APPENDIX I

HOUGHTON LAKE 2014 ANNUAL REPORT
Houghton Lake
2014 Annual Report

Prepared for:
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Introduction

Houghton Lake is Michigan's largest inland lake at 20,044 acres, but it is also shallow with an average depth of less than 10 feet (Figure 1). Aquatic plants have been abundant and diverse in Houghton Lake for many years. However, by the late 1990s, the nuisance exotic plant, Eurasian milfoil (Myriophyllum spicatum, Figure 2), had spread to approximately 11,000 acres of the lake and was crowding out beneficial native plant species.

To address this problem, the Houghton Lake Improvement Board was established in accordance with Michigan’s Natural Resources and Environmental Protection Act and commissioned a management feasibility study of Houghton Lake (Smith et al. 2002). To control the spread of milfoil in Houghton Lake, a whole-lake treatment with the aquatic herbicide fluridone (trade name Sonar®) was conducted in the spring of 2002 as part of a five-year management plan. Public hearings were held in 2006 and 2011 pursuant to statute, and the project was continued through 2016. Key components of the management plan include aquatic plant control, water quality and vegetation monitoring, information and education, and watershed management. This report provides a summary of project activities through 2014.

Figure 1. Houghton Lake depth contour map.
INTRODUCTION

Figure 2. Eurasian milfoil (Myriophyllum spicatum).
Aquatic Plants

PLANT CONTROL IN HOUGHTON LAKE 2002 – 2014

Plant control in Houghton Lake focuses exclusively on the control of exotic plant species, primarily non-native milfoil. Plant control activities conducted in Houghton Lake since 2002 are summarized in Table 1. Since the whole-lake Sonar® treatment in 2002, milfoil beds in the lake have been spot-treated, primarily with systemic herbicides. In 2014, less than 6 percent of the lake was treated (Figure 3). The extremely harsh winter and prolonged ice cover of the winter of 2013-2014 may have contributed to the reduced treatment area in 2014.

TABLE 1
HOUGHTON LAKE PLANT CONTROL HISTORY

<table>
<thead>
<tr>
<th>Year</th>
<th>Sonar®</th>
<th>Contacts</th>
<th>Systemic</th>
<th>Acres Harvested</th>
<th>Milfoil Weevils (# Stocked)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>20,044</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2003</td>
<td></td>
<td>32</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2004</td>
<td></td>
<td>44</td>
<td>81</td>
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<td></td>
</tr>
<tr>
<td>2005</td>
<td>50</td>
<td>395</td>
<td>84</td>
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<td>59</td>
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</tr>
<tr>
<td>2007</td>
<td>106</td>
<td>660</td>
<td></td>
<td>30,000</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>20</td>
<td>1,310</td>
<td>35</td>
<td></td>
<td></td>
</tr>
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<td>40</td>
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<tr>
<td>2010</td>
<td>39</td>
<td>558</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>42</td>
<td>1,747</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>84</td>
<td>1,237</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>49</td>
<td>1,902</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>51</td>
<td>1,054</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To minimize potential impacts to wild rice in Houghton Lake, the permit issued by the Michigan Department of Environmental Quality for the 2014 treatment required that low doses of the systemic herbicide triclopyr be used for Eurasian milfoil control in areas known or suspected to contain wild rice, i.e., the Middle Grounds and North Bay. The low-dose protocol was used throughout the Middle Grounds treatment area. As in the previous three years, no treatments were conducted in North Bay in order to address concerns raised by the Houghton Lake, Lake Association regarding potential treatment impacts to wild rice.
Figure 3. Houghton Lake 2014 treatment map. In addition to herbicide treatments in the main body of the lake, several of the canal areas were treated in 2014 to control Eurasian milfoil.
AQUATIC PLANTS

2014 SURVEY METHODS AND RESULTS

Aquatic plant surveys of Houghton Lake are conducted by the Houghton Lake Improvement Board’s environmental consultant, Progressive AE. In 2014, biologists from Progressive conducted plant surveys on June 16-17 and September 3-4 using the point-intercept method (Madsen 1999). Sampling locations were established with a global positioning system (GPS) at grid points spaced every 500-feet in locations where nuisance Eurasian milfoil growth had occurred historically in Houghton Lake (Figure 4). At each sampling location, a double-sided thatch rake attached to a line was dragged for approximately 15 feet in two rake tosses, one on each side of the boat. At each grid point where milfoil was found, the relative abundance of milfoil was noted. In addition to the point-intercept surveys conducted in the lake proper, each of the canal systems around the lake was surveyed to identify milfoil locations. Areas of the lake and canals where nuisance milfoil growth was observed during the June surveys were targeted for treatment. Pre-treatment and post-treatment milfoil distribution maps are shown in Figures 5 and 6.

Figure 4. Houghton Lake 2014 aquatic plant survey sampling location map.
Figure 5. Houghton Lake pre-treatment non-native milfoil distribution, June 16-17, 2014.

Figure 6. Houghton Lake post-treatment non-native milfoil distribution, September 3-4, 2014.
AQUATIC PLANTS

Recent genetic testing indicates that hybrid milfoil is present in Houghton Lake (Progressive AE 2013). Hybrid milfoil is a cross between the invasive, exotic species Eurasian milfoil (*Myriophyllum spicatum*) and the native northern milfoil (*Myriophyllum sibiricum*). Because the hybrid milfoil combines traits of the native and exotic milfoils, there is concern in the scientific community that the hybrid milfoil will be more aggressive growing than the Eurasian milfoil (Appendix A). Some hybrid milfoil variants also appear to be tolerant to certain herbicides. Genetic screening can provide a valuable tool to inform management decisions regarding the control of hybrid milfoil (Appendix B).

To better discern potential management implications of hybrid milfoil in Houghton Lake, scientists from Grand Valley State University’s (GVSU) Annis Water Resources Institute were retained in 2014 to evaluate the extent of hybrid milfoil in the lake. During the 2014 plant surveys, GVSU scientists accompanied Progressive’s biologists and, at each site where milfoil was found, a sample was collected for genetic identification at GVSU’s Annis Water Resources Institute in Muskegon. Pre-and post-treatment genetic screening results are summarized in Table 2 and in Figures 7 and 8.

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>HOUGHTON LAKE 2014 GENETIC TESTING RESULTS</th>
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<tbody>
<tr>
<td></td>
<td>Pre-treatment</td>
</tr>
<tr>
<td>Hybrid watermilfoil</td>
<td>499</td>
</tr>
<tr>
<td>Eurasian watermilfoil</td>
<td>51</td>
</tr>
<tr>
<td>Northern watermilfoil</td>
<td>2</td>
</tr>
<tr>
<td>Unidentified</td>
<td>4</td>
</tr>
</tbody>
</table>

During the initial pre-treatment survey conducted in June, milfoil was found at 556 of the 996 survey sites. Of the sites where milfoil was found, hybrid milfoil was present at 499 or 90% of the sites. In the follow-up, post-treatment survey conducted in September, milfoil was found at 309 of the 996 survey sites. Of the sites where milfoil was found, hybrid milfoil was present at 299 or 97% of the sites. These data indicate that hybrid milfoil is currently the dominant type of milfoil found in Houghton Lake.

While the 2014 treatments reduced common to dense milfoil growth overall in Houghton Lake (Figures 5 and 6), the treatments were only marginally successful in controlling hybrid milfoil. In about one-half of the treatment areas, milfoil was detected during the post-treatment survey. These data suggest that the hybrid milfoil in Houghton Lake is showing herbicide resistance.

In addition to the genetic testing conducted in 2014, plants were collected at multiple locations in the lake during the September 2014 survey and were cultured overwinter in the laboratory for herbicide susceptibility testing. Herbicide susceptibility testing is a tool that has been developed to evaluate plant response to various herbicides. This work was conducted at the SePro Research and Technology Campus laboratory in North Carolina. Screening involved exposing the plants to operational dose rates of commonly used auxin herbicides (e.g., triclopyr and 2,4-D amine) and measuring plant response. Plant response was then referenced against a pure Eurasian milfoil biotype and a hybrid biotype. Herbicide screening allows an assessment to be made of diminished responses to commonly used herbicides and to evaluate if there is a differential response between Eurasian and the hybrid milfoil biotypes. Herbicide susceptibility results are pending that will help evaluate herbicide dose rates needed to optimize treatment effectiveness in Houghton Lake in 2015.
Sample #1:
- Eurasian Milfoil (Myriophyllum spicatum)
- Hybrid Milfoil (Myriophyllum spicatum x Myriophyllum sibiricum)
- Northern Milfoil (Myriophyllum sibiricum)

Sample #2:
- Eurasian Milfoil (Myriophyllum spicatum)
- Hybrid Milfoil (Myriophyllum spicatum x Myriophyllum sibiricum)
- Northern Milfoil (Myriophyllum sibiricum)

Figure 7. Houghton Lake pre-treatment genetic screening results, June 16-17, 2014.

Sample #1:
- Eurasian Milfoil (Myriophyllum spicatum)
- Hybrid Milfoil (Myriophyllum spicatum x Myriophyllum sibiricum)
- Northern Milfoil (Myriophyllum sibiricum)

Sample #2:
- Eurasian Milfoil (Myriophyllum spicatum)
- Hybrid Milfoil (Myriophyllum spicatum x Myriophyllum sibiricum)
- Northern Milfoil (Myriophyllum sibiricum)

Figure 8. Houghton Lake post-treatment genetic screening results, September 3-4, 2014.
Lake Water Quality

Lake water quality is determined by a unique combination of processes that occur both within and outside of the lake. In order to make sound management decisions, it is necessary to have an understanding of the current physical, chemical, and biological condition of the lake, and the potential impact of drainage from the surrounding watershed.

Lakes are commonly classified as oligotrophic, mesotrophic, or eutrophic (Figure 9). Oligotrophic lakes are generally deep and clear with little aquatic plant growth. These lakes maintain sufficient dissolved oxygen in the cool, deep bottom waters during late summer to support cold water fish such as trout and whitefish. By contrast, eutrophic lakes are generally shallow, turbid, and support abundant aquatic plant growth. In deep eutrophic lakes, the cool bottom waters usually contain little or no dissolved oxygen. Therefore, these lakes can only support warm water fish such as bass and pike. Lakes that fall between these two extremes are called mesotrophic lakes.

Under natural conditions, most lakes will ultimately evolve to a eutrophic state as they gradually fill with sediment and organic matter transported to the lake from the surrounding watershed. As the lake becomes shallower, the process accelerates. When aquatic plants become abundant, the lake slowly begins to fill in as sediment and decaying plant matter accumulate on the lake bottom. Eventually, terrestrial plants become established and the lake is transformed to a marshland. The aging process in lakes is called "eutrophication" and may take anywhere from a few hundred to several thousand years, generally depending on the size of the lake and its watershed. The natural lake aging process can be greatly accelerated if excessive amounts of sediment and nutrients (which stimulate aquatic plant growth) enter the lake from the surrounding watershed. Because these added inputs are usually associated with human activity, this accelerated lake aging process is often referred to as "cultural eutrophication."

The problem of cultural eutrophication can be managed by identifying sources of sediment and nutrient loading (i.e., inputs) to the lake and developing strategies to halt or slow the inputs. Thus, in developing a management plan, it is necessary to determine the limnological (i.e., the physical, chemical, and biological) condition of the lake and the physical characteristics of the watershed as well.

Key parameters used to evaluate the limnological condition of a lake include temperature, dissolved oxygen, total phosphorus, chlorophyll-α, and Secchi transparency. A brief description of these water quality measurements is provided as an introduction for the reader. Particular attention should be given to the interrelationship of these water quality measurements.
LAKE WATER QUALITY

TEMPERATURE
Temperature is important in determining the type of organisms that may live in a lake. For example, trout prefer temperatures below 68°F. Temperature also determines how water mixes in a lake. As the ice cover breaks up on a lake in the spring, the water temperature becomes uniform from the surface to the bottom. This period is referred to as "spring turnover" because water mixes throughout the entire water column. As the surface waters warm, they are underlain by a colder, more dense strata of water. This process is called thermal stratification. Once thermal stratification occurs, there is little mixing of the warm surface waters with the cooler bottom waters. The transition layer that separates these layers is referred to as the "thermocline." The thermocline is characterized as the zone where temperature drops rapidly with depth. As fall approaches, the warm surface waters begin to cool and become more dense. Eventually, the surface temperature drops to a point that allows the lake to undergo complete mixing. This period is referred to as "fall turnover." As the season progresses and ice begins to form on the lake, the lake may stratify again. However, during winter stratification, the surface waters (at or near 32°F) are underlain by slightly warmer water (about 39°F). This is sometimes referred to as "inverse stratification" and occurs because water is most dense at a temperature of about 39°F. As the lake ice melts in the spring, these stratification cycles are repeated (Figure 10). Shallow lakes do not stratify. Lakes that are 15 to 30 feet deep may stratify and destratify with storm events several times during the year.

