ODC Network

REQUEST FOR PROPOSALS
for
PHOSPHORUS REMOVAL/REDUCTION FACILITY

The ODC Network (ODC) wishes to contract with a consultant to provide a proposal for an engineered solution to reduce phosphorus concentrations of Lake Macatawa and the Macatawa River to at least 50 µg/L, and preferably to 20-30 µg/L of total phosphorus. Responses must provide explicit detail on approach, location(s), projected effectiveness (for obtaining both the 50 and 20-30 µg/L targets), timing, and costs (construction and O&M). The facility(ies) will complement ongoing lake restoration efforts and programs. THE ODC RESERVES THE RIGHT TO POSTPONE, ACCEPT OR REJECT ANY AND ALL PROPOSALS, IN WHOLE OR IN PART, ON SUCH BASIS AS THE ODC DEEMS TO BE IN ITS BEST INTEREST. All proposals shall be subject to all applicable federal, state and local laws. The ODC is an equal opportunity employer.

I. INFORMATION FOR PROPONENTS

A. RECEIPT OF PROPOSALS

The ODC invites firms to submit electronic copies that shall be submitted to Kelly Goward (kelly@outdoordiscovery.org) until April 26, 2024, 5pm. Late proposals will not be accepted.

B. PREPARATION OF PROPOSAL

All costs associated with the preparation of the proposal shall be the responsibility of the proposing firm.

All proposals shall be signed by an officer or employee of the proposing firm authorized to contract work for the firm.

The consultant may withdraw proposals by written notice at any time prior to the date fixed for the receipt of proposals. Proposals are to be irrevocable for a period of sixty (60) days from the receipt date and shall not be withdrawn, modified or altered after the receipt date unless requested by the ODC.

C. PRE-PROPOSAL QUESTIONS

All questions related to this RFP shall be submitted via email only to Kelly Goward (kelly@outdoordiscovery.org), no later than March 4, 2024. Responses will be provided via email and posted on the ODC website by the end of business on March 11, 2024.

D. PROPOSAL EVALUATION AND METHOD OF AWARD

All proposals received by the deadline shall be subject to an evaluation by the Project Committee. Proposals must be complete and responsive to all sections of this RFP. ODC may reject proposals that do not fulfill all program requirements or omit any of the proposal contents as described in this RFP.

The proposals will be evaluated using the criteria outlined in Section VIII. Some consultants may be asked to make an oral presentation as a part of this step. The recommendation of the Project Committee must be considered and approved by the ODC Network Board of Directors.

The Project Committee is composed of ODC Network Staff and local University representatives.

II. PROPOSAL REVIEW AND SELECTION SCHEDULE

A. ISSUANCE OF RFP's: February 12, 2024

B. RECEIPT OF PROPOSAL: April 26, 2024, 5pm, via email. Any proposal received after this time and date will not be accepted.

C. EVALUATION OF PROPOSALS (including interviews, if needed and contract negotiation): April 28-May 31, 2024

D. RECOMMENDATION OF CONSULTANT SELECTION AND CONTRACT APPROVAL: early June 2024, pending ODC Network Board of Directors approval

E. AWARD AND NOTICE TO PROCEED: early to mid-June 2024

The above dates are tentative and are subject to change. ODC reserves the right to schedule interviews as needed to complete proposal evaluation. **Costs associated with the interview process are the responsibility of the proposing firm.**

III. SCOPE OF SERVICES REQUIRED

A. BACKGROUND INFORMATION

Total Phosphorus (TP) concentrations in Lake Macatawa have been reduced since the implementation of Project Clarity in 2013, declining by about half from an annual mean of ~160 µg/L prior to Project Clarity, to an annual mean of ~80 µg/L post Project Clarity (Fig. 1). There is considerable variance within these means, due to both natural variation in the system (e.g., precipitation patterns, farming practices) and the limited number of sampling events each year.

The substantial overall mean reduction in TP concentration is encouraging, but it is still far above the interim TP target of 50 µg/L. In addition, the interim target is still much higher than what is desirable for restoring ecological function and structure in west Michigan drowned rivermouth lakes, which is 20 to 30 µg/L (Steinman et al. 2008, 2015).

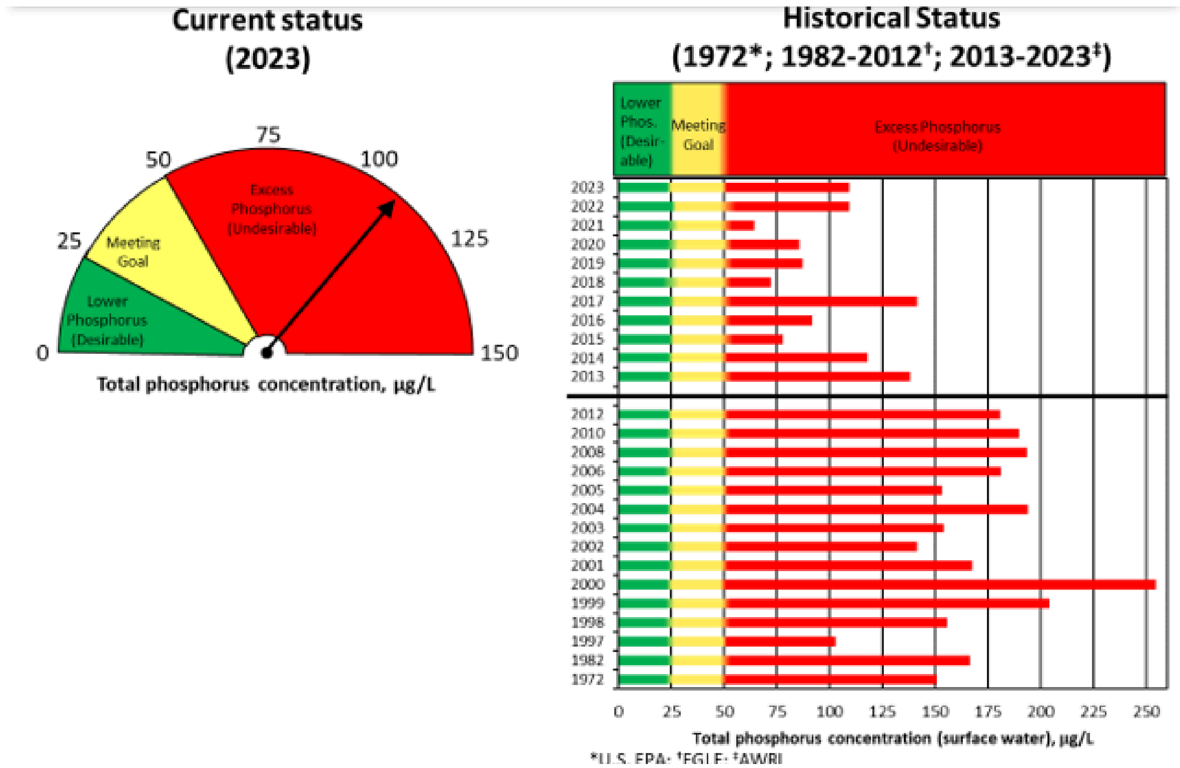

Figure 1. Left: Dashboard showing TP concentrations in 2023. Right: Historical TP annual means. Project Clarity began in 2013 (black horizontal line). The interim TMDL for Lake Macatawa is 50 µg/L. Data from Project Clarity 2023 Annual Report (Dec. 2022 – Nov. 2023).

As a consequence, there is interest in exploring an engineering solution to reduce phosphorus concentrations to at least the 50 µg/L concentration (Target A), and preferably to 20-30 µg/L (Target B) of TP. This 2-tiered approach is reflected in the scope of work below. A preliminary assessment of an in-stream phosphorus reduction solution was presented by Progressive AE in 2017 (see attachment). For this RFP, we are not restricting P reduction ideas to locations or approaches.

The ODC Network is seeking responses that provide explicit detail on approach, location(s), projected effectiveness (for obtaining both Target A and B), timing, and costs (construction and O&M). The facility(ies) will complement ongoing lake restoration efforts and programs.

