TETRA TECH

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Recommended Actions for Grand Lake St. Marys, Ohio

Prepared for:
Ohio Environmental Protection Agency and U.S. Environmental Protection Agency

Prepared by:
Tetra Tech, Inc.

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PRELIMINARY AGENCY REPORT

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1.0 INTRODUCTION

Grand Lake St. Marys has become increasingly enriched over the years because of cultural activities in the watershed that have resulted in significant external and internal loading of nutrients, organics, and sediment to the lake. The result is a lake that is overly productive and displays extremely poor water quality. This poor environmental condition is illustrated by dense blooms of cyanobacteria (blue-green algae), which regularly occur in the lake. The blooms are associated with not only algae scums leading to low dissolved oxygen, but also cyanobacteria toxins that have led to postings limiting water contact and use. To address such environmental decline and poor water quality, a combination of methods implemented in the proper sequence will provide both the in-lake treatment and external load reductions that are needed.

Phosphorus is the key element to control from the watershed (external loading) and from the existing lake sediments (internal loading) to achieve a sustainable reduction in the excess production of cyanobacteria. Reducing nitrogen is not as critical because the cyanobacteria in the lake can *fix* atmospheric nitrogen for their metabolism. Because of the history of excess external loading of phosphorus into Grand Lake St. Marys since its formation, and particularly during the past 60 to 80 years, the lake is hypereutrophic. *Hypereutrophy* is defined as having a phosphorus concentration in excess of 100 micrograms per liter (µg/L), which in turn results in phytoplanktonic production of chlorophyll *a* in excess of 50 µg/L. Grand Lake St. Marys has an average summer total phosphorus concentration of approximately 200 µg/L and chlorophyll *a* concentration of approximately 250 µg/L. The calculated inflowing phosphorus concentration from external sources is estimated to be approximately 70 percent compared to the internal entrainment of phosphorus from the lake sediments (82 µg/L from external loading and 118 µg/L from internal loading). Thus, if 85 percent of the external loading of phosphorus was controlled starting immediately, it could take the lake 30 or more years to dilute, deplete, or bury the sediment phosphorus and reduce internal loading of phosphorus to a point that would lead to a reduction in cyanobacteria. Hence, to reduce lake phosphorus concentration and therefore phytoplankton production, both external and internal management activities are needed.

This action plan describes the potential actions needed to improve water quality in the lake and to meet the restoration goals identified by Ohio Environmental Protection Agency (Ohio EPA 2010):

- Improve Grand Lake St. Marys from its present hypereutrophic and unhealthy state (200 µg/L of phosphorus) to a eutrophic state (between 25 µg/L and 50 µg/L phosphorus).
- Greatly reduce harmful algae blooms by inactivating internal nutrients.
- Restore and maintain water quality to ensure safe human recreation.
- Greatly reduce fish kills caused by insufficient dissolved oxygen levels.
- Reduce external nutrient and sediment loads into Grand Lake St. Marys.
- To ensure the level of land use management is sufficient to protect Grand Lake St. Marys.

Section 2 provides additional background information about the watershed, and Section 3 outlines potential and recommended in-lake and near-lake best management practices (BMPs). Section 4 describes practices that should be employed throughout the watershed to reduce nutrient and sediment loading to the lake. A proposed implementation strategy and schedule are presented in Section 5, and an adaptive management plan, which includes monitoring and tracking the effectiveness of BMPs, is summarized in Section 6.

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2.0 BACKGROUND

This section of the report provides background information on Grand Lake St. Marys and its corresponding watershed. More extensive descriptions of the watershed are also available from the *Grand Lake St. Marys Management Plan* (Buck n.d.) and a variety of other studies (Clark 1960; GLWWA 2009; USEPA 1975).

2.1 Site Location

Grand Lake St. Marys drains a 92-square-mile watershed in west-central Ohio (Figure 2-1). The watershed is within the glaciated Eastern Corn Belt Plains (ECBP) ecoregion. The ECBP ecoregion is characterized by rolling plains; local end moraines; extensive glacial deposits; and extensive corn, soybean, and livestock production. The watershed is divided between two counties; most of it is in Mercer County, and a small portion is in Auglaize County. The cities in the watershed include Coldwater, St. Henry, Celina, Montezuma, Chickasaw, and St. Marys.

Grand Lake St. Marys is primarily fed by tributaries flowing from the south, and it was once recognized as the largest man-made reservoir in the world. Grand Lake St. Marys is still recognized as Ohio's largest inland lake. The lake has a surface area of approximately 12,700 acres (19.8 square miles). It is approximately 9 miles long and 3 miles wide. The lake is shallow, with a maximum depth of 7 feet. A spillway on the western edge of the lake flows into Beaver Creek just south of the city of Celina. Beaver Creek flows west, where it eventually reaches the Wabash River.

The watershed consists of one 10-digit assessment unit (AU). The AU is further subdivided into 12-digit hydrologic unit code (HUC) subwatersheds, as shown in Table 2-1.

Table 2-1. Assessment unit and 12-digit hydrologic unit code designations for the Grand Lake St. Marys watershed

10-Digit AU	12-Digit HUC	Description	Drainage area (mi^2)
05120101020		**Grand Lake St. Marys and tributaries**	**112.5**
	01	Chickasaw Creek	18.65
	02	Headwaters Beaver Creek	20.30
	03	Coldwater Creek	19.39
	04	Grand Lake-St Marys	54.16

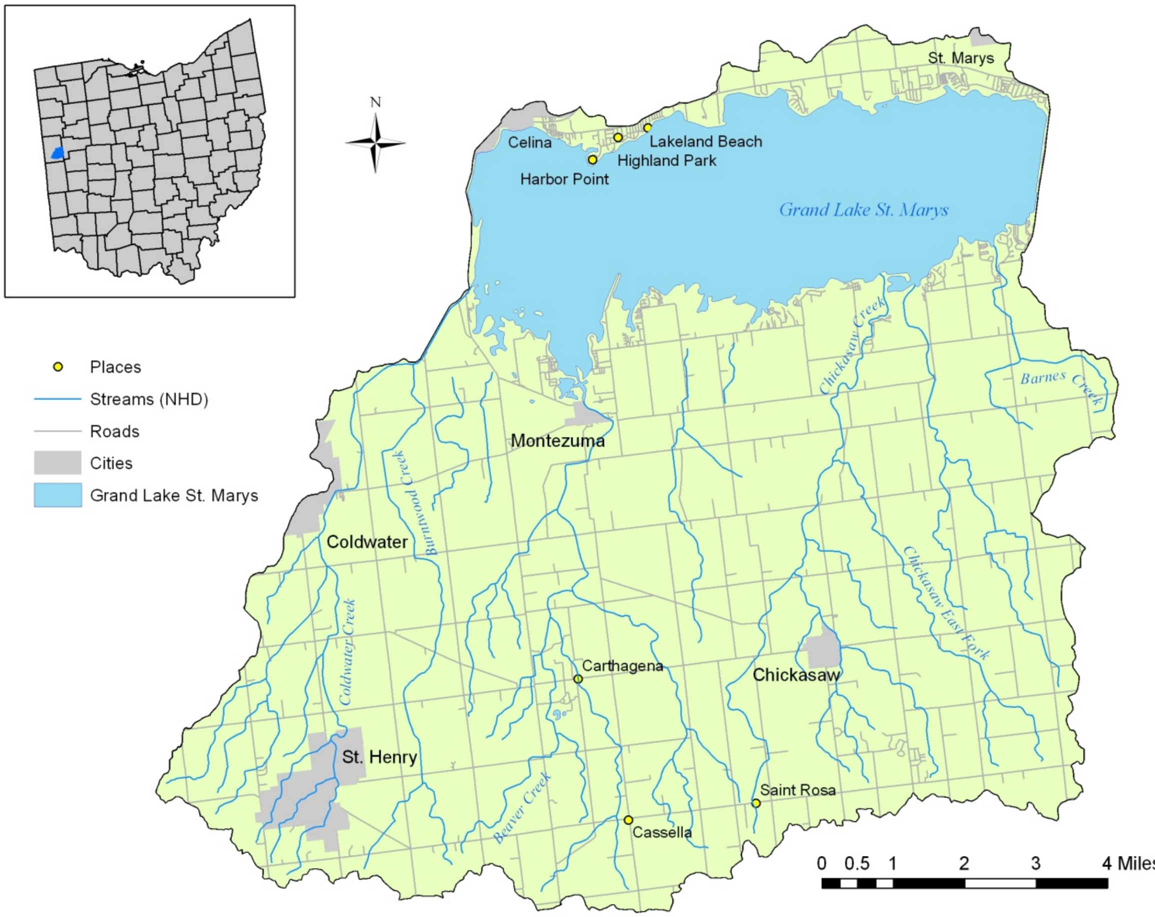

Figure 2-1. The Grand Lake St. Marys watershed.

2.2 Site History

Grand Lake St. Marys was dug by hand to make a reservoir to store water for the Miami-Erie Canal. The project was completed in 1845, when earthen dams were built on Beaver Creek and the St. Marys River. The Ohio Department of Natural Resources, Division of Parks and Recreation, operates a state park campground, three public swimming beaches, and several picnic areas on the lake. The Ohio Department of Natural Resources Division of Wildlife has the responsibility for fish and game management, including the 1,408-acre Mercer Wildlife Area in Montezuma Bay. Several boat ramps are present across the lake, and unlimited horsepower is allowed. The lake is an important source of recreation, and it supplies drinking water to Celina and rearing pond water to the St. Marys State Fish Hatchery.

2.3 Previous Studies

Both the U.S. Environmental Protection Agency (USEPA) and Ohio EPA have performed water quality sampling in Grand Lake St. Marys over the past 30 to 40 years. A Biological and Water Quality Survey of the Grand Lake/Wabash River watershed was completed in 1999. Data from that survey, along with supplemental data collected in 2006, were used to develop *TMDLs for the Beaver Creek and Grand Lake St. Marys Watershed* (Ohio EPA 2007). The total maximum daily load (TMDL) report recommends large reductions of phosphorus (at least 85 percent for many streams) to meet the in-stream nutrient targets specified by Ohio EPA. Agricultural operations were identified as the most significant source of the phosphorus loads, with the wastewater treatment plants in the watershed contributing a larger proportion of the existing loads during low-flow periods. The U.S. Army Corps of Engineers' BATHTUB model was also used to assess the degree to which those reductions would improve lake water quality, and the model indicated that such a reduction would reduce chlorophyll *a* concentrations in the lake by more than 70 percent.

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3.0 IN-LAKE AND NEAR-LAKE BMPS

In-lake and nearshore BMPs provide treatment of the lake water and can reduce nutrient levels and corresponding algal blooms. This section of the report outlines eight lake-area BMPs. All the in-lake activities discussed in the following sections have the overall intent of improving lake water quality, which, in turn, will increase the effectiveness of the treatment process for potable water supply.

- Aeration or water column circulation increases the oxygenation of the water column and does not induce a significant pH change or increase in turbidity. That measure will have limited to no impact on water supply treatment processes.
- Dredging removes sediment and contaminants from the lake and will have a localized impact on turbidity, but it will not affect the overall water quality of the lake because of the relative scale of dredging versus total lake water volume.
- Drawdown has very specific and limited application in Grand Lake St. Marys, so it will not have an impact on the overall water quality of the lake.
- Lake alum treatment—The aluminum sulfate (alum) proposed for use in Grand Lake St. Marys will be drinking water treatment grade and will not add contaminants to the water. As a phosphorus inactivation agent, it will chemically bond with phosphorus and precipitate out of the water column as part of the alum floc, which is an aluminum hydroxide complex. The dosing will be regulated or buffered as to not have an impact on water pH. The alum treatment will result in a short-term decrease in turbidity. There is no water use restriction associated with the use of alum in the lake, and more than 90 percent of the world's water supply treatment plants employ alum as part of the treatment process.
- Hydrogen peroxide followed by alum treatment—Hydrogen peroxide will oxidize organics in the water column and sediment and the result will be a release of carbon dioxide. No change in water chemistry has been observed after a hydrogen peroxide application. For the potential of alum to affect water supply treatment, see the above discussion.
- Tributary alum treatment—For the potential of alum to affect water supply treatment, see the discussion on lake alum treatment.
- Treatment systems on incoming tributaries will result in a reduction of materials entering the lake proper and therefore will have only a beneficial impact on water supply treatment. Those activities will not affect lake chemistry relative to water supply treatment requirements.

3.1 Aeration or Water Column Circulation

Aeration/circulation is the most often used technique in lake water quality management. Devices include pumps, jets, and diffused air. The most popular device is compressed air released just above the lake bottom, and its purpose is to prevent stratification and the undesirable water quality that develops in the hypolimnion (Cooke et al. 2005). Destratification and continued mixing can be achieved so long as the air flow rate is sufficient.

3.1.1 Effectiveness

The main problem alleviated with circulation/aeration is the prevention of anoxia and buildup of reduced substances, such as iron and manganese, which cause problems in water supplies. Complete mixing also prevents low dissolved oxygen in the tailwaters below dams. The technique is not used for that purpose in shallow lakes because they do not stratify. Complete circulation has also been used to reduce algal abundance through light limitation if the lake is deep enough. Neither of those purposes applies to shallow Grand Lake St. Marys.

There is, however, an additional benefit of circulation in relatively shallow lakes—neutralizing the buoyancy regulation mechanism of cyanobacteria. Under quiescent conditions, cyanobacteria can adjust their position in the water column to obtain light and nutrients by expanding and contracting gas vacuoles with buoyancy rates of 1–2 meters per hour. Non-buoyant algae (e.g., diatoms and green algae) settle out of the water column under quiescent conditions, leaving the nutrients and cyanobacteria in the lighted zone. If circulation is strong enough to exceed those buoyancy rates, diatoms or green algae or both can replace cyanobacteria in a well-mixed regime. Such an effect has been documented in an 8-m (26-ft)-deep lake in the Netherlands by aeration at a rate very near the Lorenzen and Fast rule-of-thumb rate used to maintain destratification (i.e., 9.2 m^3/km^2 per min; Cooke et al. 2005; Van der Veer et al. 1995; Visser et al. 1996; Welch and Gibbons 2009).

Whether mixing of a shallow lake like Grand Lake St. Marys (~ 1–2 m) will work to reduce cyanobacteria by neutralizing their buoyancy mechanism is unknown. However, vertical migration/sinking cycles have been observed in 1.8-m-deep ponds (Spencer and King 1987), so there is a potential chance to shift species dominance even in a shallow water column. In summary, mixing/aeration might be beneficial at site-specific areas that are partially protected from easy water exchange with the main lake, and the results of the deployed Airy-Gators will help determine where and how beneficial the treatment option might be.

3.1.2 Costs

Because the main waterbody of the lake is mostly well mixed, and whether aeration and circulation will effectively control cyanobacteria blooms is unclear, a lake-wide aeration system is not needed. However, up to 2 percent of the lake surface area in the coves and backwaters could benefit from increased aeration and circulation. The cost for installing habitat-enhancing aeration units would be $50,000 per acre with some cost reduction as the aeration sites reach areas of 4 or more acres. The estimated cost to aerate the 2 percent of the lake surface that would benefit from aeration is approximately $12,700,000 plus annual operation and maintenance costs of $200,000.

3.1.3 Lifespan

Aeration systems are mechanical systems, and therefore they are subject to typical stresses and degradation of materials as with any system exposed to a soil and water environment. The design life is usually 20 years, but in that period, several mechanical and air transmission line components will need replacement. It is suggested that the annual cost estimate for maintenance should include complete system replacement over the design period of 20 years, when a complete design, upgrade, and rebuild will be needed.

3.1.4 Measuring Effectiveness

This technique could be installed in a limited area to determine whether habitat could be improved by maintaining aerobic conditions throughout the water column. A similar-sized control area would be monitored for comparison. An appropriate but limited area could be selected to employ this technique for habitat enhancement in 2011. In the meantime, dissolved oxygen data should be collected throughout the water column in the two coves where the brush aeration systems are operating in 2010. That data should help to determine whether dissolved oxygen depletion during the quiescent period is a problem that can be addressed with continual circulation.

