in Morrison Lake to address nuisance aquatic plant growths, such as cyanobacteria (blue green algae) blooms and extensive growths of exotic, non-native and invasive rooted aquatic macrophytes such as Eurasian milfoil and curly leafed pond weed. Treatments have included the use of chemicals (e.g., copper sulfate, chelated copper, Shade, Sonar, Renovate, Cygnet Plus, 2,4-D, Hydrothol, fluridone) to eliminate growths of aquatic macrophytes and algae, and alum to remove phosphorus from the water column and bind phosphorus released from the sediment (MDEQ, 2004-2008).

Lake sediments, both aerobic (oxygenated) and anaerobic (deoxygenated), serve as internal sources of phosphorus that influence lake nutrient budgets (Jacoby et al., 1982; Twinch and Peters, 1984; and Nurnberg, 1984). These internal loads, originating from phosphorus in sediment deposits in both aerobic and anaerobic conditions, can increase eutrophication of a lake.

The lake's east basin and a portion of the central basin were treated with alum in 1988, which was effective in controlling internal (i.e., sediment-released) loads of phosphorus during the first year or two. The lake, soon thereafter, reverted back to its original condition and exhibited nuisance algal blooms (Progressive, 1996). In early May 2008, Morrison Lake received a lake-wide alum treatment to reduce in-lake concentrations of phosphorus during the spring lake turnover period and reduce the release of phosphorus from lake sediments.

Chemical treatments are effective at eliminating or reducing the effects of phosphorus enrichment; however, the effects are temporary and can have negative impacts on a lake's fishery either due to direct toxicity impacts of applied chemicals or reduction of fisheries habitat that is provided by a balanced native aquatic vegetation community.

A nutrient budget study of Morrison Lake was conducted by MDNR staff from March 1984 to February 1985 in response to citizen complaints about nuisance algal blooms and periodic fish kills (Wuycheck, 1987). Results from this study as well as periodic monitoring of the lake from 1974 through 1983 by the MDNR indicated elevated spring and fall turnover concentrations of phosphorus in the east basin. Mean spring turnover phosphorus concentrations (calculated using surface and bottom samples at a minimum, and mid-depth where collected) were 0.053 (April 1978), 0.051 (April 1982), 0.064 (April 1983), and 0.056 (May 1984) milligrams per liter (mg/L) (or parts per million) (Table 3). The overall mean spring turnover concentration of phosphorus in the east basin was 0.056 mg/L. A single mean fall turnover phosphorus concentration of 0.066 mg/L was measured in November 1984. Elevated phosphorus concentrations during the spring and fall turnover periods were likely the result of the mixing of phosphorus-rich hypolimnetic water that develops in the anoxic water layer overlying the sediments during periods of stratification with the overlying water column. Additional phosphorus contributions may include leaching from oxygenated sediments in unstratified areas of the lake, external inputs, and agitation of lake sediments by wind/wave/boating actions.

The conclusions and observations from the 1984-1985 study were that Morrison Lake was upper eutrophic to hypereutrophic, experienced frequent, sustained nuisance algal blooms, and experienced hypolimnetic dissolved oxygen depletion during the summer growing season that contributed to sediment phosphorus release to the water column in late summer and early fall. The study characterized the sources of phosphorus as both external and internal. External sources included inputs from the watershed tributaries, the immediate lake shoreline runoff, and precipitation that directly falls on the lake surface. Lake sediments were defined as the internal source of phosphorus to the system. Phosphorus load reductions were developed and recommended to restore designated uses and meet WQS (Wuycheck, 1987).

A reassessment of the 1984-1985 Morrison Lake nutrient budget was conducted by Michigan Department of Environmental Quality (MDEQ) staff from April through November 2006. The study involved monthly sampling of water quality conditions in the tributaries, east basin of the lake, and the lake outlet (Wuycheck, 2008 - in preparation).

Multiple indicators of nutrient-rich conditions were identified during the 2006 study. Secchi disk transparency average readings were less than 55 inches (4.6 feet). Wetzel (1983) identifies a mean of 96 inches (8 feet) and less to characterize nutrient-rich (eutrophic) lakes. Chlorophyll *a*, used to characterize the relative instantaneous abundance and densities of algal populations (primary productivity), for the June through September summer growing season, averaged 0.031 mg/L. This concentration is well above the average concentration of 0.014 mg/L often used to characterize eutrophic lakes (Wetzel, 1983).

Dissolved oxygen concentrations were depleted in the hypolimnion of the east basin during the summer thermal stratification months of May through September, and to some degree, in October 2006 (Table 4). The production of hydrogen sulfide odors associated with water samples collected below a depth of approximately 20 feet were evident throughout the summer months indicating deoxygenated/reduced conditions in the deeper water layers, a condition conducive to phosphorus release from the sediments. This condition was obvious in the May through August profiles that showed elevated phosphorus concentrations in the hypolimnetic samples as compared to surface (epilimnion) samples (Table 4).

Based on the oxygen depleted conditions in the east basin during stratification and the expected relative increased phosphorus loading rate as compared to the remainder of the lake, the focus of the 2006 monitoring to assess lake phosphorus conditions was on the east basin. The mean 2006 spring (April) and fall (September/October) turnover phosphorus concentrations (average of the surface, mid-depth, and outlet samples) were 0.028 mg/L and 0.073 mg/L, respectively (Table 4). The spring 2006 average concentration was substantially less than previously assessed spring turnover values ranging from 0.051 to 0.064 mg/L between 1974 and 1984 (Table 3) (Wuycheck, 1987) either due to a trend of reduced loadings or reduced loadings the previous year. The increase in the average fall phosphorus concentration (0.073 mg/l) versus the average spring turnover concentration (0.028 mg/L) is likely attributable to hypolimnetic build-up during the summer and resuspension during fall turnover.

