Appendix B: BATHTUB Modeling

A BATHTUB model has been set up for Grand Lake Saint Marys to assess the impacts of reducing total phosphorus and nitrate loads to the lake relative to existing conditions. This appendix summarizes the assumptions used to estimate the loading to the lake under both scenarios as well as the BATHTUB modeling setup and results.

1.0 ESTIMATING EXISTING LOADS TO THE LAKE

The BATHTUB model requires an estimate of total nitrogen and total phosphorus loading as well as the percent inorganic fraction for both nutrients. Simulated loads to Grand Lake Saint Marys include watershed loading (point and nonpoint sources) as well as atmospheric deposition.

1.1 Watershed Loading

1.1.1 Regression Equations

During development of the total phosphorus and nitrate TMDLs for the Grand Lake Saint Marys watershed, Tetra Tech developed regression equations to estimate nutrient loading to the lake. The regression equations are based on water quality samples collected from 1999 to 2006 by Ohio EPA and the City of Celina at six water quality stations in the watershed (to develop loading estimates only the most downstream station on each monitored tributary was used). Table 1 summarizes the equations for each station and nutrient species that was monitored and Figure 1 displays the locations of each station.

Table 1. Regression on Flow (Q cfs) for Estimating Nutrient Loads at Downstream Water Quality Stations on Tributaries to Grand Lake Saint Marys

Station	Phosphate (kg/d)	Total Phosphorus (kg/d)	Nitrite (kg/d)	Nitrate (kg/d)	Ammonia (kg/d)	TKN (kg/d)
300040	$0.8808Q^{0.9288}$	$0.2032Q^{1.4748}$	$0.1294Q^{1.188}$	$16.716Q^{1.2979}$	$0.1884Q^{1.1559}$	$1.1802Q^{1.5132}$
Z01B13/CAFO15	$0.4419Q^{1.2264}$	$0.0729Q^{1.7514}$	$0.136Q^{1.2163}$	$19.678Q^{1.3173}$	$0.141Q^{1.3367}$	$2.4185Q^{0.9675}$
300043	$2.3308Q^{0.6448}$	$0.3387Q^{1.4853}$	$0.473Q^{0.9472}$	$30.54Q^{1.2676}$	$0.5215Q^{1.1373}$	$2.176Q^{1.3447}$
CAFO2	$1.2467Q^{0.9164}$	$0.1363Q^{1.4872}$	$0.1244Q^{1.3688}$	$14.027Q^{1.348}$	$0.0823Q^{1.3371}$	$1.2496Q^{1.337}$
COC2	$1.1371Q^{1.1198}$	ND	ND	$12.797Q^{1.3395}$	$0.6973Q^{0.987}$	ND
COC1	$1.08Q^{1.1506}$	ND	ND	$8.2086Q^{1.2731}$	$0.3577Q^{1.406}$	ND

ND: No water quality samples were available to develop a regression equation for this parameter.

The regression equations require an estimate of daily average flow at each station. Flows measured at USGS Gage 03325500 on the Mississinewa River near Ridgeville, Indiana were scaled down based on the ratio of drainage area at each water quality station. The drainage area of this gage is approximately 133 square miles. Table 2 summarizes the drainage area of the most downstream water quality station on each monitored tributary as well as the total drainage area of each tributary and the shoreline drainage.

Table 2. Drainage Areas of Water Quality Stations and Tributaries of the Grand Lake Saint Marys Watershed

Tributary	Downstream Water Quality Station	Drainage Area at Station (mi^2)	Drainage Area at Lake (mi^2)
Barnes Creek	300040	3.08	4.28
Little Chickasaw Creek	CAFO15/Z01B13	5.03	8.28
Chickasaw Creek	CAFO2	16.25	17.80
Prairie Creek	300043	5.10	5.46
Beaver Creek	COC2	19.82	20.97
Coldwater Creek	COC1	18.35	19.85
Shoreline Drainage	-	-	17.43

Note: The shoreline drainage area represents all drainages not associated with one of the major tributaries listed in this table. There are currently no stations that monitor water quality from these areas.

Loads passing each water quality station were estimated based on the daily flow and regression equation for each nutrient species. The following is an example of how nutrient loads were calculated using the regression equations from Table 1. Phosphate loads at station 300040 are estimated using the corresponding regression equation:

$$\text{Station 300040 Phosphate Load} = 0.8808Q^{0.9288}$$

If the daily average flow at station 300040 was 10 cfs, the estimated phosphate load would be:

Station 300040 Phosphate Load = $0.8808(10)^{0.9288}$ = ~~$8.808^{0.9288}$ = 7.544 kg/day~~

$$\text{Station 300040 Phosphate Load} = 0.8808(10)^{0.9288} = (0.8808)(8.4879) = 7.476 \text{ kg/day *}$$

Similarly, estimating the nitrate load at station 300040 using its corresponding regression equation:

$$\text{Station 300040 Nitrate Load} = 16.716Q^{1.2979}$$

If the daily average flow at station 300040 was 10 cfs, the estimated nitrate load would be:

Station 300040 Nitrate Load = $16.716(10)^{1.2979}$ = ~~$167.16^{1.2979}$ = 768.07 kg/day~~

$$\text{Station 300040 Nitrate Load} = 16.716(10)^{1.2979} = (16.716)(19.856) = 331.919 \text{ kg/day *}$$

* These changes were made on February 25, 2008 based on corrections from Tetra Tech.