3.1.5 Applicability to Grand Lake St. Marys

Because Grand Lake St. Marys is a relatively shallow lake, it is unclear whether aeration and circulation will control cyanobacteria blooms. Demonstration projects planned for 2010 and 2011 will monitor impacts on dissolved oxygen, habitat, and algal densities and provide the data needed to assess whether the technique should be implemented in target areas. It is unlikely that aeration and circulation will be a cost-effective approach to control cyanobacteria blooms in a predictable way throughout the lake.

3.2 Dredging

Removal of the phosphorus-enriched layer of sediment through suction dredging is probably the most permanent solution to reducing internal phosphorus loading. Dredging would involve removing the top half-meter of sediment over the whole lake, or in varying depths throughout the lake, depending on measured sediment profiles. There are other purposes for dredging, such as removing toxicants and lake deepening, that are not pertinent to Grand Lake St. Marys (Cooke et al. 2005).

Unfortunately, dredging is the most expensive of the lake restoration techniques. Ten lake dredging projects[1] averaged $17,894/hectare (ha) while 13 alum treatments averaged $564/ha, both in 2002 dollars (Cooke et al. 2005). If amortized over the longevity of effectiveness, dredging cost can become much more appealing compared to alum (Cooke et al. 2005). However, even if amortized over 30 to 40 years, the initial cost for dredging a lake the size of Grand Lake St. Marys renders that option untenable. Most dredged lakes have been less than 50 ha except the most studied and successful case, Lake Trummen in Sweden, which is 100 ha. At 5,000 ha, dredging costs for Grand Lake St. Marys are too high for serious consideration. Therefore, although dredging should be employed in strategic locations, such as at the mouths of large tributaries where there is significant sediment/nutrient buildup, it is not recommended for full-scale application.

3.3 Drawdown

Although drawdown was historically practiced at Grand Lake St. Marys for a number of years before the construction of the outlet control structure, it is a management alternative that has limited long-term potential to improve water quality because of its effect on the long-term annual loading and retention of phosphorus in the lake. Drawdown in the winter results in the temporary loss of phosphorus through the lake outlet. However, when the lake is refilled in the late winter or early spring, when external loading of phosphorus is at its highest, the induced longer detention time results in higher rates of phosphorus retention because of sedimentation of the external loads. That phosphorus is, in turn, available to be recycled from the sediments to the overlying water during the summer months. From an annual mass balance assessment of phosphorus loading, drawdown therefore results in higher phosphorus availability. Unless a low-phosphorus water is used to refill the lake, the effect of drawdown in the system is a net gain in phosphorus. Such a method is therefore not considered a viable alternative.

A lake drawdown could be used to reduce the cost of site-specific dredging, but the water quality benefit would derive from the dredging and not the drawdown itself. Additionally, some benefit might result from the consolidation of sediment that would occur after a drawdown. However, the consolidation might be temporary once the sediments are rehydrated and mix with new sediment deposits.

3.4 Lake Alum Treatment

Three substances are used to inactivate the mobile fraction of sediment phosphorus that contributes to internal loading: alum (aluminum sulfate), Phoslock (bentonite clay plus lanthanum), and polyaluminum chloride. The latter two have been used in a limited number of lakes, and there is no credible published record of their immediate and long-term effectiveness, whereas alum has been used successfully for 40 years in at least 300 lakes worldwide (Cooke et al. 2005; Welch and Gibbons 2005). Therefore, alum is the recommended choice for demonstration.

[1] Dredging costs include the cost of the dredging itself plus disposal and other related costs, but not any engineering or permitting-related costs.

Alum has been used and documented to inactivate sediment phosphorus in at least 150 lakes in the world (Welch and Gibbons 2005). Most of the lakes treated have been in four states (Minnesota, Florida, Washington, and Wisconsin), and 13 lakes have been treated in Europe. The majority of treated lakes were small (< 40 ha); the largest reviewed in the Welch and Gibbons study was 700 ha[2]. Most treatments were successful if dosed properly. Figure 3-1 shows an alum application from a boat equipped with hoses.

Alum treatment will not require water use restrictions for Grand Lake St. Marys during or after application. Once alum is delivered to the lake water, it instantaneously forms an alum floc that settles out of the water column within 10 minutes to 2 hours. Because the alum dosing will be based in part on pH stability, direct water contact with the floc is not a safety concern. That is especially true considering that direct contact with the floc would have to occur seconds after the passing of the treatment barge. It is not advisable to have boats or citizens in close proximity to the treatment barge because of physical contact hazards or interference with the alum applicator, so the likelihood of individual contact is extremely small. The alum-applicator technician will need to take the required safety precautions for handling alum, including the use of gloves and eye protection.

Alum is the most widely used coagulant and has been used for water treatment for centuries. Alum is also used for

- Papermaking
- Hide preservation and tanning
- Food additives and food processing
- Dye mordant
- Producing aluminum chemicals
- Pharmaceuticals
- Construction products (fire proofing and flame retardant)
- Wastewater treatment
- Odor control
- Livestock waste management
- Poultry productivity/bird health applications

Figure 3-1. Alum application.

[2] Note that a successful alum treatment was also performed on the 2120-ha Lake Cobbossee in Maine (http://www.epa.gov/nps/success/state/me_cobb.htm).

3.4.1 Effectiveness

Internal loading of phosphorus (i.e., recycling of sediment phosphorus) can be the major source of phosphorus-causing algal blooms in both thermally stratified and unstratified lakes (Welch and Cooke 1995). Alum has been shown to be highly effective at reducing internal loading in both shallow (unstratified) and deep (stratified) lakes (Welch and Cooke 1999; Cooke et al. 2005). However, the effectiveness at reducing algae is often greater in shallow lakes because the phosphorus released from the sediment is immediately available in the lighted zone. In contrast, internally loaded phosphorus is often locked in the hypolimnion of stratified lakes and is unavailable until fall mixing of the water column, so phosphorus inactivation might not have an immediate effect in deeper lakes.

The aluminum reactions proceed at normal pH values found in surface waters and are dependent on concentration, temperature, and alkalinity. Alum is a powerful source of cationic charge and will have strong tendencies to coagulate the colloidal and particulate matter and nonorganic matter. Additionally, the metal will hydrolyze to form aluminum hydroxide precipitates (floc) that increase the amount of metal required for phosphorus precipitation. The metal hydroxide floc, in turn, adsorbs phosphorus and natural organic matter and enmeshes particulate material.

The following reaction is theoretical only and will be altered as the water quality induces more or less perturbation on the phosphorus removal chemistry.

$$Al_2(SO_4)_3 + 2H_3PO_4 \leftrightarrow 2AlPO_4 + 3H_2SO_4$$

Phosphorus inactivation is the most common and successful technique to control sediment phosphorus and provides long-term control over internal phosphorus loading. The strategy centers on chemically limiting phosphorus release from the sediments under both anoxic and oxic conditions. The formation of aluminum-bound phosphate effectively controls internal phosphorus loading until external phosphorus loading increases the sediment phosphorus concentration to the point where it exhausts the aluminum supplied by the treatment. Phosphorus inactivation by alum also strips the water column of phosphorus, leading to an immediate increase in water clarity and reduction in algal productivity.

The alum dose can be based on internal phosphorus loading estimates or more reliably by measuring the amount of mobile sediment phosphorus (i.e., iron-bound and loosely sorbed phosphorus) in the “active sediment phosphorus release zone.” The most common problem with phosphorus inactivation is alum under-dosing, resulting in a shorter period of effectiveness. To avoid under-dosing, the alum dose is defined by the amount of mobile phosphorus in the first 4 to 20 centimeters of lake sediment multiplied by 100. That dose is increased by the amount of water column competition from phosphorus and humic substances. The additional water column competition dose is determined by jar testing. The dose allows for the control of phosphorus for 7 to 20 years, possibly longer, if external inputs are low. Eventually, the aluminum becomes bound to phosphate or other compounds and can no longer retard the release of phosphorus to the overlying water, or the aluminum (alum floc) layer simply becomes buried under new sediment deposits.

The depth of the alum floc deposited on the sediment changes with time. At first the floc is unconsolidated, and the depth can vary from 1 to 8 centimeters (cm) according to dose and water column characteristics at the time of treatment. Over time, the floc condenses and its depth is greatly reduced to a small percentage of the original depth. Regardless, numerous studies have consistently shown that the long-term response of the benthic community is enhanced diversity and overall biomass reflecting the improved water quality conditions in the overlying water.

The treatment's effectiveness at reducing whole-lake total phosphorus and sediment phosphorus release rates averaged 51 and 73 percent in six unstratified lakes, and effectiveness was maintained near that level for 5 to 11 years (Cooke et al. 2005). A properly dosed shallow lake is expected to maintain effectiveness for approximately 10 years. Many lakes treated in the past were under-dosed. Dosing procedures developed in the late 1990s have resulted in larger doses on the basis of measured mobile phosphorus in sediments (Rydin and Welch 1998, 1999). Improved dosing techniques should increase the longevity of treatments. The appropriate dosage for the test coves in Grand Lake St. Marys should be determined from sediment core data collected in 2010.

The dosing procedure is based on the mobile phosphorus content of the sediment (mostly iron-bound phosphorus) because iron-bound phosphorus is replaced by aluminum-bound phosphorus, which is not redox sensitive and thus does not release phosphorus under anoxic conditions. Therefore, determining the appropriate dosage requires sediment core collection with detailed analyses of sediment-phosphorus fractions (Rydin and Welch 1998, 1999; Cooke et al. 2005). Most doses have been less than 80 grams per square meter (g/m^2) as aluminum, with an average around 30 g/m^2. A buffer might be needed if the calculated dose will remove too much alkalinity reserve and lower pH below 6. Although Al^{+3} is toxic at pH ≤ 5, problems with toxicity do not arise so long as buffering is adequate. The procedure is routine, and toxicity problems for fish and bottom fauna have been extremely rare (Cooke et al. 2005).

Sodium aluminate, added along with alum, will probably be needed to maintain pH at 6 or higher. Alum and sodium aluminate should be applied with an automatic metering device from a moving barge to obtain the prescribed dose. One week should be more than ample time to treat two relatively small (40- to 80-acre) embayments.

3.4.2 Costs

A dose of 30 g/m^2 as Al, which was the average of 100 or so reported treatments (Welch and Gibbons 2005), is assumed for determining a rough cost estimate. An accurate dose should be determined when sediment core data are available.

A general rule of cost for alum is $1.50/gal applied. Assuming 30 g/m^2 and a 1-m mean depth gives a dose per volume of 30 g/m^3. Further, assuming an area of 40–80 acres, 10 gallons of alum per pound of phosphorus removed or inactivated and 3 g/m^2 of phosphorus to remove (10Al:P) results in a cost of around $150,000–$300,000. This estimate includes total project costs: mobilization, materials, labor, equipment, and monitoring. The range in cost is because of the uncertainty regarding the required alum dose inactivate sediment phosphorus. The exact alum dose will be refined once additional sediment data have been collected. The cost of a barrier to separate the treatment area from the main lake at $60/linear foot would be approximately $120,000 for 2,000 linear feet. There are no maintenance costs for alum unless reapplication is required because of continually high external loads of phosphorus.

3.4.3 Lifespan

The longevity of alum treatments has varied from little effect or short-lived, which has been rare and due to excessive external loading or under-dosing, to as long as 20 years. Ten years is a reasonable expectation for longevity. Alum treatments wane because the alum layer sinks and is covered by new sediment or more phosphorus migrates upward from deeper sediment layers, and there are no more binding sites in the alum floc layer (Cooke et al. 2005). Without data and a better understanding of the phosphorus-loading dynamics, seasonal patterns, and internal versus external loading relative to time and effectiveness in stimulating phytoplankton production, there is a limited platform from which to predict long-term effectiveness of any whole lake activity at Grand Lake St. Marys. However, Ohio EPA is collecting data at the lake, and additional analyses can eventually be performed to help understand the phosphorus dynamics in the lake. Ultimately, a time step mass balance phosphorus model will be needed to establish confident predictions regarding long-term lake water quality.

Gizzard shad have been found to recycle phosphorus from sediment and can supply a major portion of phosphorus to algae. Moreover, shad abundance and the proportion of algal phosphorus recycled from the sediment by shad increases with increased total phosphorus (Vanni et al. 2005; Vanni et al. 2006). Therefore, to reduce shad and its effect on algae, lake total phosphorus needs to be greatly reduced by either reducing internal loading or inactivating the phosphorus in the sediment, or both.

There are no documented experiences concerning shad and alum application, but there are studies with common carp, which have been known since the mid 1970s to consume sediment organic matter and recycle phosphorus (Shapiro et al. 1975). For example, Green Lake, Washington, was treated with alum in 2004. The carp density of the lake was approximately 30 carp/ha, or one carp per 333 m^2 (Osgood et al. 2010), likely similar to the biomass of shad in Grand Lake St. Marys. As expected, the fish densities did not have any significant impact on phosphorus recycling over the relatively large lake area, and water quality remains high, 5 years after alum treatment at Green Lake.

In addition, benthivorous fish might not adversely affect alum by eating sediment containing inactivated phosphorus because of the pH levels in the stomach and intestines. As with humans and other animals, pH is low (2–5) in the stomach, but much higher in the intestine (7–9). Even though phosphorus can be desorbed from aluminum-phosphorus complexes under the acidic conditions of the stomach, phosphorus should recombine with aluminum under the alkaline conditions of the intestine. If so, neither carp nor shad should have a negative effect on sediment phosphorus inactivation with alum. Also, the results from Green Lake indicate that the effect of carp on the alum treatment was relatively small, if any.

Once the aluminum-phosphorus complex is formed, phosphorus is biologically inactivated and wind- or fish-induced mixing back into the water column will not result in breaking that bond without dramatic change in pH to either less than 4 or greater than 9. The Al-P will simply resettle to the bottle of the lake when the wind energy drops below a mixing threshold for the lake.

3.4.4 Measuring Effectiveness

Water samples should be collected every 2 weeks at a 0.5-m depth at three sites within the embayments and two sites in the open lake, adjacent to the test embayment. Lake collection sites should be at 60-m and 300-m into the open lake from the embayments. Samples should be analyzed for total phosphorus and soluble reactive phosphorus concentrations (with a minimum detection limit of 2 µg/L), as well for chlorophyll *a* (with a minimum detection limit of 1 µg/L). Standard USEPA protocols should be used for analysis. Transparency can be determined with a Secchi disk if possible (the depth might be too shallow) and by nephelometric turbidity. Other constituents analyzed should be pH and alkalinity, which should be determined hourly during treatment, and every 2 weeks, along with sample collection for the other constituents. Acquiring such data will allow for the determination of the effectiveness of phosphorus inactivation and an understanding of how reduction in phosphorus loading reduces cyanobacteria production through the measurement of chlorophyll *a*. An analysis of the assessment data will help determine the benefits of a lake-wide alum treatment.

Monitoring should be started in and outside the two selected coves during the summer of 2010. That will provide a basis to judge effectiveness by comparing water quality within the cove before (2010) and during (2011) treatment, and within and outside the cove during treatment in 2011.

3.4.5 Applicability to the Grand Lake St. Marys Watershed

One of the two coves in use for demonstrating the effect of a brush-aeration device should be treated with alum in the fall of 2010 or spring of 2011. Those coves, or treatment portions, are assumed to be on the order of 40–80 acres, and they should be closed off with barrier curtains to prevent, or at least minimize, water exchange with the open lake. Determining technique effectiveness will depend on minimizing the exchange of embayment and open-lake waters.

Previous dredging of the coves is not considered an impediment for their use as a demonstration site because the surficial sediments are expected to have a high phosphorus concentration because of continual lake mixing and external loadings; furthermore, the depth of reactive sediment is not critical for the purposes of a short-term demonstration project.

3.5 Hydrogen Peroxide Followed by Alum Treatment

Peroxide has been applied in granular form to reduce algal blooms and oxidize organic material in sediments. It should be more effective than aeration at reducing sediment organic matter because oxygen gas does not readily diffuse into bottom sediments. By removing organic matter from bottom sediments, an important cause of anoxia is removed, so phosphorus should remain bound to iron and stay in the oxic sediments. Therefore, peroxide can be an indirect process to reduce sediment phosphorus release and internal loading. Although peroxide has not been used to reduce internal phosphorus loading, it could be effective to that end. There is evidence that the removal of sediment organic matter by adding nitrate throughout 20 cm of sediment depth (to promote organic matter loss via nitrogen reduction) can reduce internal phosphorus loading and restore a lake (Ripl 1976, 1986).