B. SCOPE OF WORK

The tasks the consultant will be expected to accomplish for the project are listed below. The consultant is expected to develop and submit a work plan and schedule describing how the work will be accomplished. <u>Proponents should be prepared to proceed in early to mid June 2024 and deliver a final report, with all tasks outlined below completed, by December 31, 2024.</u>

Based on available data from Project Clarity annual reports (https://www.gvsu.edu/wri/steinman/technical-reports-71.htm), peer-reviewed scientific publications (Clement and Steinman 2017; Iavorivska et al. 2021; Kindervater and Steinman 2019; Steinman et al. 2016, 2018, 2022), and any other relevant information, provide a detailed phosphorus reduction approach.

This RFP should address approaches for each TP target separately. We recognize that the attainment of a deeper P reduction may include ideas such as increasing the dose of a chemical inactivant (if feasible) or the construction of additional facilities throughout the watershed. Regardless of approach(es), the RFP should be responsive to the following:

1. Schedule a pre-project initiation meeting with the ODC to discuss the overall project schedule including data collection, coordinating project activities, and determining objectives and outcomes.
2. Provide monthly project status reports to the ODC detailing progress towards completion of the project's goals and objectives. The Project Committee may request a brief meeting to review and ask questions about the status report.
3. <u>Project Approach and Design</u>
    - the rationale behind the selected approach and design;
    - the preferred location(s) of the facility, any land acquisition needs and a discussion of how the engineered solution would impact the current use of the site. One location that should be considered in the approach is the City of Holland Dredge Placement Facility located at 11736 Lakewood Blvd, Holland MI 49424.
    - the schematic design of the P removal facility(ies) with attention to the following points:
        - the recommended footprint (including vehicular access, all buildings, storage areas, processing areas, etc.);
        - will the location require pumping of water to the facility or is there a head difference allowing gravity flow;
        - the treatment capacity (in cfs) of the facility—high flow events carry a large proportion of the annual P load so it is critical to know not only the max cfs but also how long can the max cfs be maintained;
        - depending on the recommended treatment approach, will there be residual material that needs to be handled (e.g., floc) and if so, how will that be accomplished;
        - depending on the recommended treatment approach, the facility may be exposed to more corrosive water than that from the river. What actions, if any, will be taken to address this issue;

  - estimated costs for construction, as well as operations and maintenance, over a 20-year period of operation, including any costs that may be associated with site cleanup after it is no longer need; and
  - anticipated permitting needs, including whether or not this type of facility is permissible under existing local, state, and federal regulations.

4. Provide a detailed list and discussion of the immediate next steps needed to move the engineered solution toward implementation.

5. Final resentation to stakeholder group

IV. TECHNICAL PROPOSAL PREPARATION

All proposal information shall be presented in pdf format and may be shared directly via email or through a file sharing service. It is mandatory that the proposal contains, but is not limited to, the following information and that it is presented in the following order. There is no maximum page limit.

A. Cover page that includes the address, phone number, and contact name of the submitting consultant.

B. Table of Contents.

C. A Project Plan which details completely the execution of the project, including the submission of an acceptable final report. The plan ultimately becomes a part of the contract by reference of the proposal; therefore, it should describe in a specific and straightforward manner the proposed approach to completing the scope of work described above. Project methodology shall be described in sufficient detail to permit evaluation of the probability of success in achieving the objectives.

D. A Project Team Chart that adequately displays the organizational structure of the project team and sub-consultants (if applicable). Each team member should be included on this chart.

E. Resumes of key personnel of the project team including all sub-consultant staff assigned to this project.

F. A description of your firm's relative experience within the last three years (at least 3 projects). Each referenced project should include the type of work provided, lead staff person for the project, other staff involved in the project, project budget, project size, time schedule, outcome relative to schedule and budget, client contact person and contact telephone number/email address.

G. Other commitments of the organization and project team shall be presented in sufficient detail to indicate that the organization and all the individuals assigned to this project will be able to meet the commitment of the proposal.

H. The time required to complete the project and all tasks outlined in Section III.B shall be approximately 6 months (26 weeks). The project schedule shall include timelines for each phase or task of the work, when each phase or task will begin, how long it will continue and when it should end. The timetable should clearly delineate the points in time where the project deliverables and reports are planned.

V. FEE PROPOSAL PREPARATION

Submit a detailed fee estimate for each task, based on and directly related to the worker hour estimate, with the technical proposal. The fee proposal shall also include costs related to overhead, meetings/presentations, direct expenses (i.e. travel, reproduction, etc.), and profit.

VI. PROJECT DELIVERABLES

A. Any primary data collected.

B. Provide the ODC an electronic copy of all project documentation including maps, plans, spreadsheets, graphics, status reports, and other materials developed for the study.

C. Provide a written final report in pdf format that addresses all deliverables listed in the scope of work. Include supporting information in appendices as applicable.

D. Provide a final presentation in ppt format that the project team will be present to an ODC Network stakeholder group.

VII. ODC RESPONSIBILITIES

A. Host a project initiation meeting to discuss the overall project schedule including data collection, coordinate project activities and help determine study objectives and outcomes.

B. Provide information to the consultant that we have access to regarding the status of water quality monitoring, historic and current phosphorus reduction efforts and potential project sites in the watershed.

C. In conjunction with the Project Committee, coordinate final reviews and provide comments on the final report and recommendations.

VIII. EVALUATION

The ODC reserves the right to engage in negotiations to determine the proposal that is in the overall best interests of the ODC and the Project Committee. Neither the ODC nor the selected firm shall be legally bound in any way until a contract is signed.

The Project Committee will evaluate all complete proposals received by the submission deadline. The Project Committee will select the consultant in consideration of the following: qualifications, proposed work plan, costs, timeline and project organization, and project experience and understanding. See specific criteria and scoring in the table below. As needed, interviews will be scheduled with consultants to complete the evaluation process.

WEIGHT	DESCRIPTION
25	The qualifications of the project team and past experience with regard to similar types of studies.
20	Proposed work plan and thoroughness of the proposed scope of work.
20	Cost
15	Data collection proposal, timeline and project organization/tracking.
10	The adequacy of the staff to meet the project timelines. The reasonableness of the allocation of resources to the various tasks.
10	The consultant's demonstrated understanding of the project and local political and environmental issues.
TOTAL= 100	

IX. ADDITIONAL INFORMATION

Direct any questions concerning this Request for Proposals to:

Kelly Goward
Land & Water Director
ODC Network
4214 56th St
Holland MI 49423
kelly@outdoordiscovery.org

X. REFERENCES

Clement, D.R. and A.D. Steinman. 2017. Phosphorus loading and ecological impacts from agricultural tile drains in a west Michigan watershed. Journal of Great Lakes Research 43: 50-58. http://dx.doi.org/10.1016/j.jglr.2016.10.016.

Iavorivska, L., Veith, T.L., Cibin, R., Preisendanz, H.E., and A.D. Steinman. 2021. Mitigating lake eutrophication through stakeholder-driven hydrologic modeling of agricultural conservation practices: A case study of Lake Macatawa, Michigan. Journal of Great Lakes Research 47: 1710-1725.

Kindervater, E. and A.D. Steinman. 2019. Phosphorus Retention in West Michigan Two-stage Agricultural Ditches. Journal of American Water Resources Association 55: 1183–1195. https://doi.org/10.1111/1752-1688.12763.

Steinman, A.D., M. Ogdahl, R. Rediske, C.R. Ruetz III, B.A. Biddanda, and L. Nemeth. 2008. Current status and trends in Muskegon Lake, Michigan. Journal of Great Lakes Research 34: 169-188.

Steinman, A.D., E.S. Isely, and K. Thompson. 2015. Stormwater runoff to an impaired lake: impacts and solutions. Environmental Monitoring and Assessment 187: 1-14.

Steinman, A.D., Abdimalik, M., Ogdahl, M.E., and Oudsema, M. 2016. Nutrient impact on planktonic vs benthic algae in a eutrophic lake. Lake and Reservoir Management 32: 402-409.