DISSOLVED OXYGEN
An important factor influencing lake water quality is the quantity of dissolved oxygen in the water column. The major inputs of dissolved oxygen to lakes are the atmosphere and photosynthetic activity by aquatic plants. An oxygen level of about 5 mg/L (milligrams per liter, or parts per million) is required to support warm water fish. In lakes deep enough to exhibit thermal stratification, oxygen levels are often reduced or depleted below the thermocline once the lake has stratified. This is because deep water is cut off from plant photosynthesis and the atmosphere, and oxygen is consumed by bacteria that use oxygen as they decompose organic matter (plant and animal remains) at the bottom of the lake. Bottom-water oxygen depletion is a common occurrence in eutrophic and some mesotrophic lakes. Thus, eutrophic and most mesotrophic lakes cannot support cold water fish because the cool, deep water (that the fish require to live) does not contain sufficient oxygen.

Figure 10. Lake stratification and turnover.
LAKE WATER QUALITY

PHOSPHORUS

The quantity of phosphorus present in the water column is especially important since phosphorus is the nutrient that most often controls aquatic plant growth and the rate at which a lake ages and becomes more eutrophic. In the presence of oxygen, lake sediments act as a phosphorus trap, retaining phosphorus and, thus, making it unavailable for aquatic plant growth. However, if bottom-water oxygen is depleted, phosphorus will be released from the sediments and may be available to promote aquatic plant growth. In some lakes, the internal release of phosphorus from the bottom sediments is the primary source of phosphorus loading (or input).

By reducing the amount of phosphorus in a lake, it may be possible to control the amount of aquatic plant growth. In general, lakes with a phosphorus concentration greater than 20 µg/L (micrograms per liter, or parts per billion) are able to support abundant plant growth and are classified as nutrient-enriched or eutrophic.

CHLOROPHYLL-α

Chlorophyll-α is a pigment that imparts the green color to plants and algae. A rough estimate of the quantity of algae present in lake water can be made by measuring the amount of chlorophyll-α in the water column. A chlorophyll-α concentration greater than 6 µg/L is considered characteristic of a eutrophic condition.

SECCHI TRANSPARENCY

A Secchi disk is often used to estimate water clarity. The measurement is made by fastening a round, black and white, 8-inch disk to a calibrated line (Figure 11). The disk is lowered over the deepest point of the lake until it is no longer visible, and the depth is noted. The disk is then raised until it reappears. The average between these two depths is the Secchi transparency. Generally, it has been found that aquatic plants can grow at a depth of approximately twice the Secchi transparency measurement. In eutrophic lakes, water clarity is often reduced by algae growth in the water column, and Secchi disk readings of 7.5 feet or less are common.

Ordinarily, as phosphorus inputs (both internal and external) to a lake increase, the amount of algae the lake can support will also increase. Thus, the lake will exhibit increased chlorophyll-α levels and decreased transparency. A summary of lake classification criteria developed by the Michigan Department of Environmental Quality is shown in Table 3.

<table>
<thead>
<tr>
<th>TABLE 3</th>
<th>LAKE CLASSIFICATION CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lake Classification</strong></td>
<td><strong>Total</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Phosphorus (µg/L)</strong></td>
</tr>
<tr>
<td>Oligotrophic</td>
<td>Less than 10</td>
</tr>
<tr>
<td>Mesotrophic</td>
<td>10 to 20</td>
</tr>
<tr>
<td>Eutrophic</td>
<td>Greater than 20</td>
</tr>
</tbody>
</table>

1 µg/L = micrograms per liter = parts per billion.
LAKE WATER QUALITY

**pH and TOTAL ALKALINITY**

pH is a measure of the amount of acid or base in the water. The pH scale ranges from 0 (acidic) to 14 (alkaline or basic) with neutrality at 7. The pH of most lakes in the Upper Midwest ranges from 6.5 to 9.0 (MDEQ 2012; Table 4). In addition, according to MDEQ (2013):

> While there are natural variations in pH, many pH variations are due to human influences. Fossil fuel combustion products, especially automobile and coal-fired power plant emissions, contain nitrogen oxides and sulfur dioxide, which are converted to nitric acid and sulfuric acid in the atmosphere. When these acids combine with moisture in the atmosphere, they fall to earth as acid rain or acid snow. In some parts of the United States, especially the Northeast, acid rain has resulted in lakes and streams becoming acidic, resulting in conditions which are harmful to aquatic life. The problems associated with acid rain are lessened if limestone is present, since it is alkaline and neutralizes the acidity of the water.

Most aquatic plants and animals are adapted to a specific pH range, and natural populations may be harmed by water that is too acidic or alkaline. Immature stages of aquatic insects and young fish are extremely sensitive to pH values below 5. Even microorganisms which live in the bottom sediment and decompose organic debris cannot live in conditions which are too acidic. In very acidic waters, metals which are normally bound to organic matter and sediment are released into the water. Many of these metals can be toxic to fish and humans. Below a pH of about 4.5, all fish die.

The Michigan Water Quality Standard (Part 4 of Act 451) states that pH shall be maintained within the range of 6.5 to 9.0 in all waters of the state.

Alkalinity, also known as acid-neutralizing capacity or ANC, is the measure of the pH-buffering capacity of water in that it is the quantitative capacity of water to neutralize an acid. pH and alkalinity are closely linked and are greatly impacted by the geology and soil types that underlie a lake and its watershed. According to MDEQ (2012):

> Michigan’s dominant limestone geology in the Lower Peninsula and the eastern Upper Peninsula contributes to the vast majority of Michigan lakes being carbonate-bicarbonate dominant [which increases alkalinity and moderates pH] and lakes in the western Upper Peninsula having lower alkalinity and thus lesser buffering capacity.

The alkalinity of most lakes in the Upper Midwest is within the range of 23 to 148 milligrams per liter, or parts per million, as calcium carbonate (MDEQ 2012; Table 4).

**TABLE 4**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (in standard units)</td>
<td>Less than 6.5</td>
<td>6.5 to 9.0</td>
<td>Greater than 9.0</td>
</tr>
<tr>
<td>Total Alkalinity or ANC (in mg/L as CaCO₃)</td>
<td>Less than 23</td>
<td>23 to 148</td>
<td>Greater than 148</td>
</tr>
</tbody>
</table>

1 mg/L CaCO₃ = milligrams per liter as calcium carbonate.
LAKE WATER QUALITY

SAMPLING METHODS

Water quality samples were collected in the spring and summer of 2014 from five locations within Houghton Lake (Figure 12). Temperature was measured using a ClineFinder probe. Samples were collected at the surface and just above the lake bottom with a Kemmerer bottle to be analyzed for dissolved oxygen, pH, total alkalinity, and total phosphorus. Dissolved oxygen samples were fixed in the field and were analyzed at Progressive AE using the modified Winkler method (Standard Methods Procedure 4500-O C). pH was measured in the field using a Oakton EcoTestr 2. Total alkalinity and total phosphorus samples were placed on ice and transported to Progressive AE and to Prein and Newhof\(^1\), respectively, for analysis. Total alkalinity was titrated at Progressive AE using Standard Methods Procedure 2320.B, and total phosphorus was analyzed at Prein and Newhof using Standard Methods Procedure 4500P-E. Also at each of the five sampling locations, Secchi transparency was measured and composite chlorophyll-a samples were collected from the surface to a depth equal to twice the Secchi transparency. Chlorophyll-a samples were analyzed by Prein and Newhof using Standard Methods Procedure 10200H.

\(^1\) Prein and Newhof, 3260 Evergreen Drive, NE, Grand Rapids, MI 49525.

Figure 12. Houghton Lake sampling location map.
LAKE WATER QUALITY

SAMPLING RESULTS AND DISCUSSION

Lake water quality data is provided in Tables 5 and 6. In-lake summary statistics are included in Table 7.

### TABLE 5
HOUGHTON LAKE
2014 DEPTH PROFILE WATER QUALITY DATA

<table>
<thead>
<tr>
<th>Date</th>
<th>Station</th>
<th>Sample Depth (feet)</th>
<th>Temperature (°F)</th>
<th>Dissolved Oxygen (mg/L)</th>
<th>Total Phosphorus (µg/L)</th>
<th>pH (S.U.)</th>
<th>Total Alkalinity (mg/L as CaCO₃)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-May-14</td>
<td>1</td>
<td>1</td>
<td>50</td>
<td>11.5</td>
<td>&lt;5</td>
<td>8.5</td>
<td>77</td>
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<tr>
<td>8-May-14</td>
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<td>6</td>
<td>50</td>
<td>11.7</td>
<td>&lt;5</td>
<td>8.4</td>
<td>79</td>
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<td>8-May-14</td>
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<td>1</td>
<td>50</td>
<td>10.9</td>
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<td>8.1</td>
<td>76</td>
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<td>8-May-14</td>
<td>2</td>
<td>14</td>
<td>49</td>
<td>11.2</td>
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<td>8-May-14</td>
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<td>3</td>
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<td>8-May-14</td>
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<td>50</td>
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<td>5</td>
<td>8.2</td>
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<td>8-May-14</td>
<td>4</td>
<td>19</td>
<td>49</td>
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<td>8.5</td>
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<td>8-May-14</td>
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<td>20</td>
<td>49</td>
<td>11.2</td>
<td>&lt;5</td>
<td>8.4</td>
<td>80</td>
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<td>4-Sep-14</td>
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<td>1</td>
<td>72</td>
<td>9.5</td>
<td>41</td>
<td>8.9</td>
<td>84</td>
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<tr>
<td>4-Sep-14</td>
<td>2</td>
<td>12</td>
<td>72</td>
<td>9.1</td>
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<td>83</td>
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<tr>
<td>4-Sep-14</td>
<td>4</td>
<td>1</td>
<td>72</td>
<td>8.8</td>
<td>7</td>
<td>8.9</td>
<td>89</td>
</tr>
<tr>
<td>4-Sep-14</td>
<td>4</td>
<td>16</td>
<td>72</td>
<td>8.9</td>
<td>12</td>
<td>8.9</td>
<td>82</td>
</tr>
<tr>
<td>4-Sep-14</td>
<td>5</td>
<td>1</td>
<td>73</td>
<td>9.8</td>
<td>13</td>
<td>8.9</td>
<td>85</td>
</tr>
<tr>
<td>4-Sep-14</td>
<td>5</td>
<td>16</td>
<td>72</td>
<td>9.9</td>
<td>8</td>
<td>8.9</td>
<td>85</td>
</tr>
</tbody>
</table>

1 mg/L = micrograms per liter = parts per billion.
2 µg/L = micrograms per liter = parts per billion.
3 S.U. = standard units.
4 mg/L as CaCO₃ = milligrams per liter as calcium carbonate.
### TABLE 6
HOUGHTON LAKE
2014 SURFACE WATER QUALITY DATA

<table>
<thead>
<tr>
<th>Date</th>
<th>Station</th>
<th>Secchi Transparency (feet)</th>
<th>Chlorophyll-a (µg/L)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-May-14</td>
<td>1</td>
<td>7.0</td>
<td>0</td>
</tr>
<tr>
<td>8-May-14</td>
<td>2</td>
<td>8.0</td>
<td>0</td>
</tr>
<tr>
<td>8-May-14</td>
<td>3</td>
<td>8.0</td>
<td>1</td>
</tr>
<tr>
<td>8-May-14</td>
<td>4</td>
<td>8.5</td>
<td>1</td>
</tr>
<tr>
<td>8-May-14</td>
<td>5</td>
<td>9.5</td>
<td>1</td>
</tr>
<tr>
<td>4-Sep-14</td>
<td>2</td>
<td>6.0</td>
<td>0</td>
</tr>
<tr>
<td>4-Sep-14</td>
<td>4</td>
<td>5.0</td>
<td>0</td>
</tr>
<tr>
<td>4-Sep-14</td>
<td>5</td>
<td>5.0</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 7
HOUGHTON LAKE IN-LAKE SUMMARY STATISTICS
2003-2014

<table>
<thead>
<tr>
<th></th>
<th>Total Phosphorus (µg/L)¹</th>
<th>Secchi Transparency (feet)</th>
<th>Chlorophyll-a (µg/L)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>27</td>
<td>5.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>28</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Median</td>
<td>19</td>
<td>5.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Minimum</td>
<td>&lt;5</td>
<td>2.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>256</td>
<td>9.5</td>
<td>8.2</td>
</tr>
<tr>
<td>Number of samples</td>
<td>293</td>
<td>145</td>
<td>144</td>
</tr>
</tbody>
</table>

¹ µg/L = micrograms per liter = parts per billion.
LAKE WATER QUALITY

The shallow depths in Houghton Lake cause the lake to mix constantly from spring to fall and as such, water temperature and chemistry are fairly uniform from top to bottom. Temperatures were cool in spring and warm in summer. The water was well oxygenated from the surface to bottom during both the spring and summer sampling periods in 2014, and were well above the concentration needed to sustain a warmwater fishery. Although dissolved oxygen concentrations are adequate, water temperatures in Houghton Lake are too warm to sustain a coldwater fishery.

