



PAW PAW LAKES AND WATERSHED STUDY

Prepared for the Paw Paw Lake Foundation by Spicer Group, Inc.

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Table of Contents

<i>List of Figures</i> _____	<i>ii</i>
<i>List of Tables</i> _____	<i>ii</i>
<i>Executive Summary</i> _____	<i>1</i>
<i>Task 1: Water Input and Outflow Budget</i> _____	<i>4</i>
Task 1 Summary _____	<i>8</i>
<i>Task 2: Nutrient and Sediment Budget</i> _____	<i>9</i>
Task 2 Summary _____	<i>17</i>
<i>Task 3: Bathymetric Survey, Sediment Survey, and Water Quality Profiles</i> _____	<i>19</i>
Task 3 Summary _____	<i>21</i>
<i>Task 4: Tributary Drain Assessment</i> _____	<i>22</i>
Preliminary Inspection _____	<i>22</i>
Inspection of the Branch and Derby Drain (Sta. 0+00 to 145+00) _____	<i>23</i>
Task 4 Summary _____	<i>29</i>
<i>Watershed and Lake Management Practices</i> _____	<i>30</i>
In-Lake Management Techniques _____	<i>30</i>
Watershed Management Techniques _____	<i>35</i>
<i>Recommended Implementation Actions</i> _____	<i>39</i>
<i>Conclusions</i> _____	<i>44</i>
<i>References</i> _____	<i>45</i>

List of Appendices

Appendix A:	L-THIA Model Results
Appendix B:	Water Quality Profiles and Data
Appendix C:	Bathymetric Survey and Sediment Depth Maps
Appendix D:	Branch and Derby Drain Photographs and Location Map
Appendix E:	L-THIA Model Pollutant Source Maps
Appendix F:	Digital Version

List of Figures

<i>Figure 1: Watershed Land Use (based on visual interpretation of 2005 aerial photography) for the 10,274 acre Paw Paw Lake Watershed</i>	4
<i>Figure 2: Total Phosphorus Loading in the Paw Paw Lake Watershed</i>	10
<i>Figure 3: Typical Dissolved Oxygen Profile</i>	20
<i>Figure 4: Looking upstream from Paw Paw Lake</i>	23
<i>Figure 5: Typical Erosion, Sloughing, and Floodplain between Sta. 0+25 and 55+75</i>	24
<i>Figure 6: Bank Erosion and Sloughing at Sta. 60+00</i>	25
<i>Figure 7: Typical Channel for Sta. 87+00 to 126+00. Looking downstream at bank erosion near Sta. 118+50.</i>	26
<i>Figure 8: Looking downstream at pasture with unrestricted access to drain</i>	26
<i>Figure 9: Looking downstream from Sta. 145+50</i>	27

List of Tables

<i>Table 1: Monthly Water Budget Parameters</i>	6
<i>Table 2: Parameters for Sub-watersheds</i>	7
<i>Table 3: Nutrient Modeling Validation (avg. values across all tributaries and sampling locations)</i>	10
<i>Table 4: L-THIA Model Results</i>	11
<i>Table 5: Analysis of Nitrogen:Phosphorus (N:P) Ratio of L-THIA Loading Estimates</i>	13
<i>Table 6: 2007 Surface Water Data (collected by Water Quality Investigators, Inc.)</i>	13
<i>Table 7: Pollutant Loading Estimates</i>	15
<i>Table 8: Phosphorus Budget for Paw Paw Lake</i>	17
<i>Table 9: Estimated Dredge Volumes and Costs for Selected Locations on Paw Paw Lake</i>	19
<i>Table 10: Paw Paw Lake Depth and Nutrient Data (data collected 28 August 2007 by Water Quality Investigators, Inc.)</i>	20
<i>Table 11: Paw Paw Lake Total Phosphorus Data by Lake Strata (data collected 28 August 2007 by Water Quality Investigators, Inc.)</i>	21
<i>Table 12: Crossing Summary</i>	28
<i>Table 13: Cost Estimates for In-Lake Management Practices</i>	34
<i>Table 14: Cost Estimates for Watershed Management Practices</i>	38

Executive Summary

Spicer Group, Inc. has provided professional engineering services including field investigation, surveying, modeling, and inspection of Paw Paw Lake, Little Paw Paw Lake, Lake Stella, and their collective watershed over the past months. The intent of the study was based on water quality, with an understanding of the sources and fates of pollutants in the watershed. This report and study, in addition to previous work on the lakes and watershed, serves as a basis for recommending Best Management Practices to improve water quality within the lakes.

A hydrographic survey of the lakes was completed using dual frequency sonar equipment in August 2007. Paw Paw Lake Foundation (PPLF) volunteers supplemented this survey with pole soundings of sediment depth in six locations within Paw Paw Lake. Maps showing the bathymetry (i.e. contours) of the lakes, and the distribution of accumulated sediment within the lake were produced.

A preliminary inspection of drains tributary to the lakes was completed by Frank Jurenka, Paw Paw Lake Foundation's Director of Water Quality. Based on his inspection, Spicer Group completed a maintenance inspection of the lower 14,500 feet of the Branch and Derby Drain. The drain is experiencing widespread bank erosion and in-channel sedimentation between Paw Paw Lake and the Hagar Shore Road crossing. The drain upstream of this reach is in fair condition, with vegetation well established and notable erosion problems present intermittently. The drain is overgrown with weeds, brush, and trees in some reaches which were inspected.

Spicer Group reviewed historic reports and studies of the lake as part of this study. Land use in the watershed was visually interpreted from 2005 aerial photographs and land use characteristics for each sub-watershed were defined. Watershed and sub-watershed boundaries were supplied by the South West Michigan Planning Commissioner. Land use and soil types were input in the Long-Term Hydrologic Impact Assessment (L-THIA) model to estimate pollutant loading for each sub-watershed.

A water budget for the lakes was developed including precipitation, outflow, runoff, evaporation, and surface water withdrawals. Residence time for Paw Paw Lake was calculated to be 2.3 years; residence time for Little Paw Paw Lake was calculated to be 0.3 years. The L-THIA model results were combined with the water budget to calculate nutrient inputs and outputs. An annual accumulation of approximately 1670 kg of total phosphorus was predicted for Paw Paw Lake; accumulation of 174 kg total phosphorus for Little Paw Paw Lake.

Significant sources of nutrients and sediment in the watershed include residential areas (especially those near the lakes) and agricultural areas in the upper watershed. The continued eutrophication problems in the lake are due in part to internal recycling of nutrients (i.e. nutrient-rich sediment releases phosphorus into the water column during anoxic conditions in the summer months). ***Between the increasing bottom sediments and the steadily increasing nutrient levels, the water quality of Paw Paw Lake continues deteriorating each year. Accelerated weed and algae growth and poor water clarity will continue until nutrient levels are reduced.***

Recommendations for lake improvement are summarized below:

- 1. Aquatic Vegetation Management & Habitat Survey.** A detailed aquatic vegetation survey and development of an aquatic vegetation management plan/strategy is important in lake

management. The benefits being provided by each vegetative community should be understood before widespread treatment plans are developed. A combination of chemical treatment, harvesting, and protected or undisturbed areas is recommended.

2. **Continue Water Quality Monitoring Efforts.** Continued monitoring of water quality within the lakes and watershed is recommended. Regular monitoring of water quality provides more information for management decision making and serves to document baseline conditions and improvement within the lakes watershed.
3. **Begin a Watershed Management and Public Education Program.** Establishing a supportive, informed, involved base of citizens will be a critical factor in protection and improvement of the lakes. Public education efforts should include a survey of riparian and watershed residents, development of an educational Web site, and integration of lake and watershed management with other planning efforts in the region (recreational plans, master plans, SWMPC efforts, etc).
4. **Establish and Implement Drain Inspection & Maintenance Plan.** Open and tile drains tributary to the lakes convey water and pollutants to the lakes. Maintenance of these drains to reduce the sediment load reaching the lake will provide a direct water quality benefit. Inspection of all drains within the watershed is recommended, in addition to maintenance of the already-inspected Branch and Derby Drain (cost varies with length of drain inspected, length of drain maintained, and practices installed) Inventory. Maintenance needs are present on the Branch and Derby Drain to the degree that a petition to improve the drain is recommended at this time. A petition will allow the Drain Commissioners to address these issues all at once, rather than piecing together a solution through maintenance funds over the course of several years.
5. **Shoreline Survey.** Complete a detailed survey of shoreline land use and material. Develop demonstration site(s) of shoreline stabilization and management techniques for public education. Sites may include seawall retrofit, seawall alternatives, vegetated buffer strips, or other water quality and shoreline stabilization measures.
6. **Design and Pursue Implementation Funding for Water Quality Retrofits for Immediate Areas.** Develop a conceptual plan for low-impact development retrofits aimed at improving water quality in the “immediate area” watersheds. Pursue funding to implement demonstration site(s) for public education, possibly including rain gardens, drain inlet protection, rain barrels, soil testing and fertilizer alternatives, pervious pavement, etc.
7. **Dredging Assessment and Dredge Plan Development.** Complete a preliminary analysis of dredging plans for Paw Paw Lake and/or Little Paw Paw Lake. Assessment to include focus on areas for dredging, estimates of material to be removed, and disposal options. A preliminary dredging analysis will identify areas that dredging would be beneficial to the lake and feasible given regulatory requirements. A detailed cost estimate for a long-term dredging project will be developed for the lakes.
8. **Establish Lake Improvement Board and/or Special Assessment District.** Establishment of a funding mechanism for lake improvements is necessary for sustained improvements to Paw Paw Lake. This could include establishment of a Lake Improvement Board under PA 188 or Part 309 or PA 451. The lake improvement board established a governmental entity to aid in assessment and regulation of the lake, and provides a sustainable mechanism for ongoing lake management efforts.
9. **Review and Revise Township and/or County-wide Ordinances.** Review existing township ordinances that may impact water quality. Propose and pursue implementation or a limit or ban on phosphorus-based fertilizers for residential use in the watershed and encourage low-impact development and proper shoreline management within the watershed. Ordinance review might

include zoning, master plans, recreation plans, nuisance weed ordinances, stormwater management plans/policies, etc.

- 10. Paw Paw Lake Economic Analysis.** Complete a study of riparian property values and water resource quality for Paw Paw Lake and Little Paw Paw Lake. Complete a regional analysis of the economic impact of high-quality water resources. An analysis of this type would be designed to place a value on the natural resources in and around the lakes and analyze the impact to the local economy, riparian, and near-shore properties given degradation, maintenance, or improvement of lake water quality. This analysis would be a public education tool and aid in demonstrating what level of investment in the lake is appropriate.