3.5.1 Effectiveness

Peroxide alone is not recommended for trial in Grand Lake St. Marys because there is little published evidence on the technique’s effectiveness to control internal phosphorus loading. However, organic matter can interfere with the effectiveness of alum to bind phosphorus because organic matter competes with phosphorus for binding sites in the alum floc. Pretreatment of the second cove before an alum treatment might increase the effectiveness and longevity of the alum. Results from the cove treated with alum alone can be compared with those from the cove in which a peroxide treatment preceded alum treatment.

Sediment treatment with peroxide will precede the alum treatment in the second cove by approximately 2 weeks. Sediment cores at three sites should be collected (before the alum and at summer’s end) and analyzed for water and organic matter content to determine the extent of organic matter loss. Granular peroxide should be added at a dose of between 59 and 100 kilograms (kg) per acre. Bench-scale tests should be performed before choosing a final dose.

The purpose of using peroxide in combination with alum is to test the hypothesis that by first treating the organically rich sediments with peroxide, the aluminum more effectively forms Al-P complexes. That preliminary treatment might reduce the overall costs for whole lake treatment by reducing the amount of alum needed to inactivate the phosphorus.

3.5.2 Costs

An approximate cost for peroxide is $800/acre dosed at 100 kg/acre. The total cost would be $32,000 or $64,000 for 40 or 80 acres, respectively. That is in addition to the $150,000–$300,000 cost for alum following the peroxide and the $120,000 cost for a barrier.

3.5.3 Lifespan

Because peroxide and alum have not been used previously on a large scale in combination as outlined above, there is no information available to accurately estimate the potential lifespan of this alternative. However, reduction in sediment organic matter by peroxide will increase the contact and absorption of phosphorus by Al after an alum treatment. In addition, the reduction of organic matter in the sediment will increase the sediment density, which in turn will decrease the sinking of the alum floc into the sediment. Those two factors will increase the estimated lifespan of alum's effectiveness from 10 years to 12–15 years or more.

3.5.4 Measuring Effectiveness

As with the alum demonstration, water samples should be collected every 2 weeks at a 0.5-m depth at three sites within the embayments and two sites in the open lake, adjacent to the test embayment. The lake collection sites should be at 60-m to 300-m into the open lake from the embayments. Samples should be analyzed for total phosphorus and soluble reactive phosphorus concentrations (with a minimum detection limit of 2 µg/L), and for chlorophyll *a* (with a minimum detection limit of 1 µg/L). Standard USEPA protocols should be used for analysis. Transparency can be determined with a Secchi disk if possible (the depth might be too shallow) and by nephelometric turbidity. Other constituents analyzed should be pH and alkalinity, which should be determined hourly during treatment, and every 2 weeks, along with sample collection for the other constituents.

Monitoring should be started in and outside the two selected coves during the summer of 2010. That will provide a basis to judge treatment effectiveness by comparing water quality within the cove before (2010) and during (2011) treatment, and within and outside the core (open lake) during treatment in 2011.

3.5.5 Applicability to Grand Lake St. Marys

The effectiveness of the hydrogen peroxide pretreatment in reducing internal phosphorus loading should be determined during the 2010 and 2011 demonstration projects. Data collected during those studies will aid in the decision to use or omit that stage of the treatment process.

3.6 Tributary Alum Treatment

Phosphorus interception by inactivation with alum might also be used in tributaries before discharge to Grand Lake St Marys. As with lake treatment, the direct addition of alum into the flowing water of a tributary will result in hydrolysis of aluminum and formation of a sediment-Al-P-OH floc downstream of the injection site. This floc needs to be captured and removed from the stream to complete the sediment and phosphorus interception from the inflow and avoid physical effects on invertebrates in downstream waters (Pilgrim and Brezonik 2005; Barbiero et al. 1988). Such removal can be accomplished by direct mechanical sedimentation means or passive sedimentation ponds.

The alum injection systems consist of an alum storage tank, an alum metering pump, and an injection delivery line with or without air injection for flash mixing enhancement. Figure 3-2 shows an example of in-stream alum treatment.

Figure 3-2. Alum treatment in a stream channel.

3.6.1 Effectiveness

Alum injection can remove up to 90 percent of inflowing phosphorus. Reduced phosphorus-removal effectiveness occurs when the sediment concentration in the inflow is high and competes for adsorption sites on the aluminum hydroxide floc. Jar testing should be performed to determine the dosing and effectiveness.

3.6.2 Costs

Alum injection systems, not including the sediment-floc removal mechanisms, have costs ranging from $60,000 to $120,000 per unit with a $3,500–$10,000 annual operation and chemical cost.

3.6.3 Lifespan

If the inactivated phosphorus is removed from the inflow and not allowed to enter the lake, it represents a permanent phosphorus removal system. The injection system has a design life of 10 years with extensive annual system maintenance.

3.6.4 Measuring Effectiveness

The effectiveness of in-stream alum treatment can be measured by sampling the inflowing water upstream of the injection site and immediately downstream of the sediment-alum floc removal system. The difference in phosphorus concentration and total solids yields the treatment effectiveness of the injection system. Samples should be analyzed for total phosphorus and soluble reactive phosphorus concentrations, reliable down to 2 µg/L. Standard USEPA protocols should be used for analysis. pH should be monitored at least once a week along with sample collection for the other constituents.

3.6.5 Applicability to Grand Lake St. Marys

Phosphorus interception by alum injection is a viable long-term phosphorus-removal approach to reduce external loading of phosphorus and to enhance the removal of sediment before it enters the lake. It should, however, be considered an *end of pipe* treatment that in the long term can be phased out after upland BMPs have been implemented and are effectively reducing phosphorus loading to the tributaries. Phosphorus interception will most likely require an National Pollutant Discharge Elimination System permit.

3.7 Treatment Systems on Incoming Tributaries

Designing large-scale treatment systems on incoming tributaries will remove pollutant loading from the major inputs before discharge to Grand Lake St. Marys. For example, a potential treatment system could involve treating a tributary with alum, collecting deposited sediment, constructing and restoring wetlands in the near-lake areas, and harvesting wetland biomass to remove nutrient loading from the system. Such a system should include alternating areas of open water and vegetation to allow for sediment settling and plant uptake, as well as transitional areas with rocks to further filter the water. A pilot study including several of these components, as well as aerators, floating wetlands, and mussel treatment beds, is proposed for Prairie Creek. Some of these activities might not be as beneficial as the proposers have assumed. Specifically

- Floating wetlands are not as effective as wetland cells that have alternating open water and emergent vegetation cells. In addition, floating wetlands have a limited track record for influencing the nutrient balance of a large waterbody.
- Mussels, although native and filter feeders, might accelerate nutrient cycling instead of removing bioavailable nutrients.
- Aeration might generate excessive circulation that prevents sedimentation of colloids and other fine sediments.

3.7.1 Effectiveness

Water quality in the embayment in which a treatment system is built should be monitored to determine the system's effectiveness in improving lake water quality. If the system proves effective and the needed funding is available, similar systems could be placed at the mouths of the major tributaries. Additional sedimentation basins and strategic dredging could also be incorporated in future treatment train designs.

3.7.2 Costs

Treatment wetlands typically cost $18,000–$50,000 per acre. The proposers of the Prairie Creek treatment system have estimated the cost at $846,000. That includes construction of 10 acres of stormwater wetlands; restoration of 8 acres of natural wetlands; tributary alum treatment; one lake aerator; one lake circulator; and creation of 1 acre of mussel reefs, 1 acre of floating wetland islands, and 1,800 feet of isolation berm.

3.7.3 Lifespan

It is difficult to specify the system life of a treatment system because of the multiple components. However, it can be assumed that wetland systems will have a system life of 30 years and for mechanical equipment, a useful life of 20 years.

3.7.4 Measuring Effectiveness

Lake water samples should be collected every 2 weeks at a 0.5-m depth at three sites within the embayments and two sites in the open lake, adjacent to the test embayment. Lake collection sites should be at 60-m and 300-m into the open lake from the embayments. Samples should be analyzed for total phosphorus and soluble reactive phosphorus concentrations (with a minimum detection limit of 2 µg/L), and for chlorophyll *a* (with a minimum detection limit of 1 µg/L). Standard USEPA protocols should be used for analysis. Transparency can be determined with a Secchi disk if possible (depth might be too shallow), and by nephelometric turbidity. Other constituents analyzed should be pH and alkalinity, which should be determined hourly during treatment, and every 2 weeks, along with sample collection for the other constituents.

Monitoring should be started in and outside the two selected coves during the summer of 2010. That will provide a basis to judge effectiveness by comparing water quality within the cove before (2010) and during (2011) treatment, and within and outside the core (open lake) during treatment in 2011.

Tributary monitoring should occur upstream of the alum addition, at the outlet of the settling basin, and at the outlet of the constructed wetland. Samples should be analyzed for nutrients, total suspended solids (TSS), biochemical oxygen demand (BOD), and fecal coliform. Monitoring should occur at least once a month during dry and wet weather.

3.7.5 Applicability to Grand Lake St. Marys

The treatment system concept is expected to work well in reducing pollutant loading to Grand Lake St. Marys. Monitoring conducted in 2010 and 2011 will aid in determining the cost-effectiveness and applicability to the larger tributary inputs.

3.8 Shoreline Maintenance

Reducing erosion of lakeshore areas will reduce phosphorus and sediment loading and improve temperature and dissolved oxygen conditions by allowing vegetation to establish. Lakeshores should be inspected for signs of erosion. Banks showing moderate to high erosion rates (indicated by poorly vegetated reaches, exposed tree roots, steep banks, and the like) can be stabilized by engineering controls, vegetative stabilization, and restoration of riparian areas. Peak flows and velocities from runoff areas can be mitigated by infiltration in grassed waterways and passage of runoff through filter strips/areas.

3.8.1 Effectiveness

Reducing shoreline erosion and increasing vegetation will have direct effects on improving the water quality in Grand Lake St. Marys. Well-shaded areas will experience fewer algal blooms because both light and the pollutant loading associated with bank erosion should be reduced. In addition, a wide vegetated zone around the perimeter of the lake will provide treatment as sheet flow from adjacent areas passes through the buffer.

3.8.2 Costs

The costs associated with shoreline maintenance include the costs of inspection time, construction-related activities, planting, and possibly land easements/acquisition.

4.0 UPLAND BMPS

This section of the report describes individual BMPs that will reduce hydrologic and pollutant loading from upland areas in the Grand Lake St. Marys watershed. Strategic use of the BMPs is discussed at the end of the section, and the following critical areas should be prioritized for implementation:

- Agricultural operations less than 1,000 feet from a stream, especially when the respective streams have less than 10 feet of vegetative buffer
- Agricultural operations within the Beaver Creek, Chickasaw Creek, and Coldwater/Burntwood Creek subwatersheds
- Critical areas identified through the use of tools such as the Phosphorus Index (USDA NRCS 1994) or the Natural Resources Conservation Service (NRCS) Stream Visual Assessment Protocol (SVAP)(USDA NRCS 1998)
- Critical areas identified through the approach described in section 5.1.1.1

Additionally, the practice of applying manure on snow-covered or frozen ground should be eliminated throughout the watershed because that has been identified as a critical period that contributes to a large proportion of the annual load being delivered to the lake.

As mentioned in Section 1, phosphorus is the key element to control from the watershed to address the excessive algae problem. Reductions in nitrogen loads that can be achieved through BMPs that target phosphorus should be encouraged, but BMPs that target nitrogen should not be promoted at the expense of less control of phosphorus.

Widescale, long-term implementation of the BMPs described in this section of the report (and any other applicable BMPs) is required to reduce nutrient loading to Grand Lake St. Marys and restore the beneficial uses of this waterbody. Without reductions in pollutant loads from the watershed, the effectiveness of in-lake restoration efforts is likely to be significantly reduced.

4.1 Nutrient Management Plans and Comprehensive Nutrient Management Plans

The majority of nutrient loading from farmland occurs from fertilization with commercial and manure fertilizers (USEPA 2003). In heavily fertilized areas where more phosphorus is imported than is exported in crops or other products, soil phosphorus content has increased significantly over natural levels, and that is apparent in the Grand Lake St. Marys watershed. Soils with excessively high phosphorus content represent an important source of phosphorus loads to the lake where a transport mechanism (e.g., runoff and erosion) exists to move the phosphorus to water. Parties responsible for reducing loads due to excessive fertilization are farmers, fertilization dealers, and local agricultural service agencies that provide fertilization guidelines. The primary BMP for reducing phosphorus loading from excessive fertilization is developing and following a nutrient management plan. Animal feeding operations develop comprehensive nutrient management plans to manage manure and other on-farm nutrient sources at environmentally sensitive rates, while maintaining efficient crop production.

Regardless of the type of fertilizer used, such plans should address fertilizer application rates, methods, and timing. Initial soil phosphorus availability is determined by on-site soil testing, which is available from local vendors. Losses through crop uptake and harvest are subtracted, and gains from organic sources such as manure application or industrial/municipal wastewater are added. The resulting phosphorus content is then compared to local guidelines to determine whether fertilizer should be added to support crop growth and maintain current phosphorus levels. In some cases, the soil phosphorus content is too high, and no fertilizer or manure should be added until stores are reduced by crop uptake to target levels.

Soil phosphorus tests are used to measure the phosphorus available for crop growth. Test results reported in parts per million (ppm) can be converted to pounds per acre (lb/ac) by multiplying by 2 (USDA 2003). The Ohio State University Agricultural Extension Service recommends maintaining soil test phosphorus content in the area of Grand Lake St. Marys at 15 ppm (30 lb/ac). Soils that test at or above 40 ppm (80 lb/ac) should not be fertilized until crop uptake decreases the test results to 35 ppm (70 lb/ac). Soil phosphorus tests should be conducted once every 3 or 4 years to monitor the accumulation or depletion of phosphorus (USDA 2003).

Starting Soil Test Phosphorus	***Fertilization Guidelines***
Less than 15 ppm:	*Buildup plus maintenance*
Between 15 and 35 ppm:	*Maintenance only*
Greater than 40 ppm:	*None*

Nutrient management plans also address methods and timing of application to manage the risk of runoff losses of applied nutrients. Fertilizer can be applied directly to the surface, placed in bands below and to the side of seeds, or incorporated into the top several inches of the soil profile through drilled holes, injection, or tillage. Surface applications that are not followed by incorporation can result in accumulation of phosphorus at the soil surface and increased dissolved phosphorus concentrations in surface runoff (Mallarino 2004). Nutrient management plans typically identify the best time(s) of the year for fertilizer application to provide the needs for growing crops while reducing risks of runoff losses during critical seasons (e.g., snowmelt, major rainy seasons). Finally, nutrient management plans usually identify vulnerable areas on the farm such as wet areas or areas close to waterways where manure and fertilizer applications might need to be restricted.

4.1.1 Effectiveness

The effectiveness of comprehensive nutrient management plans (application rates, methods, and timing) in reducing phosphorus loading from agricultural land is site-specific. The following reductions are reported in the literature:

- 35 percent average reduction of total phosphorus load reported in Pennsylvania (USEPA 2003)
- 20 to 50 percent total phosphorus load reductions with subsurface application at agronomic rates (HWRCI 2005)
- 60 to 70 percent reduction in dissolved phosphorus concentrations and 20 percent reduction in total phosphorus concentrations when fertilizer is incorporated to a minimum depth of 2 inches before planting (HWRCI 2005)
- 60 to 70 percent reduction in dissolved phosphorus concentrations and 20 to 50 percent reduction in total phosphorus with subsurface application, such as deep placement (HWRCI 2005).
- 60 percent reduction in runoff concentrations of phosphorus when the following precipitation event occurred 10 days after fertilizer application, as opposed to 24 hours after application (HWRCI 2005).

Note that in cases where soil phosphorus levels are very high, reductions through nutrient management could take many years to bring soil phosphorus down to appropriate levels; such lag time can be as long as 5 to 10 years, or more (Meals et al. 2010).