In 2014, total phosphorus concentrations were generally low in spring and summer. Phosphorus data collected in recent years indicates that phosphorus levels in Houghton Lake can vary considerably both season-to-season and year-to-year (Table 5; Figure 13). This variability in phosphorus levels may be related to wind action that periodically stirs unconsolidated bottom sediments into the water column. The median phosphorus concentration of all in-lake phosphorus data collected since 2003 is 19 ppb, a level that is just below the eutrophic threshold.

Algal growth was low in 2014, as indicated by the chlorophyll-a concentrations that were 1 ppb or less. The low chlorophyll-a levels suggest that most of the phosphorus in Houghton Lake is used by rooted plants rather than algae. Secchi transparency measurements were low to moderate in 2014. Given the low chlorophyll-a concentrations, it is unlikely the poor clarity is related to algae growth. Instead, turbidity in the water column caused by wind-mixing of bottom sediments probably reduces water clarity. Similar Secchi transparency measurements were reported by Pecor et al. (1973); therefore, reduced clarity is not a new phenomenon in Houghton Lake.

During 2014, the pH and total alkalinity in Houghton Lake were moderate in comparison to other upper midwestern lakes.

Based on the data collected and presented herein, Houghton Lake is meso-eutrophic in that the lake exhibits moderately elevated phosphorus levels, low chlorophyll-a, and low transparency (Figures 13 through 15).
LAKE WATER QUALITY

Figure 13. Houghton Lake median total phosphorus concentrations, 2003 - 2014.

Figure 14. Houghton Lake average chlorophyll-a concentrations, 2003 - 2014.

Figure 15. Houghton Lake average Secchi transparency measurements, 2003 - 2014.
Information and Education

Information regarding project activities and lake board meeting dates are posted on the Houghton Lake Improvement Board web site. The site is typically updated annually with new information as it becomes available. In 2014, the web address was published multiple times in the Houghton Resorter and all property owners around the lake were mailed a post card with the web site address and information about the lake treatment program.

Figure 16. Houghton Lake Improvement Board website.
Watershed Management

In 2014, the Muskegon River Watershed Assembly completed a watershed management plan for the Upper Muskegon River Watershed that includes Houghton Lake. Key partners in the project included Grand Valley State University’s Annis Water Resources Institute and the Central Michigan District Health Department. Invasive aquatic plants and periodic elevated *E. coli* bacteria were cited in the watershed management plan as a potential concern. Key components of the plan included long term monitoring of water quality and aquatic invasive species, both of which are currently being conducted by the Houghton Lake Improvement Board.

Figure 17. Houghton Lake watershed map.
Appendix A
Hybrid Milfoil: Management Implications and Challenges
Hybrid Milfoil: Management Implications and Challenges

By: Tony Groves, Paul Hausler, and Pam Tyning
Water Resources Group, Progressive AE

Background

Millions of dollars are spent annually on programs to combat invasive aquatic plants in Michigan. A primary focus of many of these programs is the control of Eurasian milfoil (Myriophyllum spicatum), an aggressive-growing exotic plant introduced into the United States from Europe and Asia.

Eurasian milfoil is not the only type of milfoil found in Michigan. There are several native milfoil species, such as northern milfoil (Myriophyllum sibiricum). Some native species closely resemble Eurasian milfoil and are commonly mistaken for it. However, the native milfoils rarely form dense, impenetrable plant beds like Eurasian milfoil often does. In some lakes, hybridization between exotic Eurasian milfoil (M. spicatum) and native northern milfoil (M. sibiricum) is occurring. Genetic testing has found milfoil hybrids to be widely dispersed across the northern portion of the United States and hybrid milfoil appears to be widespread in Michigan. The documentation of the presence of hybrid milfoil is important because hybridity in plants is often linked to invasive traits. In fact, hybrid milfoil may be more invasive than Eurasian milfoil. There is concern in the scientific community that hybrids could have a competitive advantage over, and ultimately displace both northern milfoil and Eurasian milfoil.

In terms of physical appearance, hybrid milfoil is difficult to distinguish from Eurasian milfoil. For positive identification, genetic testing is required. Further, not all hybrid milfoils are the same. There is considerable genetic variability within hybrids.

Herbicide Treatments

Herbicide applications are the most commonly-used method to control Eurasian milfoil. However, in some lakes, herbicide treatments have become less effective. Dose rates that historically provided good control of milfoil are sometimes only partially effective, and plant die-back is incomplete and/or regrowth occurs more rapidly.

Recent research indicates that hybrid milfoils may exhibit increased tolerance to some herbicides. On average, hybrid milfoil is less susceptible to control with the commonly-used aquatic herbicide 2,4-D in comparison with Eurasian milfoil. The decreased sensitivity to 2,4-D appears to be common across different hybrid lineages. Lakes that have been treated historically with 2,4-D have a higher incidence of hybrid milfoil than non-treated lakes. This research suggests that use of certain herbicides may inadvertently allow tolerant hybrid milfoil to gain dominance.

With the aquatic herbicide fluridone (Sonar®), hybrid tolerance appears to be limited to fewer hybrid lineages. While hybrid resistance to fluridone has been observed in a small percentage of lakes, hybridity does not necessarily infer fluridone tolerance.

Management Implications

Management of hybrid milfoil presents new challenges. Fortunately, there are some new tools available to document the presence of hybrid milfoil and to evaluate the potential for herbicide resistance.
Genetic Testing: As discussed in an article in the Summer 2014 issue of the Michigan Riparian, genetic testing is now commercially available and can be used to determine the presence and distribution of Eurasian versus northern versus hybrid milfoil in a given lake. This data can, in turn, be used to inform management decisions.

Herbicide Susceptibility Screening: Another approach that is being used is herbicide susceptibility screening in which milfoil samples are collected from various locations in a lake and exposed to typical herbicide dose rates to evaluate plant response. If plant response is diminished, it may indicate the presence of hybrid milfoil and the need for reevaluation of a treatment approach, before substantial resources are committed to a treatment protocol that may not be very effective.

As with most invasive species, early detection and rapid response is key to effective control. Annual monitoring of the type and abundance of aquatic plants is an essential first step in this endeavor. In areas of the lake where milfoil is found, plant samples can be collected for further analysis.

In general, the use of herbicides with different modes of action, rather than using the same type of herbicide year after year, may help stem the spread of hybrids that are showing resistance to a particular herbicide or class of herbicides.

Given the potential management implications, genetic testing and herbicide susceptibility screening may soon become standard practices for lake managers. Additional research is ongoing to better evaluate the distribution of hybrid milfoil, its biological characteristics, herbicide treatment impacts, and its susceptibility to control measures.

Bibliography


Appendix B
Incorporating Genetic Identifications of Watermilfoils into Aquatic Vegetation Mapping to Inform Management Decisions
Aquatic vegetation mapping has long been an important component of developing and implementing aquatic plant management plans. Vegetation maps provide important information on the distribution and abundance of plants over time, which helps to identify important changes that help stakeholders identify when and where management should occur, as well as to determine the efficacy of management actions. Aquatic vegetation mapping therefore plays an important role in adaptive management of lakes, where the overall goal is to reduce uncertainty in management responses over time by careful monitoring to evaluate management actions.

Aquatic vegetation surveys have historically been conducted using visual identifications of species. However, some aquatic plant taxa can be very difficult to distinguish from others using visual identification methods alone. For these taxa, new technologies such as genetic methods of identification can provide an objective alternative to visual identifications.

For example, Eurasian watermilfoil (Myriophyllum spicatum) is an invasive aquatic plant that is extensively managed with herbicides to mitigate its large economic and ecological impacts in many lakes. Eurasian watermilfoil hybridizes with the ecologically benign and native northern watermilfoil (Myriophyllum sibiricum). These hybrids can differ significantly from Eurasian watermilfoil in patterns of nuisance growth and response to management. However, due to their morphological variability, many hybrids are difficult to distinguish from Eurasian and northern watermilfoil, even for those with aquatic plant identification training. In contrast, molecular genetic methods of identification have proven more reliable. Here, we stress the importance of careful identification of distinct watermilfoils using molecular genetic methods, and suggest incorporating genetic monitoring of watermilfoils into existing aquatic vegetation mapping to assist in the prescription and evaluation of management actions.

**More than Meets the Eye**

Watermilfoils are notoriously difficult to identify to species. Eurasian watermilfoil is most commonly confused with its native sister species, northern watermilfoil, and hybrids between these two. Eurasian watermilfoil and northern watermilfoil can be distinguished visually by counting the number of pairs of leaflets (about 9-11 for northern watermilfoil and about 12-20 for Eurasian watermilfoil). Nevertheless, the two species can be mistaken for one another. More importantly, since hybrids are a cross between Eurasian watermilfoil and northern watermilfoil, distinguishing hybrids is even more challenging. For example, leaflet counts of hybrids can resemble either Eurasian watermilfoil or northern watermilfoil. Moreover, not all hybrids look the same (Fig. 1). Finally, it is important to recognize that there are several other native species of watermilfoils, and it is important to accurately distinguish these native species from Eurasian watermilfoil or hybrids that are targeted for management.

**Figure 1.** Leaves from different genotypes of northern watermilfoil (top row), hybrid watermilfoil (middle row), and Eurasian watermilfoil (bottom row). Leaf characteristics can differ among different genotypes within taxa, and hybrids can exhibit characteristics of both Eurasian and northern watermilfoils. Genetic analyses are therefore more reliable for distinguishing Eurasian, northern, and hybrid watermilfoils.
Problems with Mistaken Identity

Accurate identifications of watermilfoils are critical for informing aquatic plant management programs. We highlight three general situations spanning the range of intensity of in-lake aquatic vegetation management in which accurate distinction of Eurasian, northern, and hybrid watermilfoils can inform management decisions.

Early Detection and Rapid Response – Early detection and rapid response provides the greatest likelihood of preventing the establishment and spread of introduced species. To be effective, introduced species must be rapidly and accurately identified and verified (see Table 1). For example, misidentifying native northern watermilfoil as non-native Eurasian or hybrid watermilfoil would lead to unnecessary management actions. In the best case, this unnecessary management would incur superfluous management costs to stakeholders; in the worst case, unnecessary removal of northern watermilfoil could open up habitat for invasion by non-native Eurasian or hybrid watermilfoil. On the flip side, misidentification of Eurasian or hybrid watermilfoil as native northern watermilfoil could result in the rapid development of a nuisance population that ultimately requires more intensive and costly management actions, and that spread to nearby water bodies.

<table>
<thead>
<tr>
<th>Visual ID (What you think it is)</th>
<th>Genetic ID (What it actually is)</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eurasian or Hybrid</td>
<td>Northern</td>
<td>Natives identified as invasive can lead to inadvertently treating native plants. Removing native plants may lead to future invasion.</td>
</tr>
<tr>
<td>Northern</td>
<td>Eurasian or Hybrid</td>
<td>Plants may not be treated and may become a problem locally and/or spread to nearby lakes.</td>
</tr>
<tr>
<td>Hybrid</td>
<td>Eurasian</td>
<td>May use more potent treatment than necessary.</td>
</tr>
<tr>
<td>Eurasian</td>
<td>Hybrid</td>
<td>Hybrids may have muted response to treatments normally effective on Eurasian.</td>
</tr>
</tbody>
</table>

Table 1. A summary of the ways to misidentify watermilfoils visually, and their potential consequences for management of non-native watermilfoil.