Task 1: Water Input and Outflow Budget

A topographic survey of drain crossings was completed for six (6) tributary crossings in the watershed, in addition to a topographic survey of the water level control structure located southwest of Paw Paw Lake. Rating curves for each structure were developed to correlate depth of flow measurements with estimates of flow rate.

Historic data provided by the PPLF was reviewed, in addition to data available from the MDEQ's Dam Safety Unit files and readily available GIS data. Sub-watershed areas were delineated by the South West Michigan Planning Commission (SWMPC) and delivered to Spicer Group in shape-file format. These boundaries, as well as the watershed boundary, were not field verified as part of this project.

Land use was visually delineated using 2005 Aerial photography. Land use was classified using the following categories: Agricultural (32.1%), Commercial (0.25%), Industrial (0.12%), Low Density Residential (8.16%), High Density Residential (8.11%), Forest (37.15%), Grass/Pasture (3.65%), and Water (10.47%). Soils were classified by hydrologic group and the Long-Term Hydrologic Impact Assessment (L-THIA) program developed by Purdue University was utilized to calculate Runoff Curve Number (RCN) for the watershed area, using a 5-meter by 5-meter grid. A curve number was then developed for each sub-watershed area, as summarized in Table 4.

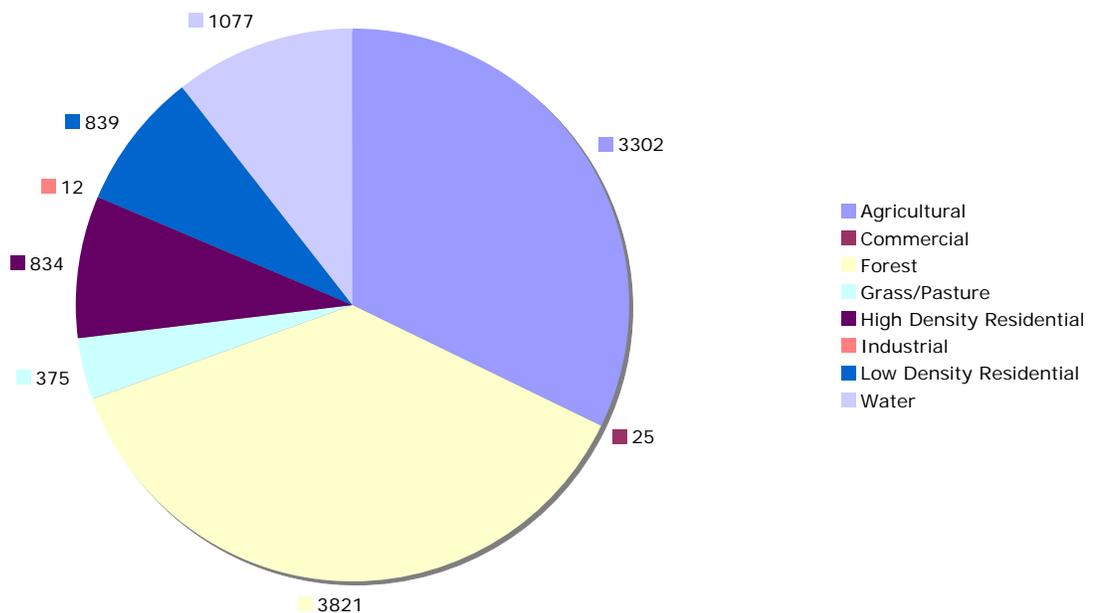


Figure 1: Watershed Land Use (based on visual interpretation of 2005 aerial photography) for the 10,274 acre Paw Paw Lake Watershed.

Baseflow for each watershed was determined through analysis of flow measurements obtained by Frank Jurenka during August and September 2007 during dry periods. The data collected was averaged to approximately 0.003 cfs/ac for the four (4) watersheds analyzed. This baseflow was scaled to all watersheds and assumed constant throughout the year, Table 2 provides a summary of baseflow for each subdistrict. For the Paw Paw Lake Immediate Areas in both Coloma and Watervliet townships it was assumed that 40% of the area-proportional baseflow would exist as an input to the lake given the drainage systems installed and evidence of residential drains with no flow during dry periods. A total baseflow of 25.5 cfs was calculated for the Paw Paw Lake Watershed, and 5.2 cfs for the Little Paw Paw Lake watershed.

Climate data for model development (average temperature and precipitation data) were obtained from the Benton Harbor AP Weather Station, located approximately seven (7) miles from Paw Paw Lake. Evaporation data was calculated using percentages from the Michigan Department of Environmental Quality (MDEQ) Guidance Memo on Water Budgetsⁱ. A total of 31 inches per year of evaporation was reported by the National Weather Surface for open water surfaces.ⁱⁱ

Table 1: Monthly Water Budget Parameters

Month	Precipitation (in)	Avg. Temp. (deg. F)	Evaporation (in)	% of Precipitation as Snow	% of Snowpack Melt	Water Withdrawals (ac-ft)	Lake Elevation (ft)
January	2.32	23.8	0.00	90%	25%	0.00	620.80
February	1.68	27.2	0.00	50%	50%	0.00	620.80
March	2.43	36.2	0.00	0%	100%	0.00	621.30
April	3.77	46.4	0.00	0%	100%	0.00	621.80
May	3.33	57.1	5.58	0%	100%	0.00	621.80
June	3.53	66.6	6.2	0%	100%	0.62	621.80
July	3.24	71.0	7.13	0%	100%	0.59	621.80
August	3.47	69.2	5.58	0%	100%	0.61	621.80
September	4.17	62.1	3.72	0%	100%	0.10	621.30
October	3.09	51.5	2.79	0%	100%	0.00	620.80
November	3.3	39.8	0.00	0%	100%	0.00	620.80
December	2.71	28.7	0.00	20%	50%	0.00	620.80

Table 2: Parameters for Sub-watersheds

Sub-watershed	Area (ac)	RCN*	Assumed Baseflow (cfs)	Surface Runoff (ac-ft / yr)	Total Flow (ac-ft/yr)
Branch and Derby	2635.0	71	7.6	2952.5	8443.6
Culter Smith	140.2	62	0.4	103.6	395.7
Dedrick	1157.8	65	3.3	999.1	3411.9
Delfield Crumb	449.1	66	1.3	405.4	1341.2
Green	539.6	74	1.6	694.8	1819.4
Lake Stella Immediate	48.6	59	0.1	29.3	130.7
Little Paw Paw Lake Drain	49.0	55	0.1	20.6	122.6
Little Paw Paw Lake Immediate	524.8	59	1.5	316.0	1409.5
McConnel Olcott	1516.4	68	4.4	1493.0	4653.0
Potter	255.4	60	0.7	165.8	698.2
Paw Paw Lake - Coloma	1211.5	47	1.4	69.6	1079.5
Paw Paw Lake - Watervliet	1167.7	47	1.3	67.1	1040.4
Sherwood	579.2	67	1.7	546.9	1753.8
<i>Little Paw Paw Lake Watershed Total</i>	<i>1822.8</i>	<i>63**</i>	<i>5.2</i>	<i>1418.6</i>	<i>5217.1</i>
<i>Paw Paw Lake Watershed Total</i>	<i>10274.4</i>	<i>63**</i>	<i>25.5</i>	<i>7863.6</i>	<i>26229.4</i>

*RCN is based on Antecedent Moisture Condition II.

**Values reported for Little Paw Paw Lake and Paw Paw Lake Totals are weighted averages.

Water withdrawals from the lake are based upon values reported in 2006 and 2007 for the golf course adjacent to the lake. Data was provided by the Paw Paw Lake Foundation. The lake elevation and volume are based upon the bathymetric survey completed and Spicer Group's understanding of the maintained legal lake levels. It was assumed the monthly precipitation fell at three storm events, representing 65%, 25%, and 10% of the total monthly precipitation respectively.

Evapotranspiration from the watershed area and groundwater inputs and outputs were not included in the water budget model. It is assumed that the groundwater inputs, groundwater outputs, and evapotranspiration from the watershed offset and are negligible.

Assuming an average lake volume of 29,030 ac-ft, residence time (a.k.a. "turnover time" or "flushing time") can be calculated as shown below. Residence time describes the theoretical time that a drop of water is in the lake from the moment it enters to the moment it exits the waterbody. A second interpretation is that this is the time it takes for the entire volume of water in the lake to be replaced by "new" water.

Paw Paw Lake Residence Time = Lake Volume / Avg. Outflow = 29,030 ac-ft / 17.5 cfs = 2.3 Years

Little Paw Paw Lake Residence Time = 1,436 ac-ft / 7.2 cfs = 0.3 Years

Task 1 Summary

As calculated above, the residence time of Paw Paw Lake is 2.3 years (or about 840 days) and 0.3 years (or about 110 days) for Little Paw Paw Lake. This means that a drop of water resides in the Paw Paw Lake for approximately 2.3 years or Little Paw Paw Lake for 0.3 years from the time it enters to the time it leaves.

The relatively short residence time for Little Paw Paw Lake provides a mechanism for the lake to better flush pollutants suspended in the water column. The shorter residence time means that the quality of the lake is determined largely by the quality of water flowing into the lake. Management of Little Paw Paw Lake for water quality should focus on watershed-based Best Management Practices (BMPs).

The residence time of 2.3 years in Paw Paw Lake suggests that the quality of the lake is influenced by the quality of surface water, lake-bottom sediment composition, and biological and chemical processes within the lake in addition to the quality of water flowing from the watershed into the lake. Management of Paw Paw Lake for water quality should focus on a balanced plan on in-lake and watershed-based BMPs for maximum impact to the lake's health.

Task 2: Nutrient and Sediment Budget

The L-THIA model was utilized to model theoretical nutrient loads based on land use, precipitation, and soils information. The model analyzed the watershed as a 5-meter by 5-meter grid. Each sub-watershed was analyzed and the entire Paw Paw Lake watershed was analyzed as a whole. Table 4 summarizes anticipated pollutant loading on a sub-watershed basis (based on precipitation data from 1 October 1965 to 30 September 1997). Appendix A provides this data in graphical format, as well as a kilogram-pollutant-per-acre comparison for each land use.

Total Phosphorus is used below to validate the model, as they have been the most consistently-sampled water quality parameter, both in-lake and in the tributaries themselves. Figure 2 shows an example of an additional benefit to utilizing the L-THIA model for watershed assessment. The map indicates areas of higher predicted phosphorus runoff based on land use and soil types. Maps for fifteen (15) pollutants within the watershed are provided in Appendix E; darker red indicates higher loading. The map legend is based upon kilograms of pollutant per grid cell (in this case, a 5 meter grid was utilized, so values are in kilograms per 25 square meters).