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, (NREPA), requires that Morrison Lake be protected for warm water 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 uses for Morrison Lake addressed by this TMDL are the “other indigenous aquatic life and wildlife” and “warm water fisheries” uses (R 323.1100(1)(e)), caused by nuisance blooms of *cyanobacteria* and nuisance growths of aquatic macrophytes (vascular plants). Excess phosphorus can stimulate nuisance growths of *cyanobacteria* and aquatic macrophytes that also cause impairments to recreational uses such as swimming and boating (e.g., unsightly blooms form surface scum); that indirectly reduce oxygen concentrations to levels that cannot support a balanced fish or aquatic macroinvertebrate community (e.g., extreme day/night time fluctuations in oxygen); and can shade out beneficial phytoplankton (algal) 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 *cyanobacteria* and nuisance growths of aquatic macrophytes 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 Morrison Lake during the summer period of July through September. Corresponding phosphorus concentrations during this period ranged from 0.040 to 0.95 mg/L in the east basin from surface to bottom depths (Table 4). The average spring turnover in April was measured at 0.028 mg/L and fall turnover in September/October (based on measurement of surface, mid-depth and outlet samples) was 0.073 mg/L. Spring and fall turnover average phosphorus numeric target concentrations of 0.030 mg/L are recommended to meet WQS in Morrison Lake. This target concentration will aid in reducing the sustained frequency and magnitude of the occurrence of nuisance algal blooms. Published literature has reported that the dominance of c*yanobacteria* in a lake tend to increase at phosphorus concentrations greater than 0.030 (Downing et al., 1992). In addition, 0.030 mg/L is considered a threshold between a less nutrient enriched eutrophic lake and a more nutrient enriched mesotrophic lake (Wetzel, 1983).

Data from the April 2006 spring turnover sampling period indicate that the target was being met during this time period. However, the 2006 sampling period was characterized as being a dryer than normal year and data from previous years indicate the spring target historically has not been met (Table 3). Future monitoring should be used to verify if the spring turnover period meets the target value of 0.030 mg/L over a sustained period of time and under various flow regimes.

SOURCE ASSESSMENT

Land Use/Land Cover

The majority of soils in the watershed are moderately fertile and have a loamy surface layer and clay loam or sandy clay loam subsoil (Progressive, 1996). The largest land use category in the watershed is agricultural (Table 2). Natural covers such as grass and pasture, forest, and open water and wetland constitute the second largest land use, with urban land areas such as commercial and residential land comprising the third highest land use category.

Phosphorus loadings to Morrison Lake likely originate from external and internal sources. Internal loading estimates are difficult to quantify and can only accurately be measured using aerobic and anaerobic bioassay measurements. For the development of this TMDL, we acknowledge that internal loading may play a significant role in the nuisance conditions of Morrison Lake. However, without conducting bioassay sediment studies of the lake sediments to accurately calculate the phosphorus release rate from the sediments, an internal loading of phosphorus from this source will not be included in the development of the TMDL at this time. Future monitoring of the lake sediments is prudent in order to quantify an internal loading of phosphorus from lake sediments. Wind-induced mixing may also play a role in sediment resuspension of phosphorus to the water column from oxygenated sediments in shallow areas of the lake. Ultimately, external sources of phosphorus will need to be reduced before internal source reductions can be realized.

All external sources of phosphorus entering the lake were characterized on an annual scale (pounds of phosphorus per year). Development of these loadings is explained as follows:

External Loadings

External loadings include those from tributaries, precipitation, and runoff from the immediate area surrounding the lake. The external loading of phosphorus to Morrison Lake was estimated using the following sources of information:

- The calculated acreage of each major land use category based on the Long-Term Hydrologic Impact Analysis (L-THIA) model (Purdue University and USEPA, 2001).

- The average annual runoff volumes and NPS losses of phosphorus using the L-THIA model (Purdue University and USEPA, 2001).

- Hydrological and flow information developed by the MDEQ, Land and Water Management Division, Hydrological Studies Unit.

- Water chemistry data collected by the MDEQ in 2006 (Wuycheck, 2008 - in preparation).

The Morrison Lake watershed (minus Morrison Lake) encompasses 6,637 acres. The area draining Leary Drain is 3,086 acres and contributes 49.4 percent of the phosphorus load to Morrison Lake (Table 5). Stuart Green Drain encompasses 1,947 acres and contributes 28.6 percent of the phosphorus loading to the lake. The remaining 1,604 acres of the lake watershed are comprised of three unnamed tributary watersheds (i.e., 744 acres, 8.8 percent), and the area immediately surrounding the lake (i.e., 860 acres, 2.4 percent). The remaining phosphorus (10.8 percent) is contributed by sources of precipitation falling directly onto Morrison Lake.

The external loading determination was broken into the following categories (Figure 2):

a. Leary Drain watershed (3,086 acres)
b. Stuart Green Drain watershed (1,947 acres)
c. Unnamed tributary to Morrison Lake at Brooks Landing (392 acres)
d. Unnamed tributary to Morrison Lake at Darby Road (187 acres)
e. Unnamed tributary to Morrison Lake at Dausman Road (165 acres)
f. Immediate Drainage of Morrison Lake watershed (e.g., total watershed minus tributaries) (860 acres)
g. Precipitation

The external loads were developed assuming that 100 percent of the phosphorus loadings from the tributaries, precipitation, and the immediate area of the lake would reach Morrison Lake and be available for algal uptake.

Calculation of Phosphorus Loadings

Leary Drain, Stuart Green Drain and Unnamed Tributary Watersheds, and Immediate Drainage Area of Morrison Lake

The L-THIA model was used to estimate land use type acreage and determine an estimated phosphorus load from the various land use types based on annual average runoff volumes from the tributary watersheds, and the immediate drainage area of Morrison Lake (Tables 6-9) (Purdue University and USEPA, 2001). 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. A percent phosphorus load contribution for each land use type was calculated by dividing the L-THIA phosphorus load estimate per land use by the total load for all land use types in a particular watershed (Table 7). For example, by dividing the L-THIA load estimate for commercial land use in the Leary Drain watershed (41 pounds) by the total load estimated by L-THIA for all land use types in that watershed (1,548 pounds), commercial land uses were estimated to contribute 2.6 percent of the phosphorus load to Morrison Lake (Table 7).

Using phosphorus concentrations collected in 2006, and estimated flow data (Lesmez, 2008), actual phosphorus loads from the Leary Drain and Stuart Green Drain watersheds (versus the estimated loads determined by L-THIA) were calculated using mean monthly flows and phosphorus concentrations when available (Appendix A). The load contribution of phosphorus from Leary Drain and Stuart Green Drain, specific to each land use type, was determined by multiplying the percent contribution of each land use (calculated using L-THIA [Table 7]) by the total external phosphorus load (calculated using measured data [Table 5]) entering the lake from these two tributaries (Table 8). For example, the commercial land use type in the Leary Drain watershed contributes 2.6 percent of the phosphorus load to the lake. Multiplying the external load of 454 pounds of phosphorus entering from Leary Drain by 2.6 percent results in a phosphorus load contribution by the commercial land use type of 11.8 pounds per year. The sum of the monthly loads of phosphorus into Morrison Lake from these two tributaries was estimated to be 717 pounds per year.