Developing Precise Management Prescriptions in Lakes with Co-occurring Watermilfoil Types – It is important to recognize that different types of watermilfoil can co-occur within a lake, either in the same or different locations (Fig. 2). Genetic surveys where multiple plants and locations were sampled have revealed that co-occurrence of distinct watermilfoils is common in lakes (Sturtevant et al. 2009; Thum, unpublished data). We posit that managers should take care to accurately identify and map watermilfoils throughout a lake to determine the distribution and abundance of any different types. For example, it may be desirable to avoid management activities, such as herbicide application, in northern watermilfoil patches to preserve this native species. Recent research demonstrates that hybrids, on the other hand, are more likely to exhibit nuisance growth conditions in lakes and ponds compared to either parent species. In addition, hybrid watermilfoils can demonstrate a muted response to some herbicides. Thus, hybrids may warrant increased vigilance in terms of prescribing and monitoring management activities (Fig 2.).

While there are a large number of factors that can influence the efficacy of any given management activity on a specific lake, we posit that significant changes in the composition of watermilfoil types in a lake is one possible cause for variation in the extent and speed of regrowth in lakes. Recall that hybrid watermilfoils have been shown to exhibit faster growth and reduced sensitivity to some herbicides. It stands to reason that the extent and speed of regrowth may change if the watermilfoil shifted from Eurasian watermilfoil to hybrid watermilfoil over time in a lake (Fig. 3). We therefore argue that frequent monitoring of watermilfoil in lakes with long-term aquatic vegetation management projects can be used to adapt management techniques. For example, in the absence of accurate monitoring data of watermilfoil types, it is impossible to determine whether any observed changes in watermilfoil regrowth or management efficacy is related to changes in the composition or distribution of different watermilfoil types (e.g., Eurasian versus hybrid) versus other factors.

Continued on page 25
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- Dredging feasibility studies
- Lake level augmentation studies
Incorporating genetic identifications of watermilfoils

Continued from page 23)

Integration of Genetic Identifications with Aquatic Vegetation Mapping –

Integrating genetic identifications into existing aquatic vegetation mapping services begs the question of how best to do it. How much sampling is required within a lake? How frequently should genetic surveys be conducted?

Ideally, genetic identifications would be integrated into standardized aquatic vegetation survey methods designed to quantify the distribution and abundance of aquatic plants, such as Point-Intercept methods. Since these surveys rely on species-specific identifications, and since Eurasian, northern, and hybrid watermilfoils can easily be misidentified, we recommend that at least one plant from each survey point with watermilfoil be genetically identified in order to accurately map their distribution and abundance. However, we recognize that this level of detailed sampling may not be economically feasible at the present time for all lakes. We predict this will become the standard, especially as the per sample costs for genetic identifications decrease with increased technology and infrastructure to support genetic identifications.

For more limited budgets, we recommend sampling plants from each area of the lake where watermilfoil is present. Because native and non-native watermilfoils can occur in the same water body, and because native and non-native watermilfoils can be difficult to distinguish, it is important to sample plants from all areas of the lake instead of sampling only plants that are thought to be non-native. For example, in early-detection-and-rapid-response scenarios, it is important to sample both the putative invasive and native plants to ensure that management actions are based on accurate identifications (see Table 1). Similarly, for lakes undergoing management, it is important to sample treated areas both before and after treatment in order to detect any important changes in biotype distribution before and after management.

The overall goal of adaptive management is to make effective decisions in the face of uncertainty. As with management of any natural resource, lake management is inherently uncertain. A critical part of adaptive management is detailed monitoring of the system in order to evaluate and modify management approaches. Aquatic vegetation mapping plays a critical role in the development and evaluation of aquatic vegetation management actions. However, in the case of watermilfoil management, limited ability to distinguish Eurasian, northern, and hybrid watermilfoils may have historically limited the ability to develop, implement, and evaluate management actions that target the selective removal of non-native watermilfoils. Genetic identifications can improve vegetation mapping by providing more accurate distribution and abundance estimates of Eurasian, hybrid, northern and other native watermilfoils. As genetic monitoring becomes routine, we believe our understanding of watermilfoil distribution and abundance over time in managed lakes will become more apparent. This, along with continued results from active research on the genetics of invasiveness, promises to provide additional tools for lake evaluation and maximizing treatment efficacy in the future. With this increased understanding will come more cost-effective and environmentally responsible aquatic vegetation management.

For more information and guidelines on genetic identifications, go to: http://www.gvsu.edu/geneticidentification/.

Figure 3. Genetic identifications provide information on whether variation in treatment efficacy and resurgence is related to changes in dominance of different watermilfoil types.
References


Physical Inventory

The Annis Water Resources Institute (AWRI) completed an inventory to identify areas in the Watershed that are contributing to nonpoint source pollution. Two methods were used to complete the inventory work: 1) an initial review of color and infrared digital 2010 orthophotography over the entire 603 square miles of watershed to help identify potential sites to investigate further, and 2) a physical inventory that included visiting identified sites to evaluate the extent, if any, of nonpoint source pollution impacting the associated water body.

The results of the physical inventory are included in the pages of this Appendix. See Figure I-1 for locations.
Big Creek

Site ID: 1 – Latitude (N)/Longitude (W): 44.497585/ -84.778641
Location: At Higgins Lake Dr. north of Dewey Ave. – (Lyon Twp. – Roscommon County)

Upstream View – June 9, 2014
Upstream Culvert – June 9, 2014
**Comments:** Higgins Lake Drive is paved. Residence mows lawn up to stream for 30’. The road edge is lacking vegetation on the upstream side.
Site ID: 2 – Latitude (N)/Longitude (W): 44.496712/ -84.776112

Location: At Treasure Blvd, north of Kenmore Ave. – (Lyon Twp. – Roscommon County)

Upstream View – June 9, 2014

Upstream Bridge – June 9, 2014
Comments: Treasure Boulevard is a paved road. Residence mows up to stream for 30’ on downstream side of bridge. A retainment wall is present on the upstream side along the residence.
Site ID: 3 – Latitude (N)/Longitude (W): 44.497755/ -84.779598
Location: At N. Harrison Rd. – (Lyon Twp. – Roscommon County)

Upstream View – June 9, 2014

Upstream Culvert – June 9, 2014
**Comments:** North Harrison Road is a major paved road. The right-of-way is heavily vegetated 20’ down to creek. No water quality issues.
Cut River

Site ID: 4 – Latitude (N)/Longitude (W): 44.433195 / -84.670032
Location: At East Higgins Lake Dr. and Cut River – (Gerrish Twp. – Roscommon County)

Upstream View – June 9, 2014

Upstream Culverts – June 9, 2014
Comments: East Higgins Lake Drive is a paved road. A retention wall is present on the upstream side for the residence. Restaurant lawn mowed up to stream on downstream side for 200’. Banks appear to be stable.
Site ID: 5 – Latitude (N)/Longitude (W): 44.395929/ -84.655681
Location: At Lansing Rd. and Cut River – (Markey Twp. – Roscommon County)

Upstream View – June 9, 2014

Upstream Bridge – June 9, 2014
Comments: Lansing Road is a gravel road. The stream banks are vegetated and stable. A terraced pebble access is present on upstream side of bridge. A recent runoff site was stabilized with riprap.
Site ID: 6 – Latitude (N)/Longitude (W): 44.39629/ -84.652738
Location: At Lansing Rd. and Cut River – (Markey Twp. – Roscommon County)

Upstream View – June 9, 2014

Downstream View – June 9, 2014
Comments: Lansing Road is a gravel road. There is no bridge, but a 150’ retention wall is present along the road. The wall is collapsed for 30’. Aside from the collapsed wall, the site is well vegetated and stable.
Site ID: 7 – Latitude (N)/Longitude (W): 44.363056 / -84.680204

Location: At East Houghton Lake Rd. (Markey Twp. – Roscommon County)

Upstream View – April 10, 2014

Bridge Over the Cut River – April 10, 2014
Comments: River is 50’ wide at this site, no water quality issues observed besides sediment in the streambed.
Backus Creek

Site ID: 8 – Latitude (N)/Longitude (W): 44.357908/ -84.612791
Location: At Roscommon Rd. (M-18) (Markey Twp. – Roscommon County)

Upstream View – June 9, 2014

Downstream View – June 9, 2014
Roscommon Road is paved. The stream bank is heavily vegetated. The culvert is in good condition. A downstream residence mows up to the creek where moderate erosion is present.
Spring Brook Creek

Site ID: 9 – Latitude (N)/Longitude (W): 44.310436/ -84.636171
Location: At Roscommon Rd. (M-18) (Denton Twp. – Roscommon County)

Upstream View – April 10, 2014

Upstream Culvert – April 10, 2014
Comments: Creek floodplain upstream of bridge is wide with extensive speckled alder. Fine sand sediment is on the bridge deck, probably from road application during winter.
Site ID: 10 – Latitude (N)/Longitude (W): 44.30566 / -84.630101
Location: At West Branch Rd. (M-55) (Denton Twp. – Roscommon County)

Upstream View – April 10, 2014

Upstream Culvert under M-55 – April 10, 2014
Comments: Creek runs in front of the Abundant Grace Church, then under M-55. Access road to church runs over the creek. Stream banks in the front of the church are devoid of vegetation, but are stable with no erosion. Also, 600 feet to the west is another access road that goes over the creek. Both sites lack bank vegetation.

The riparian area along the creek is very well vegetated for most all of its total length; these sites probably have very little impact on stream temperature.
Denton Creek

Site ID: 11 – Latitude (N)/Longitude (W): 44.299397 / -84.634286

Location: At Silverwood Dr. – Lake James lake level control structure (Denton Twp. – Roscommon County)

Downstream release from the lake level control structure – April 10, 2014
Comments: Structure is owned by the Lake James Property Owners Association. No public access to this site.

Appears that a stream bank just downstream from the structure has some minor bank erosion.
Site ID: 11a – Latitude (N)/Longitude (W): 44.302418 / -84.645062
Location: At M-55 (in Prudenville)(Denton Twp. – Roscommon County)

Upstream View – April 10, 2014

Downstream View – April 10, 2014
**Comments:** Banks are armored with cement for much of this reach of the creek. Parking lot next to gas station is dirt/gravel. Bait Shop on the banks of the creek also has dirt/gravel parking lot. Creek bottom here is heavily covered with sediment.
Site ID: 12 – Latitude (N)/Longitude (W): 44.293172 / -84.578157

Location: At Crooked Rd. and North Branch Denton Creek (Backus Twp. – Roscommon County)

Comments: Crooked Road is a gravel road. The stream banks are highly vegetated. Upstream, a wide floodplain of wetlands and shrub-carr is present. No erosion issues.
Knappens Creek

Site ID: 14 – Latitude (N)/Longitude (W): 44.298491/ -84.649349

Location: At Main St. (Denton Twp. – Roscommon County)

Upstream View – April 10, 2014

Upstream Culverts – April 10, 2014
Comments: Main St. is a paved main road. Shoulder is dirt, but well vegetated. No major water quality issues observed at this site.
Site ID: 14a – Latitude (N)/Longitude (W): 44.299664/ -84.650567
Location: At M-55 in Prudenville (Denton Twp. – Roscommon County)

Upstream View – April 10, 2014

Upstream Culvert – April 10, 2014
Comments: M-55 and creek, no major water quality issues observed at this site.
Site ID: 15 – Latitude (N)/Longitude (W): 44.28919/ -84.63783
Location: At Deer Run Blvd. (Denton Twp. – Roscommon County)

Upstream View – April 10, 2014

Upstream Culvert – April 10, 2014
Deer Run Blvd. is paved road into subdivision. The wide natural floodplain has extensive speckled alder 10’ to 20’ tall. No major water quality issues observed at this site.
Wolf Creek

Site ID: 16 – Latitude (N)/Longitude (W): 44.23565/-84.729923
Location: At Newaygo Road (Roscommon Twp. – Roscommon County)