Steinman, A.D., Hassett, M, and M. Oudsema. 2018. Effectiveness of best management practices to reduce phosphorus loading to a highly eutrophic lake. International Journal of Environmental Research and Public Health 15(10), 2111; https://doi.org/10.3390/ijerph15102111.

Steinman, A.D., M. Hassett, M. Oudsema, and C. Penn. 2022. Reduction of phosphorus using electric arc furnace slag filters in the Macatawa Watershed (Michigan). Frontiers in Environmental Science 10: 863137; doi.org/10.3389/fenvs.2022.863137.

Preliminary Feasibility Study

Macatawa Watershed Alum Injection System Preliminary Engineering Feasibility Study Final Report

Prepared for:

Travis Williams, Executive Director
Outdoor Discovery Center Macatawa Greenway

Dr. Alan Steinman, Director
Robert B. Annis Water Resources Institute

Prepared by:

Progressive AE
1811 4 Mile Road NE
Grand Rapids MI 49525

February 2017

Project No.: 72340001

progressive|ae

Macatawa Watershed Alum Injection System
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February 2017

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Introduction

Project Clarity is a multi-faceted restoration project designed to substantially reduce pollution loading to Lake Macatawa and improve water quality. The project is the result of years of study that characterized Lake Macatawa's water quality and quantified various sources of pollution loading to the lake. Key elements of the restoration effort include wetland restoration, structural and non-structural best management practices, engineered solutions, and an information and education component. This report focuses on the results of a preliminary engineering evaluation of the technical feasibility, costs, and effectiveness of a system that would use aluminum sulfate to measurably reduce phosphorus, sediment, and bacteria loading to Lake Macatawa. The system is proposed to complement and enhance ongoing lake restoration efforts and programs.

Figure 1. Lake Macatawa. Source: Outdoor Discovery Center.

> *The goal is to substantially reduce the sediment, nutrient and bacterial pollution in Lake Macatawa by at least 70 percent.*
>
> \- Project Clarity

Lake Macatawa and Its Watershed

LAKE AND WATERSHED CHARACTERISTICS

Lake Macatawa has a surface area of 1,825 acres and a mean or average depth of 12 feet (Figure 2; Table 1). The main tributary to Lake Macatawa, the Macatawa River, enters the east side of the lake, and water flows out of the west end of Lake Macatawa to Lake Michigan.

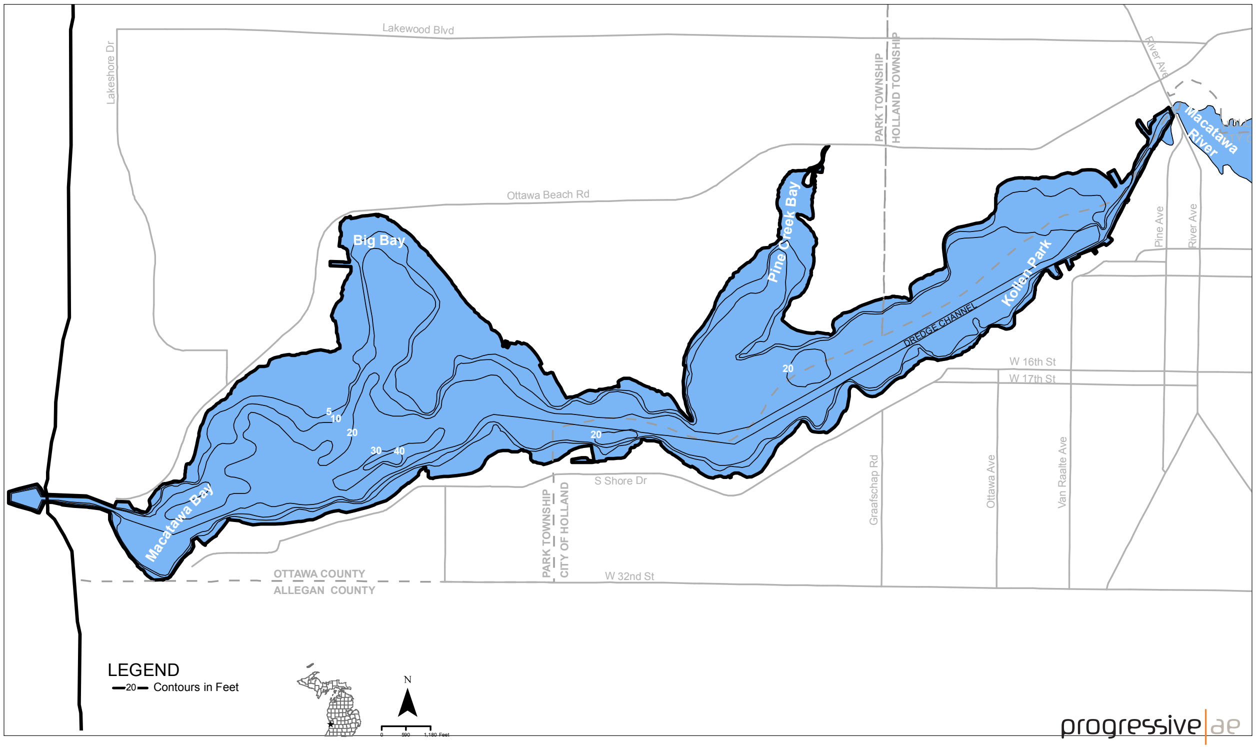

Figure 2. Lake Macatawa depth contour map. Source, depth contours: Michigan Geographic Data Library. Originator: Derived from inland lake maps created by the Michigan Department of Natural Resources. Publication date: 2005. Original soundings by War Department, 1941. Shoreline digitized from 2012 aerial orthodigital photography.

TABLE 1
LAKE MACATAWA PHYSICAL CHARACTERISTICS

Lake Surface Area	1,825	acres
Maximum Depth	40	feet
Mean Depth	12.0	feet
Lake Volume	21,978	acre-feet
Shoreline Length	18.8	miles
Shoreline Development Factor	3.1	
Mean Lake Elevation	579	feet

LAKE MACATAWA AND ITS WATERSHED

The Lake Macatawa watershed encompasses an area of 175 square miles, a land area 61 times larger than the lake itself (Figure 3). The upper portion of the watershed is primarily agricultural land while most of the lower watershed around the lake is urbanized. Soils in the western one-third of the watershed are primarily sandy, while the eastern two-thirds of the watershed is composed largely of heavier clay mixtures rich in nutrients (Fongers 2009, Macatawa Watershed Project 2012). Historical development has dramatically altered natural hydrology and drainage patterns in the watershed. Meandering streams were straightened and thousands of acres of wetlands were drained, filled, and converted to other uses (Faasen et al. 2008, Fongers 2009, Macatawa Watershed Project 2012). It has been estimated that wetland losses total nearly 90%, or approximately 16,500 acres, of the original wetlands in the Lake Macatawa watershed (Macatawa Watershed Project 2012).