Table 3 compares average model results with average field data. It is important to understand that the L-THIA model is based on statistical predictions of pollutant loading based on nation-wide data sets. Each watershed will contain unique situations that may deviate from the model's predictions. Given this assumption, we must realize the value of the L-THIA model lies not only in its quantitative predictions, but also in its ability to help identify sub-watersheds contributing disproportionate pollutant loads, and the ability to locate pollutant sources within the watershed without intensive sampling.

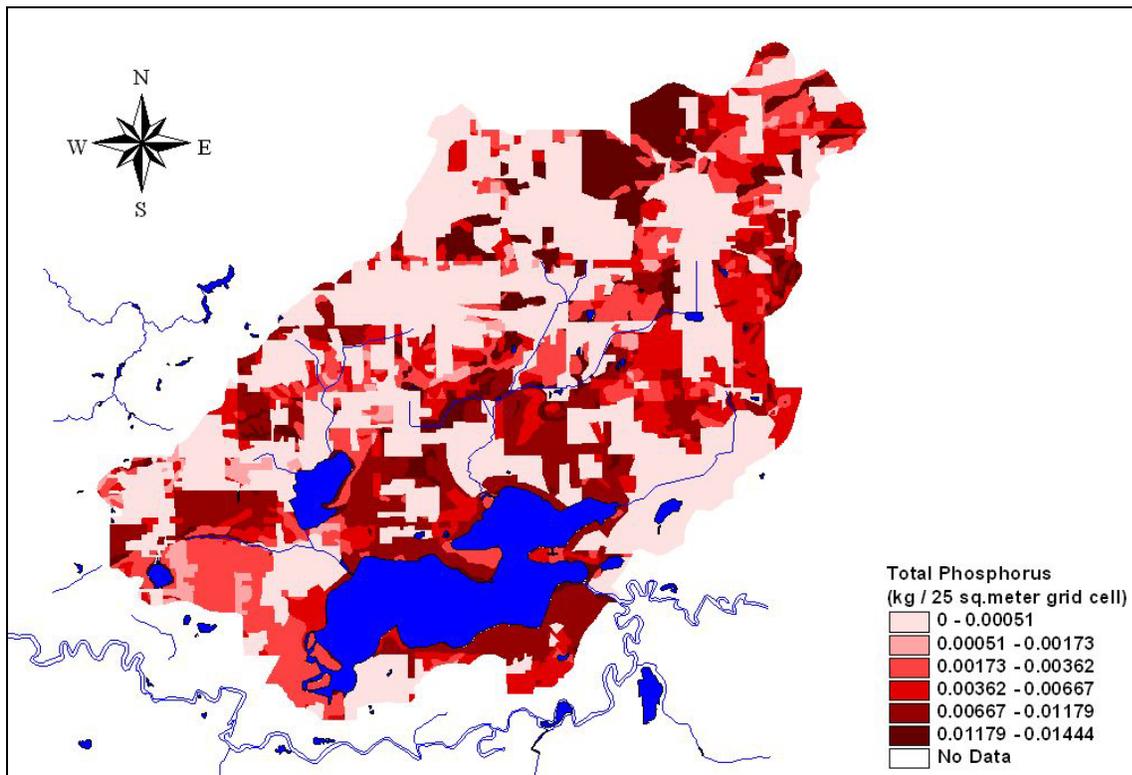


Figure 2: Total Phosphorus Loading in the Paw Paw Lake Watershed

Figure 2 shows an example of an additional benefit to utilizing the L-THIA model for watershed assessment. The map indicates areas of higher predicted phosphorus runoff based on land use and soil types. Maps for fifteen (15) pollutants within the watershed are provided in Appendix E; darker red indicates higher loading. The map legend is based upon kilograms of pollutant per grid cell (in this case, a 5 meter grid was utilized, so values are in kilograms per 25 square meters).

Table 3: Nutrient Modeling Validation (avg. values across all tributaries and sampling locations)

2007 Average* Measured Total Phosphorus (ug/L)	2001 - 2007 Average** Measured Total Phosphorus (ug/L)	Predicted Total Phosphorus (ug/L)
47.5	40.5	65.4

*Based on 18 samples

**Based on 80 samples

Primary productivity requires a specific amount of nitrogen, phosphorus, oxygen, hydrogen, carbon, silicon, calcium, potassium, magnesium, sulfur, sodium, and iron; fresh water systems are typically limited in production by the availability of either nitrogen or phosphorus, with other elements generally abundant in nature. Nitrogen is generally readily available and most freshwater inland lakes are limited in productivity (i.e. algal and plant growth) by phosphorus.

Table 4: L-THIA Model Results

	Total Nitrogen	Total Kjeldhal Nitrogen	Nitrate & Nitrite	Total Phosphorus	Dissolved Phosphorus	Suspended Solids	Dissolved Solids	Total Lead	Total Copper
Sub-watershed	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
Branch and Derby	2076.09	827.78	755.77	587.74	21.28	48140	568376	1.78	2.75
Culter Smith	48.92	19.59	18.31	12.86	0.77	1051	13444	0.07	0.12
Dedrick	414.81	174.81	149.91	110.52	11.52	8969	109795	0.68	1.11
Delfield Crumb	294.34	124.23	103.90	83.28	6.64	6982	77375	0.37	0.53
Green	452.29	187.05	160.62	128.99	8.53	10518	120622	0.45	0.68
Lake Stella Immediate	14.47	9.96	3.45	3.44	2.85	249	2075	0.08	0.14
Little Paw Paw Lake Drain	10.83	7.84	2.27	2.79	2.32	201	1357	0.06	0.10
Little Paw Paw Lake Immediate	173.50	90.41	51.12	50.95	14.35	4018	37487	0.34	0.56
McConnel Olcott	907.97	362.88	337.41	243.87	12.71	19938	249362	1.14	1.97
Potter	95.80	38.89	34.21	27.82	1.11	2328	25842	0.08	0.11
Paw Paw Lake - Coloma	550.28	409.13	95.79	167.24	116.42	12645	62353	2.39	3.90
Paw Paw Lake - Watervliet	661.88	491.91	117.82	197.05	138.74	15134	76038	3.02	4.90
Sherwood	215.15	84.17	82.99	53.97	2.73	4419	60267	0.36	0.64
<i>Little Paw Paw Lake*</i>	<i>637.23</i>	<i>284.81</i>	<i>219.34</i>	<i>174.33</i>	<i>26.64</i>	<i>14038</i>	<i>160725</i>	<i>1.10</i>	<i>1.78</i>
<i>Paw Paw Lake*</i>	<i>5916.34</i>	<i>2828.64</i>	<i>1913.56</i>	<i>1670.52</i>	<i>339.96</i>	<i>134592</i>	<i>1404393</i>	<i>10.83</i>	<i>17.50</i>
<i>Lake Stella*</i>	<i>14.47</i>	<i>9.96</i>	<i>3.45</i>	<i>3.44</i>	<i>2.85</i>	<i>249</i>	<i>2075</i>	<i>0.08</i>	<i>0.14</i>

***Sum of tributary sub-watersheds**

Table 4: L-THIA Model Results (continued)

	Total Zinc	Total Cadmium	Total Chromium	Total Nickel	Biological Oxygen Demand	Chemical Oxygen Demand
Sub-watershed	(kg)	(kg)	(kg)	(kg)	(kg)	kg
Branch and Derby	11.28	0.49	5.42	0.44	2925.49	2193.77
Culter Smith	0.32	0.02	0.15	0.02	81.53	79.27
Dedrick	3.49	0.14	1.26	0.24	940.32	1187.52
Delfield Crumb	3.20	0.08	0.76	0.16	604.79	801.26
Green	3.04	0.11	1.13	0.18	831.22	879.41
Lake Stella Immediate	0.51	0.01	0.05	0.06	154.23	294.31
Little Paw Paw Lake Drain	0.40	0.01	0.03	0.05	124.80	239.45
Little Paw Paw Lake Immediate	2.85	0.05	0.37	0.30	869.90	1480.18
McConnel Olcott	5.72	0.25	2.77	0.26	1439.01	1309.92
Potter	0.78	0.02	0.23	0.03	144.22	143.36
Paw Paw Lake - Coloma	21.46	0.20	0.90	2.52	6448.98	13075.51
Paw Paw Lake - Watervliet	26.92	0.27	1.25	3.07	7820.31	16429.02
Sherwood	1.37	0.07	0.76	0.06	324.39	281.38
<i>Little Paw Paw Lake*</i>	<i>6.66</i>	<i>0.21</i>	<i>1.78</i>	<i>0.55</i>	<i>1891.74</i>	<i>2746.97</i>
<i>Paw Paw Lake*</i>	<i>81.35</i>	<i>1.72</i>	<i>15.10</i>	<i>7.36</i>	<i>22709.18</i>	<i>38394.38</i>
<i>Lake Stella*</i>	<i>0.51</i>	<i>0.01</i>	<i>0.05</i>	<i>0.06</i>	<i>154.23</i>	<i>294.31</i>

***Sum of tributary sub-watersheds**

The average molar ratios of nitrogen to phosphorus to carbon (N:P:C) required for algal growth are approximately 15:1:105.ⁱⁱⁱ This ratio translates to approximately at 6.8:1 mass ratio for N:P, given that the atomic mass of N and P are about 14 amu and 31 amu respectively (i.e. $15 \times 14 : 1 \times 31 \approx 6.8:1$). Chapra^{iv} suggests that the ratio of N:P in biomass is about 7.2:1, so a ratio less than this level in the water indicates that phosphorus is limiting. Table 5 summarizes the annual total and dissolved (i.e. in the water) nutrient loads predicted in Paw Paw Lake and Little Paw Paw Lake.

Table 5: Analysis of Nitrogen:Phosphorus (N:P) Ratio of L-THIA Loading Estimates

	Total Nitrogen (kg)	Total Phosphorus (kg)	Total Ratio (N:P)	Kjeldahl Nitrogen (kg)	Nitrate & Nitrite (kg)	Total Dissolved Nitrogen (kg)	Dissolved Phosphorus (kg)	Dissolved Ratio (N:P)
Paw Paw Lake	5916.34	1670.52	3.54:1	2828.64	1913.56	4742.21	339.96	12.48:1
Little Paw Paw Lake	637.23	174.33	3.66:1	284.81	219.34	504.16	26.64	18.92:1

The data in Table 5: Analysis of Nitrogen:Phosphorus (N:P) Ratio of L-THIA Loading Estimates compare predicted loading only, and does not include internal recycling. As discussed in other sections of this report, the anoxic conditions in the hypolimnion are likely resulting in internal recycling of phosphorus, which would reduce the N:P ratio. Paw Paw Lake appears to be of a geometry and morphometry that phosphorus may be transferred from the hypolimnion to the epilimnion during periods of stratification due to turbulence in the lake.