Upstream View – Nov. 6, 2013

Upstream Culverts – Nov. 6, 2013
Comments: Newaygo Road is dirt/gravel and roadside vegetation is light. There is potential for stormwater runoff into creek. No major water quality issues at this site observed.
Site ID: 17 – Latitude (N)/Longitude (W): 44.219281/ -84.769724
Location: Off of Wraco Road – Site is behind a locked gate. Wraco Lodge Lake (Roscommon Twp. – Roscommon County)

Marsh – Nov. 6, 2013

Trumpeter Swans in the Open Water – A Threated Species in Michigan

Comments: Wraco Road is a dirt two-track. No water quality issues at this site.
Site ID: 17a – Latitude (N)/Longitude (W): 44.20946/ -84.791675

Location: At Old US 27 (Roscommon Twp. – Roscommon County)

Upstream View – Nov. 6, 2013

Downstream View – Nov. 6, 2013
Bridge Structure with Rip Rap – Nov. 6, 2013

Comments: Old US 27 is a major paved road. Bridge and road infrastructure are new, no water quality issues at this site.
Site ID: 18 – Latitude (N)/Longitude (W): 44.204577/ -84.814756
Location: At Wexford Rd. or Canoe Camp Rd. - County 402. (Roscommon Twp. – Roscommon County)

Upstream View – Nov. 6, 2013

Downstream View – Nov. 6, 2013
Comments: The road is a major gravel/dirt travel route. Potential exists for sediment in stormwater runoff. However, the streambanks and road right-of-way are very well vegetated. On the very rainy day these photos were taken I did not observe any issues impacting water quality. However, MDEQ survey in 2001 observed “lots of siltation and sedimentation.”
Site ID: 49 – Latitude (N)/Longitude (W): 44.237964/ -84.663139

Location: At Possum Trail Rd. (Roscommon Twp. – Roscommon County)

Comments: Possum Trail is a sandy road. The road bisects a wetland/shrub-carr floodplain. The right-of-way is well vegetated. There is no erosion present.
Site ID: 50 – Latitude (N)/Longitude (W): 44.232854 / -84.697913

Location: At S. Reserve Rd. (Roscommon Twp. – Roscommon County)

Comments: South Reserve Road is sandy. The creek is heavily forested with balsam fir and northern white cedar. There is no erosion present.
Site ID: 51 – Latitude (N)/Longitude (W): 44.23025 / -84.695662

Location: On S. Reserve Rd. just south of Pete Rd. - 0.13 miles. (Roscommon Twp. – Roscommon County)

Comments: South Reserve Road is a gravel road. The road bisects a heavily vegetated cedar swamp. The right-of-way is well vegetated.
Site ID: 52 – Latitude (N)/Longitude (W): 44.222726/ -84.700981

Location: At S. Reserve Rd. and East Branch of Wolf Creek (Roscommon Twp. – Roscommon County)

Comments: South Reserve Road is sandy. The road bisects a well vegetated wetland/ shrub-carr floodplain. A moderate amount of road debris is eroding into the creek at culverts
Bear Creek

Site ID: 19 – Latitude (N)/Longitude (W): 44.269796 / -84.810934

Location: At Snow Bowl Road (Roscommon Twp. – Roscommon County)

Upstream View – Nov. 6, 2013
Comments: Snow Bowl Road is a paved road. Some siltation is occurring at the site. A small intermittent feeder stream seems to be the source, possibly coming from the gravel driveway approximately 200’ to the west. Considering the large amount of rainfall that fell the 12 hours before this photo was taken, this is probably not unusual and does not appear to be a big problem.
Site ID: 19a – Latitude (N)/Longitude (W): 44.269689 / -84.810988

Location: Just downstream of Snow Bowl Road (Roscommon Twp. – Roscommon County)

Comments: Eroding streambank, 10’ long. Bank undercutting is occurring. Trees on bank are beginning to lean towards the creek.
Site ID: 20 – Latitude (N)/Longitude (W): 44.232295 / -84.851907

Location: At Barney Lake Road (or Sparrow Rd.) – County 402, near Bear Creek Flooding (Roscommon Twp. – Roscommon County)

Upstream View – Nov. 6, 2013

Downstream View – Nov. 6, 2013
Comments: Barney Lake Road (a dirt/gravel road) or the Bear Creek Flooding outlet structure is not causing any water quality issues at this site. Note: the Bear Creek Flooding is just upstream of the road crossing.
Nellsville Drain

Site ID: 21 – Latitude (N)/Longitude (W): 44.266163 / -84.887049
Location: At Jeffs Road (Butterfield Twp. – Missaukee County)

Upstream View – Nov. 7, 2013

Upstream Culverts – Nov. 7, 2013
Comments: Jeffs Road is paved. The perched culverts could use some attention; however, no water quality impacts at this site.
Muskegon River

Site ID: 21a – Latitude (N)/Longitude (W): 44.248697 / -84.896347

Location: At Cadillac Road (Butterfield Twp. – Missaukee County)

Upstream View – Nov. 7, 2013

Downstream View – Nov. 7, 2013
Comments: Cadillac Road is dirt/gravel; however, the bridge is paved. Crossing looks to be new. No water quality issues at this site.
Site ID: 21b – Latitude (N)/Longitude (W): 44.248697 / -84.896347
Location: At Dolph Road (Holland Twp. – Missaukee County)

Upstream View – Nov. 7, 2013

Downstream View – Nov. 7, 2013
Comments: Dolph Road is a dirt/gravel road. No observed water quality problems at the crossing.
Site ID: 21c – Latitude (N)/Longitude (W): 44.225125 / -84.875379

Location: Upstream of Dolph Road (Holland Twp. – Missaukee County)

Comments: Eroding streambank is 200’ long and about 6’-8’ bank height. Red pine trees on the bank are beginning to fall over into the river.

This site was also identified in the following report:


The report states “Severe erosion was evident on the right bank for much of the reach sampled. Heavy deposition was also obvious in the stream, which results in a lack of available habitat for macroinvertebrate colonization.”
Site ID: 22 – Latitude (N)/Longitude (W): 44.254757 / -84.898952

Location: Near the intersection of Walenjus Rd. and Boynton Rd. (Butterfield Twp. – Missaukee County)

![Muskegon River at Agricultural Field – Nov. 7, 2013](image)

Comments: A long segment of streambank along the river is void of tall shading vegetation. However, grasses are extensive and provide a buffer to the agricultural field planted with cover crops. Streambank is stable here no water quality issues at this site.
Site ID: 22a – Latitude (N)/Longitude (W): 44.254154 / -84.899367
Location: Off of agricultural field near the intersection of Walenjus Rd. and Boynton Rd. (Butterfield Twp. – Missaukee County)

Streambank Erosion Site – Nov. 7, 2013

Comments: Site is approximately 40’ long. See BEHl information for score.
Site ID: 22b – Latitude (N)/Longitude (W): 44.254775 / -84.898164

Location: Off of agricultural field near the intersection of Walenjus Rd. and Boynton Rd. (Butterfield Twp. – Missaukee County)

Comments: Eroding streambank is 100’ long (estimate) and about 3’-5’ tall down to the water. See BEHI information for score.
Site ID: A – Latitude (N)/Longitude (W): 44.349944 / -84.854399

Location: At Muskegon Rd. (County Rd. 300) (Lake Twp. – Roscommon County)

Erosion – June 10, 2014

Comments: 65’ of extensive bank erosion. Banks 6’-10’ tall with 75° slopes. The site is used for river access and camping. See BEHI information for score.
Site ID: B – Latitude (N)/Longitude (W): 44.350237 / -84.853876
Location: At Muskegon Rd. (County Rd. 300) (Lake Twp. – Roscommon County)

![Erosion – June 10, 2014](image)

Comments: 160’ of extensive bank erosion. Banks 10’-12’ tall with 90°-120° slopes. See BEHI information for score.
Site ID: C – Latitude (N)/Longitude (W): 44.335963 / -84.888888

Location: At Ben Jeff’s River Park off M-55 (Enterprise Twp. – Missaukee County)

Comments: 150’ of streambank erosion. Banks 6’-8’ tall with 80°-90° slopes. See BEHI information for score.
Site ID: D – Latitude (N)/Longitude (W): 44.316563 / -84.900079

Location: West off Jeff’s Rd. Two-track into Houghton Lake Wildlife Research Area (Butterfield Twp. – Missaukee County)

Comments: 120’ of bank erosion. Banks 10’-14’ tall with 60°-80° slopes. See BEHL information for score.
Site ID: E – Latitude (N)/Longitude (W): 44.316427 / -84.901039

Location: West off Jeff’s Rd. Two-track into Houghton Lake Wildlife Research Area (Butterfield Twp. – Missaukee County)

![Erosion – June 10, 2014](image)

Comments: 40’ of bank erosion. Banks 10’ tall with 50° slopes. Site used as a canoe/kayak landing. See BEHI information for score.
Site ID: F – Latitude (N)/Longitude (W): 44.316479 / -84.901949
Location: West off Jeff’s Rd. Two-track into Houghton Lake Wildlife Research Area (Butterfield Twp. – Missaukee County)

50’ of bank erosion. Banks 5’ tall with 40°-50° slopes. Site is an access point to the Muskegon River along with recreational activities such as camping. See BEHI information for score.
Site ID: G – Latitude (N)/Longitude (W): 44.213431 / -84.847558
Location: Off Canoe Camp Rd. (Wexford Dr.) (Roscommon Twp. – Roscommon County)

Erosion – June 11, 2014
Erosion – June 11, 2014

Comments: Very large section of bank erosion. Banks range from 1’-20’ tall with bank slopes ranging from 50°-90°. It looks like dune grass was once planted to help stabilize area.

Site is used as a river access site. There is a large area used for camping.

Banks to the west = 330’
Banks to the east = 340’
**POTENTIAL SITES OF CONCERN:**

These sites were identified in the following report:


**Report Site ID: Additional – Latitude (N)/Longitude (W): 44.203475 / -84.835397**  
**Location:** South of the end of Wolf Creek Rd. (Roscommon Twp. – Roscommon County)

**Report Site ID: Station 3 – Latitude (N)/Longitude (W): 44.208558 / -84.843328**  
**Location:** South of Canoe Camp Rd. (Roscommon Twp. – Roscommon County)

**Report Site ID: Station 2 – Latitude (N)/Longitude (W): 44.214342 / -84.852779**  
**Location:** West of Canoe Camp Rd. (Holland Twp. – Missaukee County)

All of these sites are related to recreational sites along the mainstem of the river. Stream banks at the sites are sand, lacking vegetation, and unstable. The report states that the sites “clearly contribute to the stream’s overall sand bedload. The overall sand domination of the stream is probably due to characteristics of the surrounding watershed, in which sandy soils predominate.” The sites were not visited as part of the inventory but are included as possible problem areas. Also, the locations of the sites are approximate.

This site was identified in the following report:


**Report Site ID: Station 8 – Latitude (N)/Longitude (W): 44.20813 / -84.84086**  
**Location:** South of Canoe Camp Rd. (Roscommon Twp. – Roscommon County)

The report states that “The banks are bare, steep, and sandy, and were severely eroded. The exact cause of the eroded banks is unknown, but could be a result of the historical logging that took place in the watershed, or just from the naturally occurring sandy soils that are easily eroded from natural processes.” The site was not visited as part of the inventory but is included as a possible problem area.
Butterfield Creek

Site ID: 24 – Latitude (N)/Longitude (W): 44.275347 / -84.933244
Location: At McVety Road (Butterfield Twp. – Missaukee County)

Upstream View – Nov. 7, 2013

Downstream View – Nov. 7, 2013
Comments: McVety Road is paved at the crossing. Bridge and road approaches are in excellent condition. No water quality issues at the site.

This site was also identified in the following report:


The report states “Much of the substrate was composed of soft sand covered with a layer of silt”.

McVety Road Bridge – Nov. 7, 2013
Site ID: 25 – Latitude (N)/Longitude (W): 44.270332 / -84.953407

Location: At 13 Mile Road (Butterfield Twp. – Missaukee County)

Comments: 13 Mile Road is a major paved road. Bridge structure is new and in excellent shape. No water quality issues at this site. However, a past MDEQ (2005) survey suggests a “soft sandy, stream bottom, heavy siltation”.
Site ID: 29 – Latitude (N)/Longitude (W): 44.256447 / -85.033612
Location: At 9 Mile Road (Aetna Twp. – Missaukee County)

Upstream View – Nov. 7, 2013

Downstream View – Nov. 7, 2013
Comments: 9 Mile Road has a dirt/gravel surface. Bridge structure is in good shape. No water quality issues at this site.