For tributaries with no upstream permitted discharges, total loads to the lake were scaled up by drainage area to account for the downstream portion. For tributaries that receive inputs from permitted discharges of nutrients, (e.g., wastewater treatment plants), scaling up the load would result in an over-estimation of the total load. To account for watershed inputs from drainages downstream of the water quality stations on these tributaries, an average daily loading rate (on an areal basis) was calculated from the three tributaries that do not have a contributing point source. This rate then was multiplied by the downstream drainage area to estimate the additional loading. Average areal loading rates were also used to estimate the loading from the unmonitored shoreline drainages.

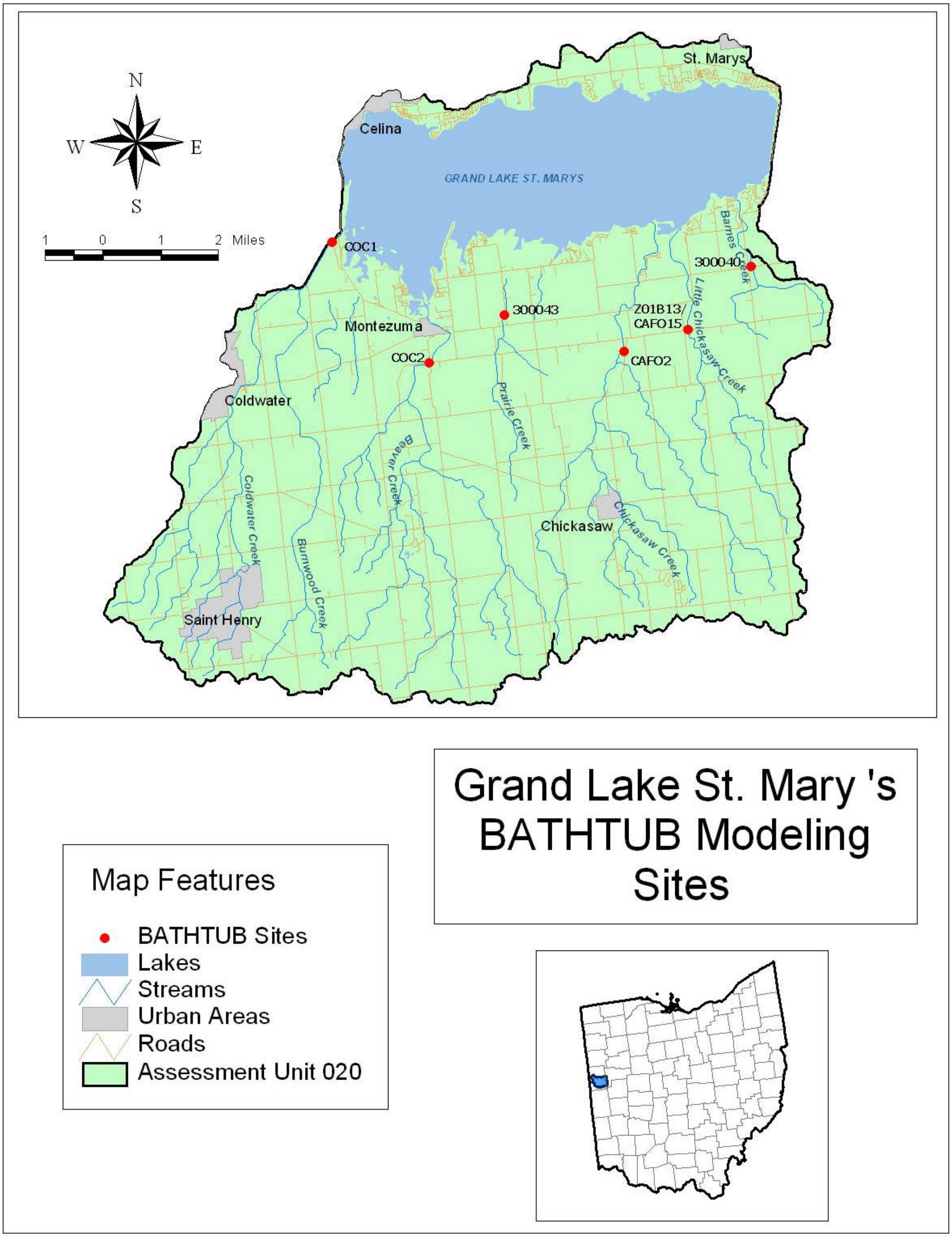

Figure 1. BATHTUB modeling station locations within the Grand Lake St. Marys watershed.