Previous studies have suggested that nitrogen may be the limiting nutrient in the system during some portions of the year. 2007 sampling data collected by Water Quality Investigators in March and August suggests that the N:P ratio is near the 6.8-7.2:1 threshold derived above. A ratio of 10:1 to 20:1 has been previously suggested as a measurement in which phosphorus is clearly the limiting nutrient. This study concurs with the 10:1 to 20:1 rule, but seeks to provide a minimum ratio for primary (algal) production.

Table 6: 2007 Surface Water Data (collected by Water Quality Investigators, Inc.)

	Nitrate (ug/L)	Total Phosphorus (ug/L)	N:P Ratio
30 March 2007 – Paw Paw Lake			
Site 1	318	26	12.2:1
Site 2	310	19	16.3:1
Site 3	288	19	15.2:1
Site 4	288	23	12.5:1
Site 5	303	20	15.2:1
28 August 2007 – Paw Paw Lake			
Site 1	96	28	3.4:1
Site 2	66	26	2.5:1
Site 3	81	28	2.9:1
Site 4	66	24	2.8:1

Site 5	66	25	2.6:1
28 August 2007 – Little Paw Paw Lake			
Site 1	148	20	7.4:1
Site 2	140	22	6.4:1
Site 3	148	17	8.7:1

By combining the water budget with the L-THIA model results the concentration of pollutants with the tributary flow to the lakes can be calculated. Annual loads were assumed to be constant in concentration for the baseflow and surface runoff, given the monthly time step of the model. Table 7 provides a summary of inputs to the lakes, with concentrations reported at micrograms per liter.

An average monthly phosphorus budget was developed based upon the results of the L-THIA model, the water budget, and available sampling data. The annual anticipated total phosphorus loading of 1670.5 kg was distributed on a monthly basis proportional to surface runoff and baseflow. The March and August 2007 surface water samples were averaged for Paw Paw Lake and interpolated to compute concentrations for surface water and subsequent phosphorus outflows.

Table 7: Pollutant Loading Estimates

	Total Nitrogen	Total Kjeldhal Nitrogen	Nitrate & Nitrite	Total Phosphorus	Dissolved Phosphorus	Suspended Solids	Dissolved Solids	Total Lead	Total Copper
Sub-watershed	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
Branch and Derby	199.34	79.48	72.57	56.43	2.04	4622	54573	0.17	0.26
Culter Smith	100.23	40.14	37.52	26.34	1.58	2152	27542	0.15	0.25
Dedrick	98.56	41.54	35.62	26.26	2.74	2131	26089	0.16	0.26
Delfield Crumb	177.92	75.09	62.80	50.34	4.01	4221	46771	0.22	0.32
Green	201.54	83.35	71.57	57.48	3.80	4687	53750	0.20	0.30
Lake Stella Immediate	89.79	61.81	21.43	21.35	17.70	1545	12873	0.48	0.88
Little Paw Paw Lake Drain	71.60	51.80	15.01	18.42	15.36	1330	8975	0.38	0.67
Little Paw Paw Lake Immediate	99.80	52.00	29.40	29.30	8.26	2311	21561	0.20	0.32
McConnel Olcott	158.20	63.23	58.79	42.49	2.21	3474	43447	0.20	0.34
Potter	111.25	45.16	39.73	32.30	1.28	2703	30008	0.10	0.12
Paw Paw Lake - Coloma	413.26	307.25	71.93	125.60	87.43	9497	46826	1.79	2.93
Paw Paw Lake - Watervliet	515.73	383.30	91.80	153.54	108.10	11792	59249	2.35	3.82
Sherwood	99.46	38.91	38.36	24.95	1.26	2043	27859	0.17	0.30
<i>Little Paw Paw Lake*</i>	<i>99.05</i>	<i>44.44</i>	<i>33.98</i>	<i>27.14</i>	<i>4.24</i>	<i>2185</i>	<i>24897</i>	<i>0.17</i>	<i>0.28</i>
<i>Paw Paw Lake*</i>	<i>226.89</i>	<i>128.91</i>	<i>62.06</i>	<i>65.44</i>	<i>24.83</i>	<i>5172</i>	<i>44368</i>	<i>0.62</i>	<i>1.00</i>
<i>Lake Stella*</i>	<i>89.79</i>	<i>61.81</i>	<i>21.43</i>	<i>21.35</i>	<i>17.70</i>	<i>1545</i>	<i>12873</i>	<i>0.48</i>	<i>0.88</i>

*Average of tributary sub-watersheds (area-weighted)

Table 7: Pollutant Loading (continued)

	Total Zinc	Total Cadmium	Total Chromium	Total Nickel	Biological Oxygen Demand	Chemical Oxygen Demand
Sub-watershed	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
Branch and Derby	1.08	0.05	0.52	0.04	280.89	210.64
Culter Smith	0.66	0.04	0.31	0.03	167.02	162.40
Dedrick	0.83	0.03	0.30	0.06	223.43	282.17
Delfield Crumb	1.94	0.05	0.46	0.09	365.57	484.34
Green	1.35	0.05	0.51	0.08	370.40	391.87
Lake Stella Immediate	3.15	0.05	0.32	0.37	956.85	1825.98
Little Paw Paw Lake Drain	2.67	0.04	0.21	0.32	825.16	1583.19
Little Paw Paw Lake Immediate	1.64	0.03	0.21	0.17	500.34	851.36
McConnel Olcott	1.00	0.04	0.48	0.05	250.73	228.23
Potter	0.91	0.02	0.27	0.03	167.48	166.48
Paw Paw Lake - Coloma	16.12	0.15	0.68	1.89	4843.14	9819.63
Paw Paw Lake - Watervliet	20.98	0.21	0.98	2.39	6093.55	12801.41
Sherwood	0.63	0.03	0.35	0.03	149.95	130.07
<i>Little Paw Paw Lake*</i>	<i>1.05</i>	<i>0.03</i>	<i>0.27</i>	<i>0.09</i>	<i>298.81</i>	<i>436.82</i>
<i>Paw Paw Lake*</i>	<i>5.14</i>	<i>0.07</i>	<i>0.52</i>	<i>0.54</i>	<i>1482.20</i>	<i>2847.42</i>
<i>Lake Stella*</i>	<i>3.15</i>	<i>0.05</i>	<i>0.32</i>	<i>0.37</i>	<i>956.85</i>	<i>1825.98</i>

*Average of tributary sub-watersheds (area-weighted)

The known inflow, outflow, and surface water concentrations of total phosphorus allow an estimate of total phosphorus accumulation in the lakes. Inputs, outputs, and accumulation are summarized in Table 8: Phosphorus Budget for Paw Paw Lake. Paw Paw Lake is accumulating about 1350 kg of phosphorus annually; accumulation calculations were performed using the following equations. The impacts of phosphorus accumulated in the lake are discussed in Task 3 as part of the sediment survey.

$$\text{Accumulation (kg)} = \text{Input (kg)} - \text{Outflow (kg)}$$

$$\text{Outflow (kg)} = \text{Concentration (ug/L)} * \text{Outflow Volume (m3)} * (1000 \text{ L} / 1 \text{ m3}) * (1 \text{ kg} / 10^9 \text{ ug})$$

Table 8: Phosphorus Budget for Paw Paw Lake

	Surface Water Concentration (ug/L)	Total Phosphorus Input (kg)	Total Phosphorus Outflow (kg)	Total Phosphorus Accumulation (kg)
January	22.77	102.56	17.75	109.23
February	22.09	102.56	31.16	95.82
March	21.40	125.63	37.04	48.90
April	22.36	161.61	34.01	90.30
May	23.32	146.78	18.14	94.09
June	24.28	152.81	21.12	97.14
July	25.24	144.42	14.49	95.39
August	26.20	150.61	22.93	152.36
September	25.51	177.03	45.69	159.06
October	24.83	140.88	27.89	143.52
November	24.14	145.95	30.55	139.83
December	23.46	119.68	20.36	123.74
<i>Average</i>	28.80	139.21	26.76	112.45
<i>Annual total</i>	--	1670.52	321.13	1349.39

Task 2 Summary

While the total N:P loading ratio indicates that nitrogen may be limiting (ratio < 6.8-7.2:1), primary aquatic production will occur using dissolved nutrients. The dissolved N:P loading ration indicates that phosphorus is the limiting nutrient. The system is, therefore, sensitive to increased loading in phosphorus. Additional dissolved phosphorus input may degrade water quality of Paw Paw Lake and Little Paw Paw Lake. As production in the hypolimnion uses all available dissolved oxygen, the sediment begins to release phosphorus as oxygen is stripped from otherwise stable compounds in the sediment. The increased P in the lake allows for additional production, or plant growth, in the lake. This added organic matter compounds the internal recycling.

Table 6 suggests that Paw Paw Lake may be nitrogen-limited during the summer months. It is notable that the samples collected are comparing nitrate to total phosphorus, and may not be representative of the

nutrients available in the water column. It is important to recognize that these samples provide a snapshot in time of a dynamic system, and additional sampling should be performed to verify these data.

If nitrogen is, in fact, the limiting nutrient during periods of the year this is due to the unnatural abundance of phosphorus in the lake (i.e. enough phosphorus enters the water column through inputs from the watershed and internal recycling that the minimum ratio for production is not limited by phosphorus). In this case a reduction in nitrogen entering the lake may have some impact on water quality. While it appears that during summer months the lake may be limited by nitrogen, the ultimate cause of the increased level of productivity is the elevated phosphorus concentration.

Harvesting of aquatic vegetation has been recommended as a Phosphorus-control measure in subsequent sections. This removal also combats the accumulation of organic matter on the lake bottom and serves to reduce the oxygen demand of the decaying bottom sediments.

Task 3: Bathymetric Survey, Sediment Survey, and Water Quality Profiles

A bathymetric survey of Paw Paw Lake, Little Paw Paw Lake, and Lake Stella was completed in August 2007, with a transect spacing of approximately 400 to 600 feet. In preparation for this survey Spicer Group prepared and revised a survey plan with input from the PPLF, and developed a survey control network necessary to complete the bathymetric survey of the project lakes. Data collected was processed and a Digital Elevation Model (DEM) of the lake bottom was developed. Maps for each lake were developed, with contours shown at 5-foot intervals for each, and have been delivered in both hard copy format, and electronically as JPG, PDF, and SHP formats.

PPLF volunteers were trained on use of a GPS unit and survey rod for sediment depth soundings in selected locations. Equipment was provided for use for a period of ten (10) business days for the initial survey, and again for approximately twenty (20) business days to characterize a morphological feature on the lake bottom at the request of the PPLF. Data was processed and sediment depth maps for six (6) locations in Paw Paw Lake were developed based on pole soundings. In addition to these maps, estimates of dredge volume to remove unconsolidated sediment have been developed, and are summarized below in Table 9. These estimates are based upon the boundaries of the sediment depth mapping completed by PPLF volunteers. A dredge plan must be developed and permitting requirements met before any dredging of the lake can take place.