Suitable phosphorus concentration data could not be collected from the unnamed tributaries and the immediate drainage surrounding the lake in 2006. Therefore, phosphorus loads from these areas were estimated as follows: The measured phosphorus loads for Leary Drain and Stuart Green Drain were 3.41 and 1.96 times, respectively, lower than the phosphorus loads estimated using L-THIA (Table 9). Therefore, the phosphorus loads from the unnamed tributaries and immediate drainage area were estimated by reducing the L-THIA estimated loads for these areas (Table 7) by 2.68 times (the average difference for the Leary Drain and Stuart Green Drain, i.e., 3.41 + 1.96 = 5.37/2 = 2.68) (Table 9).

Precipitation

An additional source of phosphorus to the lake includes the contribution from precipitation. The direct inputs from precipitation are difficult to quantify, but were estimated to contribute 99 pounds of phosphorus directly to the lake on an annual basis. A phosphorus load estimate of 99 pounds was based on an annual total of 31.6 inches precipitation (December 2005 through November 2006) falling directly onto the 336 acre (1,359,792 m2) lake surface at an annual precipitation phosphorus load rate of 0.297 pounds/acre/year. The precipitation estimate was based on findings for a study of Gull Lake in Kalamazoo County, Michigan (Tague, 1977) and details can be found in Appendix A.

NPDES Permitted Sources

A review of Michigan's National Pollutant Discharge Elimination System (NPDES) permit Management System (NMS, 2008) indicates one NPDES-permitted source within the Morrison Lake watershed, the Michigan Department of Transportation (MDOT) statewide Municipal Separate Storm Sewer System (MS4 - NPDES - MI00557364). This permit addresses less than one percent (approximately 50 acres) of the 6,637 acre Morrison Lake watershed area. A detailed estimation of the phosphorus load contribution from this source, which is assumed to be part of the commercial land use category, can be found in the *Load Capacity* section.

<u>External Loading Summary</u>

The current annual external phosphorus load to the lake is estimated to be 919 pounds per year (0.307 g/m^2/year) from external sources that include tributary watershed, precipitation, and the area immediately surrounding the lake (Table 5).

Allowable Loading Development

Empirical modeling was used to determine the allowable loading rate of phosphorus to Morrison Lake given a target of 0.030 mg/L (Reckhow, 1977). 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 Morrison Lake was developed:

Step 1: Choosing the Model

Numerous lake models exist that describe the relationship between phosphorus loads and phosphorus concentrations. The MDEQ reviewed several lake models before choosing one to characterize the conditions in Morrison Lake (Table 11). The Reckhow Anoxic 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 at least a portion of Morrison Lake becomes anoxic 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 range of in-lake concentrations for Morrison Lake is 0.025 to 0.072 mg/L and the range of influent concentrations is 0.038 to 0.162 mg/L, both of which meet the model constraints.

The model predicted an in-lake phosphorus concentration of 0.056 mg/L using a current annual loading rate (including external sources) of 919 pounds per year (0.307 g/m^2/yr) (see *Source Assessment, Calculation of Phosphorus Loadings* for description of annual loading rate). This predicted concentration is less than the measured concentration of 0.073 mg/L fall turnover value; however, the Reckhow Anoxic model produced the closest estimated fall turnover concentration of the models evaluated (Table 11). The difference between the measured and predicted values is likely due to the internal loading of phosphorus, which is not completely addressed by the Reckhow Anoxic model. Therefore, the Reckhow Anoxic model was suggested to be the appropriate predictive tool to calculate the load of phosphorus necessary to attain the target phosphorus concentration of 0.03 mg/L.

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) = 0.92 years
D_m = mean lake depth (meters) = 3.94 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) = 0.92 years
D_m = mean lake depth (meters) = 3.94 meters

The model predicts the goal of 0.030 mg/L can be obtained with a maximum annual phosphorus load of 0.165 g/m^2/year from all sources. Converting this load to pounds per year equates to an annual target load of 495 pounds per year. This is the load that is necessary to attain an in-lake phosphorus concentration of 0.03 mg/L during the spring and fall overturn periods in Morrison Lake and attain designated uses.

LOAD CAPACITY DEVELOPMENT

The Morrison Lake phosphorus TMDL defines an allowable phosphorus load to meet WQS. The TMDL goal establishes a phosphorus load reduction of external loads, recognizing that a reduction of the internal load is also necessary to achieve a spring and fall turnover average phosphorus concentration of 0.030 mg/L.

Concurrent with the selection of numeric targets, development of the load capacity (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 Morrison 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 April (spring) and October (fall). Spring and fall phosphorus turnover concentrations are a good predictor and a reflection, respectively, of summer nutrient concentrations. The concentration target, if achieved, is expected to restore designated uses by reducing the frequency and magnitude of nuisance algal blooms, and improving water clarity.

LOAD CAPACITY

The LC represents the maximum load of a pollutant (phosphorus in this case) that can be discharged to a water body and still 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 (LA) made up of the combined 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 495 pounds per year (1.36 pounds per day) based on a target goal of 0.03 mg/L (Table 10).

WLA

Queries of the MDEQ NMS database resulted in one NPDES permit, the MDOT statewide MS4 permit. There are no individual industrial storm water permits or construction site Notice of Coverage permits in the Morrison Lake watershed. In addition, there are no Concentrated Animal Feeding Operation (CAFO) permits.

The Morrison Lake watershed area of 6,637 acres includes approximately 50 acres, or 0.7 percent, of MDOT Right-of-Way associated with Interstate 96 (located in the upper watershed), which is covered by the MDOT MS4 NPDES storm water permit (MI00557364). The phosphorus load contribution from this source was determined to be 0.7 percent, or 0.09 pound per year, of phosphorus from the commercial land use type in the Morrison Lake watershed (total commercial load = 12.92 pounds phosphorus per year). Because this source of phosphorus is relatively insignificant, no load reductions are proposed (Table 10).

Load Allocation

The LA component of the TMDL defines the fraction of the LC for phosphorus from NPS including the following: forest, grass/pasture, water/wetlands, agriculture, residential, commercial (minus the WLA), and precipitation. An estimated current annual load of 100 pounds per year is attributed to runoff from forest, grass/pasture, water/wetlands, and precipitation (Table 10). No reductions from the forest, grass/pasture and water/wetland land uses, or precipitation are proposed because the expected concentrations of phosphorus are less than the 0.03 mg/L numeric phosphorus target for the lake (Purdue University and USEPA, 2001).