1.1.2 Total Phosphorus

During the load estimation exercise, Tetra Tech found that predicted total phosphorus loads were less than predicted phosphate loads at each of the four stations where regression equations were available for both parameters. Though phosphate was measured approximately 33 times per station, total phosphorus was only measured 8 times per station. In addition, the parameters were measured by two different agencies that rarely sampled on the same day. On 5/11/2006, samples of both species were collected at three sites and in each case the total phosphorus concentrations were approximately three times lower than the corresponding phosphate concentration. Raw data sheets from the lab that processed the phosphate samples confirm that both species are reported as phosphorus (not as phosphate). Figure 2 through Figure 5 show the total phosphorus (TP) and phosphate (PO4) concentrations plotted against the area weighted flow for each station where both species were sampled.

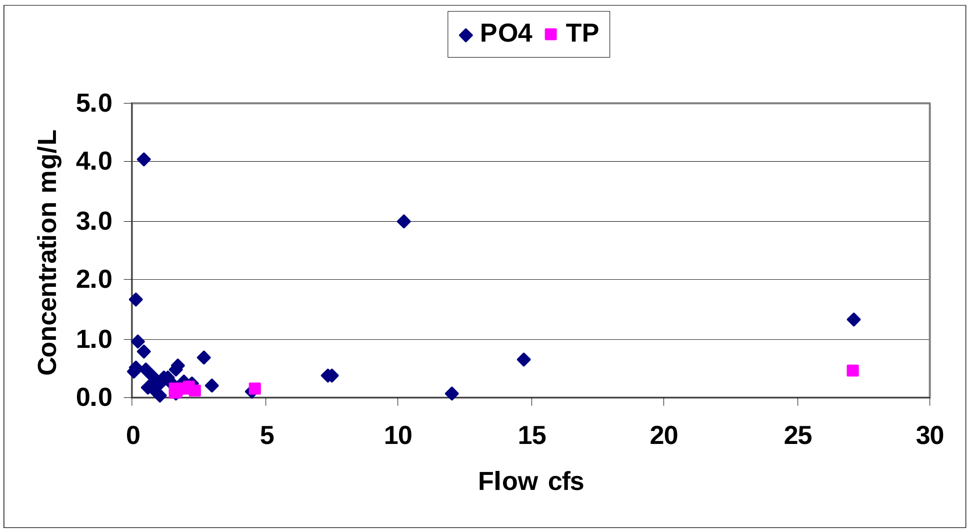

Figure 2. Total Phosphorus and Phosphate Measurements at Station 300040 on Barnes Creek

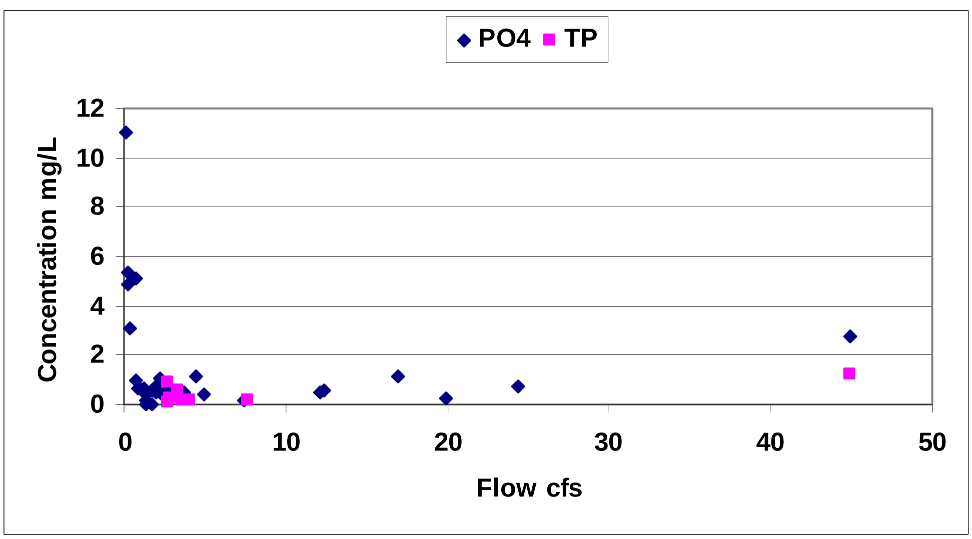

Figure 3. Total Phosphorus and Phosphate Measurements at Station CAFO15/Z01B13 on Little Chickasaw Creek