Note: 0.6 miles due south along 9 Mile Road there is an active agriculture operation with confined feeding and a manure pit.

Note: 0.4 miles due south along 9 Mile Road there is an active, small pasture for horses.

No possible vectors for contamination from either of these sites were identified.
Site ID: 31 – Latitude (N)/Longitude (W): 44.255774 / -85.053695

Location: At 8 Mile Road (Aetna Twp. – Missaukee County)

Upstream View – Nov. 7, 2013

Downstream View – Nov. 7, 2013
Comments: 8 Mile Road is a major, paved road. Bridge and culvert are in excellent shape. No water quality issues at this site.

Note: 600’ due south along 8 Mile Road there is an active cattle pasture. However, I do not see any potential sources of contamination from this site.
Site ID: 32 – Latitude (N)/Longitude (W): 44.267144 / -85.07398
Location: At 7 Mile Road (Aetna Twp. – Missaukee County)

Comments: 7 Mile Road is a major, paved road. Bridge and culvert are in good shape. No water quality issues at this site.

Note: 1000’ south of this site along 7 Mile Road there is a very large confined feeding operation with a large manure pit. The pit is 200’ from the creek. Site has potential for water quality issues.
Site ID: 33 – Latitude (N)/Longitude (W): 44.273358 / -85.094081

Location: At Forward Road (Aetna Twp. – Missaukee County)

Comments: Forward Road is a major, paved road. Bridge and culvert are in good shape. No water quality problems at this site.

Note: 1/2 mile south of the site is a large confined feeding operation. I see no apparent vectors of contamination however.
This site was also identified in the following report:

The report states “Most of the substrate was composed of sand. Woody debris or other substrates.....were heavily embedded or silted over.”
Site ID: 34 – Latitude (N)/Longitude (W): 44.294702 / -85.124382

Location: At Kelly Road (Reeder Twp. – Missaukee County)

Upstream View – Nov. 7, 2013

Upstream Culverts – Nov. 7, 2013
Comments: Kelly Road is a major paved road. Bridge and culverts are in good condition. No water quality issues at this site. Creek size is down to 5’-6’ wide, floodplain is extensive speckled alder and scattered balsam fir.
Site ID: 34a – Latitude (N)/Longitude (W): 44.293907 / -85.095349

Location: At Forward Road and feeder no-name stream to Butterfield Creek (Reeder Twp. – Missaukee County)

Comments: Forward Road is a paved road. Water is very slow moving here, banks are extensive grass/shrubs. No water quality issues here.

No Photos
Site ID: 35 – Latitude (N)/Longitude (W): 44.306959 / -85.135093

Location: At VanDermullen Road (Reeder Twp. – Missaukee County)

Upstream View – Nov. 7, 2013

Downstream View – Nov. 7, 2013
VanDermullen Road is a major, paved road. Bridge and culvert are in good shape. No water quality issues at this site. Creek floodplain vegetation is predominately speckled alder, balsam fir, and Northern-white cedar.
West Branch Muskegon River

Site ID: 36 – Latitude (N)/Longitude (W): 44.335874 / -84.921589

Location: At M-55 (Enterprise Twp. – Missaukee County)

Upstream View – Nov. 8, 2013

Downstream View – Nov. 8, 2013
Comments: M-55 is a paved road. At this site there is a turnout off of M-55 to access the river. The turnoff is dirt, but there is a good amount of vegetation buffering the stream. There is potential for water quality impacts, but on this wet, rainy day I did not see any evidence of sediment getting into the stream.

Note there is an old spring also at this site. See photo below.
Site ID: 39 – Latitude (N)/Longitude (W): 44.355209 / -84.944307

Location: At N. Merritt Rd. (Enterprise Twp. – Missaukee County)

Upstream View – Nov. 8, 2013

Downstream View – Nov. 8, 2013
Comments: Merritt is a major, paved road. The West Branch is about 70’- 80’ wide at the site. No evidence of water quality issues at this site.
**Site ID:** 40 – Latitude (N)/Longitude (W): 44.354981 / -84.984652  
**Location:** At Star City Rd. (West Branch Twp. – Missaukee County)

**Upstream View – Nov. 8, 2013**

**Downstream View – Nov. 8, 2013**

**Comments:** Star City is a major paved Road. Road and bridge structure in excellent shape, no water quality issues at this site. Silt and sand present on stream bottom, source unknown.
Site ID: 40a – Latitude (N)/Longitude (W): 44.355333 / -84.984969
Location: At Star City Rd. – west side of road (West Branch Twp. – Missaukee County)

Comments: Landowner mowing to edge of stream (30 lineal feet). Also some minor streambank undercutting is occurring (about 10’), may want to consider some best management practices at this site.
Site ID: 42 – Latitude (N)/Longitude (W): 44.369759 / -85.014955

Location: At Stevens Rd. (West Branch Twp. – Missaukee County)

Upstream View – Nov. 8, 2013

Downstream View – Nov. 8, 2013

Comments: Downstream on private property, some evidence of streambank erosion that seems to be stable at this time.
Bridge over the River – Nov. 8, 2013

Comments: Stevens Road is a gravel/dirt road. Road is cement on the bridge. Structure is new, no water quality issues at this site.
Site ID: 44 – Latitude (N)/Longitude (W): 44.365682 / -85.07601

Location: At Seven Mile Rd. (West Branch Twp. – Missaukee County)

Upstream View – Nov. 8, 2013

Downstream View – Nov. 8, 2013
Comments: Seven Mile Road is a paved road. Crossing is in fine shape, no water quality issues. Floodplain with extensive speckled alder, 10’-15’ tall.
Haymarsh Creek

Site ID: 45 – Latitude (N)/Longitude (W): 44.389529 / -84.886088
Location: At Dorr Road (Enterprise Twp. – Missaukee County)

Upstream View – Nov. 8, 2013

Downstream View – Nov. 8, 2013
**Comments:** Dorr Road is a paved road. Haymarsh Creek is about 20’ wide at this site. Road and bridge are in good shape, no water quality issues at this site. An active beaver hut is at the crossing.
Site ID: 46 – Latitude (N)/Longitude (W): 44.412378 / -84.973489
Location: At Nelson Road (Enterprise Twp. – Missaukee County)

Comments: Nelson Road is a paved road. Crossing at this site is in good shape. No water quality issues observed. The floodplain has extensive speckled alder and red-osier dogwood shrubs to 15’ tall.
Addis Creek

Site ID: 47 – Latitude (N)/Longitude (W): 44.430939 / -84.91974

Location: At Beuthien Road (Norwich Twp. – Missaukee County)

Upstream View – June 9, 2014

Downstream View – June 9, 2014
Comments: Beuthien Road is a two-track dirt road. Road bisects natural creek with extensive floodplain. No apparent water quality issues.
Willow Run Creek

Site ID: 48 – Latitude (N)/Longitude (W): 44.466697 / -84.903156

Location: At Moorsetown Road (Norwich Twp. – Missaukee County)

Upstream View – June 9, 2014

Upstream Culvert – June 9, 2014
Comments: Moorsetown Road is a gravel road. A small amount of gravel and sand are washing into creek at the bridge.
Recommended Best Management Practices (BMPs) and Estimated Load Reductions
for the Upper Muskegon River Watershed

Prepared by the Annis Water Resources Institute
As Part of the Upper Muskegon River Watershed Management Plan
July 10, 2014
The following areas were identified during our physical inventory work. These sites are recommended for BMP implementation. All streambank erosion sites were evaluated and prioritized using Rosgen’s Bank Erosion Hazard Index (BEHI).
Site ID: 19a – Latitude (N)/Longitude (W): 44.269689 / -84.810988
Location: Just downstream of Snow Bowl Road (Roscommon Twp. – Roscommon County)

Waterbody: Bear Creek

Eroding Streambank – Nov. 6, 2013

BEHI Score: 14.35 = Moderate

Site Length: 10 feet  Bank Height: 3 feet

BMP Recommendation: Streambank stabilization – Supplies include: Coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $170 (value of supplies only, labor not included)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Sediment Load Reduction Per Year (Tons): 0.3
Phosphorus Load Reduction Per Year (lbs): 0.2
Nitrogen Load Reduction Per Year (lbs): 0.5
Site ID: 21c – Latitude (N)/Longitude (W): 44.225125 / -84.875379

Location: Upstream of Dolph Road (Holland Twp. – Missaukee County)

Waterbody: Muskegon River – Main Stem

Beattie Eroding Streambank – Nov. 7, 2013

BEHI Score: 14.3 = Moderate

Site Length: 200 feet  Bank Height: 7 feet

BMP Recommendation: Streambank stabilization – Supplies could include: Rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $13,200 (approx. value of supplies, labor, machinery, and engineering and construction layout)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Sediment Load Reduction Per Year (Tons): 23.1

Phosphorus Load Reduction Per Year (lbs): 19.6

Nitrogen Load Reduction Per Year (lbs): 39.3
Site ID: 22a – Latitude (N)/Longitude (W): 44.254154 / -84.899367

Location: Off of agricultural field near the intersection of Walenjus Rd. and Boynton Rd. (Butterfield Twp. – Missaukee County)

Waterbody: Muskegon River – Main Stem

![Eroding Streambank – Nov. 7, 2013](image)

BEHI Score: 14.3 = Moderate

Site Length: 40 feet   Bank Height: 5 feet

BMP Recommendation: Streambank stabilization – Supplies could include: rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $3,030 (approx. value of supplies, labor, machinery, and engineering and construction layout)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Sediment Load Reduction Per Year (Tons): 1.1

Phosphorus Load Reduction Per Year (lbs): 0.9

Nitrogen Load Reduction Per Year (lbs): 1.9
Site ID: 22b – Latitude (N)/Longitude (W): 44.254775 / -84.898164

Location: Off of agricultural field near the intersection of Walenjus Rd. and Boynton Rd. (Butterfield Twp. – Missaukee County)

Waterbody: Muskegon River – Main Stem

BEHI Score: 14.3 = Moderate

Site Length: 100 feet  Bank Height: 4 feet

BMP Recommendation: Streambank stabilization – Supplies could include: rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $7,400 (approx. value of supplies, labor, machinery, and engineering and construction layout)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Sediment Load Reduction Per Year (Tons): 6.6

Phosphorus Load Reduction Per Year (lbs): 5.6

Nitrogen Load Reduction Per Year (lbs): 11.2
Site ID: 40a – Latitude (N)/Longitude (W): 44.355333 / -84.984969
Location: At Star City Rd. – west side of road (West Branch Twp. – Missaukee County)

Waterbody: West Branch Muskegon River

Bare streambank – no native vegetation

Site Length: 30 feet  Bank Height: 1-2 feet

BMP Recommendation: Install native riparian buffer-filter strip – Supplies include: grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $1,100 (approx. value of supplies, labor, machinery, and engineering and construction layout)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Total Suspended Solids Load Reduction Per Year (lbs): 112

Phosphorus Load Reduction Per Year (lbs): 0.2

Nitrogen Load Reduction Per Year (lbs): 1.2
Site ID: A – Latitude (N)/Longitude (W): 44.349944 / -84.854399

Location: At Muskegon Rd. (County Rd. 300) (Lake Twp. – Roscommon County)

Waterbody: Muskegon River

Site Length: 65 feet  Bank Height: 6-10 feet

BMP Recommendation: Streambank stabilization – Supplies could include: rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $6,105 (approx. value of supplies, labor, machinery, and engineering and construction layout)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Total Suspended Solids Load Reduction Per Year (Tons): 11.4

Phosphorus Load Reduction Per Year (lbs): 9.7

Nitrogen Load Reduction Per Year (lbs): 19.4
Site ID: B – Latitude (N)/Longitude (W): 44.350237 / -84.853876
Location: At Muskegon Rd. (County Rd. 300) (Lake Twp. – Roscommon County)