Approximately 818 pounds per year is attributable to residential, commercial, and agricultural land use areas (Table 10). To achieve the numeric target of 0.03 mg/L in Morrison Lake as a spring and fall overturn concentration, a reduction of 538 pounds of phosphorus per year from these LA sources is necessary.

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 explicit MOS was used in developing the target loads for attaining WQS. An explicit MOS of ten percent was included to account for the uncertainty used in developing the external loads of phosphorus to Morrison Lake. This MOS of 23 percent is a percentage over the predicted in-lake phosphorus concentration (0.056 mg/L) using the Reckhow Anoxic model (Reckhow, 1977) from the actual in-lake phosphorus concentration during fall turnover (0.073 mg/L).

The MOS was calculated as follows:

MOS = 0.23 x (495 pounds per year) = 113.85 or 114 pounds per year

SEASONALITY

The critical season for expression of nutrient concerns in Morrison Lake is summer when nuisance algal blooms have been reported and observed. Meeting a spring and fall turnover goal of 0.03 mg/L, with its associated annual load of 495 pounds per year, should ensure Morrison Lake meets WQS the entire year.

MONITORING PLAN

An MDEQ-authorized lake-wide alum treatment of Morrison Lake was conducted in Morrison Lake in early May 2008 to suppress internal phosphorus loadings to the lake. The MDEQ Certificate of Approval for the project required the Morrison Lake Improvement Board to submit an approvable work plan for the project prior to the alum application that includes monitoring before and subsequent to (twice annually for five years) the alum application for various water chemistry parameters, including temperature, phosphorus, pH, and dissolved oxygen.

Following the implementation of any necessary NPS best management practices (BMPs) and other control measures in the watershed, the MDEQ will conduct periodic monitoring of Morrison Lake to assess progress toward meeting the TMDL goal. Sampling of Morrison Lake will initially be conducted annually in April, September, and October to evaluate the spring and fall overturn phosphorus concentrations. Assessments and BMP implementation will continue until results from two consecutive years demonstrate attainment of the 0.030 mg/L fall turnover goal.

REASONABLE ASSURANCE

In 1987, the Ionia County Soil Conservation District received a Clean Lakes Program Phase I planning grant from the USEPA to develop a watershed management plan, which included identification and prioritization of NPS of phosphorus, identification of BMPs, and development of a watershed management plan. In 1988, the Ionia County Soil and Water Conservation

District submitted the Morrison Lake watershed management plan in its application for a USEPA Clean Lakes Program Phase II implementation grant and received state and federal funds to initiate the implementation phase. The goal of the plan was to provide information/education; technical assistance; and cost-shares to individual land owners to promote voluntary use of BMPs such as filter strips, livestock exclusion fencing, alternate water sources for livestock, animal waste facilities, stream bank protection, and erosion control (Ionia County Soil and Water Conservation District, 1990).

Funds were appropriated to the Morrison Lake Improvement Board and Ionia Soil and Water Conservation District in 1988 by the MDNR for Morrison Lake improvements. The Clean Lakes Program was established in 1972 to provide financial and technical assistance to states in restoring publicly-owned lakes. Funds provided to the Morrison Lake Improvement Board were used in 1988 for water quality monitoring and an alum treatment to reduce sediment phosphorus levels (Progressive, 1996).

Many agricultural-related BMPs have been completed in the watershed and primarily consist of animal exclusion fencing in pasture and animal access areas adjacent to the watershed tributaries, reduced use of phosphorus containing fertilizers, and increased vegetative buffer zones. In addition, a wetland in the lower reach of Leary Drain in the vicinity of the golf course was constructed by the Ionia County Drain Commission to improve Leary Drain water quality prior to its discharge to Morrison Lake.

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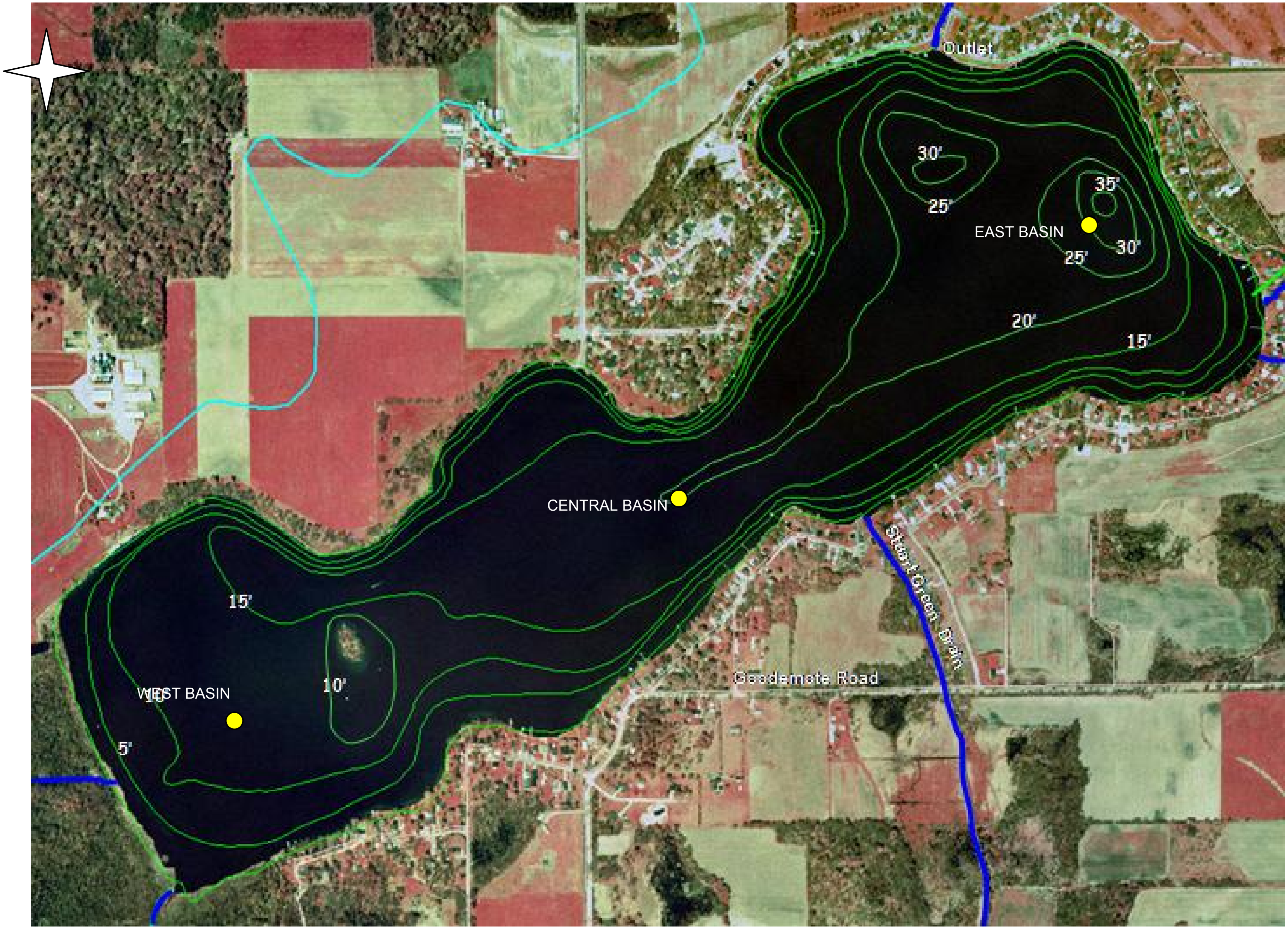