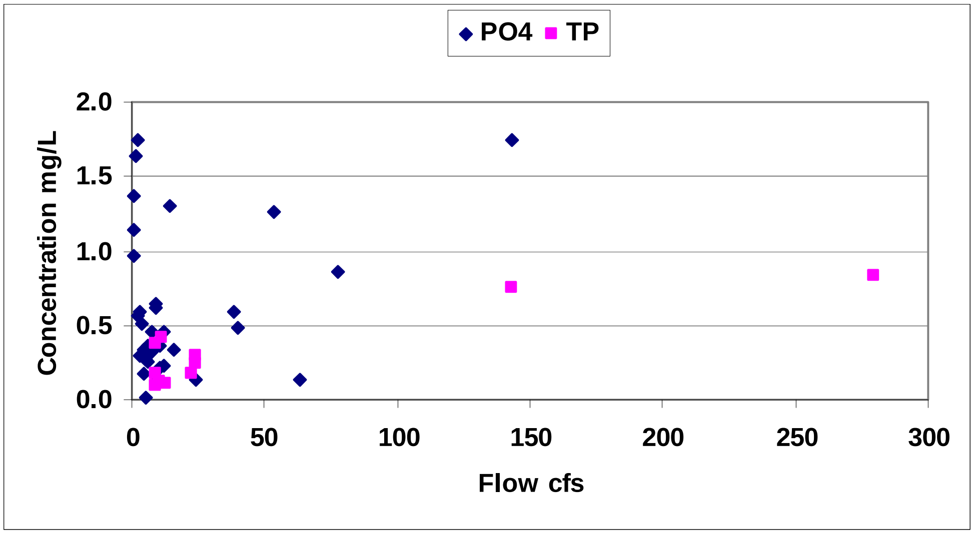

Figure 4. Total Phosphorus and Phosphate Measurements at Station CAFO2 on Chickasaw Creek

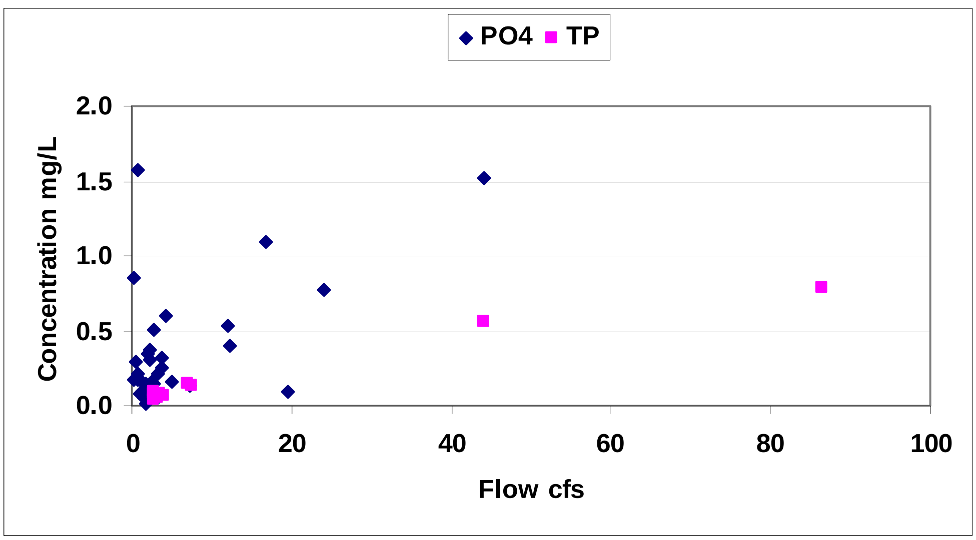

Figure 5. Total Phosphorus and Phosphate Measurements at Station 300043 on Prairie Creek

Regardless of flow, the general trend is that total phosphorus measurements are less than phosphate measurements. Because more phosphate samples are available, these measurements are assumed to more accurately reflect water quality in the system. Based on the available water quality data, total phosphorus loads cannot be estimated with regression equations. Instream measurements collected at various locations in the Wabash River watershed indicate that the mean ratio of total phosphorus to phosphate is two. Therefore, total phosphorus loading is estimated at each water quality station by multiplying the estimated phosphate load by two. As more data become available, this assumption can be modified.

1.1.3 Additional Watershed Loads

Two of the water quality stations (COC1 and COC2 on Coldwater Creek and Beaver Creek, respectively) did not have monitoring data for total phosphorus, nitrite, or Total Kjeldahl Nitrogen (TKN). Because these tributaries receive inputs from permitted nutrient dischargers, loads were estimated based on the areal loading rates of tributaries with no wastewater discharges as well as some assumptions regarding nutrient inputs from the upstream point sources.

Coldwater Creek receives input from the St. Henry WWTP (OH0020028). The average daily discharge rate is 2.0272 MGD. Limited data concerning effluent quality are available from the EPA Permit Compliance System (PCS) database. Two monthly average ammonia concentrations were reported with a resulting average concentration of 11 mg/L. Though ammonia is already accounted for in the regression equations, organic nitrogen can be estimated from ammonia based on EPA TMDL guidance (U.S. EPA, 1997) that suggests a ratio of 0.53 for organic nitrogen to ammonia concentrations. The assumed organic nitrogen concentration for this facility is therefore 5.8 mg/L. Nitrite loads from the plant are assumed negligible. The average total phosphorus concentration is assumed to be 5 mg/L based on typical secondary effluent concentrations reported by U.S. EPA (1997).

Beaver Creek receives point source loading from the Montezuma Club WWTP (OH0078409). This facility has seasonal permit limits for ammonia as well as limits on total suspended solids. Total phosphorus monitoring is required in the permit though no limit is assigned. The ammonia loads from the plant are adequately represented by the regression equation developed for this station. Total phosphorus loading from the plant is based on the average discharge reported flowrate of 1.7088 MGD and the average total phosphorus concentration of 1.65 mg/L reported in the EPA Permit Compliance System (PCS) database. The organic nitrogen concentration in the plant effluent is assumed to be 0.4 mg/L based on the average reported ammonia concentration of 0.711 mg/L and EPA TMDL guidance (U.S. EPA, 1997) concerning the ratio of organic nitrogen to ammonia in typical secondary effluent (0.53). Nitrite loads from the plant are assumed negligible.