Table 9: Estimated Dredge Volumes and Costs for Selected Locations on Paw Paw Lake

Region	Location	Area (ac)	Sediment (ac-ft)	Estimate of Cost
A	West end of South Lobe	4.46	0.3	\$9,000
B	North Site of South Lobe	4.37	2.2	\$64,000
C	Lake Stella / Paw Paw River Inlet	7.23	10.4	\$302,000
D	Sherwood Drain Outlet	8.57	21.9	\$636,000
E	Branch & Derby Drain Outlet	1.28	1.1	\$32,000
F	West Bay in North Lobe	1.39	5.6	\$163,000

Twenty (20) sediment samples were collected from a total of fifteen (15) locations on Paw Paw Lake and Little Paw Paw Lake in four (4) to ten (10) feet of water depth. No laboratory or chemical analysis of these samples was completed. The samples were characteristic of moderate organic content in several locations. Sulfuric odor of many samples indicates anoxic conditions at and within the sediment. This is likely an accumulation of organic matter on the lake bottom due to eutrophication. It must be noted that the samples collected were from shallow areas of the lake, where resuspension is likely high, and demonstrated little organic “muck” accumulation. Samples collected from deeper portions of the lake, as in the 2004-2006 study by Dr. Fusiller^v, demonstrated higher organic content because settling occurs at a much higher rate in these deeper areas of the lake.

Water quality profiles were collected on August 6th, 2007 at three (3) locations on Paw Paw Lake and one (1) location on Little Paw Paw Lake. Figure 3, below, provides a representative dissolved oxygen profile; all data collected is included as an attachment to this letter. The profiles collected suggest stratified lakes with severe anoxia in the hypolimnion.

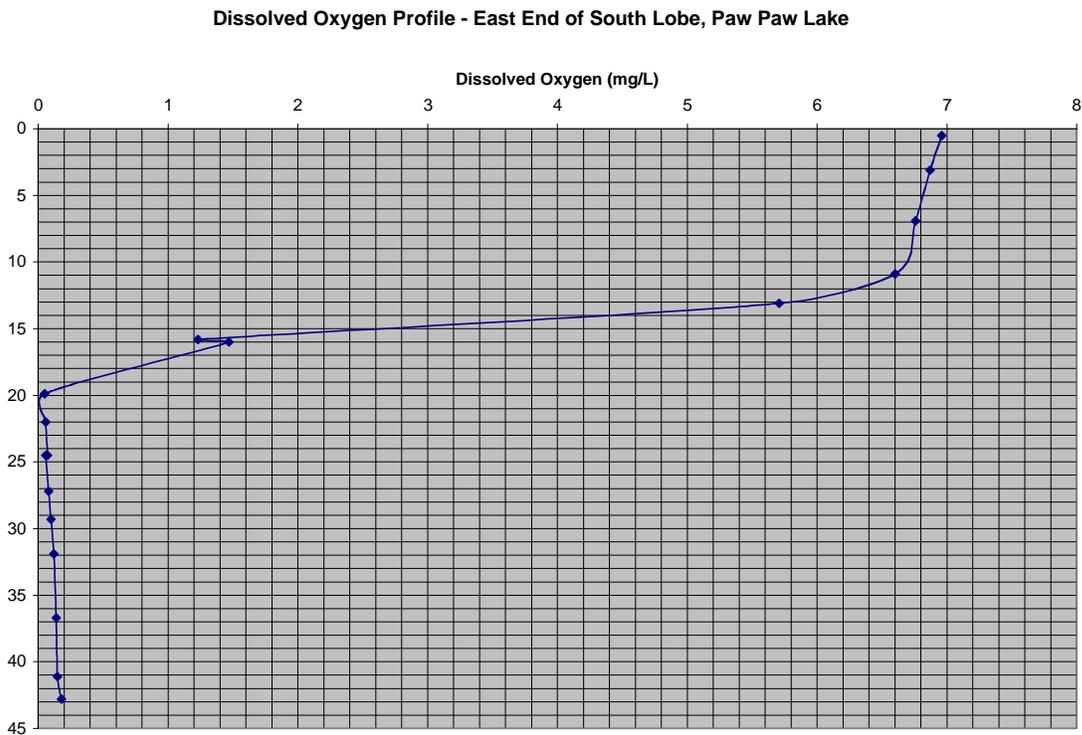


Figure 3: Typical Dissolved Oxygen Profile

Water quality data collected by Dr. Fusiller in 2007 suggests that phosphorus is relatively constant throughout the water column (see Table 10 below)^{vi}. Studies from 1976^{vii}, 1980^{viii}, and 2006^{ix} suggest that phosphorus retained in the lake settles to the bottom and serves as a nutrient source (described as “internal recycling” of nutrients).

Table 10: Paw Paw Lake Depth and Nutrient Data (data collected 28 August 2007 by Water Quality Investigators, Inc.)

Depth (ft)	0	10	20	30	40	50	60	70	80	90
Total Phosphorus (ug/L)	24	24	22	21	22	24	23	24	28	31
Temperature (deg C)	25	25	23	13	10	9	8	8	8	8

Despite the initial appearance of consistency in the 2007 data, internal recycling of nutrients appears to be present in Paw Paw Lake and Little Paw Paw Lake. Table 11 presents averages for the epilimnion, metalimnion, and hypolimnion. While the average difference between epilimnion and hypolimnion appears minimal at 2.2 ug/L (and is significantly less than the differentials recorded in the past), this concentration difference in the 5820 ac-ft hypolimnion represents about 15 kg of phosphorus in the water column below the thermocline. For comparison purposes, the entire lake at a concentration of 23 ug/L contains about 828 kg of phosphorus in 29,172 ac-ft of water.

Table 11: Paw Paw Lake Total Phosphorus Data by Lake Strata (data collected 28 August 2007 by Water Quality Investigators, Inc.)

Lake Strata	Depth of Data Points Included (ft)	Total Phosphorus (ug/L)
Epilimnion	0, 10, 20	23.3
Metalimnion	20, 30, 40	21.7
Hypolimnion	40, 50, 60, 70, 80, 90	25.5

Task 3 Summary

The annual accumulation of phosphorus in the lake is stored in the bottom sediments. Phosphorus accumulates when organic materials dies and settles to the bottom, and when phosphorus attached to suspended sediment particles settles to the lake bottom. Anoxic conditions (as noted in the dissolved oxygen profiles) found in the hypolimnion cause the release of phosphorus from bottom sediments into the water column.

Pole soundings completed by PPLF volunteers located sedimentation of up to six feet in areas surveyed. It is important to note that these soundings were not completed across the lake. Obtaining deep-water samples from the lake bottom would aid in understanding where accumulation is taking place in the lakes, and a detailed aquatic vegetation or “weed” map should be compared to these bottom samples.

Task 4: Tributary Drain Assessment

Preliminary Inspection

Prior to any inspection by Spicer Group, Frank Jurenka completed a preliminary survey of tributary drains within the watershed. This preliminary assessment provides a brief summary of each drain, and was used to focus the efforts of Spicer Group on the Branch and Derby Drain. The following is a summary of Jurenka's comments for each drain:

Sherwood Drain

Nutrient data has always shown concentrations well below lake level. Visual inspection of flow has shown clear water.

Dedrick Drain

Modest nutrient level based on sampling. Drain investigated and found to be largely sandy substrate. Sand bar at outlet of drain into Little Paw Paw Lake. Visual inspection of flow is clear even during rain events.

Delfield and Crumb Drain

Concern over nutrient levels. Twenty-foot (20) buffer along the DeGroot agricultural fields. Significant portion of watershed is agricultural land use.

McConnell and Olcott Drain

Nutrient data are modest relative to the Paw Paw Lake. Visual inspection of water is clearer than the Branch and Derby Drain (its receiving water) during storm events.

Green Drain

No conclusive nutrient data. Minimal agricultural area within the watershed. The Paw Paw Lake Foundation attempted to divert this drain into an existing wetland; the diversion was unsuccessful and the drain was reopened in 2007.

Little Paw Paw Lake Immediate Area

Approximately 19% residential land use within watershed. Many drains are operated by the road commission.

Little Paw Paw Lake Drain

Pond at Paw Paw Lake Road serves as a sedimentation basin for tributary drains.

Branch and Derby Drain

Highest nutrient levels of all drains. Significant blueberry production in watershed (fertilizer contains no phosphorus and high nitrogen). Historically high *E. Coli* levels; have not been tested in recent past. The reach between M-140 and Hagar Shore Road appears to be in good condition. The channel between Paw Paw Lake Road and the lake has been dredged several times in the past.

Inspection of the Branch and Derby Drain (Sta. 0+00 to 145+00)

For inspection purposes, the drain was divided into reaches exhibiting similar characteristics. Reaches are described below and each includes a representative photograph. All references to left and right are assumed to be looking upstream. A crossing summary is provided in Table 12.

In summary, the drain between Paw Paw Lake and the Hagar Shore Road Crossing (the lower approximately 1.2 miles) is experiencing significant bank erosion and sloughing. The drain upstream of this reach is largely stable and well-vegetated, with a vegetated buffer between the drain and adjacent land use. Maintenance of the lower reach of the drain will reduce erosion and sediment loads reaching Paw Paw Lake.

Paw Paw Lake Outlet to Paw Paw Lake Road Crossing (Paw Paw Lake to Sta. 0+25)

Seawalls and stabilized banks are present on both sides of the drain. Sheet piling and concrete have been used to stabilize banks in a majority of this reach. Vegetation of drain banks appears to be well established where seawalls are not present.



Figure 4: Looking upstream from Paw Paw Lake

Paw Paw Lake Road Crossing to Paw Paw Lake Road Crossing (Sta. 0+25 to 55+75)

- Vegetation is not established on high banks in several locations, likely due to the heavy canopy.
- Toe of slope erosion and bank sloughing are widespread through this reach, with significant erosion occurring on all outside bends of the drain.
- Near-vertical banks are present in multiple locations.
- Log jams have impeded or redirected flow in several locations in the drain.
- Upstream of the southern Paw Paw Lake Road Crossing the drain appears to have an accessible floodplain.

- Adjacent land use largely undeveloped, wooded lots with the exception of one home in the lower end of the reach.
- An access lane is present along the left side of the drain for approximately 40% of the reach.
- An outfall was observed at approximately Sta. 51+00 (see photo 065).