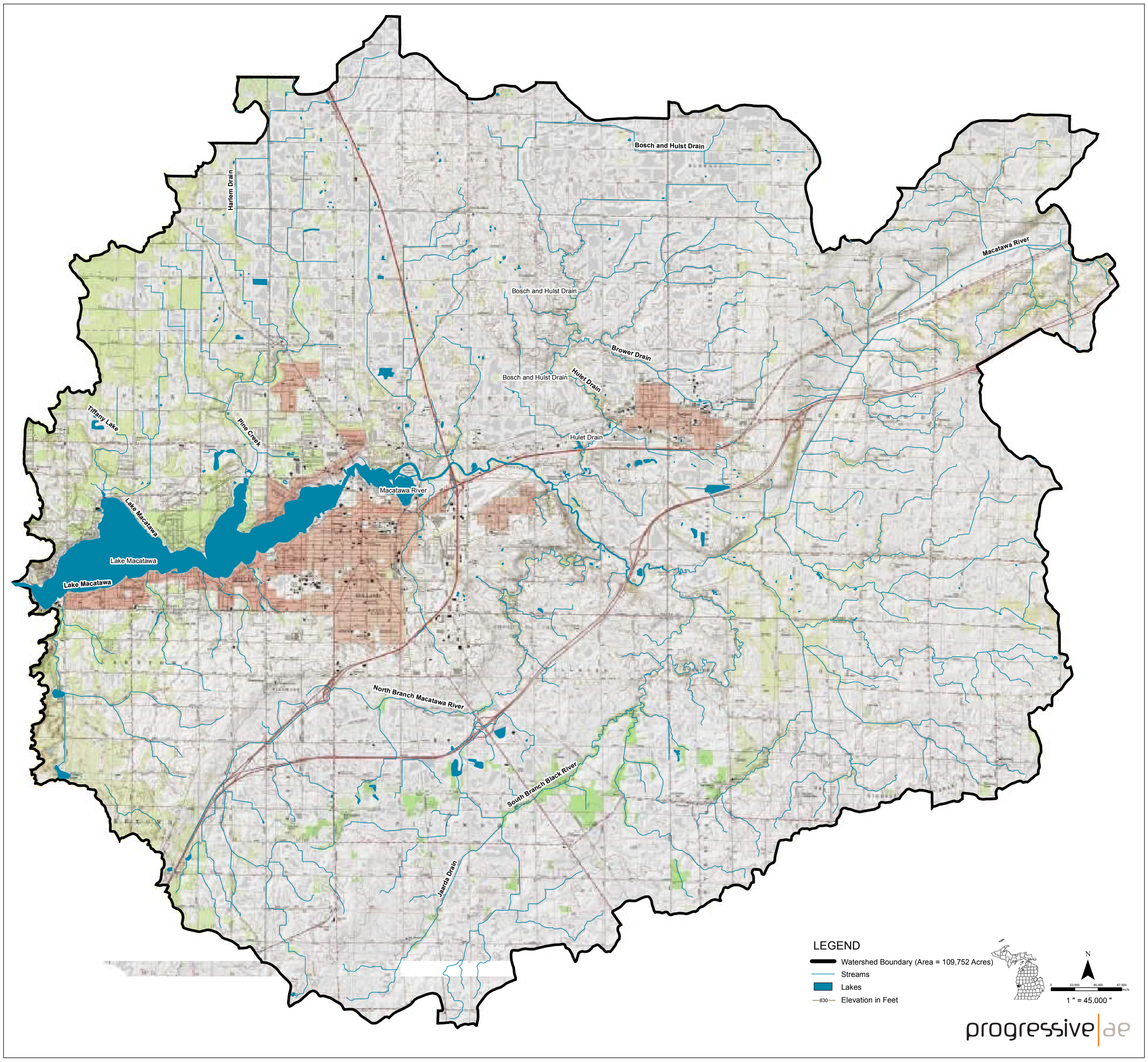

Figure 3. Lake Macatawa watershed map. Base map source: United States Geological Survey. Watershed boundary source: Michigan Geographic Data Library. Originator: Michigan Department of Environmental Quality. Publication date: 1998.

LAKE WATER QUALITY

Lake Macatawa is one of the most nutrient-enriched lakes in Michigan (Holden 2014). The Michigan Department of Environmental Quality has determined that neither Lake Macatawa nor any of its major tributaries meet water quality standards (Macatawa Watershed Project 2012).

In a recent water quality assessment (Holden 2014), it was noted that:

> Lake Macatawa displays the classic symptoms of a hypereutrophic lake, including: extremely high nutrient and chlorophyll a levels, excessive turbidity, periodic nuisance algae blooms, low dissolved oxygen levels, and a high rate of sediment deposition.

Elevated *E. coli* bacteria levels have also been documented in the lake (Macatawa Watershed Project 2012).

MACATAWA RIVER FLOW CHARACTERISTICS

Average daily discharge measured at USGS gaging station 04108800 (Figure 4) from October 1, 1984 to September 30, 2015 was examined in order to characterize streamflow in the Macatawa River.

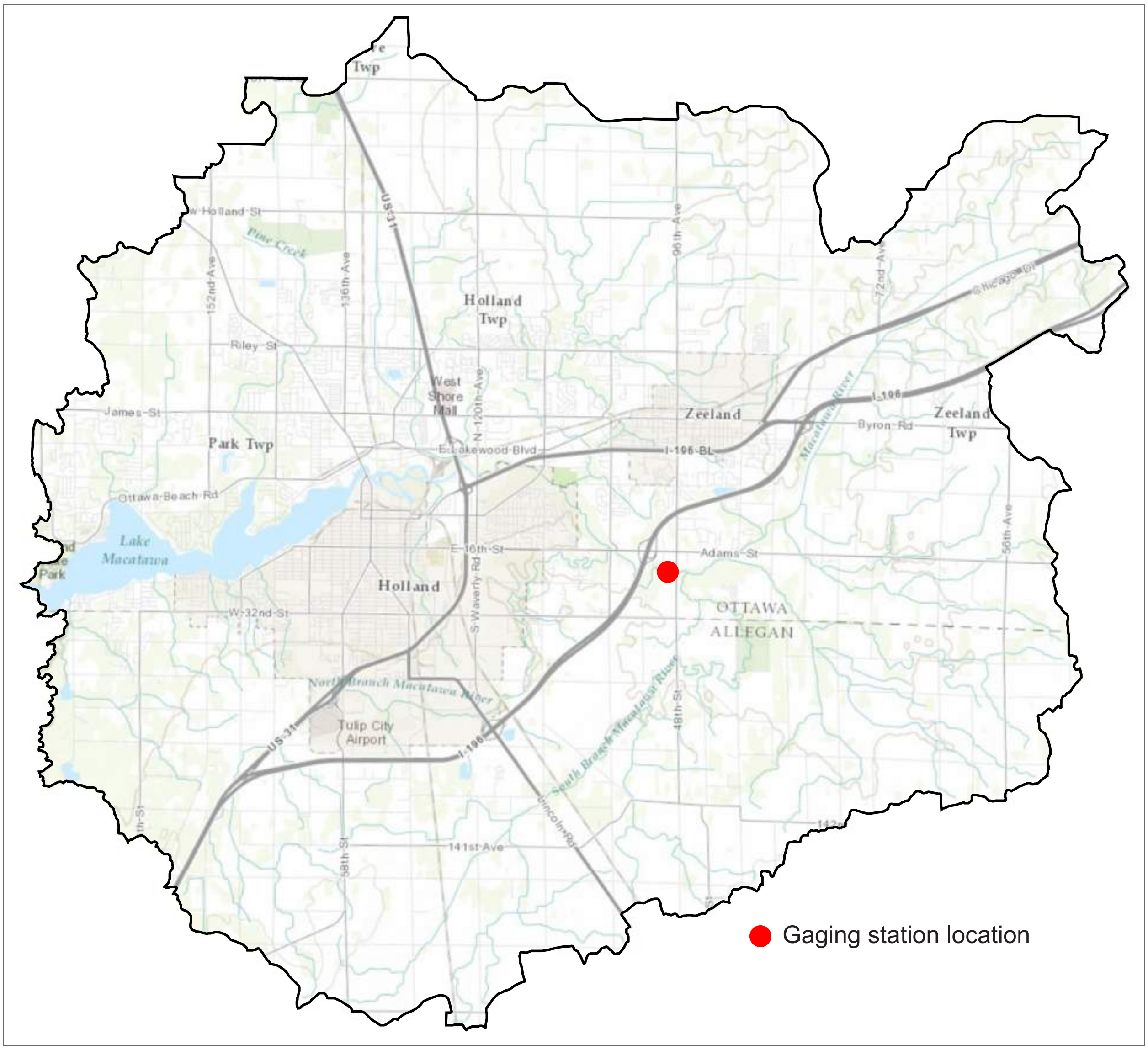

Figure 4. Location map for USGS stream gaging station 04108800.