The Northwood WWTP discharges effluent to an unmonitored tributary that drains directly to the lake. Loads from this facility were not represented by the regression equations, so Monthly Operating Reports were used to estimate monthly loads to the system based on reported discharge flow rates and concentrations of ammonia, nitrite, nitrate, TKN, and total phosphorus. Phosphate concentrations were estimated based on EPA guidance that suggests a ratio of phosphate to total phosphorus in secondary effluent of 0.7 (U.S. EPA, 1997).

1.2 Atmospheric Deposition

The BATHTUB model input includes rates of direct deposition to the lake surface for total nitrogen and total phosphorus. The EPA Clean Air Status and Trends Network (CASTNET) database reports annual average total nitrogen deposition rates at two sites relatively close to Grand Lake Saint Marys. Site SAL133 is located in Wabash County, IN and site OXF122 is located in Butler County, OH. Table 3 lists the reported total nitrogen deposition rate at each site from 1996 through 2004. The average of the rates reported for these two stations was used to estimate the deposition rate to Grand Lake Saint Marys. If only one rate was reported, no average was taken. The CASTNET site does not report measurements for 2005 or 2006, so the overall average total nitrogen deposition rate of 8.5 lb/ac/yr was used to represent atmospheric loading for these years. Figure 6 displays CASTNET sampling stations near the Grand Lake St. Marys watershed.

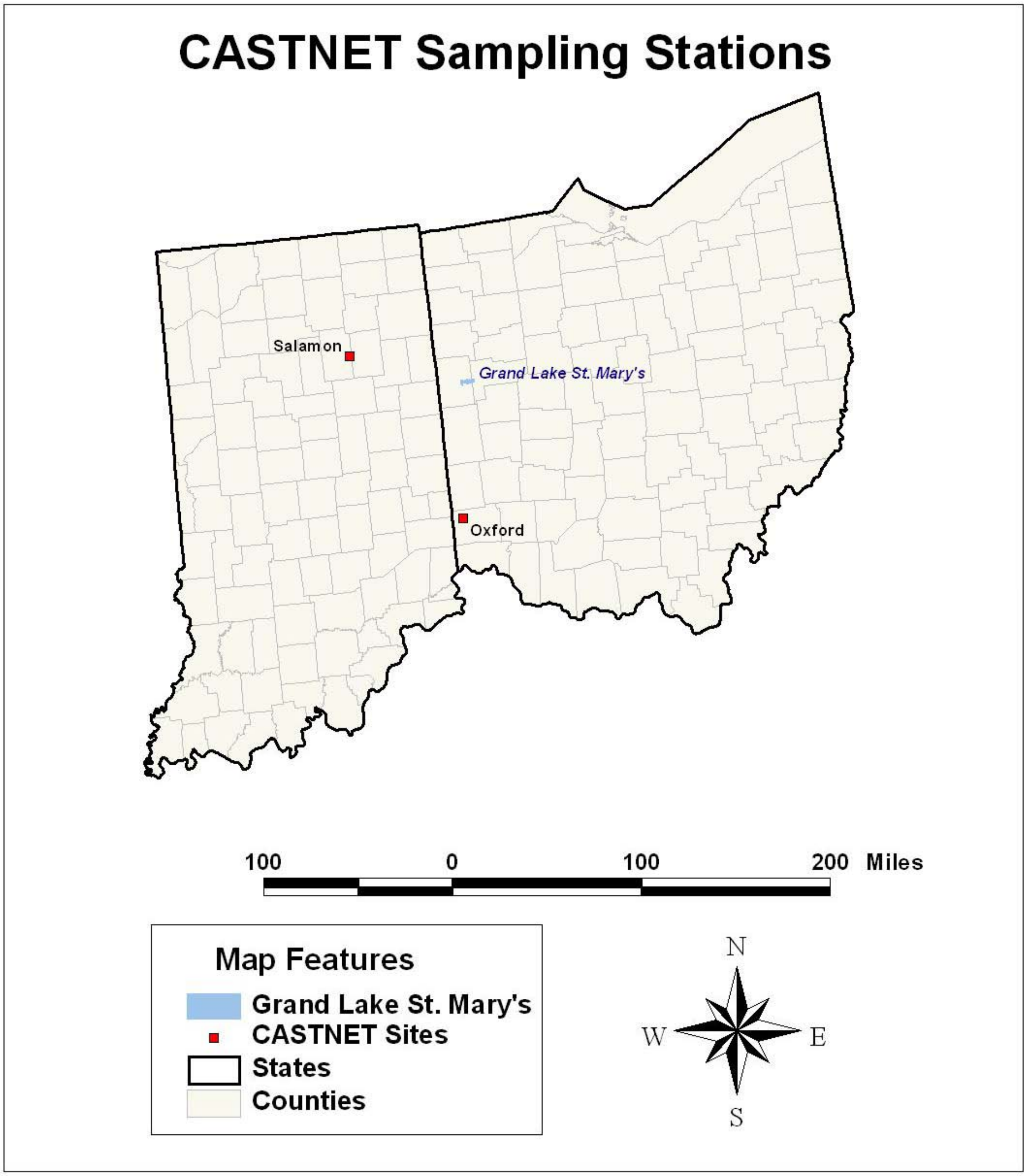

Figure 6. CASTNET sampling station locations near the Grand Lake St. Marys watershed.