Figure 5: Typical Erosion, Sloughing, and Floodplain between Sta. 0+25 and 55+75

Paw Paw Lake Road Crossing to Hagar Shore Road Crossing (Sta. 55+75 to 61+75)

- Vegetation is well established on the drain banks in most locations.
- Erosion and bank sloughing are present at Sta. 60+00. Approximately 150 linear feet of the drain bank are bare soil 10-12 feet high.
- A buffer of undeveloped woods and meadow parallels the drain. Agricultural fields are present in the more distant overbanks.



Figure 6: Bank Erosion and Sloughing at Sta. 60+00

Hagar Shore Road Crossing to M-140 Road Crossing (Sta. 61+75 to 87+00)

- Not Inspected.

M-140 Road Crossing to N. Watervliet Road Crossing (Sta. 87+00 to 126+00)

- Vegetation is well-established along a majority of the drain and banks.
- A pasture with unrestricted access to the drain is present from Sta. 92+00 to 94+50.
- Adjacent land use is mostly undeveloped, wooded land.
- Heavy brush is present in the channel and on the drain banks in multiple locations.
- Bank erosion of approximately 100 linear feet is present near Sta. 118+50.



Figure 7: Typical Channel for Sta. 87+00 to 126+00. Looking downstream at bank erosion near Sta. 118+50.



Figure 8: Looking downstream at pasture with unrestricted access to drain

N. Watervliet Road Crossing to Private Crossing (Sta. 126+00 to 145+50)

- Vegetation is well established on drain banks in most locations.
- A buffer of natural vegetation existing between adjacent agricultural land use and the drain in most locations.
- Washouts are present at Sta. 127+00, 128+50, 129+00, and 135+00 from the right side of the drain. All should be stabilized with riprap spillways.

- Erosion is present for approximately 100 feet on the right bank near Sta. 131+50.



Figure 9: Looking downstream from Sta. 145+50

Table 12: Crossing Summary

Approx. Station	Road / Owner	Surface Type	Crossing Type	Crossing Condition	Headwall Type	Headwall Condition	Erosion	Sedimentation	Notes
0+25	Paw Paw Lake Road	Bituminous	Concrete Bridge	Good	Concrete	Good	Yes	No	Erosion from roadside ditches
36+00	Private	Wood	Footbridge	Good	--	--	No	No	No debris present
55+75	Paw Paw Lake Road	Bituminous	CMP	Fair	Mitered	Fair	Minor	0.5-1 ft	Corrosion, erosion from roadside ditch SE of crossing
61+75	Hagar Shore Road	Bituminous	CMP	Good	Projecting	Fair	No	<0.5 ft	No debris present
87+00	M-140	Bituminous	Twin RCP	Good	Concrete	Good	No	<0.5 ft	Neither RCP appears to be favored by flow
94+50	Private	Gravel	Concrete Bridge	Fair	Concrete	Poor	No	<0.5 ft	Headwalls cracking and spalling
100+75	Private	Wood	Steel I-beam Bridge	Fair	Earth	Fair	No	<0.5 ft	Debris accumulation upstream
126+00	N. Watervliet Road	Bituminous	Steel I-beam Bridge	Fair	Concrete	Fair	No	No	No debris present
145+50	Private	Native	CMP	Good	Projecting	Good	No	<0.5 ft	No debris present.

Task 4 Summary

Maintenance needs are present on the Branch and Derby Drain to the degree that a petition to improve the drain is recommended at this time. A petition will allow the Drain Commissioners to address these issues all at once, rather than piecing together a solution through maintenance funds over the course of several years.

The residential drains, tributary to the lakes, are likely a source of significant pollutant loading given the L-THIA model results. These drains should be mapped and inspected in coordination with the Berrien County Drain Commissioner, Watervliet Township, and Coloma Township as appropriate. It is further recommended that a maintenance inspection of additional tributary open drains be completed and the results provided to the Drain Commissioner(s) for their review.

Watershed and Lake Management Practices

Management of lakes and their watersheds is a process that requires a well-researched and planned strategy to meet the goals and objectives of all stakeholders in the watershed.

In-Lake Management Techniques^x

A number of in-lake management alternatives have been successfully implemented in inland lakes to meet the goals and objectives of stakeholders. Many in-lake techniques are focused on treating the symptom rather than the cause of problems in the lake. It is important to understand both the symptoms and causes of lake issues, as treating the symptoms and ignoring the causes may lead to endless and increasing management costs to address continued pollutant loading and degradation. Table 13 provides cost estimates for the following management techniques.

1. Aeration of Hypolimnion
 - a. Description:
Addition of oxygen to hypolimnion to create oxic conditions.
 - b. Benefits:
Reduced internal recycling of phosphorus, improved aquatic habitat, improved water quality.
 - c. Disadvantages:
May cause destratification of lake (harmful to ecosystem).
 - d. Notes:
May be cost prohibitive.

2. Circulation
 - a. Description:
Mixing of water to reduce thermal stratification and improve anoxic conditions in hypolimnion.
 - b. Benefits:
Oxygenation of hypolimnion, disrupted growth of some algae, may eliminate localized issues.
 - c. Disadvantages:
May spread local issues throughout lake, may increase oxygen demand, may increase turbidity in-lake.

3. Dilution / Flushing
 - a. Description:
Addition of clean water to the lake to increase flushing of pollutants and reduce residence time.
 - b. Benefits:
Reduce concentration of nutrients in-lake, reduced response to increased pollutant loading.
 - c. Disadvantages:
Downstream water body must be able to receive additional water and pollutants, may disturb ecosystem in-lake.

4. Water Level Control (Drawdown / Flooding)
 - a. Description:
Control of water level in-lake to achieve multiple objectives.
 - b. Benefits:
Drawdown provides aeration, compaction, and decomposition of bottom sediments and nutrients. Drawdown may also kill rooted vegetation. Flooding may kill rooted vegetation.
 - c. Disadvantages:
Degradation of emergent wetlands, degradation of shoreline ecosystem, alteration of downstream flows.

5. Dredging
 - a. Description:
Removal of bottom sediment.
 - b. Benefits:
Removal of source of nutrient recycling. Aquatic vegetation may be removed by dredging. Increased water depth increases navigation and may decrease aquatic vegetation growth through shading.
 - c. Disadvantages:
Destruction of existing habitat, significant permitting and engineering requirements, disposal facility must be located.
 - d. NOTE: Dredging of small portions of the lakes is not likely to have a significant impact on overall lake water quality. This type of dredging may improve navigation, recreational opportunity, and localized weed growth in some situations. Dredging to create an in-lake sedimentation basin is not recommended due to ongoing maintenance expenses and a difficult permitting process.

6. Dyes / Benthic Barriers
 - a. Description:
Introduction of dyes or shading layers to reduce light penetration in lake. Benthic barriers prevent plant growth.
 - b. Benefits:
Reduced algal growth. Reduced aquatic vegetation growth, may cover undesirable substrate.
 - c. Disadvantages:
May facilitate anoxic conditions at sediment interface, does not control surface growth, limits recreational use of lake.

7. Water Withdrawal
 - a. Description:
Withdrawal of water from a specific strata of the lake; typically the low-oxygen high-nutrient water in the hypolimnion is removed.
 - b. Benefits:
Removes nutrients from the water column, may prevent/reduce anoxia in hypolimnion, may enhance coldwater fisheries downstream.

- c. Disadvantages:
Receiving body must be capable of increased flow, may result in degradation of downstream water body if not treated, may eliminate in-lake cold water habitat, may cause lake level drawdown.
8. Algaecide / Herbicide
- a. Description:
Use of a chemical designed to kill algae or aquatic vegetation.
 - b. Benefits:
Rapidly eliminates algae and/or aquatic vegetation. May result in movement of nutrients from water column to lake bottom. Localized and whole-lake treatments.
 - c. Disadvantages:
May be toxic to non-targeted organisms, may restrict water use after treatment, decaying organic matter may increase oxygen demand and create anoxic conditions, may encourage nutrient recycling.
 - d. Notes:
A variety of chemical treatments are readily available and may be applied by a licensed applicator. A contact herbicide kills on contact and organic matter remains in the lake for decomposition; a systemic herbicide is taken-up by the plant and kills the organism to the root, preventing future growth.
9. Phosphorus Inactivation
- a. Description:
Chemical treatments are applied to the lake to (1) precipitate phosphorus from the water column and (2) bind phosphorus in a form that cannot be released back into the water column.
 - b. Benefits:
Rapid decrease in phosphorus in water column, minimized nutrient recycling potential, may remove excess nitrogen from water column.
 - c. Disadvantages:
May be toxic to fish and macroinvertebrates, anoxic conditions may still cause phosphorus release, may cause fluctuation in water chemistry, increased clarity may allow aquatic vegetation to spread, flocculated particles may be resuspended in littoral zone.
10. Sediment Oxidation
- a. Description:
Calcium nitrate is injected into bottom sediments to oxidize (decompose) organic matter and promote denitrification.
 - b. Benefits:
Reduced phosphorus supply from internal recycling, may decrease sediment oxygen demand.
 - c. Disadvantages:
Degradation of benthos, long-term effects unknown.
 - d. Notes:
High external loading may overwhelm effects of treatment.

11. Biological Controls

- a. Description:
Species are introduced or encouraged to thrive in the ecosystem.
- b. Benefits:
Natural processes used to control algae and aquatic vegetation.
- c. Disadvantages:
Effects may not be controllable or naturally sustainable. Unanticipated ecosystem response. May migrate into other ecosystems.

12. Mechanical Removal

- a. Description:
Harvesting and disposal of aquatic vegetation. May include hand pulling, cutting, rototilling, harvesting, hydroraking.
- b. Benefits:
Can be applied to localized areas. May be used to balance recreational needs with ecosystem. Removes nutrients and oxygen demand from lake.
- c. Disadvantages:
May generate turbidity, may remove non-invasive species, may spread undesirable species through fragmentation.