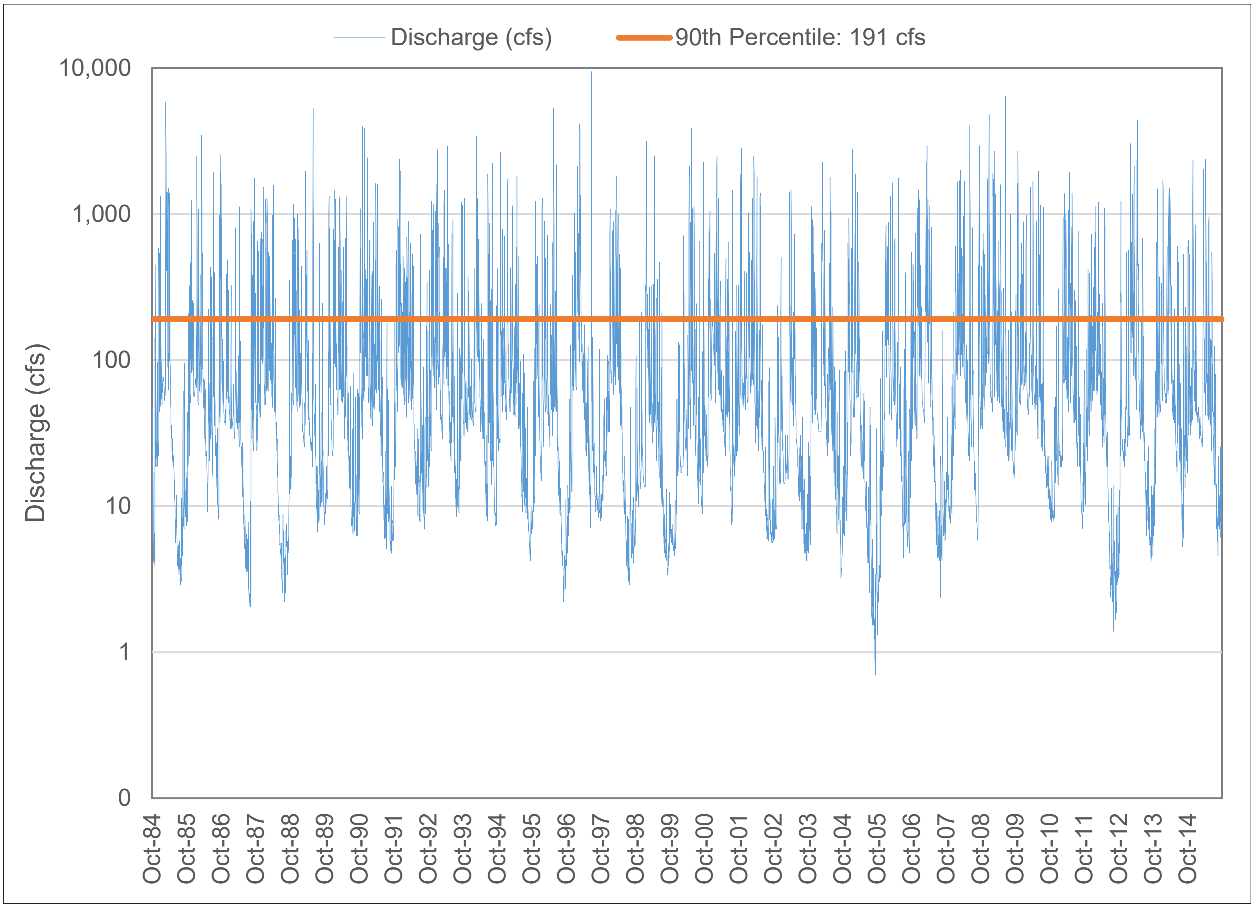

Figure 5. Macatawa River discharge, water years 1985-2015. Measurements recorded at USGS stream gaging station 04108800. Note logarithmic scale for discharge (vertical axis).

USGS uses the term “water year” to apply to the annual time period beginning October 1 and ending September 30, and are named for the year that includes January through September. Thus, Macatawa River data was examined for water years 1985 to 2015, a period which includes 11,322 daily average streamflow records (Figure 5). It was important to examine a dataset that was large enough to cover a wide variety of flow conditions, but recent enough that any watershed land use changes and climatic trends (e.g., global climate change) would be reflected in the data.

Table 2 and Figure 6 summarize the 30-year daily average streamflow data for water years 1985 to 2015. The mean and median flow are 81 and 25 cfs, respectively. The mean and median are both measures of average flow, but are calculated in different ways. The median flow of 25 cfs indicates that half of the 11,322 flow records are less than 25 cfs and half are greater than 25 cfs. The fact that the mean flow, at 81 cfs, is greater than the median flow indicates that high flows skew the mean upwards, above the median. This skewed distribution in the data is borne out when we examine the percentiles of flow. “Percentiles” refer to the percentage of records that are smaller than the percentile value. For example, the 10th percentile of flow, at 4 cfs, means that 10 percent of the flow measurements were less than 4 cfs; the 90th percentile of flow, at 191 cfs, indicates that 90 percent of the flow measurements were less than 191 cfs.

The very highest flow measurements occur infrequently, but exceed the “normal” or average flow by two orders of magnitude. The maximum flow measurement recorded in the Macatawa River during the 1985-2015 water years was 5,540 cfs, which is over 200 times greater than the median flow of 25 cfs. Only 5 percent of the records exceeded 378 cfs, the 95th percentile, but the 378 cfs flow rate is fifteen times greater than the median.

TABLE 2
MACATAWA RIVER DISCHARGE SUMMARY STATISTICS
October 1, 1984 - September 30, 2015

Statistic	Discharge (cfs)
Mean	81
Standard deviation	200
Minimum	0.4
10th Percentile	4
20th Percentile	7
30th Percentile	12
40th Percentile	18
Median	25
60th Percentile	33
70th Percentile	46
80th Percentile	77
90th Percentile	191
95th Percentile	378
99th Percentile	950
Maximum	5,540

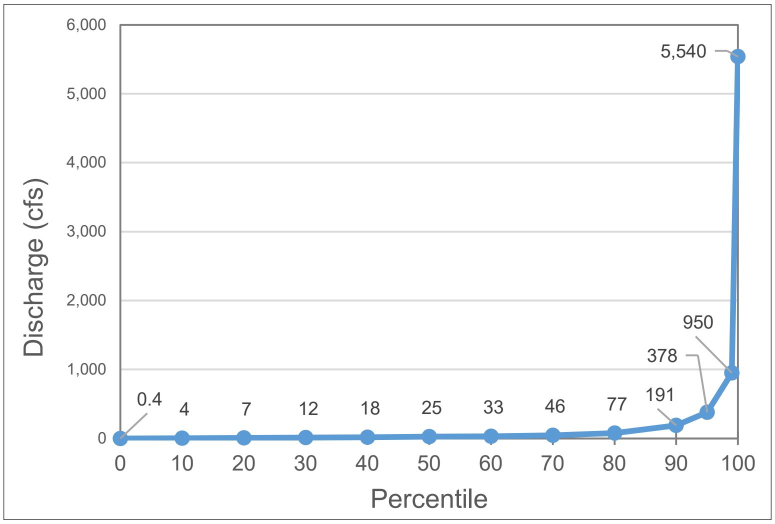

Figure 6. Macatawa River discharge percentiles, water years 1985-2015.

When daily average discharge is averaged on a monthly basis over the 30-year timeframe, it is apparent that Macatawa River streamflow peaked in March and decreased to the lowest levels in late summer (Figure 7), as is typical with temperate streams.