Table 3. Total Nitrogen Deposition Rates at Two CASTNET Monitoring Stations

Year	TN Deposition at OXF122 (lb/ac/yr)	TN Deposition at SAL133 (lb/ac/yr)	Average TN Deposition (lb/ac/yr)
1996	9.6	NA	9.6
1997	7.9	8.9	8.4
1998	10.0	9.3	9.6
1999	7.0	8.5	7.8
2000	8.4	8.7	8.5
2001	9.2	8.2	8.7
2002	7.6	8.2	7.9
2003	8.7	NA	8.7
2004	6.2	8.7	7.4
Average	**8.3**	**8.6**	**8.5**

Direct atmospheric deposition of phosphorus to a lake surface is generally considered insignificant compared to watershed loading rates. In studying phosphorus inputs to Lake Michigan, the USGS determined that atmospheric deposition rates in agricultural areas were approximately 0.18 lb/ac/yr (Robertson, 1996). This rate was used for all simulation years (1996 through 2006).

2.0 ESTIMATING LOADS TO THE LAKE UNDER THE TMDL SCENARIO

The TMDLs for the Grand Lake Saint Marys watershed recommend total phosphorus and nitrate reductions for each major tributary across five flow regimes. Table 4 summarizes the TMDL reductions at the most downstream water quality station on each major tributary.

Table 4. TMDL Reductions for Total Phosphorus and Nitrate Loads by Flow Regime.

Tributary	Monitoring Station	Parameter	High	Moist Conditions	Mid-Range	Dry Conditions	Low
Little Chickasaw Creek	At Mercer CR 219-A (Z01B13/CAFO15)	TP	91%	78%	82%	96%	92%
		NO3	98%	90%	89%	ND	ND
Chickasaw Creek	At Mercer CR 219-A (CAFO2)	TP	95%	81%	87%	96%	97%
		NO3	98%	94%	91%	ND	ND
Beaver Creek	At bridge on Cassella-Montezuma Road (COC2)	TP	94%	92%	91%	96%	95%
		NO3	98%	93%	92%	ND	ND
Prairie Creek	At bridge on Kittle Road (300043)	TP	95%	88%	91%	99%	99%
		NO3	99%	95%	95%	ND	ND
Barnes Creek	At bridge on State Route 364 near St. Marys Twp Building (300040)	TP	91%	78%	82%	96%	92%
		NO3	98%	90%	89%	ND	ND
Coldwater Creek	At bridge on Johnston Road (COC1)	TP	97%	93%	89%	96%	97%
		NO3	96%	90%	86%	ND	ND

ND: No water quality samples were available to develop reductions for this flow regime.

As discussed in Section 1.1.1, daily flows at each water quality station were estimated based on USGS flows reported on the Mississinewa River near Ridgeville, Indiana. Daily flows were categorized by flow regime and the appropriate reduction applied for total phosphorus and nitrate. If no water quality samples were available in a specific flow regime to estimate the necessary reduction, the daily flow and estimated load was used to calculate the instream concentration. If the concentration was greater than the water quality standard for total phosphorus (0.08 mg/L) or nitrate (1 mg/L), then the required reduction was applied to reduce the concentration to the water quality standard. Loads from the Northwood WWTP and the shoreline drainages were not included in the TMDL reductions. For this scenario, loads from these sources remain at existing levels.

Impacts of the TMDL reductions on the total phosphorus and total nitrogen loads to Grand Lake Saint Marys are shown in Table 5 and Table 6, respectively. On average, the TMDLs will result in a 68 percent reduction in total nitrogen loading and a 75 percent reduction in total phosphorus loading.

Table 5. Total Nitrogen Loads to Grand Lake Saint Marys

Year	Existing TN (ton/yr)	Reduced TN (ton/yr)	Percent Reduction
1996	3,650	1,155	68.3
1997	2,261	736	67.5
1998	2,576	833	67.7
1999	1,488	503	66.2
2000	1,220	435	64.3
2001	2,041	677	66.8
2002	2,501	802	67.9
2003	4,085	1,285	68.6
2004	2,074	685	67.0
2005	5,506	1,686	69.4
2006	2,561	833	67.5
Average	**2,724**	**875**	**67.9**

Table 6. Total Phosphorus Loads to Grand Lake Saint Marys

Year	Existing TP (ton/yr)	Reduced TP (ton/yr)	Percent Reduction
1996	116	29	74.9
1997	83	20	75.3
1998	90	23	74.9
1999	65	16	75.0
2000	66	17	74.0
2001	84	22	74.3
2002	87	22	75.4
2003	130	33	74.4
2004	87	23	73.9
2005	148	37	74.6
2006	96	24	74.6
Average	**96**	**24**	**74.7**

3.0 BATHTUB MODELING FOR GRAND LAKE ST. MARYS

3.1 Model Setup

BATHTUB is a steady state model that predicts eutrophication response based on empirical formulas developed for nutrient balance calculations and algal response. The model requires nutrient loading inputs from the upstream watershed and atmospheric deposition, morphometric data for the lake, and estimates of mixing depth and nonalgal turbidity. For Grand Lake Saint Marys, limited samples from 1999 are available for calibration of the model but no measurements of mixing depth and nonalgal turbidity are available. The BATHTUB User's Manual (Walker, 1987) lists equations for estimating these parameters.