4.1.2 Costs

Nutrient management plans typically include soil testing, manure analysis, scaled maps, and site-specific recommendations for fertilizer management (USEPA 2003). A good nutrient management plan should address the rates, methods, and timing of nutrient applications from all sources. Local Soil and Water Conservation District (SWCD) offices develop plans for farms in the Grand Lake St. Marys watershed for free. Applying fertilizer at recommended rates will likely reduce farmers' fertilizer costs. Coordination with a local SWCD field technician and testing of soil and manure should be repeated every 3 to 4 years.

4.1.3 Lifespan

Nutrient management plans should be reevaluated once every 3 to 4 years. Soil testing should be conducted at least every 3 years to track progress toward soil phosphorus goals.

4.1.4 Measuring Effectiveness

The effectiveness of nutrient management plans can be measured by continuing to test soil phosphorus regularly to determine the degree to which phosphorus is being reduced in agricultural soils. Testing can be done in conjunction with ongoing updates of the management plan.

4.1.5 Applicability to the Grand Lake St. Marys Watershed

Nutrient management will have the greatest effect if applied to land areas that represent critical source areas for phosphorus loading to Grand Lake St. Marys. Most notably, areas where high soil phosphorus and improper management coincide with transport mechanisms such as runoff channels, surface and subsurface drainage, and streams. Identification of such critical areas is challenging and could require application of sophisticated geospatial analysis of soils, topography, and hydrology. Accepted simplified tools such as the Phosphorus Index (USDA NRCS 1994) or the NRCS SVAP (USDA NRCS 1998) can be very useful. Without site-specific information, a starting point could be implementation on farms within 1,000 feet of a stream, farms that are extensively drained, and farms that have less than 10 feet of streamside buffers and permanent vegetation. Farms and animal operations in Coldwater/Burntwood Creeks, Chickasaw Creek, and Beaver Creek subwatersheds have the greatest lengths of streams with poor vegetative buffers and the highest number of animal operations within 1,000 feet of a stream (GLWWA 2009). Operations in those three subwatersheds are considered critical priority for implementation of nutrient management plans. Operations in other subwatersheds are considered high priority for implementation, especially fields that receive fertilizer or manure at high rates or preceding high runoff events. Such fields are capable of transporting large quantities of nutrients to Grand Lake St Marys via the extensive network of subsurface and surface drainages that exist in the watershed.

The Natural Resources Conservation Service (NRCS) provides additional information on nutrient management planning at
http://efotg.sc.egov.usda.gov/references/public/OH/OH590_Nutrient_Mgt_June2003.pdf

4.2 Proper Manure Handling and Storage

Animal operations are typically pasture-based or confined, or sometimes a combination of the two. The operation type dictates the practices needed to manage manure from the facility. If excess manure is produced, the manure is typically scraped with a tractor to a storage bin constructed on a concrete surface. Stored manure can then be land-applied when the ground is not frozen and precipitation forecasts are low. Rainfall runoff should be diverted around the storage facility with berms or grassed waterways. Runoff from the feedlot area is considered contaminated and is typically treated in a lagoon or captured and managed with the rest of the animal waste.

Confined facilities (typically dairy cattle, swine, and poultry operations) often collect manure in storage pits under slatted floors. The wash water used to clean the floors and remove manure buildup combines with the solid manure to form a liquid or slurry in the pit. The mixture is usually stored in a lagoon and later land-applied or transported off-site.

Final waste disposal usually involves land application on the farm or transportation to another site. Given the high soil phosphorus content of many of the soils in the Grand Lake St. Marys watershed, exporting manure out of the watershed might be required to ensure that nutrients are being applied at environmentally sensitive rates. Manure is typically applied to the land once or twice a year. To maximize the amount of nutrients and organic material retained in the soil, application should not occur on frozen ground or when precipitation is forecast during the next several days. Storage facilities should be large enough to store at least 120 days of manure to ensure that capacity is not exceeded during the winter season.

Figure 4-1 is an example of a waste storage lagoon.

(Photo courtesy of USDA NRCS.)

Figure 4-1. Waste storage lagoon.

The NRCS provides additional information on waste storage facilities and cover at
http://efotg.sc.egov.usda.gov/references/public/OH/OH_313_Waste_Storage_Facility_2-2-10.pdf
http://efotg.sc.egov.usda.gov/references/public/OH/Standard_Waste_Treatment_Lagoon_359_7-11-06.pdf
http://efotg.sc.egov.usda.gov/references/public/OH/OH_367_Waste_Facility_Cover_2-2-10.pdf

4.2.1 Effectiveness

Manure has a greater risk of contaminating streams and lakes with excessive nutrients, organic material, and bacteria when it is applied at rates greater than crop demands or before runoff events. Storing manure before it is placed elsewhere does not significantly alter the phosphorus[3] content, and land application at environmentally sensitive rates retains more phosphorus on the field and reduces phosphorus levels in downstream waters. In addition, storing manure for at least 30 days has been shown to reduce fecal coliform concentrations in runoff by 97 percent (Meals and Braun 2006). Applying manure before heavy precipitation or runoff events results in loss of nutrients from the field and should be avoided. Figure 4-2 shows a poorly managed feed lot discharging contaminated water off-site.

Figure 4-2. Contaminated runoff from an animal feedlot.

4.2.2 Costs

Depending on whether the production facility is pasture-based or confined, manure is typically deposited in feedlots, around watering facilities, and in confined spaces such as housing units and milking parlors. Except for feedlots serving a low density of animals, each location requires the collection and transport of manure to a storage structure, holding pond, storage pit, or lagoon before final disposal.

Manure collected from open lots and watering areas is typically collected by a tractor equipped with a scraper. The manure is in solid form and is typically stored on a concrete pad surrounded by three walls that allow for stacking the contents. Depending on the climate, a roof might be required to protect the manure from frequent rainfall. Clean water from rooftops or up-grade areas should be diverted around waste stockpiles and heavy-use areas with berms, grassed channels, or other means of conveyance (USEPA 2003). Waste storage lagoons, pits, and aboveground tanks are good options for large facilities. The methane gas recovered from anaerobic treatment processes can be used to generate electricity and thereby recover some of the investment in manure management systems.

4.2.3 Lifespan

The NRCS assumes that the useful life for practices requiring construction is 20 years. That lifespan applies to storage areas with walls, roof, and concrete pad; lagoons; pits; and methane recovery systems.

[3] Substantial nitrogen can be lost through ammonia volatilization. Storage and composting can also change the form and therefore availability of manure nutrients.

4.2.4 Measuring Effectiveness

Properly handling, storing, and applying manure has significant impacts on water quality, particularly following rainfall or snowmelt events. Measuring effectiveness could occur at the BMP itself, and in downstream tributaries. However, to truly measure effectiveness in the tributaries will require a thoroughly designed and somewhat intensive sampling program.

4.2.5 Applicability to the Grand Lake St. Marys Watershed

According to the *Grand Lake Saint Marys/Wabash River Watershed Action Plan* (GLWWA 2009), there are 298 animal operations housing 105,185 animal units in the watershed. Water quality impacts resulting from animal operations are most likely to occur when facilities are less than 1,000 feet from a stream, when a significant drainage or other conveyance system exists; when the respective streams have less than 10 feet of permanent, vegetative buffer; and when the manure production rates are high relative to the capacity of the available land base to accept the manure at environmental rates. There are three subwatersheds in the Grand Lake St. Marys watershed that have those three characteristics. Proper manure management is a critical priority for facilities in the Beaver Creek, Chickasaw Creek, and Coldwater/Burntwood Creek subwatersheds and a high priority at animal operations in the remaining subwatersheds.

4.3 Cover Crops

One method to lengthen the period during which crops are able to utilize nutrients from manure is to plant a cover crop following harvest of the cash crop. Cover crops are typically grasses or legumes used on permanently fallow fields or during the winter season to take up excess nutrients remaining from the cash crop, reduce soil erosion potential, and improve soil quality. Examples of cover-crop grasses are rye, oats, and wheat; legumes include clover, hairy vetch, field peas, and alfalfa.

Cover crops are a useful BMP on any field following crop harvest. Fields composed of highly erodible soils will see the most benefit in reduced soil erosion. Cover crops are also useful in conservation tillage systems following low-residue crops such as soybeans. Planting non-legume cover crops also extends the usefulness of fields as a means to dispose of winter manure stores because grasses provide uptake of both nitrogen and phosphorus. Use of cover crops is illustrated in Figure 4-3.

(Photo courtesy of NRCS)

Figure 4-3. Use of cover crops.

4.3.1 Effectiveness

Cover crops effectively reduce nutrient and sediment loading and improve soil quality. In addition to those benefits, the reduction in runoff losses reduces bank erosion in receiving streams, further reducing sediment loads and allowing for the establishment of vegetation and canopy cover. Reported reductions are listed below:

- 50 percent reduction in soil and runoff losses with cover crops alone; when combined with no-till systems, may reduce soil loss by more than 90 percent (University of Illinois Extension 2002)
- 70 to 85 percent reduction in phosphorus loading on naturally drained fields (HRWCI 2005)
- Reduction in fertilizer and pesticide requirements (OSUE 1999)
- Useful in conservation tillage systems following low-residue crops such as soybeans (USDA 1999)

Planting the cash crop in wet soil that is covered by heavy surface residue from the cover crop might impede emergence by prolonging wet, cool soil conditions. Cover crops should be killed off 2 or 3 weeks before planting the cash crop either by herbicide application or mowing and incorporation, depending on the tillage practices used.

4.3.2 Costs

The costs associated with cover crops include seed costs for the grass or legume, and the cost of herbicide (if that is the selected method for killing). Grasses tend to have low seed costs and establish relatively quickly, but they can impede cash crop development by drying out the soil surface or releasing chemicals during decomposition that might inhibit the growth of a following cash crop. Legumes take longer to establish, but they are capable of fixing nitrogen from the atmosphere, thus reducing nitrogen fertilization required for the next cash crop. Legumes, however, are more susceptible to harsh winter environments and might not have adequate survival to offer sufficient erosion protection. Cover crops are expected to save on subsequent fertilizer, herbicide, and insecticide costs. There are also benefits regarding soil improvement (e.g., reduced erosion, increased organic matter, less drying and sealing at the surface, greater infiltration rates).

4.3.3 Lifespan

When planted in rotation with a cash crop, cover crops provide seasonal benefits. Permanently fallow fields can be also be planted with a cover crop to provide longer-term benefits.

4.3.4 Measuring Effectiveness

The use of cover crops reduces the transport of soil, nutrients, and manure from the field during runoff events and might reduce the costs of fertilizer, herbicides, and insecticides. Measuring effectiveness could occur at the BMP itself and in downstream tributaries. In addition, tracking the pounds per acre of chemicals applied, the appearance of the soil, and changes in crop yield provides indications of the success of this BMP. Note that improvements to soil structure and crop yield will take time to develop.

4.3.5 Applicability to the Grand Lake St. Marys Watershed

Cover crops will benefit any operation, but their use should be prioritized on fields receiving manure during the winter months. Water quality impacts are most likely to occur when manure is applied during the winter months near streams that have a poorly vegetated buffer. On the basis of the tons of manure produced per year and the area available to apply the manure, cover crops will provide the greatest improvement to water quality if implemented in the Beaver Creek, Chickasaw Creek, and Coldwater/Burntwood Creek subwatersheds. Fields containing highly erodible soils will also benefit greatly from cover crops. Those three subwatersheds also have the highest percentages of highly erodible soils, further indicating that cover crops will reduce pollutant loading from the areas. Fields in those three subwatersheds are considered critical priority for implementation of cover crops. Operations in other subwatersheds are considered high priority for implementation.

The NRCS provides additional information on cover crops at
http://efotg.sc.egov.usda.gov/references/public/OH/oh340_Cover_Crop_Job_Sheet_05-10-10.pdf

4.4 Conservation Tillage

Conservation tillage practices and residue management are commonly used to control erosion and surface transport of pollutants from fields used for crop production. Crop residues not only provide erosion control, but also provide a nutrient source to growing plants, and continued use of conservation tillage results in a more productive soil with higher organic and nutrient content. Increasing the organic content of soil has the added benefit of reducing the amount of carbon in the atmosphere by storing it in the soil. Researchers estimate that croplands and pasturelands could be managed to trap 5 to 17 percent of the greenhouse gases produced in the United States (Lewandrowski et al. 2004). Corn residues are more durable and capable of sustaining the required 30 percent cover required for conservation tillage. Soybeans generate less residue and the residue degrades more quickly, so supplemental measures or special care might be necessary to meet the 30 percent cover requirement (UME 1996). Figure 4-4 shows a comparison of ground cover under conventional and conservation tillage practices.

Figure 4-4. Comparison of conventional (left) and conservation (right) tillage practices.

4.4.1 Types and Methods

Several practices are commonly used to maintain the suggested 30 percent cover:

- No-till systems disturb only a small row of soil during planting and typically use a drill or knife to plant seeds below the soil surface.
- Strip till operations leave the areas between rows undisturbed but remove residual cover above the seed to allow for proper moisture and temperature conditions for seed germination.
- Ridge till systems leave the soil undisturbed between harvest and planting. Cultivation during the growing season is used to form ridges around growing plants. During or before the next planting, the top half to 2 inches of soil, residuals, and weed seeds are removed, leaving a relatively moist seed bed.
- Mulch till systems include any practice that results in at least 30 percent residual surface cover, excluding no-till and ridge till systems.

4.4.2 Effectiveness

Using some form of conservation tillage will reduce sediment and nutrient loading from fields. In addition, the organic material and nutrients remaining on the field should be recycled into the soil matrix, improving the soil and increasing crop yields. Tillage practices leaving 20 to 30 percent residue cover after planting reduce erosion by approximately 50 percent compared to bare soil. Practices that result in 70 percent residue cover reduce erosion by approximately 90 percent (University of Illinois Extension 2002). USEPA (2003) reports the findings of several studies regarding the impacts of tillage practices on pesticide loading. Ridge till practices reduced pesticide loads by 90 percent, and no-till reduced loads by an average of 67 percent. In addition, no-till reduced runoff losses by 69 percent, which protects streambanks from erosion and loss of canopy cover (USEPA 2003). Czapar et al. (2006) report that strip till and no-till practices are capable of reducing phosphorus loads by 68 percent and 76 percent, respectively, relative to chisel plowing.

Though no-till systems are more effective than conventional till systems in reducing sediment loading from crop fields, they tend to concentrate phosphorus in the upper 2 inches of the soil profile because of surface application of fertilizer and decomposition of plant material and the lack of regular soil mixing (University of Illinois Extension 2002; UME 1996). That pool of phosphorus readily interacts with precipitation and can lead to increased concentrations of dissolved phosphorus in surface runoff. Chisel plowing could be required once every several years to reduce phosphorus stratification in the soil profile.

4.4.3 Costs

Conservation tillage practices generally require fewer trips to the field, saving on labor, fuel, and equipment repair costs, though increased weed production can result in higher pesticide costs relative to conventional till (USDA 1999). In general, conservation tillage results in increased profits relative to conventional tillage (Olson and Senjem 2002; Buman et al. 2004; Czapar 2006). The HRWCI (2005) lists no additional costs for conservation tillage.

Hydrologic inputs are often the limiting factor for crop yields and farm profits. Conservation practices reduce evaporative losses by covering the soil surface. The U.S. Department of Agriculture (USDA) (1999) reports a 30 percent reduction in evaporative losses when 30 percent ground cover is maintained. Harman et al. (2003) and the Southwest Farm Press (2001) report substantial yield increases during dry years on farms managed with conservation or no-till systems compared to conventional till systems.

Depending on the type of equipment currently used, replacing conventional till equipment with no-till equipment can result in either a net savings or a slight cost to the producer. For new equipment, purchasing no-till equipment is less expensive than conventional equipment (Al-Kaisi et al. 2000). Other researchers report a net gain when conventional equipment is sold to purchase no-till equipment (Harman et al. 2003).

4.4.4 Lifespan

Equipment used for conservation tillage practices should have lifespans meeting or exceeding conventional tillage equipment because the equipment is used less frequently.