Waterbody: Muskegon River

Erosion – June 10, 2014

BEHI Score: 21.4 = High

Site Length: 160 feet  Bank Height: 10-12 feet

BMP Recommendation: Streambank stabilization – Supplies could include: rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $10,120 (approx. value of supplies, labor, machinery, and engineering and construction layout)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Total Suspended Solids Load Reduction Per Year (Tons): 38.7
Phosphorus Load Reduction Per Year (lbs): 32.9
Nitrogen Load Reduction Per Year (lbs): 65.8
Site ID: C – Latitude (N)/Longitude (W): 44.335963 / -84.888888

Location: At Ben Jeff’s River Park off M-55 (Enterprise Twp. – Missaukee County)

Waterbody: Muskegon River

Erosion – June 10, 2014

BEHI Score: 16.3 = Moderate

Site Length: 150 feet  Bank Height: 6-8 feet

BMP Recommendation: Streambank stabilization – Supplies could include: rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $9,750 (approx. value of supplies, labor, machinery, and engineering and construction layout)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Total Suspended Solids Load Reduction Per Year (Tons): 6.9

Phosphorus Load Reduction Per Year (lbs): 5.9

Nitrogen Load Reduction Per Year (lbs): 11.8
Site ID: D – Latitude (N)/Longitude (W): 44.316563 / -84.900079

Location: West off Jeff’s Rd. Two-track into Houghton Lake Wildlife Research Area (Butterfield Twp. – Missaukee County)

Waterbody: Muskegon River

BEHI Score: 26.4 = High

Site Length: 120 feet  Bank Height: 10-14 feet

BMP Recommendation: Streambank stabilization – Supplies could include: rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $10,400 (approx. value of supplies, labor, machinery, and engineering and construction layout)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Total Suspended Solids Load Reduction Per Year (Tons): 38.8

Phosphorus Load Reduction Per Year (lbs): 33.0

Nitrogen Load Reduction Per Year (lbs): 66.0
**Site ID: E – Latitude (N)/Longitude (W): 44.316427 / -84.901039**

**Location:** West off Jeff’s Rd. Two-track into Houghton Lake Wildlife Research Area (Butterfield Twp. – Missaukee County)

**Waterbody:** Muskegon River

![Erosion – June 10, 2014](image)

**BEHI Score:** 24.4 = High

**Site Length:** 40 feet  **Bank Height:** 10 feet

**BMP Recommendation:** Streambank stabilization – Supplies could include: rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

**Repair Cost:** $3,580 (approx. value of supplies, labor, machinery, and engineering and construction layout)

**Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)**

- Total Suspended Solids Load Reduction Per Year (Tons): 8.8
- Phosphorus Load Reduction Per Year (lbs): 7.5
- Nitrogen Load Reduction Per Year (lbs): 15.0
Site ID: F – Latitude (N)/Longitude (W): 44.316479 / -84.901949

Location: West off Jeff’s Rd. Two-track into Houghton Lake Wildlife Research Area (Butterfield Twp. – Missaukee County)

Waterbody: Muskegon River

Erosion – June 10, 2014

BEHI Score: 18.3 = Moderate

Site Length: 50 feet  Bank Height: 5 feet

BMP Recommendation: Streambank stabilization – Supplies could include: rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $3,350 (approx. value of supplies, labor, machinery, and engineering and construction layout)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Total Suspended Solids Load Reduction Per Year (Tons): 1.7

Phosphorus Load Reduction Per Year (lbs): 1.4

Nitrogen Load Reduction Per Year (lbs): 2.8
Site ID: G (West) – Latitude (N)/Longitude (W): 44.213431 / -84.847558

Location: Off Canoe Camp Rd. (Wexford Dr.) (Roscommon Twp. – Roscommon County)

Waterbody: Muskegon River

Erosion – June 11, 2014

BEHI Score: 22.9 = High

Site Length: 330 feet  Bank Height: 1-20 feet

BMP Recommendation: Streambank stabilization – Supplies could include: rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

Repair Cost: $19,610 (approx. value of supplies, labor, machinery, and engineering and construction layout)

Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)

Total Suspended Solids Load Reduction Per Year (Tons): 81.9

Phosphorus Load Reduction Per Year (lbs): 69.6

Nitrogen Load Reduction Per Year (lbs): 139.2
Site ID: G (East) – Latitude (N)/Longitude (W): 44.213431 / -84.847558

Location: Off Canoe Camp Rd. (Wexford Dr.) (Roscommon Twp. – Roscommon County)

Waterbody: Muskegon River

![Erosion – June 11, 2014](image)

**BEHI Score:** 23.3 = High

**Site Length:** 340 feet  **Bank Height:** 4-12 feet

**BMP Recommendation:** Streambank stabilization – Supplies could include: rip-rap, coir logs, grass seed, plant plugs, shrubs, and erosion control blanket.

**Repair Cost:** $19,780 (approx. value of supplies, labor, machinery, and engineering and construction layout)

**Modeled Load Reductions (Based on Michigan Pollutants Controlled Spreadsheet – 2010)**

- Total Suspended Solids Load Reduction Per Year (tons): 61.3
- Phosphorus Load Reduction Per Year (lbs): 52.1
- Nitrogen Load Reduction Per Year (lbs): 104.3
<table>
<thead>
<tr>
<th>Objectives</th>
<th>Recommended BMPS (Prioritized by BEHI Score)</th>
<th>Load Reductions</th>
<th>BMP Cost Estimate</th>
<th>Operations and Maintenance Costs Estimates</th>
<th>Technical Support</th>
<th>Regulatory Authority</th>
<th>Potential Funding Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization (Rip-rap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket) (Physical Inventory Site ID: G-West) HIGH</td>
<td>Soil Loss Per Year (Tons): 81.9  Phosphorus Input Per Year (lbs): 69.6  Nitrogen Input Per Year (lbs): 139.2</td>
<td>$19,610 (AWRI 2014)</td>
<td>$100/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)</td>
<td>Roscommon Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
</tr>
<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization (Rip-rap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket) (Physical Inventory Site ID: G-East) HIGH</td>
<td>Soil Loss Per Year (Tons): 61.3  Phosphorus Input Per Year (lbs): 52.1  Nitrogen Input Per Year (lbs): 104.3</td>
<td>$19,780 (AWRI 2014)</td>
<td>$100/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)</td>
<td>Roscommon Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
</tr>
<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization (Rip-rap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket) (Physical Inventory Site ID: D) HIGH</td>
<td>Soil Loss Per Year (Tons): 38.8  Phosphorus Input Per Year (lbs): 33.0  Nitrogen Input Per Year (lbs): 66.0</td>
<td>$10,400 (AWRI 2014)</td>
<td>$100/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)</td>
<td>Missaukee Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
</tr>
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Table J-1 BMP Load Reductions and Cost Estimates for inventoried sites
<table>
<thead>
<tr>
<th>Objectives</th>
<th>Recommended BMPS (Prioritized)</th>
<th>Load Reductions</th>
<th>BMP Cost Estimate</th>
<th>Operations and Maintenance Costs Estimates</th>
<th>Technical Support</th>
<th>Regulatory Authority</th>
<th>Potential Funding Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization (Riprap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket) (Physical Inventory Site ID: B) HIGH</td>
<td>Soil Loss Per Year (Tons): 38.7</td>
<td>$10,120 (AWRI 2014)</td>
<td>$100/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)</td>
<td>Roscommon Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
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<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization (Riprap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket) (Physical Inventory Site ID: A) HIGH</td>
<td>Soil Loss Per Year (Tons): 11.4</td>
<td>$6,105 (AWRI 2014)</td>
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<td>Roscommon Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
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<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization (Riprap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket) (Physical Inventory Site ID: E) HIGH</td>
<td>Soil Loss Per Year (Tons): 8.8</td>
<td>$3,580 (AWRI 2014)</td>
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<td>Missaukee Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
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Table K-1 BMP Load Reductions and Cost Estimates for inventoried sites (continued)
<table>
<thead>
<tr>
<th>Objectives</th>
<th>Recommended BMPS (Prioritized)</th>
<th>Load Reductions¹</th>
<th>BMP Cost Estimate</th>
<th>Operations and Maintenance Costs Estimates</th>
<th>Technical Support</th>
<th>Regulatory Authority</th>
<th>Potential Funding Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization (Rip-rap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket) (Physical Inventory Site ID: 21c)</td>
<td>MODERATE</td>
<td>Soil Loss Per Year (Tons): 23.1</td>
<td>$13,200 (AWRI 2014)</td>
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<td>Missaukee Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
</tr>
<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization (Rip-rap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket) (Physical Inventory Site ID: C)</td>
<td>MODERATE</td>
<td>Soil Loss Per Year (Tons): 6.9</td>
<td>$9,750 (AWRI 2014)</td>
<td>$100/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)</td>
<td>Missaukee Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
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<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization (Rip-rap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket) (Physical Inventory Site ID: 22b)</td>
<td>MODERATE</td>
<td>Soil Loss Per Year (Tons): 6.6</td>
<td>$7,400 (AWRI 2014)</td>
<td>$100/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)</td>
<td>Missaukee Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
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</tbody>
</table>

¹ Load Reductions: Soil Loss Per Year (Tons), Phosphorus Input Per Year (lbs), Nitrogen Input Per Year (lbs).
### Objectives

<table>
<thead>
<tr>
<th>Recommended BMPS (Prioritized)</th>
<th>Load Reductions</th>
<th>BMP Cost Estimate</th>
<th>Operations and Maintenance Costs Estimates</th>
<th>Technical Support</th>
<th>Regulatory Authority</th>
<th>Potential Funding Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stabilize streambank erosion sites</strong> (Physical Inventory Site ID: F) MODERATE</td>
<td>Soil Loss Per Year (Tons): 1.7</td>
<td>$3,350 (AWRI 2014)</td>
<td>$50/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)</td>
<td>Missaukee Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
</tr>
<tr>
<td>Streambank Stabilization (Rip-rap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket)</td>
<td>Phosphorus Input Per Year (lbs): 1.4</td>
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<td></td>
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<tr>
<td></td>
<td>Nitrogen Input Per Year (lbs): 2.8</td>
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<td></td>
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<tr>
<td><strong>Stabilize streambank erosion sites</strong> (Physical Inventory Site ID: 22a) MODERATE</td>
<td>Soil Loss Per Year (Tons): 1.1</td>
<td>$3,030 (AWRI 2014)</td>
<td>$50/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)</td>
<td>Missaukee Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
</tr>
<tr>
<td>Streambank Stabilization (Rip-rap, Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket)</td>
<td>Phosphorus Input Per Year (lbs): 0.9</td>
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<tr>
<td></td>
<td>Nitrogen Input Per Year (lbs): 1.9</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stabilize streambank erosion sites</strong> (Physical Inventory Site ID: 19a) MODERATE</td>
<td>Soil Loss Per Year (Tons): 0.3</td>
<td>$970 (AWRI 2014)</td>
<td>$50/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)</td>
<td>Roscommon Conservation District, Local Engineering Firm – site plans and installation</td>
<td>MDEQ</td>
<td>MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Pollution Implementation, Private Landowner Contributions</td>
</tr>
<tr>
<td>Streambank Stabilization (Coir Logs, Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket)</td>
<td>Phosphorus Input Per Year (lbs): 0.2</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Nitrogen Input Per Year (lbs): 0.5</td>
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<td></td>
</tr>
</tbody>
</table>

Table K-1 BMP Load Reductions and Cost Estimates for inventoried sites (continued)
## Objectives

### Recommended BMPS (Prioritized)

- **Stabilize streambank erosion sites**
  - Riparian Buffer-Filter Strip (Grass Seed, Plant Plugs, Shrubs, and Erosion Control Blanket) (Physical Inventory Site ID: 40a) LOW
  - **Soil Loss Per Year (Tons):** 0.056
  - **Phosphorus Input Per Year (lbs):** 0.2
  - **Nitrogen Input Per Year (lbs):** 1.2

### Load Reductions

- **Soil Loss Per Year:** 280.565 Tons
- **Phosphorus Input Per Year:** 238.6 Lbs.
- **Nitrogen Input Per Year:** 478.4

### BMP Cost Estimate

- **Soil Loss Per Year (Tons):** $1,100 (AWRI 2014)
- **Phosphorus Input Per Year (lbs):** $30/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)
- **Nitrogen Input Per Year (lbs):** $30/year. For the first 3 years repair/replace materials as needed. (AWRI 2014)

### Technical Support

- Missaukee Conservation District, Local Engineering Firm – site plans and installation

### Regulatory Authority

- MDEQ

### Potential Funding Source

- MDEQ – Clean Michigan Initiative; USEPA – Nonpoint Polluton Implementation, Private Landowner Contributions

### Total Load Reductions

<table>
<thead>
<tr>
<th>Total Load Reductions</th>
<th>BMP Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Loss Per Year</td>
<td>$108,395</td>
</tr>
<tr>
<td>Phosphorus Input Per Year</td>
<td></td>
</tr>
<tr>
<td>Nitrogen Input Per Year</td>
<td></td>
</tr>
</tbody>
</table>

**AWRI – Grand Valley State University, Anni Water Resources Institute.**

**MDEQ – Michigan Department of Environmental Quality**

**USEPA – U.S. Environmental Protection Agency**

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1. Pollutant Load Reductions based on the “Michigan Pollutants Controlled Spreadsheets 2010,” version 7/13/2010. Specifically, the “Bank Stabilization Worksheet” was used. The inputs required are: 1) soil textural class (sands) 2) length-ft.-of erosion, 3) height-ft.-of eroding bank, and 4) lateral recession rate-ft/yr.