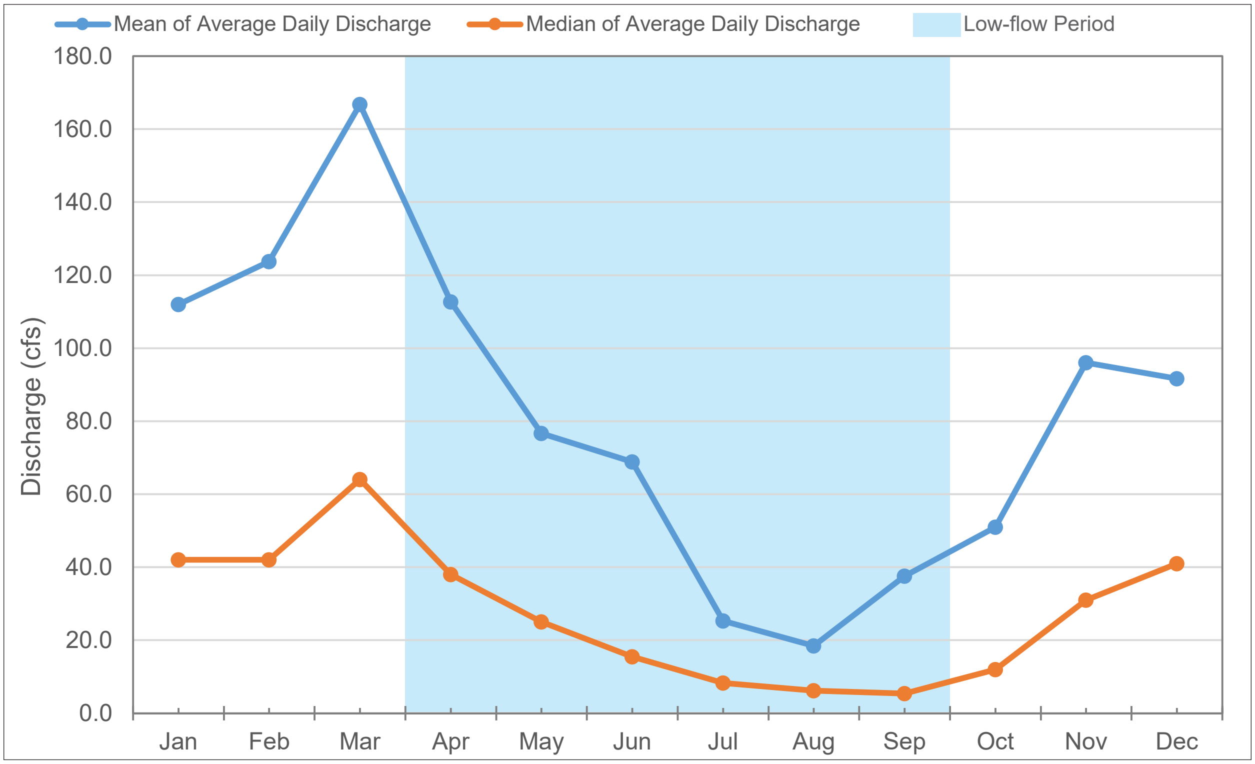

Figure 7. Macatawa River mean and median of average daily discharge, by month, for water years 1985-2015. Measurements recorded at USGS stream gaging station 04108800.

The Macatawa River is a "flashy" stream that experiences rapid changes in flow (Fongers 2009). The term flashiness reflects the frequency and rapidity of short term changes in streamflow, especially during runoff events (Baker et al. 2004). For example, during the 2015 water year, discharge in the Macatawa River during storm events rapidly increased by two orders of magnitude over baseflow conditions (Figure 8). The magnitude of episodic storm events in the Lake Macatawa watershed could have a significant impact on the efficacy of an alum injection system.

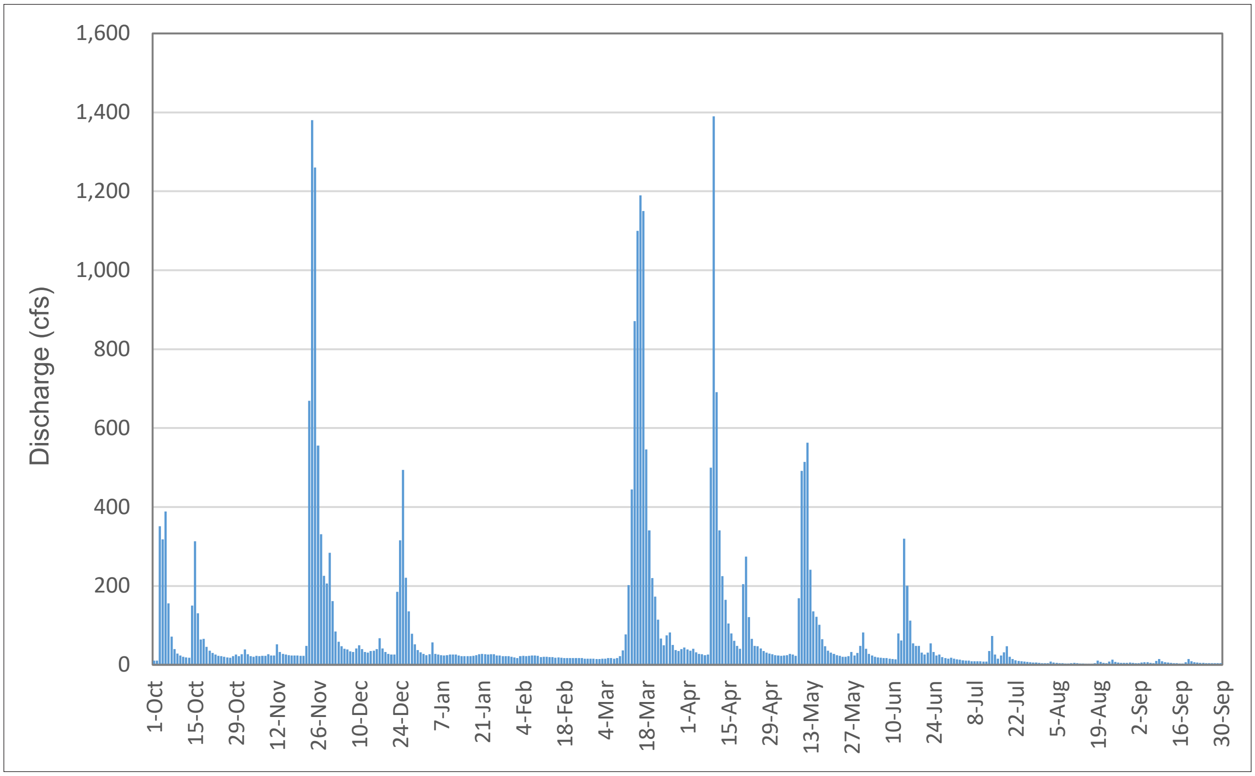

Figure 8. Macatawa River mean daily discharge for water year 2015. Measurements recorded at USGS stream gaging station 04108800.

LOADING SOURCES

Sources of pollution loading to Lake Macatawa have been studied extensively. Point-source loadings are estimated to be a relatively small portion of the total annual loading to the lake (Holden 2014), and internal loading does not appear to be significant (Steinman and Rediske 2005, Holden 2014). Agricultural tile drains appear to contribute a significant portion of the nonpoint phosphorus load to Lake Macatawa (Clement and Steinman 2016). Monitoring results indicate that phosphorus concentrations in Lake Macatawa are generally lower after extended periods of low stream-flow and are substantially higher during periods of high-flow storm events (Holden 2014). Holden (2014) noted that when flows are greater than 100 cfs, phosphorus concentrations in Lake Macatawa have the potential to exceed 300 ppb. Total phosphorus concentrations in the Macatawa River averaged 100 ppb during baseflow conditions and increased 10 to 35-fold during storm conditions (Hassett et al. 2016). Episodic storms in the Lake Macatawa watershed have the potential to carry a large portion of the pollution load to the lake. Recent monitoring of sediment, phosphorus, and *E. coli* bacteria levels at multiple locations throughout the watershed indicate that the highest rates of pollution loading are from the sub-basins in the upper watershed (Hope College et al. 2011). The five highest ranked sub-basins in terms of pollution loading potential, listed in descending order, are: Peters Creek, the Upper Macatawa River, North Branch Macatawa River, Noordeloos Creek, and South Branch Macatawa River (Hope College et al. 2011; Figure 9).