4.4.5 Measuring Effectiveness

Conservation tillage practices reduce the transport of soil and nutrients from the field during runoff events. As organic material is incorporated back into the soil, improvements to soil texture and content should be evident, and the soil should retain more moisture following rain events. Measuring effectiveness could occur at the BMP itself and in downstream tributaries. In addition, tracking the appearance of the soil, changes in crop yield, and irrigation requirements relative to precipitation received provides indications of the success of this BMP. Note that improvements to soil structure and crop yield will develop over time.

4.4.6 Applicability to the Grand Lake St. Marys Watershed

Conservation tillage will benefit each farm, but implementation should be prioritized on fields containing highly erodible soils. Water quality impacts are most likely to occur when fields are near streams that have a poor vegetated buffer. On the basis of the amount of highly erodible soils and length of unprotected stream channel in each subwatershed, conservation tillage will provide the greatest improvement to water quality if implemented in the Beaver Creek, Chickasaw Creek, and Coldwater/Burntwood Creek subwatersheds. Fields in those three subwatersheds are considered critical priority for implementation of conservation tillage practices. Operations in other subwatersheds are considered high priority for implementation.

The NRCS provides additional information on mulch till, ridge till, no-till, and strip till practices at
http://efotg.sc.egov.usda.gov/references/public/OH/OH_345_standard_05-24-10.pdf
http://efotg.sc.egov.usda.gov/references/public/OH/OH_346_standard_05-24-10.pdf
http://efotg.sc.egov.usda.gov/references/public/OH/OH_329_standard_05-24-10.pdf

4.5 Filter Strips/Areas

Filter strips/areas are areas that are generally placed adjacent to watercourses and planted with perennial grasses, legumes and forbs. Such areas provide a setback between watercourses and agricultural activities, reduce erosion, trap pollutants and nutrients, improve water quality and provide habitat. If topography allows, filter strips/areas can be used to treat from tile drain outlets. A grass filter strip/area is shown in Figure 4-5.

(Photo courtesy of NRCS)

Figure 4-5. Grass filter strip protecting stream from adjacent agriculture.

It is important to recognize that sheet flow of runoff from field to streams is rare in the Grand Lake St. Marys watershed. Therefore, to be effective, the filter strips/areas must be designed to intercept and disperse runoff through the entirety of the filter area. There are numerous instances in Ohio where streamside buffers are called *filter strips*, but they in fact do not meet the specifications in the NRCS Field Office Technical Guide Standard (code 393). Because runoff is not dispersed through the filter but enters surface water via concentrated flow paths and/or subsurface tiles, the filter strip is more properly called *conservation cover*.

4.5.1 Effectiveness

Properly designed filter strips/areas that meet NRCS code 393 guidelines have been found to effectively remove pollutants from agricultural runoff. The following reductions are reported in the literature (USEPA 2003; Kalita 2000; Woerner and Lorimer 2006):

- 65 percent reduction in total phosphorus
- 55 to 87 percent reduction in fecal coliform
- 11 to 100 percent reductions for atrazine
- 65 percent reductions for sediment (and likely manganese)

Filter strips/areas also serve to reduce the quantity and velocity of runoff. Filter strip/area sizing depends on site-specific features such as climate and topography. At a minimum, the area of a filter strip/area should be no less than 2 percent of the drainage area for agricultural land (OSUE 1994). The minimum width suggested by NRCS (2002a) is 30 feet.

4.5.2 Costs

The costs associated with filter strips/areas include grading, seeding, and mowing costs. Additionally, some area will need to be taken out of production, which will reduce income from the filter strip area. Filter strips/areas will require maintenance, including grading and seeding, to ensure distributed flow across the filter and protection from erosion. Periodic removal of vegetation will encourage plant growth and uptake and remove nutrients stored in the plant material. Filter strips/areas are most effective on sites with mild slopes of generally less than 5 percent, and to prevent concentrated flow, the upstream edge of a filter strip/area should follow one elevation contour (NCDENR 2005).

4.5.3 Lifespan

Filter strips/areas are assumed to function properly with annual maintenance for 30 years before requiring replacement of soil and vegetation.

4.5.4 Measuring Effectiveness

Filter strips/areas treat runoff and remove sediment, nutrients, and other pollutants. Water quality monitoring at a demonstration site should be performed before and following construction and establishment.

4.5.5 Applicability to the Grand Lake St. Marys Watershed

Filter strips/areas provide buffers between fields and streams and also provide treatment of runoff contaminated with manure. The Beaver Creek, Chickasaw Creek, and Coldwater/Burntwood Creek subwatersheds contain the largest number of animal operations and the greatest length of streams with less than 10 feet of permanent, vegetated buffer. Installing and maintaining *properly designed* filter strips/areas in those subwatersheds is a critical priority. Implementation in other subwatersheds is a high priority.

The NRCS provides additional information on filter strips/areas at:
http://efotg.sc.egov.usda.gov/references/public/OH/Oh393_Standard_Filter_Strip_June_2002.pdf

4.6 Grassed Waterways

Grassed waterways are grass-lined stormwater conveyances that prevent erosion of the transport channel. They are often used to divert clean upgrade runoff around contaminated feedlots and manure storage areas (NRCS 2003). In addition, the grassed channel can reduce runoff velocities, allow for some infiltration, and filter out some particulate pollutants. A grassed waterway providing surface drainage for a corn field is shown in Figure 4-6.

(Photo courtesy of NRCS)

Figure 4-6. Grassed waterway.

The NRCS provides additional information on grassed waterways at:
http://efotg.sc.egov.usda.gov/references/public/OH/Grassed_Waterway_412_5-30-08.pdf

4.6.1 Effectiveness

The primary purpose of a grassed waterway is to transport surface runoff and reduce channel erosion. As such, they are often components of practice systems, rather than a standalone practice for water quality. Grassed waterways that allow for water infiltration can reduce pesticide loads by 25 to 35 percent (Kansas State University 2007).

To increase the effectiveness of grassed waterways, the NRCS recommends inspecting the waterway after runoff events, periodically removing accumulated sediment, repairing bare or eroded areas, excluding livestock, and periodically mowing the vegetation.

The NRCS provides additional information on grassed waterways at:
http://efotg.sc.egov.usda.gov/references/public/OH/Grassed_Waterway_412_5-30-08.pdf

Additionally, fertilizers and pesticides should not be applied to the grass in the waterway; a setback distance of 30 feet is recommended to prevent chemicals from entering and being transported through the waterway.

4.6.2 Costs

The costs associated with grassed waterways include grading, seeding, and mowing costs. There could be additional first-year costs involved in creating berms to protect the waterway during establishment and the subsequent removal of those temporary features. These treatment systems do not usually require taking cropland out of production because they are typically constructed where drainage paths already exist.

4.6.3 Lifespan

With annual maintenance including reseeding and regrading when necessary, grassed waterways have an indefinite system life.

4.6.4 Measuring Effectiveness

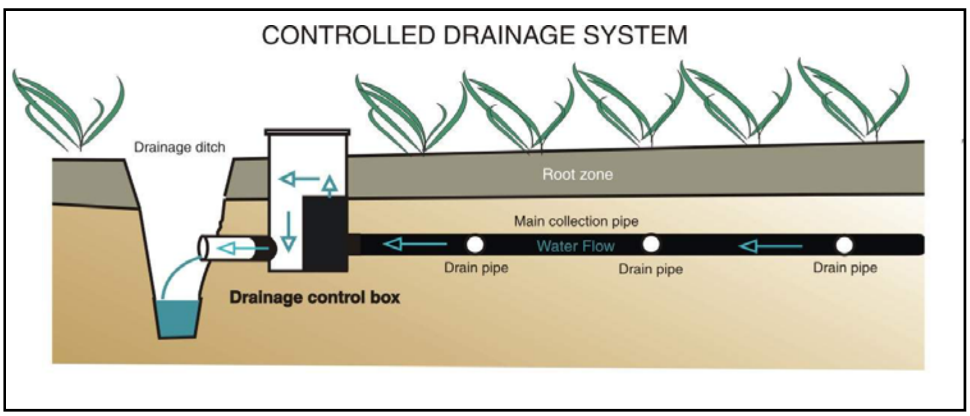
Grassed waterways reduce erosion of the transport channel. Water quality monitoring of transport water before and after the construction and establishment of grassed waterways at a demonstration site should occur after runoff events to measure the impacts of the BMP on water quality.

4.6.5 Applicability to the Grand Lake St. Marys Watershed

Grassed waterways are particularly useful for diverting clean, upland runoff away from animal feedlots and manure storage areas. The Beaver Creek, Chickasaw Creek, and Coldwater/Burntwood Creek subwatersheds contain the largest number of animal operations. Installing grassed waterways in those subwatersheds is a critical priority. Implementation in other subwatersheds is a high priority.

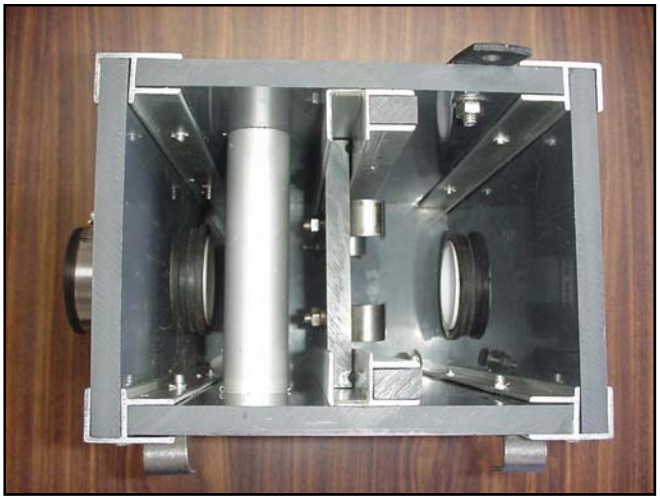
4.7 Outlet Control Devices

A conventional tile drain system collects infiltrated water below the root zone and transports the water quickly to a down-gradient surface outlet. Placing a water-level-control structure at the outlet (Figure 4-7 and Figure 4-8) allows for storage of the collected water to a predefined elevation. The stored water becomes a source of moisture for plants during dry conditions and undergoes biological, chemical, and physical processes that result in lower nutrient concentrations in the final effluent. Similar structures can be installed at the outlets of surface drainage systems to store water and allow for infiltration and pollutant removal before discharge to a receiving stream.



(Illustration courtesy of the Agricultural Research Service Information Division)

Figure 4-7. Controlled drainage structure for a tile drain system.



(Photo courtesy of CCSWCD)

Figure 4-8. Interior view of a drainage control structure with an adjustable baffle height.

4.7.1 Effectiveness

Use of control structures on conventional tile drain systems in the coastal plains has resulted in reductions of total phosphorus loading of 35 percent (Gilliam et al. 1997). Researchers at the University of Illinois also report reductions in phosphorus loading with tile drainage control structures. Concentrations of phosphate were reduced by 82 percent, although total phosphorus reductions were not quantified in that study (Cooke 2005). Going from a surface-drained system to a tile-drained system with outlet control reduces phosphorus loading by 65 percent (Gilliam et al. 1997).

Storage of tile-drained water for later use via subsurface irrigation has shown decreases in dissolved phosphorus loading of approximately 50 percent (Tan et al. 2003). However, accumulated salts in the reuse water might eventually exceed plant tolerance and result in reduced crop yields. Mixing stored drain water with fresh water or alternating irrigation with natural precipitation events reduces the negative impacts of reuse. Salinity thresholds for each crop should be considered and compared to irrigation water concentrations.

4.7.2 Costs

The costs associated with outlet control structures include the costs of mapping the existing tile drain network if present, installing and maintaining outlet control structures, and installing a new tile drain network if none exists. The yield increases associated with installation of tile drain systems and outlet control devices are expected to offset the cost of installation (Cooke 2005).

4.7.3 Lifespan

Outlet control structures for tile drain systems are expected to last 30 years.

4.7.4 Measuring Effectiveness

Outlet control structures provide removal of phosphorus relative to tile drain systems without outlet control or fields with no subsurface drainage. Monitoring water quality before and after installation of outlet control devices at a demonstration site assists in determining their effectiveness. In addition, tracking changes in crop yield and irrigation requirements relative to precipitation received can provide indications of the success of this BMP. Note that increases in crop yield are most evident during dry periods.

4.7.5 Applicability to the Grand Lake St. Marys Watershed

Controlled drainage structures effectively remove phosphorus from subsurface drainage and provide stored water to the root zone of crops during dry periods. Their use should be particularly encouraged in watersheds with additional sources of phosphorus loading (i.e., animal operations) that have poorly vegetated buffers near stream channels. The Beaver Creek, Chickasaw Creek, and Coldwater/Burntwood Creek subwatersheds are the most threatened with regard to those characteristics and are critical priority for implementing this BMP. Installation of controlled drainage structures are high priority in the other subwatersheds.

The NRCS provides additional information on drainage management at:
http://efotg.sc.egov.usda.gov/references/public/OH/Drainage_Water_Management_554_final_2-16-05.pdf

4.8 Ditch Management

Drainage patterns throughout the Grand Lake St. Marys watershed have been extensively altered with subsurface tile drain networks, straightened surface flow channels, and removal of riparian vegetation. Ditches and channels can be managed in such a way to reduce sediment and nutrient transport while removing excess surface and subsurface flows. This section outlines steps that land owners may take to effectively manage ditches and pollutant transport:

- Researchers have found that the sediments and vegetation in ditch networks can be effective at retaining nutrients via sorption to soil particles and uptake by vegetation (Smith and Pappas 2007; Sharpley et al. 2007). However, such retention is decreased following dredging because vegetation and unconsolidated bed material are removed, exposing compacted soil layers that have limited interaction with ditch water and altered biogeochemical properties. Smith and Pappas (2007) suggest that ditch dredging occur during periods of low phosphorus transport and that phosphorus not be applied during or immediately after dredging.
- Because of the sorptive properties of some soils, ditch bed sediments typically have high phosphorus concentrations and high organic content resulting from algae, vegetation, and other organisms. Sharpley et al. (2007) suggest that dredge material be deposited away from ditch banks and adjacent field edges, preferably on soils with low phosphorus concentrations. When used as a soil amendment, ditch spoils can improve soil structure and water-holding capacity.
- Woody vegetation should be removed selectively with a carefully applied herbicide; broad application of herbicide will kill grass growing along the streambanks, reducing bank stability and increasing sediment and nutrient transport (Needelman et al. 2007). Broadcast pesticide use would also result in mass quantities of pesticides being delivered through the ditch network to the natural streams and ultimately to Grand Lake St. Marys.
- Outlet control devices (Section 4.7) can be placed along ditches to raise the water table and provide water in the root zone of plants during dry periods. Such devices can be outfitted with bioreactors (any system that supports a biologically active environment) that provide uptake of nutrients and filtering of sediment particles.
- The two-stage ditch design can be used to convert straightened ditches and channels into a more natural configuration. Two-stage ditches provide an effective means to transport surface runoff while improving habitat and bank stability. In addition, grasses grown along the bench of the high-flow channel will provide channel shading, bank stability, and nutrient assimilation. The two-stage ditch is capable of transporting increased flow volumes during heavy precipitation events relative to conventional channels (Mecklenburg 2004). Ohio State University and Ohio Department of Natural Resources are developing empirical equations for proper sizing of two-stage ditches as part of the Ohio Natural Channel Design Project. Figure 4-9 shows an example of a two-stage ditch.

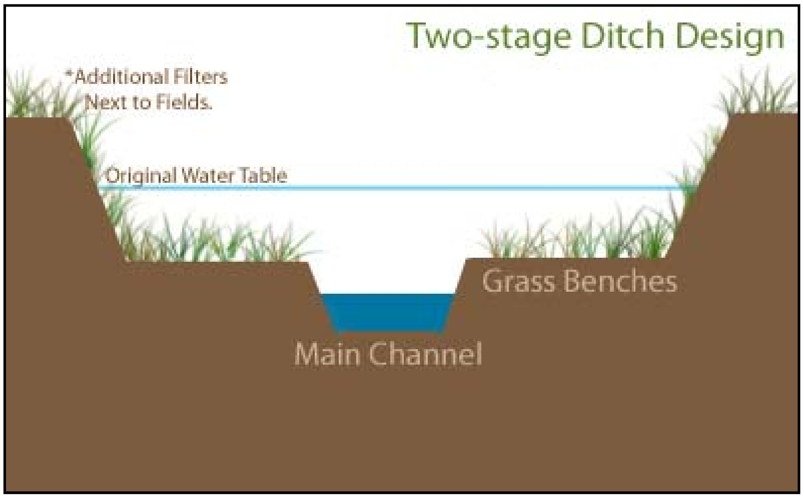


Image courtesy of The Nature Conservancy

Figure 4-9. Example of a two-stage ditch.