Figure 1. Morrison Lake contours, depth as feet, Ionia County, Michigan.

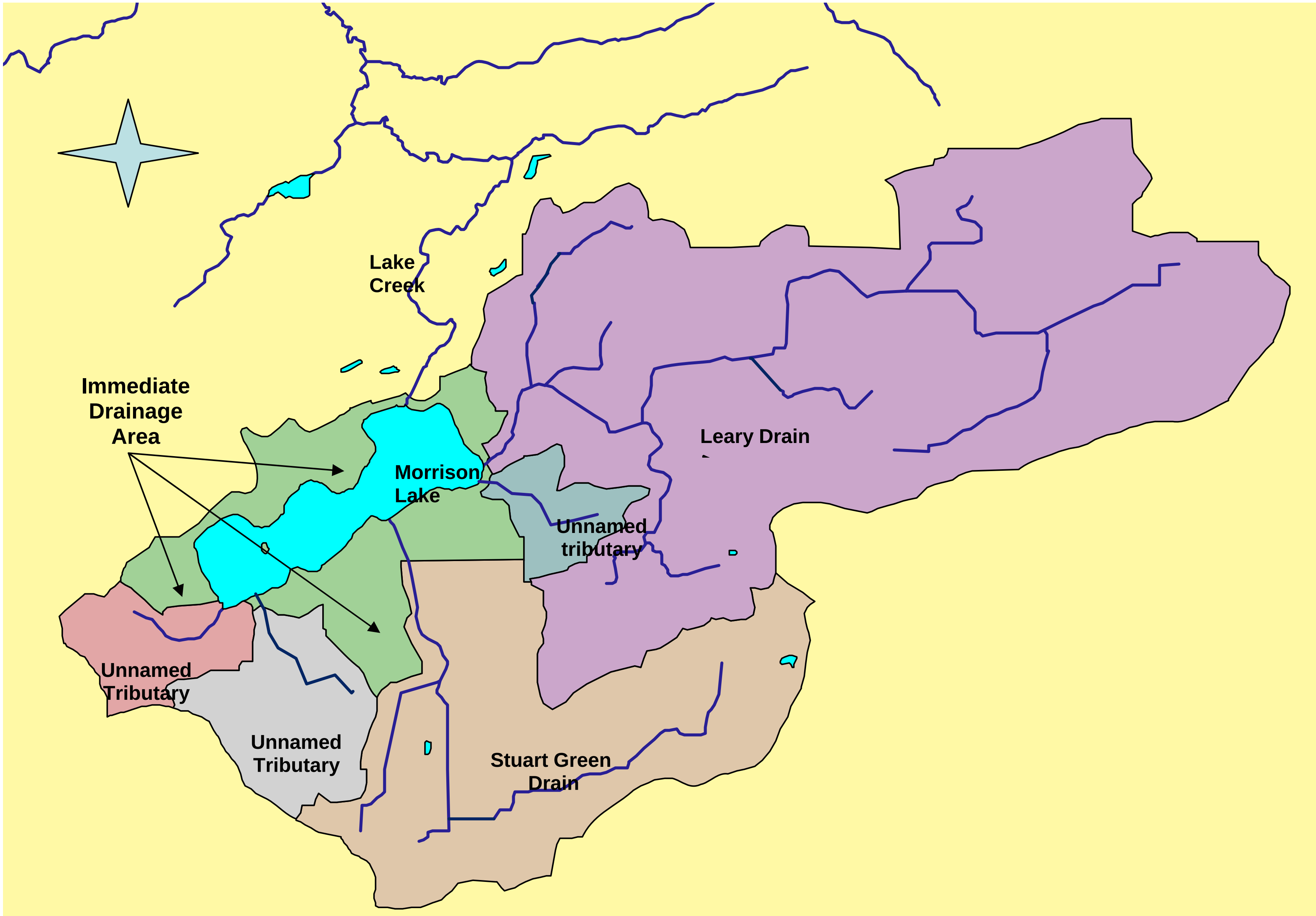

Figure 2. Morrison Lake sub-basin watersheds (Lesmez, 2008).