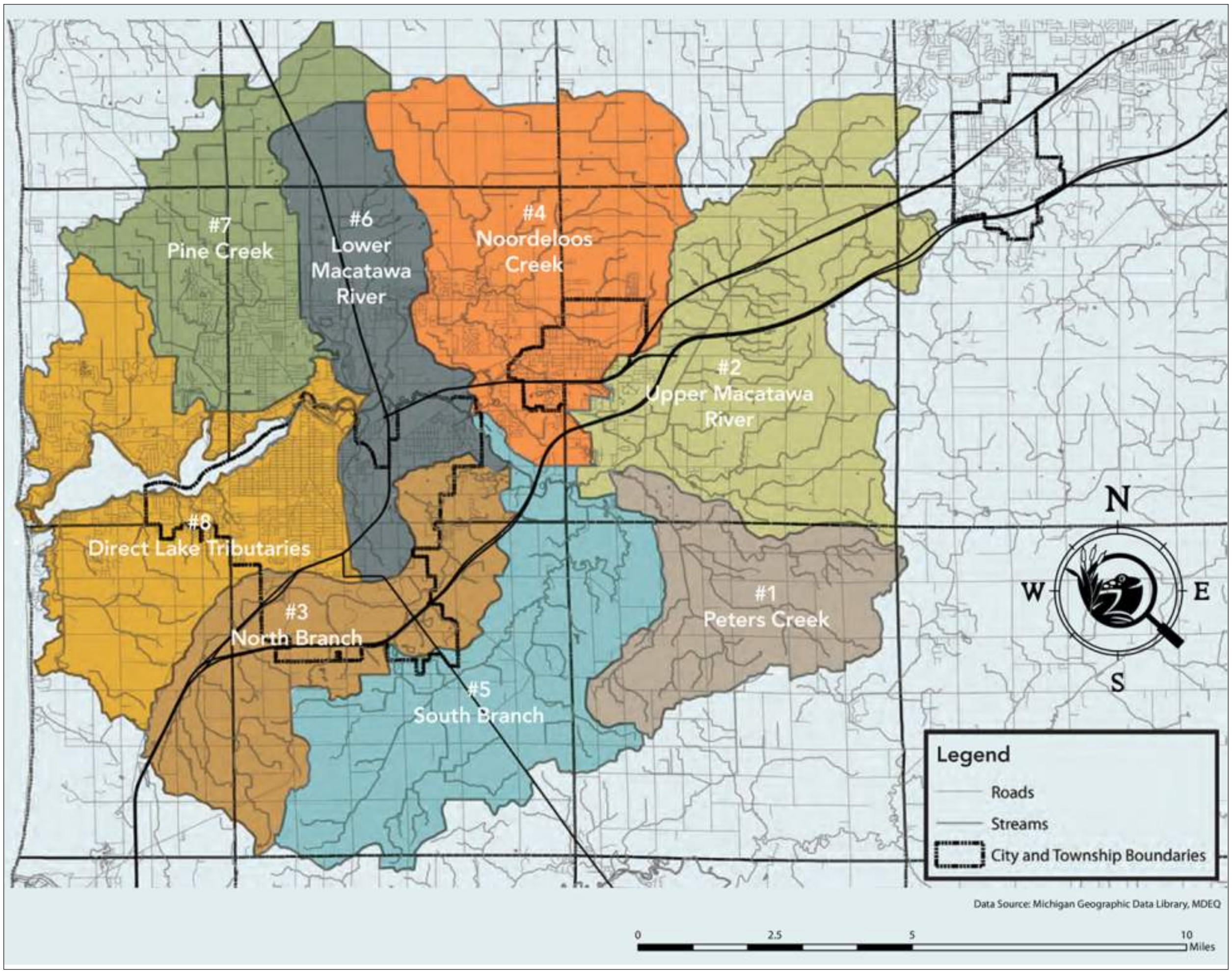

Figure 9. Lake Macatawa watershed sub-basins map. Source: Williams (2012).

The Total Maximum Daily Load (TMDL) established for Lake Macatawa prescribes a decrease in annual phosphorus loading from 138,500 pounds to 55,000 pounds. A loading reduction of this magnitude would reduce the estimated in-lake total phosphorus concentration from 125 to 50 parts per billion (ppb; Walterhouse 1999). Since the point-source dischargers to Lake Macatawa have an annual allocated discharge limit of 20,000 pounds, nonpoint source loadings need to be reduced by 70% to 35,000 pounds to achieve the loading reduction targeted in the TMDL (Macatawa Watershed Project 2012). A primary goal of Project Clarity is to reduce sediment, nutrient and bacterial loading to Lake Macatawa by at least 70%.

Alum Injection Systems

ALUM

Alum (aluminum sulfate) is a chemical that has been used successfully in lakes to reduce phosphorus levels and algae blooms, primarily by preventing phosphorus release from lake sediments (Cooke et al. 2005). Once applied, alum binds with phosphorus in the water column and settles to the bottom as a floc. The floc inhibits the release of phosphorus from lake sediments.

Steinman and Ogdahl (2011) documented that an alum treatment conducted in nearby Spring Lake in 2005 resulted in reduced in-lake phosphorus levels and internal loading five years post-treatment. Byram Lake in Genesee County, Michigan, was treated with alum in 1990 and phosphorus levels and algae growth in the lake have been greatly reduced in the 25 years since treatment (Progressive AE 2014).

In addition to lake treatments, alum is commonly used in the treatment of wastewater and drinking water, including drinking water at the Holland Water Treatment Plant.

In recent years, alum injection has been used to reduce pollutant levels in stormwater (Harper 2013). Since 1985, over 70 alum injection systems have been constructed in Florida (Harper 2013). Other states, including Iowa, Connecticut, Tennessee, and Georgia, and federal agencies (U.S. Environmental Protection Agency and Federal Highway Administration) have incorporated alum injection systems into their stormwater best management practices guidance manuals. Appendix A includes an article that provides an overview of the use of alum as a stormwater best management practice.

Alum provides for highly efficient removal of phosphorus, sediment, and bacteria primarily through the process of coagulation and sedimentation. The mechanism by which alum removes pollutants from water is described by Harper et al. (1999):

> The addition of alum to water results in the production of chemical precipitates which remove pollutants by two primary mechanisms. Removal of suspended solids, algae, phosphorus, heavy metals and bacteria occurs primarily by enmeshment and adsorption onto aluminum hydroxide precipitate according to the following net reaction:
>
> $$Al^{+3} + 6H_2O \bullet \bullet Al(OH)_{3(s)} + 3H_3O^{+} \qquad (1)$$
>
> Removal of additional dissolved phosphorus occurs as a result of direct formation of $AlPO_4$ by:
>
> $$Al^{+3} + H_nPO_4^{n-3} \bullet \bullet AlPO_{4(s)} + nH^{+} \qquad (2)$$
>
> The aluminum hydroxide precipitate, $Al(OH)_3$, is a gelatinous floc which attracts and adsorbs colloidal particles onto the growing floc, thus clarifying the water. Phosphorous removal or entrapment can occur by several mechanisms, depending on the solution pH. Inorganic phosphorous is also effectively removed by adsorption to the $Al(OH)_3$ floc. Removal of particulate phosphorous is most effective in the pH range of 6-8 where maximum floc occurs (Cooke and Kennedy, 1981). At higher pH values, OH^- begins to compete with phosphate ions for aluminum ions, and aluminum hydroxide-phosphate complexes begin to form. At lower pH values and higher inorganic phosphorus concentrations, the formation of aluminum phosphate ($AlPO_4$) is favored.

ALUM INJECTION SYSTEMS

A typical alum injection stormwater treatment system consists of a flow meter to measure the discharge rate of stormwater, a variable-speed chemical-metering pump, and an alum storage tank. Alum is injected in proportion to the flow rate in order to maintain a constant dose (Harper 2013). Alum injection can occur where alum is injected directly into receiving waters on-line, or water can be diverted offline and injected with alum.

Harper (2013) noted that the floc-generation rate is a function of the applied alum dose, but is generally less than 0.5% of the treated water volume. Floc disposal generally occurs by one of three methods: direct discharge into the receiving waterbody; collection and storage in a dedicated settling pond; or collection and disposal into a sanitary sewer system.