- Several additional BMPs can be incorporated into an improved ditch management plan. Ditches may be bordered by filter strips and buffer zones or redesigned to mimic natural channels and wetland systems (Sections 4.5 and 4.10).

4.8.1 Effectiveness

Proper management of ditch networks can reduce pollutant loading by reducing bank erosion and providing filtering, sorption, and vegetative uptake of nutrients.

4.8.2 Costs

The costs associated with ditch maintenance include inspection, grading, seeding, and herbicide costs for woody vegetation. Because the two-stage ditch is wider than the conventional ditch, there will be some income loss from the land used to accommodate the top width of the high flow channel. Maintenance costs, however, should be lower than those for a conventional channel because the two-stage channel is designed to more efficiently transport sediment. The frequency of clean-out events will be substantially reduced, assuming proper design, relative to a conventional channel.

4.8.3 Lifespan

With annual maintenance including reseeding and regrading when necessary, properly managed ditches will have an indefinite system life.

4.8.4 Measuring Effectiveness

The effectiveness of a ditch management program may be assessed visually. The sides and top of the ditch should be covered in grassy vegetation that also serves as a buffer between crops and the drainage ditch. If a two-stage system is employed, the bench should also be covered in grass, and a meandering low flow channel should eventually form between the benches. Bank erosion should not be evident in either system.

4.8.5 Applicability to the Grand Lake St. Marys Watershed

An extensive drainage network exists in the Grand Lake St. Marys Watershed. Proper ditch maintenance and incorporation of two-stage channels is a high priority throughout the watershed. The Beaver Creek, Chickasaw Creek, and Coldwater/Burntwood Creek subwatersheds are a high priority for implementation of this BMP because of the additional sources of phosphorus loading present in them and the length of unprotected stream channel.

4.9 Constructed Wetlands

Constructed wetlands used to treat animal wastes are typically surface flowing systems composed of cattails, bulrush, and reed plants. Before treating animal waste in a constructed wetland, storage in a lagoon or pond is required to protect the wetland from high pollutant loads that might kill the vegetation or clog pore spaces. After treatment in the wetland, the effluent is typically held in another storage lagoon and then land-applied (USEPA 2002). Alternatively, the stored effluent can be used to supplement flows to the wetland during dry periods. Constructed wetlands that ultimately discharge to a surface waterbody require a permit, and the receiving stream must be capable of assimilating the effluent during low-flow conditions (NRCS 2002b). Figure 4-10 shows an example of a lagoon-wetland system.

4.9.1 Effectiveness

Wetland environments treat wastewater through sedimentation, filtration, plant uptake, biochemical transformations, and volatilization. Reported pollutant reductions found in the literature are listed below:

- 42 percent reduction in total phosphorus (USEPA 2003)
- 59 to 80 percent reduction in BOD_5 (USEPA 2002)
- 92 percent reduction in fecal coliform (USEPA 2002)
- 53 to 81 percent reduction in TSS (USEPA 2002)
- 50 percent reduction in pesticides in wetlands with a retention time of 35 days (Moore 1999)

(Photo courtesy of USDA NRCS.)

Figure 4-10. Constructed wetland system for animal waste treatment.

4.9.2 Costs

Researchers of the use of constructed wetlands for animal waste management generally agree that the systems are a lower-cost alternative compared to conventional treatment and land-application technologies. Reductions in the phosphorus content of the final effluent have been shown to reduce the costs associated with disposal and completely offset the costs of constructing and maintaining the wetland within 7 years (CPAAC 1999). The costs associated with these systems consist of construction of the pretreatment basin and wetland, operation and maintenance including electricity to run pumps, maintenance of pumps and berms, and dredging the wetland cells once every several years.

4.9.3 Lifespan

Constructed wetland systems are assumed effective for 30 years, with proper maintenance, especially management of accumulating solids.

4.9.4 Measuring Effectiveness

Constructed wetlands provide treatment of contaminated runoff and liquid wastes from animal operations. Monitoring changes in water quality at a demonstration site (nutrients, TSS, fecal coliform, and BOD) before and after construction assists in determining the effectiveness of the treatment option.

4.9.5 Applicability to the Grand Lake St. Marys Watershed

Constructed wetlands are most effective at operations housing large numbers of animals. On the basis of the mass of waste produced by subwatershed (GLWWA 2009), the larger facilities are likely in the Beaver Creek, Chickasaw Creek, and Coldwater/Burntwood Creek subwatersheds.

The NRCS provides additional information on constructed wetlands at
http://efotg.sc.egov.usda.gov/references/public/OH/OH_656_Constructed_wetland_1-29-10.pdf

4.10 Restoration of Riparian Buffers and Stream Channels

Riparian corridors, including both the stream channel and adjacent land areas, are important components of watershed ecology. The streamside forest slowly releases nutrients as twigs and leaves decompose. The nutrients are valuable to the fungi, bacteria, and invertebrates that form the basis of a stream's food chain. Tree canopies of riparian forests also cool the water in streams, which can affect the composition of the fish species, the rate of biological reactions, and the amount of dissolved oxygen the water can hold. Channelization or widening of streams moves the further separates the canopy, decreasing the amount of shaded water surface, increasing water temperatures, and decreasing dissolved oxygen concentrations.

Preserving natural vegetation along stream corridors can effectively reduce the water quality degradation associated with human disturbances. The root structure of the buffer vegetation enhances infiltration of runoff and subsequent trapping of nonpoint source pollutants. However, the buffers are effective in this manner only when the runoff enters the buffer as a slow-moving, shallow *sheet*; concentrated flow in a ditch or gully quickly passes through the buffer, offering minimal opportunity for retention and uptake of pollutants.

Even more important than the filtering capacity of the buffers is the protection they provide to streambanks. The root systems of the vegetation serve as reinforcements in streambank soils, which help to hold streambank material in place and minimize erosion. Because of the increase in stormwater runoff volume and peak rates of runoff associated with agriculture and development, stream channels are subject to greater erosional forces during stormflow events. Thus, preserving natural vegetation along stream channels minimizes the potential for water quality and habitat degradation due to streambank erosion and enhances the pollutant removal of sheet flow runoff from developed areas that pass through the buffer.

NRCS suggests maintaining a three-zone riparian buffer. Zone 1 starts at the top of the bank of the stream channel and extends perpendicularly 15 feet. Vegetation in the zone should be composed of existing or planted trees and shrubs. Maintenance in the zone should be minimal. Zone 2 starts at the edge of Zone 1 and extends out an additional 25 feet. Tree removal and fruit harvesting are allowed periodically in this zone. Zone 3 separates Zone 2 and the adjacent cropland and consists of grasses, which can be mowed periodically. A riparian buffer protecting the stream corridor from adjacent agricultural areas is shown in Figure 4-11.

(Photo courtesy of NRCS)

Figure 4-11. Riparian buffer between stream channel and agricultural areas.

4.10.1 Effectiveness

Riparian buffers should consist of native species and can include grasses, grass-like plants, forbs, shrubs, and trees. Minimum buffer widths of 25 feet are required for water quality benefits. Higher removal rates are provided with greater buffer widths. Riparian corridors typically treat a maximum of 300 feet of adjacent land before runoff forms small channels that short-circuit treatment. Buffer widths based on slope measurements and recommended plant species should conform to NRCS Field Office Technical Guidelines. The following reductions are reported in the literature:

- 25 to 30 percent reduction of total phosphorus for 30-foot-wide buffers (NCSU 2002).
- 70 to 80 percent reduction of total phosphorus for 60- to 90-foot-wide buffers (NCSU 2002).
- 62 percent reduction in BOD_5 for 200-foot-wide buffers (Wenger 1999).
- 70 to 90 percent reduction of sediment (and likely manganese) (NCSU 2002).
- 80 to 90 percent reduction of atrazine (USEPA 2003).
- Increased canopy cover provides shading, which may reduce water temperatures and improve dissolved oxygen concentrations (NCSU 2002). Wenger (1999) suggests buffer width of at least 30 feet to maintain stream temperatures.

- Increased channel stability will reduce streambank erosion.

4.10.2 Costs
The cost associated with riparian buffers includes construction costs and income losses associated with converting farm land into buffers. Maintenance of a riparian buffer should be minimal but could include items such as periodic inspection of the buffer, minor grading to prevent short circuiting, and replanting/reseeding dead vegetation following premature death or heavy storms.

4.10.3 Lifespan
The expected life of a buffer system is 30 years, though plants can reseed naturally, extending the life of the buffer.

4.10.4 Measuring Effectiveness
Buffers function best when flow enters the system as sheet flow. Monitoring water quality at a demonstration site should be conducted using a flow diverter and collection system. Monitoring changes in water quality (nutrients, TSS, fecal coliform, and BOD) at the outer edge of the buffer and as runoff enters the stream channel will assist in determining the effectiveness of this treatment option. Monitoring should begin after the buffer is established and occur until effectiveness has been determined.

4.10.5 Applicability to the Grand Lake St. Marys Watershed
Ideally, riparian buffers would be established or restored along all stream segments in the Grand Lake St. Marys watershed. Subwatersheds with the greatest length of channel with less than 10 feet of permanent vegetation are Chickasaw, Coldwater/Burntwood, and Beaver Creek (GLWWA 2009). Those are also the subwatersheds with the greatest amount of highly erodible soils and animal operations near stream channels. Riparian buffer creation is a critical priority in those subwatersheds and a high priority in the other subwatersheds.

The NRCS provides additional information on riparian buffers at:
http://efotg.sc.egov.usda.gov/references/public/OH/Oh391_Standard_Riparian_Forest_Buffer.pdf

4.11 Conservation Planning

Water quality problems associated with farming typically are not solved with just one BMP. In most cases, several BMPs used concurrently provide the most benefit to the environment and to the farmer. Use of a comprehensive conservation plan can assist each farmer in identifying the resources and problems specific to his or her operation. Local NRCS and SWCD staff can help develop and update these plans.

The following questions should be answered when developing a conservation plan to ensure selection of the appropriate BMPs:

- What is the average slope of the land?
- Where are the highly erodible soils and critical erosion areas?
- Are there areas of gullying or rill erosion?
- Is there a stream on the property? Is there at least 10 feet of permanent riparian vegetation adjacent to the channel?
- Are animals excluded from streams and riparian areas by vegetation or fencing?
- Where are animals fed? Is clean water diverted around the area? Where does contaminated water flow?
- How is manure collected? How frequently? Where is it stored?

- How often is manure land-applied? Is there adequate storage for manure during the winter months?
- Has a nutrient management plan been developed for the farm? Is the nutrient content of manure being accounted for?
- In what condition is the soil? Does it contain organic matter? Does it crack and seal when dry?
- Is there a subsurface drainage system? Have outlet control structures been installed?

Tools such as the Phosphorus Index (USDA NRCS 1994) or the NRCS SVAP (USDA NRCS 1998) can be useful for assessing water quality issues on the farm or stream reach level. Once those questions have been answered, it will be possible for the farmer and NRCS and SWCD staff to prioritize concerns and develop a comprehensive plan that will reduce pollutant loading while improving soil condition and crop yields. Plans will likely incorporate comprehensive nutrient management plans, cover crops, filter strips, increased riparian zones, control of tile drainage, and treatment and reduction of the volume of runoff to control phosphorus loading.

Example plans addressing common concerns for crop production are online at

https://csg.sc.egov.usda.gov/CSGReporteFOTG.aspx?csg_statecounty_code=39107

Conservation planning practices for animal operations are online at

http://efotg.sc.egov.usda.gov/references/public/OH/CNMP_Tech_Guidance_2000.pdf

Figure 4-12 through Figure 4-14 show examples of BMP systems used to reduce pollutant loading.

Figure 4-12. Covered manure storage facility discharging to a filter strip/area.

Figure 4-13. Agronomic fertilizer application to no-till corn during dry weather.

Figure 4-14. Restored stream channel protected by vegetated buffer.

4.11.1 Effectiveness

The effectiveness of comprehensive plans in reducing pollution is specific to the location, depending on the level of existing pollutant loading and BMPs implemented. The World Bank (2003) reports that concurrent use of conservation tillage, nutrient management plans, and erosion control measures have been shown to reduce nitrogen loading by about 75 percent and phosphorus loading by about 85 percent.

4.11.2 Costs
Costs for individual BMPs are described in the sections above. Some reductions in cost can be realized as measures are implemented simultaneously (reduced seed costs, construction costs, and the like).

4.11.3 Lifespan
BMPs require maintenance and replacement at the frequencies described for each individual BMP in the sections above.

4.11.4 Measuring Effectiveness
BMP systems effectively reduce pollutant contamination in runoff and subsurface drainage water. Monitoring changes in the water quality of runoff before and after implementing a demonstration system assists in the quantification of load reductions for nutrients, organic material, fecal coliform, and sediment. Monitoring locations in Grand Lake St. Marys will depend on the type and location of BMPs implemented. Sampling should occur during or immediately after runoff events at least once per quarter to evaluate trends.

4.11.5 Applicability to the Grand Lake St. Marys Watershed
Agricultural operations are the predominate land use in the Grand Lake St. Marys watershed, and reducing pollutant loading from such operations is necessary to improve lake water quality and reduce the frequency of toxic algae blooms. Conservation planning and implementation of BMP systems is encouraged across the watershed. Farms and operations near streams with poor vegetative buffers should be prioritized to reduce loading to the stream system that ultimately discharges to the lake. As with the prioritization of individual BMPs, these systems will be most beneficial in the Beaver, Chickasaw, and Coldwater/Burntwood subwatersheds, which produce the highest amounts of animal waste, have the greatest number of animal operations less than 1,000 feet from a stream, have the greatest length of poorly vegetated stream channel, and have the largest areas of highly erodible soils. Development of conservation plans is a critical priority in those three subwatersheds and a high priority throughout the remainder of the watershed.

4.12 Homeowner Responsibilities

Residential properties are another potential source of pollutant loading to Grand Lake St. Marys, particularly those adjacent to the lake or a stream. Pollutant loading typically originates from fertilizer and pesticide application to lawns and household sewage treatment systems (HSTS). The following list outlines steps that homeowners can take to reduce pollutant loading from their properties:

- Properly maintain HSTS
    - Inspect system annually
    - Pump system every 3 to 5 years, depending on the tank size and number of residents per household
    - Refrain from trampling the ground or using heavy equipment above a septic system (to prevent collapse of pipes)
    - Prevent septic system overflow by conserving water, not diverting storm drains or basement pumps into septic systems, and not disposing of trash through drains or toilets
    - Disconnect all systems discharging to a tile drain network, ditch, or channel

- Carefully apply lawn fertilizers and pesticides, only when needed
    - Follow label directions precisely
    - Apply lawn fertilizers according to soil test results

  - Apply lawn fertilizers at optimum season
  - Consider using a no-phosphorus lawn fertilizer
  - Do not apply lawn chemicals when heavy rains are forecast
  - Do not apply lawn chemicals near streams or lakeshores

- Properly maintain streambanks and lake shorelines
  - Do not use herbicides to remove grass from ditches, streams, or shores
  - Allow permanent vegetation, including grasses, shrubs, and trees, to grow next to streams and the lakeshore
  - Inspect streambanks and shorelines for signs of erosion and stabilize all eroding areas

4.12.1 Effectiveness

Properly maintaining HSTS has a significant impact on phosphorus, organic material, and fecal coliform loading to downstream waterbodies. Applying lawn chemicals at appropriate rates, away from waterbodies, will reduce the amount of fertilizers and pesticides transported to Grand Lake St. Marys.

4.12.2 Costs

Septic tanks are designed to accumulate sludge in the bottom portion of the tank while allowing water to pass into the drain field (Figure 4-15). If the tank is not pumped out regularly, the sludge can accumulate and eventually become deep enough to enter the drain field. Pumping the tank every 3 to 5 years prolongs the life of the system by protecting the drain field from solid material that can cause clogs and system backups.