Lake morphometry information was acquired from the Ohio DNR and a newspaper article from 2006 that reported on an interview with Dr. Robert Hiskey, associate professor of biology at the Lake Campus, regarding the nutrient problems in Grand Lake Saint Marys. According to the article, the average depth of the lake is two meters (Maki, 2006). Ohio DNR reports a normal lake surface area of 13,981 ac and normal pool volume of 62,914 ac-ft (Ogden, 2006).

The BATHTUB User's Manual (Walker, 1987) provides an equation for estimating the mixed depth of a lake when direct measurements are not available. For lakes less than 3 meters, the formula estimates a mixed depth equivalent to the average depth of the lake. Thus, for Grand Lake Saint Marys, the mixed depth is 2 meters.

Nonalgal turbidity can be estimated from measurements of Secchi depth and chlorophyll *a*. The BATHTUB User's Manual suggests a minimum value of 0.08/m. For the Grand Lake Saint Marys, the equation for nonalgal turbidity resulted in a number less than the suggested minimum, so the value was fixed at 0.08/m. Volunteer monitoring of the lake in 1999 confirmed the assumption of low nonalgal turbidity. The Custor Color Strip test showed a bright green color, which indicates more algal turbidity relative to sediment based turbidity (Oleskiewicz and Carlson, 1999).

BATHTUB allows the user to choose the period of time over which its calculations will be carried out. This averaging period is typically a summer season or complete year. In the case of the Grand Lake Saint Marys, an annual simulation is most appropriate based on the mass residence time and nutrient turnover calculations described in the User's Manual (Walker, 1987). In addition, Ohio EPA states in a response to comments for the Grand Lake Saint Marys TMDL that the majority of nutrient loading to Grand Lake Saint Marys occurs from late fall to late spring, not in the summer when plant uptake and soil infiltration rates are high (http://www.mercercountyohio.org/commissioners/QA_OEPA.pdf).

3.2 Simulation of Inlake Nitrogen, Phosphorus, and Chlorophyll *a* Concentrations

Second order sedimentation functions were chosen to simulate nitrogen and phosphorus concentrations in the lake. Modeling Option 2 was chosen, which varies the sedimentation rate based on the inorganic fraction of the load. This method is recommended for lakes with a long residence time and normal to high inorganic fractions.

Nutrient data were collected in Grand Lake Saint Marys during the 1999 Wabash study and the data were provided by Ohio EPA to Tetra Tech. Average total phosphorus concentration of the lake during that summer was 0.21 mg/L and ranged from 0.11 mg/L to 0.31 mg/L. Calibrating the phosphorus model requires an adjustment factor of 0.4, which decreases the sedimentation rate. The allowable range of adjustment for the phosphorus model is 0.33 to 3, so the calibration is within allowable range. The need for calibration of total phosphorus indicates that either the ratio used to scale up the phosphate loads to estimate total phosphorus loads is too small or inlake resuspension of phosphorus is contributing significant loading to the lake. The calibration factor for phosphorus can be used to account for either of these conditions. However, because only one year of data were available for calibration, and this year was particularly dry, the calibration may not be accurate. Though the model may not accurately predict phosphorus concentrations across a wide range of hydrologic conditions, it can still be used to compare the relative impacts of TMDL reductions on lake water quality.

The nitrogen sedimentation equation was not calibrated (in other words the adjustment factor is one). The inlake samples taken in 1999 indicate TKN concentrations ranging from 1.4 mg/L to 4.1 mg/L with an average concentration of 2.5 mg/L. Nitrite plus nitrate concentrations, however, remain constant at 0.1 mg/L, which may be the detection limit of the test. Given that nitrate loads are estimated to be 90 percent of the total nitrogen load to the lake, it seems unlikely that concentrations would be less than detection unless nitrate uptake by algae and plants is rapid. Because the Grand Lake Saint Marys is fairly insensitive to nitrogen relative to phosphorus, the sedimentation rates were not adjusted to match the average total nitrogen concentration indicated by the data (2.6 mg/L). The average nitrogen concentration based on the unadjusted model is approximately 5 mg/L.

The BATHTUB User's Manual (Walker, 1987) describes several variables that assess the sensitivity of a lake to nitrogen, phosphorus, light, and flushing rates. Based on comparison of nutrient ratios, inorganic fractions, and measured values of chlorophyll *a*, Secchi depth, and total phosphorus concentrations, the lake is highly sensitive to phosphorus inputs with little sensitivity to nitrogen inputs, light availability, or flushing rate. Based on the degree of phosphorus sensitivity, the Jones and Bachman chlorophyll *a* model was chosen to simulate algal response in Grand Lake Saint Marys.