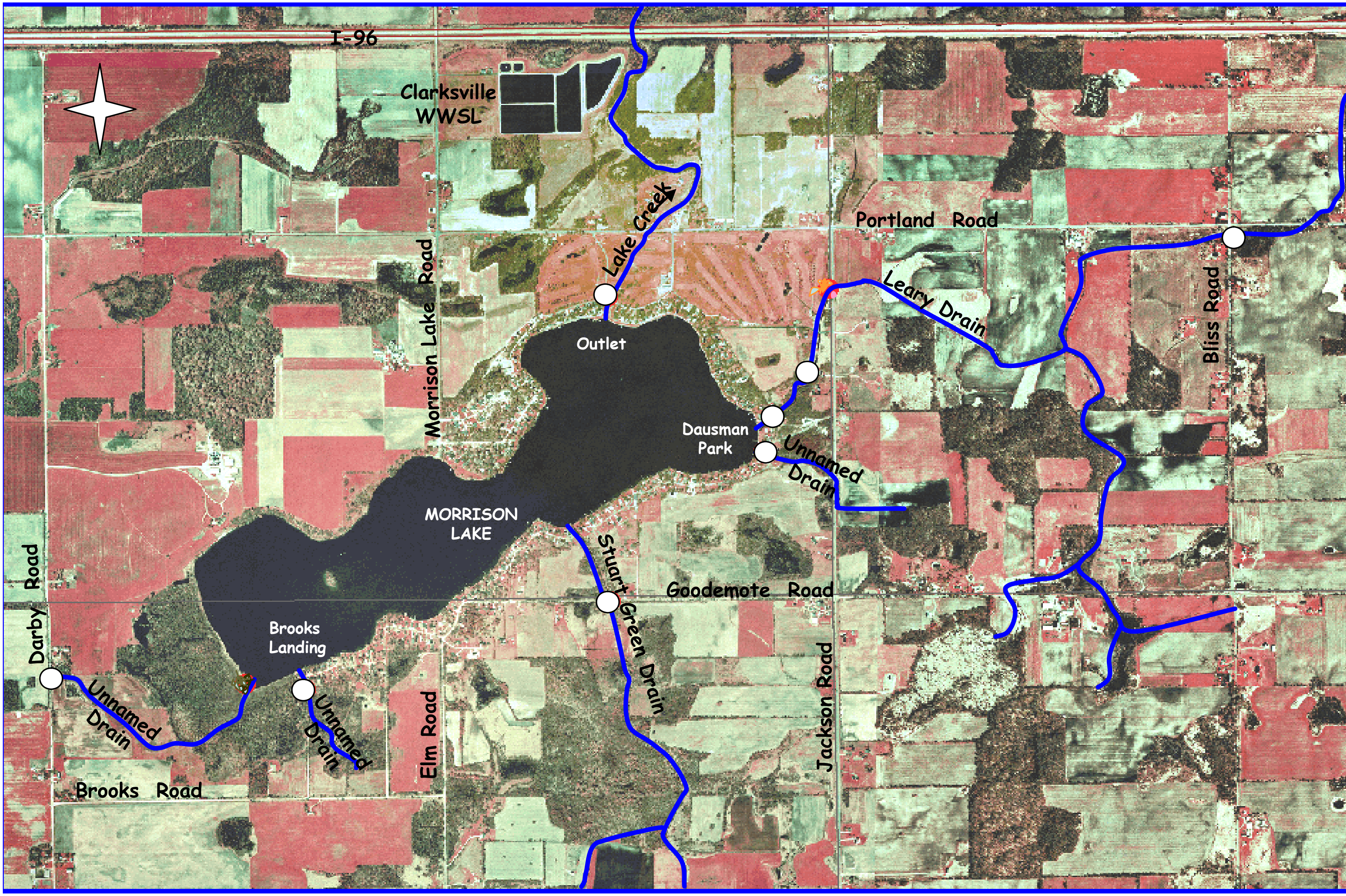

Figure 3. Morrison Lake 2006 outlet and tributary sampling and monthly mean flow estimate locations, Ionia County, Michigan.

Table 1. Morrison Lake Watershed Characteristics.

Subject	Size
Morrison Lake watershed	6,973 acres
Morrison Lake	336 acres
Morrison Lake watershed minus lake area	6,637 acres
Lake mean depth	12.8 feet
Lake maximum depth	35 feet

Table 2. Morrison Lake watershed land use types as estimated with the L-THIA model (Purdue University and USEPA, 2001).

Land Use Description	Acres	Watershed Percentage
Commercial	**59**	0.9
Residential	**64**	1.0
Low Density	(59)	
High Density	(5)	
Agricultural	**3,428**	52
Forest	**1,143**	17
Grass/Pasture	**1,608**	24
Open Water/Wetlands	**335**	5
Total	**6,637**	100

Table 3. Summary of Select Historical Morrison Lake Monitoring Parameters (Wuycheck, 1987).

Date	Depth (feet)	Temperature (ºC)	Temperature (ºF)	TP[1] (µg/l)	Mean TP[1] (mg/l)	Secchi Disk Transparency (inches)	Chlorophyll *a* (µg/L)
2/24/1974	0	1.5	35	90	0.077	-	-
	12	2.5	37	60			
	24	4	39	80			
4/26/1978	0	7.8	46	51	0.053	24	-
	15	7.8	46	54			
	33	7.2	45	54			
9/4/1980	0	24	75	28	0.073	42	10
	25	14.5	58	60			
	35	9.5	49	130			
4/28/1982	0	12.2	54	53	0.051	36	7
	25	9.7	49.5	48			
8/26/1982	0	22	72	34	0.047	60	5
	25	15.5	60	60			
9/2/1982	0	21	70	32	0.212	48	3
	25	14	57	44			
	31	12	54	560			
4/6/1983	0	6	43	58	0.064	30	-
	15	5	41	64			
	31	5	41	70			
5/2/1984	0	-	-	51	0.056	41	19
	25	-	-	61			
8/20/1984	0	25	77	26	0.036	47	12
	10	24.2	75.5	34			
	20	19.9	68	34			
	25	14.8	59	48			
11/27/1984	0	-	-	67	0.066	59	18
	25	-	-	64			

[1] Total phosphorus

Table 4. Morrison Lake, East Basin, and outlet monitoring results for phosphorus in samples collected as part of the nutrient budget study conducted from April through November 2006, Ionia County, Michigan.

Date	Sampling Location	DO(3)	Temp. ° F	Secchi (inches)	Chlorophyll *a* (µg/l)	TP(4) (mg/L)
Apr 10	Surface	12.96	48.99	38	-	0.026
	5	12.71	48.97	-	-	-
	7.5	-	-	-	28	-
	10	12.3	48.2	-	-	-
	15 (mid-depth)(1)	11.65	46.45	-	-	0.028
	20	10.4	46.11	-	-	-
	25	9.38	45.66	-	-	-
	28	-	-	-	-	0.030
	30	8.62	45.24	-	-	-
	Outlet	-	-	-	-	0.025
May 9	Surface	9.81	62.51	42	-	0.035
	5	9.70	62.54	-	-	-
	8.75	-	-	-	6	-
	10	9.27	60.98	-	-	-
	15	6.89	58.83	-	-	-
	18 (mid-depth)	-	-	-	-	0.033
	20	3.9	57.29	-	-	-
	25	1.1	54.06	-	-	-
	29	-	-	-	-	0.113
	30	0.44	49.92	-	-	-
	Outlet	-	-	-	-	0.033
Jun 13	Surface	13.67	72.46	76	-	0.025
	5	12.72	72.42	-	-	-
	10	12.17	71.75	-	-	-
	15 (mid-depth)	7.3	63.3	-	10	0.041
	20	2.52	59.75	-	-	-
	25	0.93	57.67	-	-	-
	29	0.7	56.97	-	-	-
	31	-	-	-	-	0.137
	Outlet	-	-	-	-	0.026
Jul 11	Surface	8.14	78.06	74	-	0.040
	5	7.21	77.68	-	-	-
	10	6.15	77.05	-	-	-
	15	4.38	75.98	-	17	-
	18 (mid-depth)	-	-	-	-	0.090
	20	1.09	63.17	-	-	-
	25	0.58	57.27	-	-	-
	30	0.49	56.23	-	-	0.540
	Outlet	-	-	-	-	0.047

Table 4. cont. Morrison Lake, East Basin, monitoring results for phosphorus in samples collected as part of the nutrient budget study conducted from April through November 2006, Ionia County, Michigan.