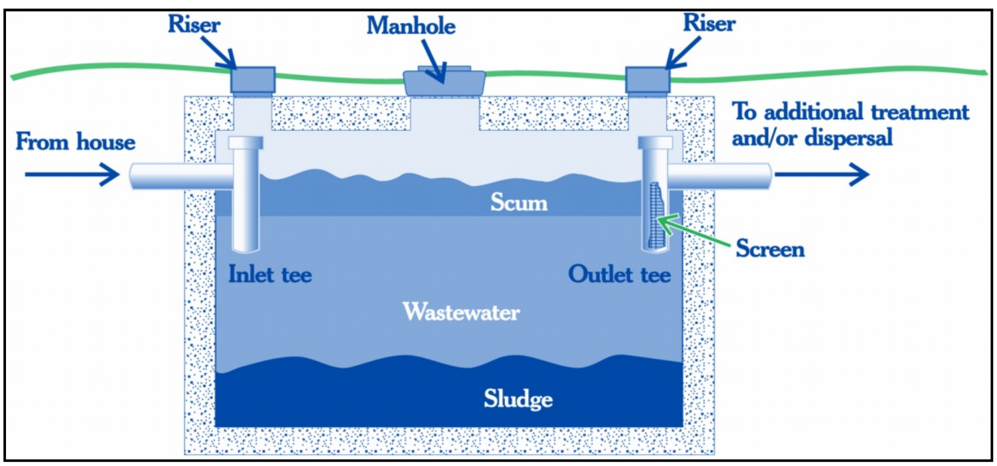


Image courtesy of USEPA.

Figure 4-15. Diagram of a typical septic tank.

The cost to pump a septic tank ranges from $250 to $350 depending on how many gallons are pumped out and the disposal fee for the area. If a system is pumped once every 3 to 5 years, the expense averages out to less than $100 per year. Septic tanks that are not maintained will likely require replacement which can cost between $2,000 and $10,000.

Applying lawn chemicals at appropriate rates and eliminating applications near waterbodies will likely reduce the amount of chemicals applied and save the homeowner money.

4.12.3 Lifespan

A properly maintained HSTS will last 20 to 30 years. Lawn maintenance and stabilization of eroding streambanks and lakeshores will likely occur at seasonal or annual intervals.

4.12.4 Measuring Effectiveness

Problems associated with malfunctioning HSTS are typically not evident until a significant failure occurs (e.g., effluent surfacing on the ground above the tank or leach field, backup of sewage into the house). Implementing a formal inspection program has shown success in confirming that systems are being maintained properly. Maintaining a database of septic systems including age, location, and maintenance events would allow local officials to track where problems are likely to occur.

Inspecting streambanks and lakeshores will provide an indication of the level at which bank stability controls are being implemented. Proper application of lawn chemicals should result in less nutrient loading and algal growth in the receiving streams and Grand Lake St. Marys. The changes can be assessed visually, but quantified pollutant load reductions will be difficult to measure.

4.12.5 Applicability to the Grand Lake St. Marys Watershed

Homeowners throughout the Grand Lake St. Marys watershed should exercise good housekeeping measures related to application of lawn chemicals and maintenance of HSTS. Homes adjacent to streams or the lake are a high priority for implementing these measures.

5.0 IMPLEMENTATION STRATEGY AND SCHEDULE

Improving the water quality in Grand Lake St. Marys will need to be a multiyear effort and will require a continued commitment to reducing pollutant loading to the lake. Short-term improvements in water quality from implementing actions such as an alum treatment will not be enough to ensure the long-term sustainability of the lake. A watershed management committee should be formed to oversee the development and implementation of a comprehensive lake/watershed management plan. The committee can also evaluate whether alternative technologies not presented here—such as methane digesters and gasification technology—make sense for the watershed taking into account issues such as buyback rates, manure supply, and the like.

The actions presented below, by year, are suggested building blocks for the long-term comprehensive effort that is needed. Because of the extent of the watershed and the size of the lake, a strategic series of management actions has been proposed to most efficiently improve lake water quality on the basis of a combination of in-lake measures supported by sufficient levels of watershed management.

5.1 Year 1 Actions

The first year of implementation should focus on education of landowners, farmers, and homeowners; alum demonstration projects; strategic aeration; and data collection. Each action item is described briefly below, categorized by watershed activities and in-lake activities.

5.1.1 Watershed Activities

The following watershed activities should be considered for year 1.

5.1.1.1 Determine Critical Areas

During year 1, critical areas of phosphorus loading in the watershed should be identified. Critical areas are those that contribute a disproportionate load to the lake based on a combination of their biophysical setting and human behavior. Such areas can be identified by taking the following steps:

1. Use biophysical measures (e.g., stream locations, topography, land use, soils) to identify vulnerable locations in the watershed
2. Assess the salient behaviors in these locations to determine where disproportionality might be occurring
3. Gain an understanding of why inappropriate behaviors are occurring in those locations
4. Design an intervention effort based on this understanding

5.1.1.2 Education of Landowners, Farmers, and Homeowners

Workshops, public announcements, and education/outreach materials should be developed to educate citizens regarding the water quality issues in Grand Lake St. Marys and demonstrate how different activities have a direct impact on water quality.

Information targeted to homeowners will include

- Maintenance of on-site wastewater treatment systems
- Proper use of fertilizers and pesticides for lawn care
- Use of zero-phosphorus fertilizers for lakefront homeowners
- Proper disposal of pet waste

Information targeted to farmers will include

- Use of BMPs to improve soil condition, crop yield, and water quality
- Importance of conservation planning and protection of critical areas
- Restoration of riparian corridors
- Proper manure management practices
- Understanding of the importance of reducing external nutrient loading to Grand Lake St. Marys in conjunction with application of in-lake treatments

Table 5-1 summarizes the pollutant load reductions associated with BMPs that should be encouraged in the Grand Lake St. Marys watershed.

5.1.1.3 Enhanced Farm Conservation Planning

BMP installation should continue to occur within the watershed, with a focus on comprehensive conservation planning. The local conservation delivery systems should focus on getting farmers to implement contract-backlogged BMPs across the watershed. This effort should continue during years 2 and 3, with continued emphasis on comprehensive conservation planning.

Table 5-1. Potential effectiveness of various upland BMPs

BMP	Description and removal mechanism	Estimated effectiveness at reducing total phosphorus
Nutrient management plan	Site-specific guidance on appropriate fertilization rates, methods of application, and timing. Appropriate application rates for optimized crop yield reduce loading from excessive nutrient application.	Approximately 20%
Conservation tillage	Reduced tillage practice with a minimum of 30% cover of crop residuals. Reduces erosion rates and phosphorus losses. Increases soil quality by providing organic material and nutrient supplementation.	30% to 40%
Cattle exclusion from streams	Placement of fencing between the cattle grazing area and stream channel. Reduces streambank trampling and deposition of fecal matter in the stream.	15% reduction in phosphorus loading[a]
Grazing land protection	Use of cover crop or rotational grazing patterns to maximize ground cover and reduce soil compaction.	49% to 60% reduction in phosphorus loading[a]
Precision feeding	Feeding strategies designed to reduce nitrogen and phosphorus losses include more precise diet formulation, enhancing the digestibility of feed ingredients, genetic enhancement of cereal grains and other ingredients resulting in increased feed digestibility, and improved quality control.	20% to 30% reduction in phosphorus loading[d]
Cover crop	Use of ground cover plants on fallow fields. Reduces erosion, provides organic materials and nutrients to soil matrix, reduces nutrient losses, suppresses weeds, and controls insects.	70% to 85% removal of total phosphorus[b]
Filter strips/areas	Placement of vegetated strips in the path of field drainage to treat sediment and nutrients.	~ 65% removal of total phosphorus[e,f]

BMP	Description and removal mechanism	Estimated effectiveness at reducing total phosphorus
Grass swales	A runoff conveyance that provides storage for approximately 24 hours. Removes pollutants by sedimentation and plant uptake. Reduces peak flow velocities and subsequent erosion.	Minimal
Conservation easements	Conversion of highly erodible land or land near nutrient sensitive waterbodies to grass or forest cover. Reduces loading rates to natural conditions.	90% reduction in phosphorus loading rates[c]
Restoration of riparian buffers	Conversion of land adjacent to stream channels to vegetated buffer zones. Removes pollutants by sedimentation and plant uptake. Provides streambank stability, stream shading, and aesthetic enhancement.	78% removal of total phosphorus from treated area, assuming a 90 ft buffer width[g]
Conservation planning	Formulation of a comprehensive plan to protect environmental resources, reducing pollutant loading, and improve soil quality and crop yield.	Variable depending on the current level of phosphorus loss and BMPs implemented; can be up to 85%
Proper use of on-site wastewater disposal systems	Includes periodic maintenance (e.g., pumping every 3 to 5 years) and inspection of all on-site wastewater disposal systems in the watershed. Requires immediate repairs (or replacement) of malfunctioning systems, as well as disconnection of direct discharges to tile drainage systems.	Variable depending on the degree and type of failure and the type of on-site system used

Notes

a. USEPA (U.S. Environmental Protection Agency). 2003. *National Management Measures to Control Nonpoint Source Pollution from Agriculture*. EPA 841-B-03-004.

b.HRWCI (Heartland Regional Water Coordination Initiative). 2005. *Agricultural Phosphorus Management and Water Quality in the Midwest*. Iowa State University, Kansas State University, the University of Missouri, the University of Nebraska–Lincoln, and the USDA Cooperative State Research, Education and Extension Service.

c. Haith, D.A., R. Mandel, and R.S. Wu. 1992. GWLF, Generalized Watershed Loading Functions, Version 2.0, User’s Manual. Department of Agricultural and Biological Engineering, Cornell University, Ithaca, NY.

d. USEPA. 2002. *Development Document for the Final Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations*. EPA-821-R-03-001.

e. Winer, R. 2000. National Pollutant Removal Performance Database for Stormwater Treatment Practices, 2nd ed. Center for Watershed Protection, Ellicott City, MD.

f. Kalita, P. 2000. *Vegetative Filter Strips to Reduce Pathogens and Nutrients in Runoff from Livestock Feedlots*. Department of Crop Sciences College of Agriculture, Consumer and Environmental Sciences, University of Illinois Extension.

g. NCSU (North Carolina State University). 2002. *Riparian Buffers and Controlled Drainage to Reduce Agricultural Nonpoint Source Pollution*. Departments of Soil Science and Biological and Agricultural Engineering, North Carolina Agricultural Research Service, North Carolina State University Raleigh, NC. Technical Bulletin 318, September 2002.

5.1.1.4 BMP Demonstration Projects

BMPs aimed at reducing pollutant loading from agricultural operations should be implemented at demonstration sites to provide assessment of effectiveness in reducing nutrient, sediment, and fecal coliform loading. Local NRCS and SWCD staff should continue to develop nutrient management and conservation plans and identify strategic locations for BMP implementation. Section 4.0 describes each BMP and the demonstration projects in more detail.

Another example of a BMP demonstration project is the tributary alum demonstration project recently proposed by the Mercer County Commissioners in their Section 319(h) Nonpoint Source Program Grant Application. This project will involve treating a tributary with alum, collecting deposited sediment, constructing and restoring wetlands in the near-lake areas, and harvesting wetland biomass to remove nutrient loading from the system, as described in Section 3.7.

5.1.2 In-Lake Activities

The following in-lake activities should be considered for year 1.

5.1.2.1 Alum Demonstration Projects

Year 1 of the implementation plan also includes demonstration of phosphorus demobilization in separate embayments of the lakes. The two techniques recommended are (1) alum treatment and (2) pretreatment with peroxide followed by alum treatment. Each of those two approaches should be used in separate embayments that are between 40 and 80 acres. The embayments should be closed off with curtains (barriers) to prevent, or at least minimize, water exchange with the open lake.

Selection of test embayments should proceed as soon as possible on the basis of local desire and need. Alum treatments would ideally occur in late March or early April to have a whole summer's worth of data to determine treatment effectiveness, but fall applications are an equally effective time of year. Water samples should be collected every 2 weeks at a 0.5-m depth at three sites in the embayment and two sites in the open lake, adjacent to the test embayment. Lake collection sites should be at 60-m and 300-m into the open lake from the embayments. Samples should be analyzed for total phosphorus, soluble reactive phosphorus (with a detection limit not greater than 2 μg/L), and chlorophyll *a*. Standard USEPA protocols should be used for analysis. Transparency can be determined with a Secchi disk if possible (depth might be too shallow) and by nephelometric turbidity. Other constituents analyzed should be pH and alkalinity, which should be determined hourly during treatment, and every 2 weeks, along with sample collection for the other constituents.

Sediment treatment with peroxide will precede the alum treatment in the second embayment by approximately 2 weeks. Sediment cores at three sites should be collected (before alum) and analyzed for water and organic matter content to determine the extent of organic matter loss. Granular peroxide should be added at a dose of between 59 and 100 kg/acre. Bench-scale tests should be performed before choosing a final dose.

The final calculated alum dose should be determined from mobile phosphorus concentrations in sediment cores according to procedures in Cooke et al. (2005) and Rydin and Welch (1998, 1999). One sediment core should be collected from the center of each of the selected embayments, and core subsamples should be sectioned into 2-cm intervals for the first 10-cm and sectioned into 5-cm intervals from 10-cm to 30-cm. Each sediment sample should be analyzed for organic content (loss on ignition), water content, and phosphorus fractions. The cost for analysis should be approximately $250 per core.

5.1.2.2 Strategic Aeration

Strategically placed aerator units in channels and bays will improve dissolved oxygen levels, help to reduce the amount of organic materials in the sediment, and keep the water circulating, which will reduce odor. Aerators are discussed in more detail in Section 3.1.

5.1.2.3 Development of a Lake Mass Balance Model

Often, lakes that experience episodic cyanobacteria blooms have internal loading of phosphorus from bottom sediments, which is an important source of phosphorus to the water column during the summer and fall. In shallow lakes, such sediment-derived phosphorus is immediately available to algae. After reviewing the existing data, internal loading of phosphorus is probably an important factor in the cyanobacteria blooms observed in Grand Lake St. Marys. Determining the magnitude and timing of internal loading, relative to external loading, requires a non-steady-state total phosphorus model. A model based on adequate data should be capable of estimating the time necessary for recovery of lake total phosphorus from external load reduction. Recovery in a reasonable time might be possible because the water residence time is relatively short (~1.6 year). With such a short residence time, initial lake total phosphorus can mostly wash out in 7 to 30 years, assuming that external loading is reduced almost tenfold from its current condition. Continued transport of low phosphorus water through the lake will dilute internally loaded phosphorus and begin to deplete sediment phosphorus stores. Historic, high-phosphorus sediment should be buried with new low-phosphorus sediment. The longevity of that process can be estimated from sediment core data and modeling.

The data necessary to construct a total phosphorus mass balance model to aid in assessing the parameters are as follows:

- At least monthly monitoring of inflows, although twice-monthly or continuous water collection for total phosphorus analysis and continuous flow recording are desirable where streams enter the lake.
- At least monthly total phosphorus sampling from three sites in the lake during the ice-free period. Samples should be taken at 0.5 m from the surface. The data are necessary for calibrating a mass balance model, which can be used to estimate the sediment loss rate of total phosphorus during early spring when internal loading is low or before internal loading starts.
- Determination of the outflow volume and phosphorus load. Lake total phosphorus can be assumed equal to total phosphorus in the outflow. However, total phosphorus in the outflow will need to be measured directly during periods of ice cover.

By using the sediment loss rate determined from non-internal loading periods, gross internal loading can be calculated as the unknown variable during the warm summer period when both internal loading and sedimentation are operating simultaneously. Internal loading in shallow lakes is often related to temperature, even though there can be several mechanisms controlling the rate such as wind-driven resuspension, release from the iron-phosphorus complex during calm periods when dissolved oxygen can reach low levels at the sediment surface, high pH caused by intense photosynthesis together with wind resuspension of particulate phosphorus, decomposition of algae-derived organic matter from the previous year's blooms, and so forth (Cooke et al. 2005; Welch and Jacoby 2004).