Table 13: Cost Estimates for In-Lake Management Practices ^x

Cost estimates adjusted from 2001 estimates utilizing the following equation: 2006 Cost = 2001 Cost / 0.861

No.	In-Lake Management Practice	Per-acre Cost		Paw Paw Lake Whole-lake Cost (a)	
1	Aeration of Hypolimnion	\$929	\$3,484	\$827,875	\$3,104,530
2	Circulation	\$581	\$8,130	\$517,422	\$7,243,902
3	Dilution / Flushing (b)	\$581	\$2,904	\$517,422	\$2,587,108
3	Dilution / Flushing (b)	\$5,807	\$29,036	\$5,174,216	\$25,871,080
4	Water Level Control	\$0	\$6	\$0	\$5,174
5	Dredging (d)	\$17,422	\$92,915	\$15,522,648	\$82,787,456
6	Dyes	\$116	\$581	\$103,484	\$517,422
6	Benthic Barriers (e)	\$23,229	\$58,072	\$20,696,864	\$51,742,160
7	Water Withdrawal (f)	\$1,161	\$3,484	\$1,034,843	\$3,104,530
8	Algaecide / Herbicide (g)	\$58	\$2,323	\$51,742	\$2,069,686
9	Phosphorus Inactivation (h)	\$581	\$1,161	\$517,422	\$1,034,843
10	Sediment Oxidation	\$9,292	\$13,937	\$8,278,746	\$12,418,118
11	Biological Controls	\$581	\$3,484	\$517,422	\$3,104,530
12	Mechanical Removal (harvesting)	\$232	\$1,858	\$206,969	\$1,655,749

Notes:

- (a) Assumes 891 acres, or the entire Paw Paw Lake. Little Paw Paw Lake is approximately 102 acres in size and cost may be approximated based on the per-acre costs provided.
- (b) Assumes water is readily available
- (c) Assumes water pumping, piping, and treatment is required
- (d) Assumes 2-5 feet of sediment removal
- (e) Includes annual maintenance expense
- (f) Includes infrastructure and treatment
- (g) Dependant upon chosen chemical, application rate, and number of treatments
- (h) Alum (or similar) treatment

Watershed Management Techniques

The health of Paw Paw Lake and Little Paw Paw Lake are dependant upon the inputs received from their respective watersheds. As discussed above, the watershed provides a significant input of nutrients to the lake that result in degradatation of water quality and recreational opportunities on the lake.

1. Public Education
 - a. Description:
Public education and involvement with the health of the lakes and their tributaries is a vital part of a successful lake and watershed management plan. Non-point source pollution is a result of the daily activity of watershed residents and their education is critical in the preservation, restoration, and enhancement of the ecosystem.
 - b. Benefits:
Low-cost and high-return investment, develops a sense of community.
 - c. Disadvantages:
Requires effort from motivated individuals to sustain an education program.

2. Residential Fertilizer Reduction
 - a. Description:
Eliminate a direct source of nutrients in the watershed. Phosphorus-free fertilizers are readily available on a national level and can be carried by stores.
 - b. Benefits:
Reduced direct nutrient loading to the lakes.
 - c. Disadvantages:
Requires change in thinking for watershed residents, requires coordination with retailers.

3. Street Sweeping Program
 - a. Description:
Sweeping of streets to remove accumulated sediment and prevent it from entering the storm drainage system.
 - b. Benefits:
Reduced sediment load to lakes.
 - c. Disadvantages:
Cost of activity.

4. Lawn Waste Collection & Disposal
 - a. Description:
Collection and proper disposal of lawn clippings, leaves, woody debris, etc.
 - b. Benefits:
Reduced organic matter loading to lakes will reduce nutrient input and oxygen demand in the lake.
 - c. Disadvantages:
May require specialized pick-up or composting facilities for disposal. May be difficult to coordinate.

5. Streambank Stabilization
 - a. Description:
Stabilization of eroding streambanks to reduce sediment load reaching lakes.
 - b. Benefits:
May be performed as maintenance under the Michigan Drain Code. Reduced pollutant load.
 - c. Disadvantages:
Permitting may be difficult for tributaries that are not county drains.

6. Sedimentation Basin / Treatment Wetland
 - a. Description:
Construction of a sediment basin with wetland vegetation that can be maintained. Often located at or near the outlet to tributaries to the lakes.
 - b. Benefits:
Reduced sediment and nutrient load reaches the lakes.
 - c. Disadvantages:
Requires regular maintenance, may require land acquisition. May be completed under the Michigan Drain Code.

7. Drain Inspection and Maintenance
 - a. Description:
Inspection and regular maintenance of drainage systems tributary to the lakes.
 - b. Benefits:
Regular inspection and maintenance identifies and corrects pollutant sources and causes.
 - c. Disadvantages:
Michigan Drain Code limits maintenance to \$2,500 per mile per year. Some landowners are in multiple drainage districts and could face assessment in each district.

8. Buffer Strips (on-lake)
 - a. Description:
Establishment of a 10-20 foot strip of native vegetation at the water's edge (on land).
 - b. Benefits:
Provides filtration for runoff from lawns. Reduce sediment and nutrient loading reaching the lakes. Native vegetation provides habitat and may discourage nuisance waterfowl.
 - c. Disadvantages:
Not a traditional lawn area, may be met with resistance from homeowners.

9. Buffer Strips (off-lake)
 - a. Description:
Non-production buffers between tributary drains and agricultural fields.
 - b. Benefits:
Native vegetation filters sediment and nutrients before runoff reaches the drainage system.
 - c. Disadvantages:
Requires coordination with non-lakefront landowners, may be costly to implement.

10. Construction Activity Soil Erosion and Sedimentation Control (SESC)
 - a. Description:
Reduction of sediment reaching tributary drains and the lakes themselves due to earth disturbance related to construction activities.
 - b. Benefits:
Reduced pollutant loading to the lakes.
 - c. Disadvantages:
Requires more strict enforcement of SESC plans.

11. Agricultural Best Management Practices
 - a. Description:
Agricultural practices such as conservation tillage, contour farming, crop rotation, fertilizer management, pesticide management, and cover cropping may reduce sediment and nutrient loading reaching the lake.
 - b. Benefits:
Improved agricultural production and efficiency.
 - c. Disadvantages:
Requires coordination with non-lakefront landowners. Practices may be costly to implement.

12. Low Impact Development Retrofits
 - a. Description:
Retrofit of existing drainage systems to replicate historic hydrology and/or provide treatment before discharge to drainage system.
 - b. Benefits:
Reduced runoff reaches drainage system. Treatment of first-flush of polluted runoff.
 - c. Disadvantages:
Retrofits may require easements to construct and maintain.

13. Low Impact Development Requirements
 - a. Description:
Require low-impact development techniques and first-flush treatment for new development within the watershed.
 - b. Benefits:
Reduced runoff reaches drainage system. Treatment of first-flush of polluted runoff.
 - c. Disadvantages:
May be difficult to enact or enforce.

14. Seawall Retrofit
 - a. Description:
Retrofit of seawalls to absorb rather than reflect wave energy.
 - b. Benefits:
Reduced resuspension of bottom sediments due to wave activity. May reduce transfer of phosphorus from hypolimnion to epilimnion during stratified periods. Increased in-lake habitat.
 - c. Disadvantages:
Requires buy-in of lakefront landowners. May be disruptive to implement during busy months on the lake.

Table 14: Cost Estimates for Watershed Management Practices

No.	Watershed Management Practice	Estimated Cost	Notes / Assumptions
1.	Public Education	\$3,000 to \$5,000	Consultant development of materials and facilitation of three educational meetings. Development of public opinion survey.
2.	Residential Fertilizer Reduction	Unknown	PPLF volunteer coordination with township and county government. Legal fees may be incurred in development of an ordinance or policy.
3.	Street Sweeping Program	\$65 to \$150 per curb-mile	Includes disposal costs for sediment collected
4.	Lawn Waste Collection & Disposal	Unknown	May be coordinated with local pickups. Many government entities aid in organization and coordination of this service on a local or regional basis.
5.	Streambank Stabilization	\$50-\$200 per foot	Includes engineering, survey, permitting, construction
6.	Sedimentation Basin / Treatment Wetland	\$5,000 to \$15,000	As part of drain maintenance project and within existing right of way
7.	Drain Inspection and Maintenance	\$750 to \$1,500 per mile	Depends upon level of inspection and data collection required
8.	On-lake Buffer Strips	\$1 to \$10 per sq.ft. of practice	Varies with plant selection and level of volunteer effort.
9.	Off-lake Buffer Strips	\$20,000 to \$80,000 per acre of practice	Assumes permanent conservation easement is purchased. Actual cost depends on landowner.
10.	Construction Activity SESC	Unknown	Varies with each development or construction project.
11.	Agricultural Best Management Practices (BMPs)	Unknown	Varies with equipment and techniques currently utilized. Public education estimate includes distribution of agricultural BMPs
12.	LID Retrofits	\$10 to \$20 per sq.ft. of practice	Constructed wetlands, vegetated swales, and rain gardens may be constructed to treat runoff from existing conditions.
13.	LID Requirements	\$2,500 to \$10,000	PPLF volunteers and local governmental entities coordinate. Fee is estimated for consultant and/or legal fees.
14.	Seawall Retrofits	\$150 to \$500 per lin.ft.	Assumes riprap or cobble placed on seaward side of wall. May include planting of native vegetation. Permitting costs not included.

Recommended Implementation Actions

Based upon a review of previous studies, assessment of the lake and watershed completed as part of this study, the Management Practices outlined above, and our understanding of the goals of the Paw Paw Lake Foundation, Spicer Group recommends implementation of the following activities (prioritized in the order as listed):

1. Aquatic Vegetation Management & Habitat Survey

- a. Conduct an aquatic vegetation and habitat survey of Paw Paw Lake and Little Paw Paw Lake. A limnologist will identify habitat values throughout the lake and provide management input for aquatic habitat and permitting.
 - I. Assess habitat quality of shoreline land use and shallow-water habitat around the lakes.
 - II. Obtain and review fisheries information within the lake and desired fisheries for the water body. Existing fisheries will be identified and opportunities for enhancement prioritized with cost estimates.
 - III. Develop a map of high-quality natural habitat within the lakes.
 - IV. Develop a map of boating/recreational traffic for the lakes.
 - V. Develop a map of aquatic vegetation and proposed control measures for the lakes.
- b. Treat Aquatic Vegetation with a Systemic Herbicide (such as 2,4-D or Fluridone) rather than using contact herbicides. It is ***not recommended*** that an algaecide be used on Paw Paw Lake or Little Paw Paw Lake at this time. It is ***not recommended*** that a whole-lake treatment (i.e. Sonar / Fluridone) be implemented until the work described in part (a) is completed.
- c. Investigate weed harvesting methods for implementation rather than chemical treatment. Some aquatic vegetation (including Eurasian Milfoil) spread by fragmentation and harvesting these plants could spread their territory in the lake.

2. Continue Water Quality Monitoring Efforts,

- a. At three (3) stations in Little Paw Paw Lake and seven (7) stations within Paw Paw Lake: Water clarity using Secchi Disc at each location, monthly.
- b. At one (1) station in Little Paw Paw Lake and at least one (1) station within Paw Paw Lake: Vertical profile in-lake at 10-foot intervals, once per season Spring to Fall:
 - I. Temperature
 - II. pH
 - III. Dissolved Oxygen
 - IV. Nitrogen (as Nitrate / Nitrite and Total Nitrogen)
 - V. Phosphorus (as Total Phosphorus)
 - VI. Chlorophyll-a
- c. At six (6) stations within the Paw Paw Lake Watershed: Monthly Sampling of:
 - I. Wet-weather flows for: Total phosphorus, Total nitrogen, Nitrate/nitrite, Total Kjeldahl nitrogen, Dissolved Oxygen, Temperature, Conductivity
 - II. Dry-weather flows for: Total phosphorus, Total nitrogen, Nitrate/nitrite, Total Kjeldahl nitrogen, Dissolved Oxygen, Temperature, Conductivity
 - III. Record depth of flow at crossings and lake level during collection of each sample.