2. Cost estimates based on the approximate value of supplies needed, labor, machinery operation, and engineering and construction layout.

---

**Table K-1 BMP Load Reductions and Cost Estimates for inventoried sites (continued)**
<table>
<thead>
<tr>
<th>Objectives</th>
<th>Recommended BMPS (Prioritized by BEHI Score)</th>
<th>Measurable Milestones Years 1-5</th>
<th>Measurable Milestones Years 6-10</th>
<th>Components for Monitoring Progress and Implementation</th>
<th>Evaluation Criteria</th>
<th>Responsible Evaluation Partner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization 6 High Ranked Sites</td>
<td>Y1-2) Contact landowners for project discussions Y3-4) Secure Project Funding Y5) Site Designs Prepared</td>
<td>Y6-8) Installation of BMPs</td>
<td>- Landowner agreements established</td>
<td>- Before and after site photographs showing completed projects</td>
<td>MRWA, MCD, RCD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Secured funding source</td>
<td>- Reduced stream sedimentation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Finalized project proposal with certified site plans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization 6 Moderate Ranked Sites</td>
<td>Y6) Contact landowners for project discussions Y7-8) Secure Project Funding Y9) Site Designs Prepared Y10) Installation of BMPs</td>
<td></td>
<td>- Landowner agreements established</td>
<td>- Before and after site photographs showing completed projects</td>
<td>MRWA, MCD, RCD</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>- Secured funding source</td>
<td>- Reduced stream sedimentation</td>
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<td></td>
<td></td>
<td></td>
<td>- Finalized project proposal with certified site plans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stabilize streambank erosion sites</td>
<td>Streambank Stabilization 1 Low Ranked Site</td>
<td>Y1) Contact landowner for project discussion Y2) Secure Project Funding Y3) Site Design Prepared Y4) Install BMP</td>
<td></td>
<td>- Landowner agreement established</td>
<td>- Before and after site photographs showing completed project</td>
<td>MRWA, MCD, RCD</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>- Secured funding source</td>
<td>- Reduced stream sedimentation</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Finalized project proposal with certified site plan</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table K-2 Measurable Milestones for Problem Sites identified during Physical Inventory
PLOAD

PLOAD is a simplified GIS-based model within the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) 4.0 program developed by CH2M Hill for the United States Environmental Protection Agency (USEPA). PLOAD estimates pollutant loads for watersheds on an annual average basis for any user-specified nonpoint sources of pollution (U.S. Environmental Protection Agency 2001). PLOAD contains two methods for calculating pollutant loadings: the Simple Method, which empirically estimates nonpoint source pollutant loads from urban development sites within watersheds one square mile or smaller, and the Export Coefficient Method, which takes on a similar approach as the Simple Method, but is more applicable to land uses such as agriculture and undeveloped areas, or watersheds larger than one square mile (Steinman and Thompson 2009).

The Upper Muskegon River Watershed, which is 603.48 mi² (386,228 acres), seemingly calls for the Export Coefficient Method, simply due to its size; however, both the Rein in the Runoff project team (Steinman and Thompson 2009) and a USGS project team (Syed and Jodoin 2006) that underwent similar studies found several challenges with using the Export Coefficient Method. This method utilizes a specified pollutant loading rate to calculate pollutant loads, and does not incorporate precipitation or impervious surface area. Also, it requires export coefficient tables to derive those pollutant loading rates. Each of these issues and the lack of availability of export coefficient tables for Michigan and similar regions forced the Rein in the Runoff project team, who was studying the Spring Lake Watershed, to reconsider using the Simple Method. Both the USGS team and the Rein in the Runoff team decided to divide their watersheds into smaller sub-basins and run PLOAD with the Simple Method, and neither team found any significant issues with running the model with large sub-watersheds (Syed and Jodoin 2006; Steinman and Thompson 2009). Therefore, the Upper Muskegon River Watershed team decided to adopt the aforementioned teams’ methodologies and employed the Simple Method. Accordingly, the Upper Muskegon River Watershed was divided into 56 catchments, ranging from 0.43 mi² to 78.15 mi² (277-50,016 acres) with an average of 10.78 mi² (6,897 acres).

To obtain estimates for total nitrogen (TN), total phosphorus (TP), and total suspended solid (TSS) nutrient loads in the Upper Muskegon, BASINS project files were created for the Upper Muskegon River catchments map, as well as for each of the land use and land cover GIS data layers (1998, 2010, and 2050). The catchments layer was used to provide delineated sub-basins areas and spatial context so that the PLOAD model could calculate pollutant loadings for each individual sub-basin. The land use and land cover datasets were created in vector polygon data formats from the analysis.
of satellite images (1998 and 2010), and were then converted to raster format in order to analyze land use change and predict future land use (2050) as described above.

Each land use layer was modeled separately, providing pollutant loading comparisons between years to determine the effects of land use change. Therefore, for each PLOAD modeling run, the Upper Muskegon River catchments layer was specified as the sub-basin boundary layer, while each land use layer (1998, 2010, and 2050) was used for each separate run. An annual precipitation of 28.43 inches was also identified during the modeling process to be used as an input for the model. The final requirement for the PLOAD model was a user-defined table containing event mean concentrations (Table K-1). The EMC table provides the appropriate EMC values for TN, TP, and TSS and percent imperviousness according to the specific land use categories identified by the VALUE field. The Upper Muskegon River Watershed team relied on the work of the Spring Lake Watershed and Duck Creek Watershed projects, and the USGS project to help derive the EMC values used in this project, with adjustments made in order to better suit the land use categories and characteristics of the Upper Muskegon River region.

As a result of each run, the PLOAD model creates three discrete GIS layers of each pollutant for each land use layer: the EMC value applied to each sub-basin, the total load of the pollutant (in lbs), and the pollutant load by acre for each sub-basin (Figure K-1). The output layers created by PLOAD provided a means for the creation of additional results displays, including various tables of pollutant loadings (Tables K-2 to K-4), graphs of total loadings (Figure K-2), and maps of loadings by sub-basin (Figures K-3 to K-11). These tables and figures show increases in the total loadings for each pollutant from each year to the next when comparing the 1998, 2010, and the 2050 land use layers. From 1998 to 2010, TN increased by 6.3%, TP by 8.9%, and TSS by 7.7%. From 2010 to 2050, TN increased by 15.9%, TP by 21.5%, and TSS by 16.3%. These results correspond to the expectations that urban growth will continue at the expense of natural land use/cover types, contributing higher pollutant loads than areas of grass or forest would produce.

It is important to note that some minor discrepancies in the area measurements exist because of the nature of the project’s procedures; the original 1998 and 2010 land use layers were created in an accurate vector polygon format, but had to be changed to raster format in order to use IDRISI’s Land Change Modeler. Since the raster format converted the vector layer into a matrix of cells, or pixels, the boundaries do not match exactly from vector to raster. In contrast, PLOAD requires vector layers to run the model, so to maintain consistency, all land use layers (1998, 2010, and 2050) were converted from raster to vector and used in PLOAD, rather than using the original 1998 and 2010 vector polygon layers. These raster converted numbers are used entirely throughout this appendix,
and the only use of the original vector layers in this document was for mapping purposes to portray the PLOAD results (Figures K-3 to K-11).

### EVENT MEAN CONCENTRATION (EMC) TABULAR INPUT DATA FOR PLOAD MODEL RUNS

<table>
<thead>
<tr>
<th>Value</th>
<th>Land Use and Cover Type</th>
<th>Percent Impervious Surface Area</th>
<th>TN (mg/L)</th>
<th>TP (mg/L)</th>
<th>TSS (mg/L)</th>
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</thead>
<tbody>
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<td>1</td>
<td>Residential</td>
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<td>Transportation</td>
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<td>Extractive</td>
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Table L-1  Event Mean Concentration (EMC) Tabular Input Data for PLOAD Model Runs
Figure L-1  Output window from BASINS 4.0 for the Upper Muskegon River Watershed PLOAD runs
# APPENDIX L

## POLLUTANT LOADING ESTIMATES (PLOAD)

### PLOAD RESULTS FOR THE UPPER MUSKEGON RIVER WATERSHED IN 1998

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Acres</th>
<th>TN Load</th>
<th>TN Load/Acre</th>
<th>TP Load</th>
<th>TP Load/Acre</th>
<th>TSS Load</th>
<th>TSS Load/Acre</th>
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### APPENDIX L

**POLLUTANT LOADING ESTIMATES (PLOAD)**

**PLOAD RESULTS FOR THE UPPER MUSKEGON RIVER WATERSHED IN 1998 (CONTINUED)**

<table>
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<tr>
<th>Catchment</th>
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<th>TN Load</th>
<th>TN Load/Acre</th>
<th>TP Load</th>
<th>TP Load/Acre</th>
<th>TSS Load</th>
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Table L-2 PLOAD results for the Upper Muskegon River Watershed in 1998 (Load measured in pounds)
## APPENDIX L

### POLLUTANT LOADING ESTIMATES (PLOAD)

#### PLOAD RESULTS FOR THE UPPER MUSKEGON RIVER WATERSHED IN 2010

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<th>TP Load</th>
<th>TP Load/Acre</th>
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## APPENDIX L

### POLLUTANT LOADING ESTIMATES (PLOAD)

## PLOAD RESULTS FOR THE UPPER MUSKEGON RIVER WATERSHED IN 2010 (CONTINUED)

<table>
<thead>
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<th>Catchment</th>
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<th>TP Load</th>
<th>TP Load/Acre</th>
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Table L-3  PLOAD results for the Upper Muskegon River Watershed in 2010 (Load measured in pounds)
PLOAD RESULTS FOR THE UPPER MUSKEGON RIVER WATERSHED IN 2050

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## APPENDIX L

### POLLUTANT LOADING ESTIMATES (PLOAD)

#### PLOAD RESULTS FOR THE UPPER MUSKEGON RIVER WATERSHED IN 2050 (CONTINUED)

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<th>TP Load</th>
<th>Acres</th>
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Table L-4  PLOAD results for the Upper Muskegon River Watershed in 2050 (Load measured in pounds)
Figure L-2  Estimated pollutant loads for the Upper Muskegon River Watershed in 1998, 2010, and 2050
APPENDIX L
POLLUTANT LOADING ESTIMATES (PLOAD)

Figure L-3  Total Nitrogen results for the Upper Muskegon River Watershed in 1998
Figure L-4  Total Phosphorus results for the Upper Muskegon River Watershed in 1998
Figure L-5 Total Suspended Solids results for the Upper Muskegon River Watershed in 1998
Figure L-6  Total Nitrogen results for the Upper Muskegon River Watershed in 2010
Figure L-7  Total Phosphorus results for the Upper Muskegon River Watershed in 2010
APPENDIX L
POLLUTANT LOADING ESTIMATES (PLOAD)

Figure L-8  Total Suspended Solids results for the Upper Muskegon River Watershed 2010
Figure L-9  Total Nitrogen results for the Upper Muskegon River Watershed in 2050
Figure L-10 Total Phosphorus results for the Upper Muskegon River Watershed in 2050
Figure L-11  Total Suspended Solids results for the Upper Muskegon River Watershed in 2050