The prospects for recovery might look better as new inflow total phosphorus data are collected. Typically, shallow eutrophic lakes experience internal loading that drives algal blooms in the summer-fall low inflow period. On the basis of available data, Grand Lake St. Marys fits those characteristics with total phosphorus around 200 to 250 μg/L in summer. High total phosphorus inputs to Grand Lake St. Marys appear to occur primarily in the early spring and winter, which is consistent with internal loading controlling summer water quality.

5.1.2.4 Data Collection

To support the year 1 action items, several data collection efforts are warranted. Many of the efforts will continue over the next several years:

- Intensive monitoring of total phosphorus in the lake and tributaries to support development of a phosphorus mass balance model
- Monitoring of changes in lake water quality due to alum treatment and aeration projects
- Monitoring of water quality changes in agricultural runoff before and after treatment or implementation of BMPs at the upland BMP demonstration sites
- Creation of a geospatial database of existing and newly created BMPs

Collection of data is discussed in more detail in Section 6.0, Adaptive Management.

5.2 Year 2 and 3 Actions

Implementation activities planned for years 2 and 3 include widescale lake treatments and focused effort on external load reductions. This section describes those activities in more detail, categorized by watershed activities and in-lake activities.

5.2.1 Watershed Activities

The following watershed activities should occur in years 2 and 3.

5.2.1.1 Targeted Agricultural BMPs in Critical Areas

Critical areas in the watershed that have not yet been managed should be targeted for implementation of BMPs. Examples of focus items include severe erosion of fields or streambanks, sparse riparian buffers, and poor manure management practices.

5.2.1.2 Installation of Two Wetland Treatment Trains

Two tributaries along the south shore of Grand Lake St. Marys should be identified for implementation of wetland treatment trains. As described in Section 3.7, the Mercer County Commissioners recently applied for a Section 319(h) grant to install a wetland treatment train at the mouth of Prairie Creek. Treatment train installation must be closely correlated with upstream installation of BMPs to ensure effectiveness.

5.2.1.3 Continued Education and Monitoring

Efforts to educate farmers and homeowners should continue during years 2 and 3. Collection of monitoring data in the lake, tributaries, and at BMP demonstration sites should also be continued as needed. As more farmers implement BMPs in the watershed, the geospatial database of BMPs will continue to be updated.

5.2.2 In-Lake Activities

The following in-lake activities should occur in years 2 and 3.

5.2.2.1 Whole Lake Alum Treatment

Assuming that the in-lake alum demonstration projects demonstrate that alum addition is an effective means to reduce internal phosphorus loading and improve water quality in Grand Lake St. Marys, a full-scale alum treatment application should be implemented. Additional sediment core samples should be collected to confirm dosing requirements at a broad scale. The success of the project depends on the level of implementation of agricultural BMPs throughout the watershed.

5.2.2.2 Strategic Aeration

Placement of aerators will continue at strategic locations around the lake, depending on the success and outcomes of the year 1 aeration projects.

5.3 Year 4 and 5 Actions

Implementation activities planned for years 4 and 5 include comprehensive lake monitoring, continued reductions in external loading, and stabilization of the Grand Lake St. Marys shoreline. This section describes those activities in more detail, categorized according to watershed activities and in-lake activities.

5.3.1 Watershed Activities

The following watershed activities should occur in years 4 and 5

5.3.1.1 Installation of Wetland Treatment Trains

Two to four additional tributaries along the south shore of Grand Lake St. Marys should be identified for implementation of wetland treatment trains. Such systems will provide further treatment of tributary pollutant loads already partially reduced through continued implementation of upland BMPs.

5.3.1.2 Continued Education and Monitoring

Education efforts of farmers and homeowners should continue during years 4 and 5. Collection of monitoring data in the lake, tributaries, and at demonstration sites should also be continued as needed. As more farmers implement BMPs in the watershed, the geospatial database of BMPs will continue to be updated.

5.3.2 In-Lake Activities

The following in-lake activities should occur in years 4 and 5.

5.3.2.1 Comprehensive Lake Monitoring

A comprehensive lake monitoring effort will indicate the effectiveness of the Grand Lake St. Marys implementation plan in improving lake water quality and reducing the frequency and severity of cyanobacteria blooms. If water quality goals are being met in the lake, implementation activities and use of BMPs should be continued along the current path. If water quality goals are not being met, the implementation plan should be reevaluated, and new strategies should be defined for bringing the lake into compliance.

5.3.2.2 Lake Shoreline Stabilization BMPs

During years 4 and 5, efforts should be made to stabilize the shoreline of Grand Lake St. Marys. As described in Section 3.8, banks should be inspected for signs of erosion and stabilized with a combination of engineering controls and plantings.

6.0 ADAPTIVE MANAGEMENT

Adaptive management is an iterative implementation process that makes progress toward achieving water quality goals while using newly acquired data and information to reduce uncertainty and adjust implementation activities. The recommendations for improving lake water quality contained in this action plan are based on the best information and data available. However, as new information is collected or conditions change in the future, there must be a strategy in place to evaluate the new information, react to it, and adjust components of the plan if necessary. The proposed adaptive management approach will allow the Grand Lake St. Marys stakeholders to move forward with water quality improvement activities at the same time that additional data gathering occurs. The data will then be used to confirm or adjust some of the plan's technical assumptions, to fill remaining data limitations, and to evaluate the effectiveness of restoration measures on an individual and collective basis.

6.1 Monitoring

The first major component of an adaptive management plan is the collection of additional data. In the Grand Lake St. Marys watershed, three endpoints are defined: improving water quality in the lake, reducing the frequency and severity of cyanobacteria blooms, and meeting the requirements of the TMDLs developed for tributaries in the watershed (Ohio EPA 2007). Water quality monitoring in the lake and tributaries provides the means to evaluate whether those goals are being met.

As part of developing the overall management plan, a comprehensive monitoring program should be developed that will be able to assess the effectiveness of the management approach, track implementation, and provide the public with status reports on the condition of the lake.

In addition to monitoring changes in water quality at the BMP demonstration sites (described in Sections 3.0, 4.0, and 5.0), monitoring should continue at the previously established stations on each tributary to Grand Lake St. Marys (Figure 6-1) and at several in-lake stations. At a minimum, the in-lake stations should include three locations evenly spaced along the longitudinal center-line of the lake and one location at each recreational facility. The following items outline the components of this monitoring plan. A more detailed monitoring plan describing specific in-lake stations and quality assurance procedures should be developed to ensure that the time and resources used to collect the data result in an accurate representation of the system.

- Monitoring should occur at least once per month at each tributary and in-lake station.
- At least one wet weather event should be monitored during each season (if necessary this wet weather monitoring should be in addition to the monthly monitoring).
- Tributary monitoring should include dissolved oxygen, temperature, pH, conductivity, nitrate, nitrite, ammonia, total Kjeldahl nitrogen (TKN) or organic nitrogen, total phosphorus, orthophosphate, TSS, 5-day biochemical oxygen demand (BOD_5), and fecal coliform.
- In-lake monitoring should include Secchi depth, dissolved oxygen, temperature, pH, conductivity, nitrate, nitrite, ammonia, TKN or organic nitrogen, total phosphorus, orthophosphate, TSS, BOD_5, fecal coliform, and chlorophyll *a*. Samples should be taken at 0.5 m from the surface.
- Microcystin levels should continue to be monitored at current locations and frequencies.

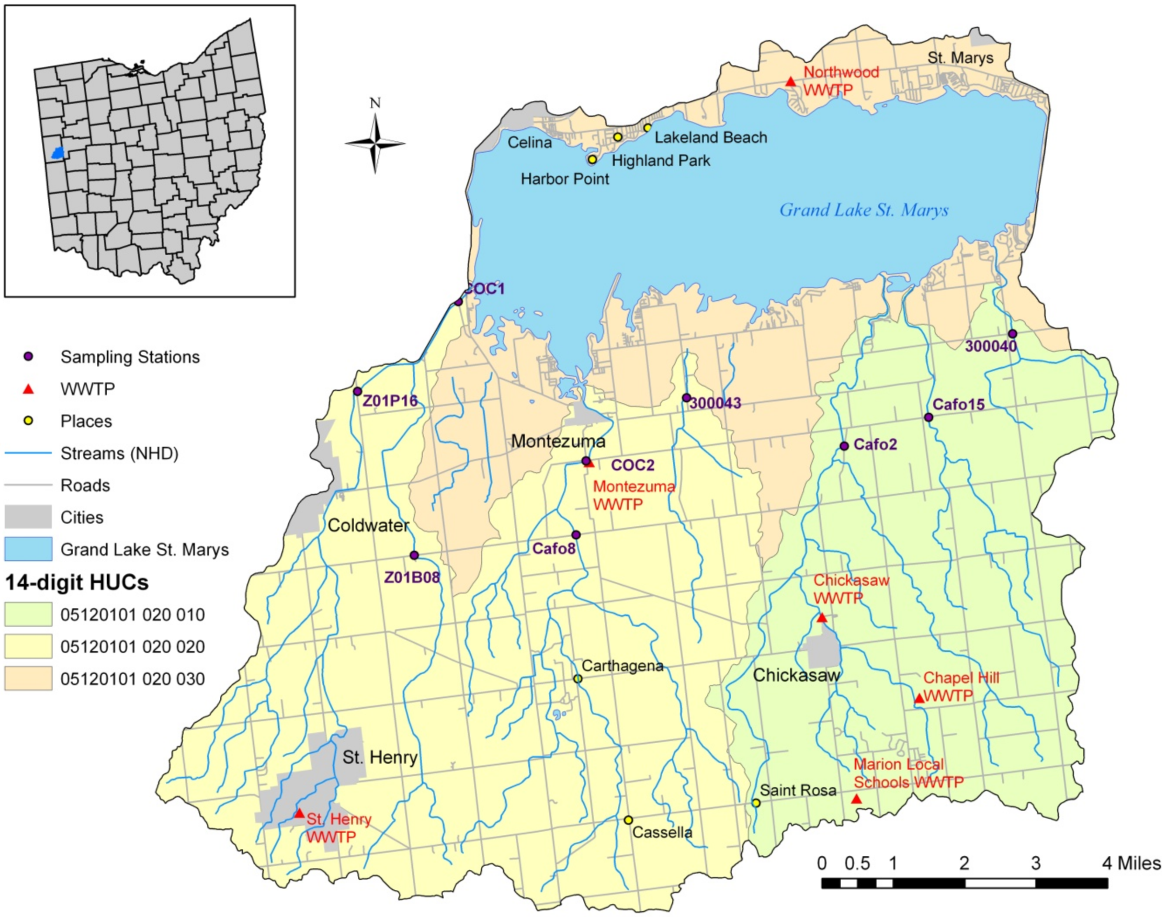


Figure 6-1. Monitoring sites in the Grand Lake St. Marys tributaries.

6.2 Tracking Implementation

The second component of adaptive management is tracking the implementation of BMPs throughout the watershed and the lake. As more BMPs are implemented across the watershed, it is expected that water quality will improve in both the tributaries and the lake. Establishing exactly when and where each BMP is used will help determine which BMPs are having the greatest impact on water quality and where additional BMPs are needed to reduce pollutant loading. Tracking the BMPs and changes in land management will also help facilitate their ongoing operation and maintenance and agency follow-up and inspection of certain BMPs, such as nutrient management plans, is recommended

Little information exists regarding the use of BMPs in the watershed, and a spatial inventory of implemented BMPs should be conducted. Annual documentation of all installed practices should be made, including geo-referencing their locations and information on ongoing operation and maintenance. Social survey information should also continue to be collected to learn about landowner preferences for installing and maintaining different types of BMPs.

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GLOSSARY

Aeration: A process that promotes biological degradation of organic matter in water. The process can be passive (as when waste is exposed to air), or active (as when a mixing or bubbling device introduces the air).

Aerobic: Life or processes that require, or are not destroyed by, the presence of oxygen. (See: anaerobic.)

Algae: Simple, rootless plants that grow in sunlit waters in proportion to the amount of available nutrients. They can affect water quality adversely by lowering the dissolved oxygen in the water. They are food for fish and small aquatic animals.

Algal blooms: Sudden spurts of algal growth, which can affect water quality adversely and indicate potentially hazardous changes in local water chemistry.

Anaerobic: A life or process that occurs in, or is not destroyed by, the absence of oxygen.

Benthic/benthos: An organism that feeds on the sediment at the bottom of a waterbody such as an ocean, lake, or river.

Best management practice (BMP): Methods and or measures that have been determined to be the most effective, practical means of preventing or reducing pollution from nonpoint sources.

Biochemical oxygen demand (BOD): A measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. The greater the BOD, the greater the degree of pollution.

Biomass: All the living material in a given area; often refers to vegetation.

Broadcast application: The surface spreading of materials over an entire area.

Clay soil: Soil material containing more than 40 percent clay, less than 45 percent sand, and less than 40 percent silt.

Conventional tilling: Tillage operations considered standard for a specific location and crop and that tend to bury the crop residues; usually considered as a base for determining the cost-effectiveness of control practices.

Cover crop: A crop that provides temporary protection for delicate seedlings and/or provides a cover canopy for seasonal soil protection and improvement between normal crop production periods.

Decomposition: The breakdown of matter by bacteria and fungi, changing the chemical makeup and physical appearance of materials.

Dredging: Removal bottom material from waterbodies.

Effluent: Wastewater--treated or untreated--that flows out of a treatment plant, sewer, or industrial outfall. Generally refers to wastes discharged into surface waters.

External loading: Loading to a waterbody that originates from outside the waterbody itself, including loading from the watershed, direct point source discharges, and atmospheric deposition.

Eutrophication: The slow aging process during which a lake, estuary, or bay evolves into a bog or marsh and eventually disappears. During the later stages of eutrophication, the waterbody is choked by abundant plant life from higher levels of nutritive compounds such as nitrogen and phosphorus. Human activities can accelerate the process.

Infiltration rate: The quantity of water that can enter the soil in a specified time interval.

Internal loading: Loading to a waterbody that originates from within the waterbody. This can include material scoured or diffused from the underlying sediment through the mineralization or biological transfer of phosphorus, as well as material that is created within the waterbody, such as organic material created by algal growth. External pollutant loading can add to sediment storages that subsequently become a source of internal loading.

Grassed waterway: Natural or constructed watercourse or outlet that is shaped or graded and established in suitable vegetation for the disposal of runoff water without erosion.

Hypolimnion: Bottom waters of a thermally stratified lake. The hypolimnion of a eutrophic lake is usually low or lacking in oxygen.

Land application: Discharge of wastewater, manure, and/or biosolids onto the ground for treatment or reuse

Nitrogen: A nutrient that is used by plants and animals to form proteins. Excess nitrogen in certain waterbodies can cause undesirable algae growth which degrades water quality for aquatic life. Excess nitrogen in groundwater or surface water can also degrade the quality of the resource for drinking water.

Nonpoint sources: Diffuse pollution sources (i.e. without a single point of origin or not introduced into a receiving stream from a specific outlet). The pollutants are generally carried off the land by runoff or subsurface flow from snow melt or storm water.

Nutrient: Any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus in wastewater, but it is also applied to other essential and trace elements.

Phosphorus: An essential chemical food element that can contribute to the eutrophication of lakes and other waterbodies. Increased phosphorus levels result from discharge of phosphorus-containing materials into surface waters.

Sediment: Topsoil, sand, and minerals washed from the land into water, usually after rain or snow melt.

Total maximum daily load (TMDL): A calculation of the highest amount of a pollutant that a waterbody can receive and safely meet water quality standards set by the state, territory, or authorized tribe.

Treatment train: A management process of intercepting and collecting pollutants from the top to the bottom of the watershed using a sequence of different types of practices, such as source control, pollutant capture, infiltration, and re-use.

Turbidity: Is a measure of the cloudy condition in water due to suspended material such as silt or organic matter.

Water quality standards: State-adopted and USEPA-approved ambient standards for waterbodies. The standards prescribe the use of the waterbody and establish the water quality criteria that must be met to protect designated uses.

Watershed: The land area that drains into a stream; the watershed for a major river may encompass a number of smaller watersheds that ultimately combine at a common point