3. **Begin a Watershed Management and Public Education Program** (estimated cost of \$3,000 to \$5,000 for items a and b. Item c may be contracted on an as-needed basis or completed by volunteers)
 - a. Conduct a survey of lakefront property owners and watershed residents to understand their goals and objectives for the lakes and drainage infrastructure. A thorough understanding of the desires of the watershed residents will provide a basis for decision-making with regard to the lake.
 - b. Develop and implement a Public Education program for the Paw Paw Lake Watershed.
 - c. Work with SWMPC to integrate proposed activities with Paw Paw River Watershed Management Plan -OR- apply for grant funding to develop a Paw Paw Lake Watershed Management Plan. A watershed management plan will help create opportunities for obtaining grant funding to implement watershed and lake improvements.

4. **Establish and Implement Drain Inspection & Maintenance Plan** (cost varies with length of drain inspected, length of drain maintained, and practices installed)
 - a. Drain Inventory
 - I. Complete a maintenance inventory on all county drains within the watershed. The recommended priority of these inspections is based on L-THIA predicted loading for suspended solids and nutrients within the watershed, and is prioritized by sub-watershed as follows:
 1. Branch and Derby (partially inspected in 2007)
 2. McConnel-Olcott
 3. Dedrick Drain
 4. Delfield & Crumb Drain (and E. and W. Branches)
 5. Sherwood Drain
 6. Potter Drain
 7. Cutler & Smith Drain
 - II. Complete preliminary drain inventory for residential drains located in Immediate Areas for Paw Paw Lake and Little Paw Paw Lake (including the Forest Beach Drain, Kelly Drain, and Smith & Strong Drain).
 1. Develop inspection maps for the drains using available drain data from the Berrien County Drain Commissioner's office.
 2. Field-locate drainage structures using a sub-meter accuracy GPS unit.
 3. Note structure condition, pipe sizes and inverts, and sediment present in sump.
 4. Develop a maintenance program in coordination with the Berrien County Drain Commissioner, Coloma and Watervliet Townships, and the Berrien County Road Commission for regular maintenance of the systems.
 - III. Develop prioritized implementation plan for maintenance activities identified during inspection.
 - b. Branch and Derby Drain Maintenance
 - I. Support a petition from Watervliet, Coloma, Covert, Bangor, and Hartford Townships to the Van Buren and Berrien County Drain Commissioners for maintenance and improvements of the Branch and Derby Drain, including:
 1. Complete maintenance on the Branch and Derby Drain between Paw Paw Lake and Hagar Shore Road, in coordination with the Berrien County Drain Commissioner and Coloma and Watervliet Townships.

Installation of a sedimentation basin within the drain right-of-way that can be maintained on a regular basis is recommended.

2. Complete maintenance on the Branch and Derby Drain between M-140 and N. Watervliet Road, in coordination with the Berrien County Drain Commissioner and Coloma and Watervliet Townships.
 3. Install a sedimentation basin upstream of Paw Paw Lake to capture sediment being transported by the drain to the lake.
- c. Maintenance of In-line Ponds in County Drains
- I. Remove sediment from the pond in the Little Paw Paw Lake Drain. Reshape pond as needed to encourage sedimentation. Establish wetland fringe vegetation for pollutant filtration.
 - II. Investigate the pond located on the Delfield and Crumb Drain at Interlocken Road to determine what water quality improvements, if any, could be gained from modification to this pond. Modification may include dredging, vegetation establishment, pond management techniques, or other practices designed to create a healthy pond ecosystem and provide water quality treatment.
5. **Shoreline Survey** (estimated cost of \$2,000 to \$10,000, depending on level of detail and volunteer effort)
- a. Conduct a survey of shoreline land use (i.e. undeveloped, residential, etc.) shoreline material (i.e. seawall, rock wall, beach, etc.), and off-shore sediment characteristics (muck, sand, etc). The survey should include estimates of the cost and water quality benefit of implementing various lakeshore management practices.
 - b. Data will be obtained using a handheld GPS unit, and photographs obtained to characterize the land use for the entire shoreline of the lakes.
 - c. In conjunction with the Paw Paw Lake Association develop a “Demonstration Site” for shoreline buffer planting and seawall retrofit techniques. Consider offering buffer design services and educational programs to encourage the implementation of these designs.
6. **Design and Pursue Implementation Funding for Water Quality Retrofits for Immediate Areas** (estimated cost of \$10,000 for preliminary design and cost estimate)
- a. Develop a conceptual plan for low-impact development retrofits within the immediate areas of the watershed (specifically targeting shoreline properties and properties within residential areas).
 - b. Develop a detailed cost estimate and preliminary drawings for the proposed retrofits. Quantify the benefit to the lake based on the proposed practices.
7. **Dredging Assessment and Dredge Plan Development** (estimated cost of \$15,000 to \$25,000)
- a. Landowner Coordination
 - I. Develop a map showing the estimated sediment accumulation for the entire Paw Paw Lake based on historic Michigan Department of Natural Resources and 2007 Spicer Group contours.
 - II. Prepare for and attend one (1) stakeholder meeting and one (1) PPLF board meeting to discuss the benefits of dredging and outline a proposed timeline and work plan to complete the work on the lakes.
 - III. Assess the desires of lakefront residents to complete a dredging project. Multiple objectives for dredging that should be considered include water quality benefit, navigation benefit, potential habitat enhancement, removal of accumulated sediment.

- IV. Develop prioritization matrix and corresponding map for dredge location analysis.
 - b. Dredge Plan Development
 - I. Post-process bathymetric survey returns for statistical sediment characterization.
 - II. Acquire a total of fifteen (15) representative sediment samples from Paw Paw Lake and Little Paw Paw Lake. Complete laboratory analysis of sediments. Samples will be processed based on MDEQ required sampling for dredging projects (Part 115, Solid Waste Management, of the Natural Resources and Environmental Protection Act, 1994 PA 451), including: arsenic, barium, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, zinc, poly-nuclear aromatic hydrocarbons (PAHs), poly-chlorinated biphenyls (PCBs), sieve analysis and hydrometer analysis, loss by ignition analysis.
 - III. Complete a Synthetic Precipitation Leaching Procedure (SPLP) analysis of samples whose bulk sediment analysis indicated additional testing will be required by the MDEQ (at an additional cost of approximately \$100 per sample per parameter)
 - IV. Develop a map of sediment distribution, statistical classification, and sediment analysis.
 - V. Based on the results of sediment testing, identify at least five (5) possible spoil deposition locations within the watershed. Provide a prioritization matrix for disposal sites, and a summary of disposal site requirements.
 - VI. Identify at least two (2) methods for sediment removal and spoil deposition.
 - VII. Prepare a letter report summarizing the proposed dredge plan, includes estimates of cost and prioritized dredge and deposition locations.
 - c. Dredge Plan Coordination
 - I. Schedule, prepare for, and attend one (1) meeting with landowners and the PPLF Board to discuss results of Preliminary Dredge Plan.
 - II. Schedule, prepare for, and attend one (1) on-site meeting with MDEQ representatives to discuss proposed plans and review their comments and concerns. (*NOTE: there is an additional fee payable to the MDEQ for this meeting*).
- 8. Establish Lake Improvement Board and/or Special Assessment District** (estimated cost of \$10,000 to \$15,000)
- a. Obtain up-to-date parcel information from Berrien County in a GIS format.
 - b. Review historic records with Berrien County Drain Commissioner to determine what special assessment district, if any, has been established as part of past projects.
 - c. Develop or update special assessment district(s) for Paw Paw Lake and Little Paw Paw Lake, including draft assessment rolls, in coordination with the Berrien County Drain Commissioner, Watervliet Township, Coloma Township, and the Paw Paw Lake Association.
 - d. Develop a “mock” roll in Microsoft Excel that can be utilized to estimate the economic burden to property owners for a variety of lake improvement projects.
 - e. Hire legal council to work with townships, PPLF, and PPLA to establish a lake improvement board.
- 9. Review and Revise Township and/or County-wide Ordinances** (estimated cost of \$0 to \$15,000, dependant upon legal fees, effort donated by governmental entities, etc.)

- a. Develop a sub-committee within the Paw Paw Lake Association and PPLF to develop and implement ordinance and codes with the following intents:
 - I. Implement an ordinance to limit or ban the residential use of fertilizers containing phosphorus within the watershed, two-township area, or on a county-wide basis.
 - II. Require or encourage low-impact development strategies for all future development within the watershed.
- b. Coordinate efforts with the Paw Paw River Watershed management efforts and SWMPC.

10. Paw Paw Lake Economic Analysis (estimated cost of \$10,000 to \$15,000)

- a. Complete a study of riparian property values and water resource quality. Project future trends in land value if lakes improve, degrade, or maintain current water quality.
- b. Complete a regional impact assessment based on the water quality of Paw Paw Lake and Little Paw Paw Lake. Assessment will estimate the economic impact of the lake on Coloma, Watervliet, and the Paw Paw Lake Watershed as a whole.

Conclusions

Paw Paw Lake and Little Paw Paw Lake are stratified deep lakes with hypolimnetic phosphorus transfer. The lakes are borderline eutrophic, and this condition will likely worsen if pollutant loading continues at current levels. Reduction of phosphorus and nitrogen loading to the lake should be considered a priority to slow the eutrophication process.

Due to the existing phosphorus and nitrogen in the lakes (Paw Paw Lake, in particular), the water quality will likely be insensitive to initial reductions in nutrient loading. The lake, however, may experience degradation to increased loading or prolonged nutrient loading at current rates.

With the exception of treatment for nuisance aquatic vegetation, most in-lake management practices are not recommended as priority implementation activities. Until the nutrient load reaching the lakes from their watersheds is reduced, many of the in-lake activities will be overwhelmed and their impact may not be fully recognized. It is the professional opinion of Spicer Group that the top priority for Paw Paw Lake and Little Paw Paw Lake be addressing non-point source pollutants in the watershed. In-lake improvements will not be sustained if pollutant loading continues at current rates.

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- ^v Paw Paw Lake Water Quality Study
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- ^{vii} 1976 Snow Report
- ^{viii} 1980 Ten Ech Report
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