Date	Sampling Location[1]	DO[(3)]	Temp. ° F	Secchi (inches)	Chlorophyll a (µg/l)	TP[(4)] (mg/l)
Aug 15	Surface	10.13	76.94	24		0.073
	4	-	-	-	47	-
	5	9.63	76.96	-	-	-
	10	9.29	76.92	-	-	-
	15	9.03	76.86	-	-	-
	20	3.56	69.23	-	-	-
	23 (mid-depth)	-	-	-	-	0.570
	25	2.39	58.86	-	-	-
	30	2.37	56.05	-	-	0.950
	Outlet	-	-	-	-	0.075
Sep 12	Surface	5.6	68	52	-	0.070
	5	5.2	68.05	-	-	-
	10	4.93	68	-	-	-
	8.5	-	-	-	22	-
	15	4.94	67.87	-	-	-
	20	5.35	66.93	-	-	-
	22 (mid-depth)	-	-	-	-	0.072
	25	1.59	61.34	-	-	-
	30	0.7	56.39	-	-	(2)
	33	-	-	-	-	-
	Outlet	-	-	-	-	0.078
Oct 10	Surface	10.65	59.87	48	-	0.072
	5	9.21	59.93	-	-	-
	10	9.06	59.92	-	37	-
	15 (mid-depth)	6.89	59.82	-	-	0.069
	20	5.86	59.86	-	-	-
	25	5.54	59.58	-	-	-
	30	4.74	59.31	-	-	-
	32	-	-	-	-	0.153
	Outlet	-	-	-	-	0.077
Nov 14	Surface	10.73	43.97	72	-	0.049
	5	10.36	43.95	-	48	-
	10	9.91	43.93	-	-	-
	15 (mid-depth)	9.97	43.91	-	-	0.054
	20	9.96	43.95	69	42	-
	25	9.63	44.13	-	-	-
	30	6.96	44.4	-	-	-
	32	-	-	-	-	0.099
	Outlet	-	-	-	-	0.050

1 Surface samples represent the epilimnion, mid-depth samples represent the metalimnion, and the deepest sample represents the hypolimnion.
2 Sample corrupted and result not reported.
3 Dissolved oxygen.
4 Total phosphorus.

Table 5. Measured and estimated phosphorus loads (pounds per year) for the Morrison Lake watershed.

Source	Phosphorus Load (lbs/yr)	Phosphorus Contribution (%)
Tributaries		
Leary Drain	454	49.4
Stuart Green Drain	263	28.6
Unnamed Tributary at Brooks Landing	42	4.6
Unnamed Tributary at Darby Road	25	2.7
Unnamed Tributary at Dausman Road	14	1.5
Precipitation*	99	10.8
Immediate Drainage Area	22	2.4
Total	919	100

* See Appendix A

Table 6. Total acreage estimates in the Morrison Lake watershed.

Land Use Category	Whole Watershed[1] Acres	Water Body (acres)						
		Leary Drain	Stuart/Green Drain	Unnamed Trib Brooks Landing	Unnamed Trib Darby Rd	Unnamed Trib Dausman Rd	Total Trib Acres	Immediate Drainage Area
Water/Wetlands	335	0.4	0.7	0.4	---	0.2	1.7	331.6
Commercial	59	53.7	0.7	---	---	0.2	54.6	4.4
Agricultural	3428	1969.2	958.8	211.6	127.2	69.4	3336.2	91.8
(High) Residential- 1/8 acre	5	3.6	---	---	---	---	3.6	1.4
(Low) Residential - 1/2 acre	59	10.2	2.4	---	---	0.9	13.5	45.5
Grass/Pasture	1608	659.8	545.6	108.4	45.4	47.9	1407.1	200.9
Forest	1143	386.5	439.1	71.8	15	46.1	958.5	184.5
Total	**6637**	**3086.4**	**1947.3**	**392.2**	**187.6**	**164.7**	**5775.2**	**861.8**

[1] Estimates calculated using L-THIA.

Table 7. Phosphorus external load estimates in the Morrison Lake watershed estimates using L-THIA.

Land Use Category	Whole Watershed lbs P/yr[1]	P Load by Water Body, pounds per year and (%)						
		Leary Drain	Stuart/Green Drain	Unnamed Trib Brooks Landing	Unnamed Trib Darby Rd	Unnamed Trib Dausman Rd	Total Tribs	Immediate Drainage Area
Water/Wetlands	0	0	0	0	---	0	0	0
Commercial	44	41 (2.6)	0.485 (0.09)	---	---	0.131 (0.004)	41.62	2.4 (0.04)
Agricultural	2280	1500 (97)	513 (99.6)	113 (99.6)	68 (99.9)	37 (99)	2231	49 (0.83)
(High) Residential 1/8 acre	3.962	3 (0.19)	---	---	---	---	3	1 (0.017)
(Low) Residential ½ acre	10	3 (0.19)	0.365 (0.07)	---	---	0.136 (0.36)	3.5	6.5 (0.11)
Grass/Pasture	1.8	1 (0.06)	0.6 (0.12)	0.1 (0.0009)	0.05 (0.0007)	0.05 (0.001)	1.8	0
Forest	1.066	0.5 (0.03)	0.327 (0.06)	0.05 (0.0004)	0.011 (0.0001)	0.034 (0.0009)	0.922	0.1 (0.0017)
Total	**2340.8**	**1548.5**	**514.7**	**113.15**	**68.06**	**37.35**	**2281.8**	**59**

[1] Estimated phosphorus loads determined using L-THIA.

Table 8. Phosphorus external load estimates in the Morrison Lake watershed using measured/estimated data.