3.3 Model Results for Existing and TMDL Scenarios

The BATHTUB model was set up from 1996 to 2006 to simulate eutrophication under existing loading conditions and under a reduced loading scenario (applying the TMDL reductions for total phosphorus and nitrate). Table 7 through Table 10 compare the nutrient, chlorophyll *a*, and Secchi depth results for both scenarios. The TMDL reductions result in an average reduction of total nitrogen concentration of 50 percent, an average reduction of total phosphorus concentration of 59 percent, an average reduction of chlorophyll *a* concentration of 73 percent, and an average increase in the Secchi depth of 250 percent.

Table 7. Simulated Total Nitrogen Concentrations in Grand Lake Saint Marys

Year	Existing TN (mg/L)	Reduced TN (mg/L)	Percent Reduction
1996	5.8	2.8	51.2
1997	4.6	2.3	49.8
1998	4.8	2.4	50.5
1999	3.9	2.1	47.1
2000	3.4	1.8	46.6
2001	4.4	2.2	49.0
2002	4.8	2.4	50.3
2003	6.0	2.9	51.9
2004	4.1	2.0	51.3
2005	7.3	3.5	51.3
2006	4.9	2.4	49.9
Average	**4.9**	**2.4**	**50.1**

Table 8. Simulated Total Phosphorus Concentrations in Grand Lake Saint Marys

Year	Existing TP (mg/L)	Reduced TP (mg/L)	Percent Reduction
1996	0.28	0.11	60.9
1997	0.24	0.10	58.7
1998	0.24	0.10	59.8
1999	0.21	0.10	53.8
2000	0.20	0.09	53.9
2001	0.24	0.10	57.1
2002	0.24	0.10	59.3
2003	0.29	0.11	61.4
2004	0.22	0.09	59.8
2005	0.34	0.13	60.6
2006	0.26	0.11	59.0
Average	**0.25**	**0.10**	**58.8**

Table 9. Simulated Chlorophyll *a* Concentrations in Grand Lake Saint Marys

Year	Existing Chlorophyll *a* (ug/L)	Reduced Chlorophyll *a* (ug/L)	Percent Reduction
1996	366	93	74.6
1997	283	78	72.5
1998	294	78	73.5
1999	244	79	67.6
2000	225	72	67.7
2001	285	83	71.0
2002	297	80	73.1
2003	385	96	75.0
2004	257	68	73.6
2005	482	124	74.3
2006	320	87	72.8
Average	**312**	**85**	**72.7**

Table 10. Simulated Secchi Depth in Grand Lake Saint Marys

Year	Existing Secchi Depth (m)	TMDL Scenario Secchi Depth (m)	Percent Increase
1996	0.11	0.42	285
1997	0.14	0.49	253
1998	0.13	0.49	267
1999	0.16	0.49	200
2000	0.18	0.53	201
2001	0.14	0.47	235
2002	0.13	0.48	262
2003	0.10	0.40	291
2004	0.15	0.56	266
2005	0.08	0.32	289
2006	0.12	0.44	252
Average	**0.13**	**0.46**	**250**

4.0 CONCLUSIONS

A BATHTUB model was developed for Grand Lake Saint Marys based on nutrient inputs estimated for 1996 through 2006. The calibration is based on one year of sampling conducted in 1999, so the model should be used to assess general trends in water quality rather than to exactly predict inlake concentrations of nutrients or chlorophyll *a*.

Though Ohio EPA does not currently have lake water quality standards for nutrients or chlorophyll *a*, the lake is considered hypereutrophic and not supporting its designated uses of recreation and aquatic life support. The calibrated BATHTUB model indicates that the TMDL reductions will have a significant impact on lake water quality, reducing average chlorophyll *a* concentrations from over 300 µg/L to approximately 85 µg/L.

5.0 REFERENCES

Maki, Eric. 2006. Biologist speaks on future of Grand Lake St. Marys. *The Evening Leader*. Monday, November 6, 2006.

Ogden, Mark. 2006. Email to Ian Hughes at Tetra Tech dated November 14, 2006. Ohio Department of Natural Resources.

Oleskiewicz, Dana and Robert Carlson. 1999. Ohio's CLAM Program. Citizen Lake Awareness and Monitoring Sponsored by The Ohio Lake Management Society, 1999 Summary of Results.

Robertson, D.M. 1996. Sources and Transport of Phosphorus in the Western Lake Michigan Drainages. USGS Fact Sheet FS-208-96.

U.S. EPA. 1997. Technical Guidance Manual for Developing Total Maximum Daily Loads, Book II: Streams and Rivers, Part I: Biochemical Oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication. Office of Science and Technology, U.S. Environmental Protection Agency, Washington, DC.

Walker, W. W., Jr. 1987. Empirical Methods for Predicting Eutrophication in Impoundments: Report 4—Phase III: Applications Manual. Technical Report E-81-9. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.