	Total Pounds of Phosphorus per Year						
Land Use Category	Leary Drain	Stuart Green Drain	Unnamed Trib Brooks Landing	Unnamed Trib Darby Road	Unnamed Trib Dausman Road	Tributary Total	Immediate Drainage Area
Water/wetland	0	0	0	0	0	0	0
Commercial	11.8	0.24	0	0	0	12.04	0.88
Agricultural	440	262	42	25	14	783	18.26
Residential	1.73	0.18	0	0	0	1.9	2.8
Grass/Pasture	0.27	0.32	0	0	0	0.59	0
Forest	0.14	0.16	0	0	0	0.3	0.037
Totals	**454**	**263**	**42**	**25**	**14**	**798**	**22**

Table 9. Summary of external phosphorus loadings based on L-THIA and measured or estimated values.

	L-THIA	Measured/ Estimated	Ratio L-THIA/ measured
	lbs P/yr	lbs P/yr	
Tributaries			
Leary	1549	454 (measured)	3.41
Stuart/Green	515	263 (measured)	1.96
Unnamed trib @ Brooks Rd	114	42*	2.68
Unnamed trib @ Darby Rd	68	25*	2.68
Unnamed trib @ Dausman	37	14*	2.68
Total	**2283**	**798**	
Precipitation	99	99	NA
Immediate drainage area	59	22*	2.68
Total	**2441**	**919**	

* Estimated value determined by dividing L-THIA value by 2.68, which is the mean of the Leary Drain and Stuart/Green Drain ratio of L-THIA/measured, i.e. 3.41 + 1.96 = 5.37/2 = 2.68.

Table 10. TMDL phosphorus allocations on an annual basis for Morrison Lake.

Source	Current Load	Load Capacity*	Reduction	
	lbs P/yr	lbs P/yr	lbs P/yr	%
MOS		114		
WLA				
MDOT Statewide MS4	0.09	0.09	0	0
LA				
Agricultural	801	272	529	66
Commercial	12.83	6.41	6.42	50
Residential	4.7	2.35	2.35	50
Forest	0.33	0.33	0	0
Grass/Pasture	0.59	0.59	0	0
Water/Wetlands	0	0	0	0
Precipitation	99	99	0	0
Total	**919**	**495**	**538**	

* 381 lbs P/yr (495 lbs P/yr – 114 lbs P/yr MOS) is available for allocation among the LA and WLA sources, a 538 lbs P/yr reduction (919 – 381 = 538 lbs P/yr).

Table 11. Lake Model Calculations.

(1) Reckhow (1978)

$$P = \frac{Pa}{(11.6 + 1.2\,(D_m/DT))} = \frac{0.307\ g/m2/yr}{(11.6 + 1.2\,(4.28))} = \frac{0.307}{16.74} = 0.018\ mg/l$$

(2) Walker Model (1977)

$$P = \frac{P_a \times DT/D_m}{1 + 0.824 \times DT^{0.454}} = \frac{.307 \times (.92)/3.94}{1 + 0.824 \times .92^{0.454}} = \frac{0.072}{1.793} = 0.04\ mg/l$$

(3) Jones and Bachmann (1976)

$$P = \frac{0.84 \times Pa}{D_m \times (0.65 + DT^{-1}))} = \frac{0.84 \times 0.307}{(3.94 \times (0.65+0.92^{-1}))} = \frac{0.258}{6.84} = 0.038\ mg/l$$

(4) Vollenweider (1975)

$$P = \frac{Pa}{D_m/DT}\left[\frac{1}{1 + \sqrt{\frac{D_m}{D_m/DT}}}\right] = \frac{0.307}{3.94/.92}\left[\frac{1}{1 + \sqrt{\frac{3.94}{3.94/.92}}}\right] = 0.072\ (0.51) = 0.037\ mg/l$$

(5) Reckhow Oxic Model (1977)

$$P = \frac{Pa}{\frac{18D_m}{10+Dm} + 1.05\,(D_m/DT)\,e^{0.012(Dm/DT)}} = \frac{0.307}{\frac{(18)(3.94)}{10 + 3.94} + 1.05\,(4.28)\,(1.052)} = \frac{0.307}{9.82} = 0.031\ mg/l$$

(6) Reckhow Anoxic Model (1977)

$$P = \frac{L}{.17D_m + 1.13D_m/DT} = \frac{0.307}{.17(3.94) + 1.13\,(3.94/0.92)} = \frac{0.307}{5.51} = 0.056\ mg/l$$

Where: Pa = 0.307 (current annual P load to Morrison Lake)
Dm = Average lake depth (m) = 3.94 m
DT = Detention time (yr) = 0.92 yr

APPENDIX A

(1) Phosphorus Load from Precipitation Directly on the Lake (Tague, 1977):

Lake Area = 336 acres (1359792 m^2)
Concentration = 0.0333 gm/m^2
Conversion Factor to Pounds = 2.2×10^{-3}
Annual Phosphorus Precipitation Load = 1359792 * 0.0333 * 0.0022 = 99 pounds

(2) Leary and Stuart Green Drain tributary loadings:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Days in Month	31	28	31	30	31	30	31	31	30	31	30	31
Leary Drain												
TP [(1)]	0.073	0.073	0.073	0.054	0.061	0.101	0.146	0.085	0.1	0.075	0.038	0.073
Mean Flow (MGD)[(3)]	1.9	3	5.9	4.5	2.1	1.6	0.7	0.4	0.5	1	1.5	2.1
Daily Load	1.1567	1.8264	3.59203	2.0266	1.0683	1.34774	0.8523	0.2835	0.417	0.6255	0.4753	1.2785
Monthly Load	35.8595	51.1408	111.353	60.7986	33.1189	40.4323	26.4227	8.7903	12.51	19.3905	14.2614	39.6341
Total annual 2006	453.712											
Stuart Green Drain												
TP [(2)]	0.106	0.106	0.106	0.091	0.087	0.093	0.106	0.106	0.099	0.106	0.162	0.106
Mean Flow (MGD	0.8	1.2	2.4	1.8	0.8	0.6	0.3	0.1	0.2	0.4	0.6	0.8
Daily Load	0.707232	1.06084	2.12169	1.366	0.58046	0.4653	0.2652	0.0884	0.165132	0.3536	0.8106	0.7072
Monthly Load	21.9241	29.7037	65.7725	40.9827	17.9943	13.9611	8.2215	2.7405	4.95396	10.9621	24.3194	21.9241
Total annual 2006	263.4606											

(1) No total phosphorus data collected December through March. These values determined as the average of the April through November months (0.073 mg/L).
(2) No total phosphorus data collected December through March, July, August and October. These values determined as the average of the April, May, June, September and November months (0.106 mg/L).
(3) Lesmez, 2007.