Harper (2013) stated that:

> A unique aspect of alum injection systems is that the capital cost is largely independent of watershed size since the components required to treat a 100-acre watershed are the same as the components to treat a 1,000-acre watershed, although the annual chemical requirements would differ.

While the above statement would apply to basic alum injection infrastructure, the size and cost of settling ponds to treat water offline would likely increase significantly for larger watershed areas.

POLLUTANT REMOVAL EFFICIENCY

Removal efficiencies derived from hundreds of laboratory tests of various parameters at different alum dose rates are summarized in Table 3. As previously noted, primary pollutants of concern in the Lake Macatawa watershed include phosphorus, sediment, and bacteria. All three of these pollutants are substantially reduced through the dosing of alum.

TABLE 3
TYPICAL LABORATORY POLLUTANT REMOVAL EFFICIENCIES
FOR ALUM-TREATED STORMWATER RUNOFF[1]

	Alum Dose (mg/L)		
Parameter	**5**	**7.5**	**10**
Dissolved Ortho-Phosphorus	96%	98%	98%
Particulate Phosphorus	82%	94%	95%
Total Phosphorus	86%	94%	96%
Turbidity	98%	99%	99%
Total Suspended Solids	95%	97%	98%
Fecal Coliform Bacteria	96%	99%	99%

Water that is highly colored or contains elevated levels of soluble reactive phosphorus, such as agricultural streams, may require a higher dose of alum to achieve the same removal efficiencies as urban runoff (Harper 2013). Thus, in a heavily agricultural watershed such as Lake Macatawa, an alum dose rate of 10 mg/L or greater would likely be required to achieve optimum removal efficiencies. Note that actual removal efficiencies for Macatawa water would need to be verified through laboratory testing.

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[1] Source: Harper (2013).

APOPKA BEAUCLAIR CANAL NUTRIENT REMOVAL FACILITY: A FLORIDA EXAMPLE

A large-scale alum injection facility has been operational since 2009 in Lake County, Florida. The facility is located on the Apopka Beauclair Canal downstream of Lake Apopka. Nutrient-laden water from the canal flows north and is diverted offline, treated and discharged downstream to Lakes Beauclair, Dora, Eustis, and Griffin (Figure 10). The facility has a maximum treatment capacity of 300 cfs and includes an alum pumping and control building, alum storage tanks, and two nine-acre treatment and settling ponds. Accumulated floc is removed with automated hydraulic dredges, dewatered with a centrifuge and stored onsite (Figure 11).

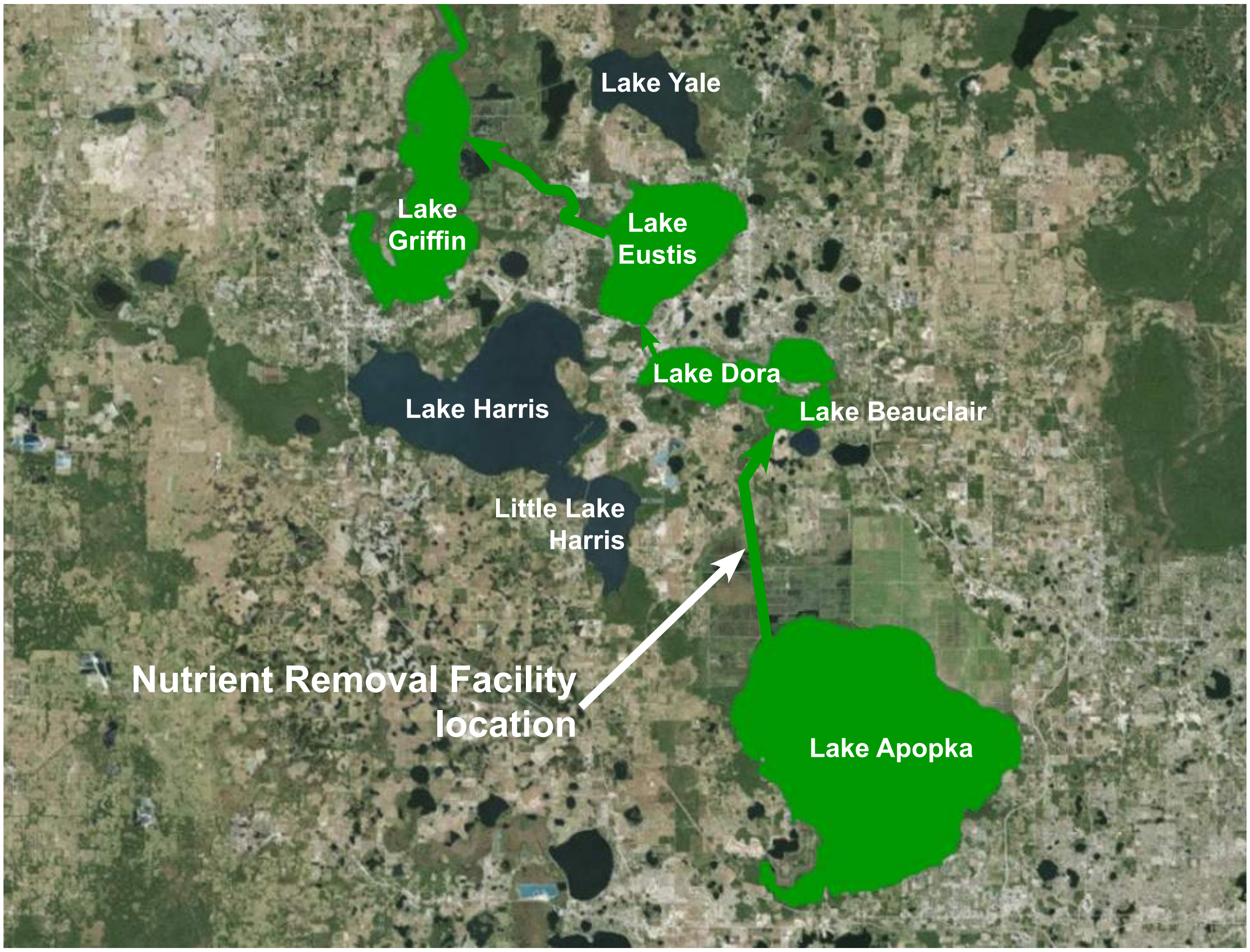

Figure 10. Apopka Beauclair Canal Nutrient Removal Facility location map. Modified from Lake County Water Authority.

The facility was constructed on approximately 50 acres of land provided by Florida's St. Johns River Management District and is operated by the Lake County Water Authority. Partial funding for the project was provided by Florida's Department of Environmental Protection (DEP). The facility cost $7.2 million to construct, and the annual operation and maintenance budget is $1 million. If operated continuously, annual alum use is 1.5 million to 3 million gallons per year (Harper 2013).

Based on daily inflow and outflow data collected by the Lake County Water Authority between March 2009 and April 2012, the average inflow total phosphorus concentration was 81 ppb and the average post-treatment outflow from the facility was 33 ppb, a 59% reduction.

Figure 11. Apopka Beauclair Canal Nutrient Reduction Facility. Modified from Harper (2013). Graphic is for informational purposes only and illustrates some of the infrastructure components that may be included in a large-scale alum injection facility.

Macatawa Watershed Alum Injection System Alternatives

POLLUTION REMOVAL POTENTIAL

To evaluate pollution removal potential in the Lake Macatawa watershed, samples were collected on May 6, 2015 from upstream at Paw Paw Drive (downstream from the five priority watershed sub-basins, site 1; Figure 12), the mouth of the Macatawa River (at North River Avenue, site 2), and the main basin of Lake Macatawa (site 3). The flow rate measured at the USGS gaging station on that date was 28 cfs, close to the median flow of the river (Table 2). Samples were placed in 1-liter jars and dosed with alum at various rates and measurements were made of pH, alkalinity, total phosphorus and total suspended solids.[1] Jar test results are summarized in Tables 4 through 7.

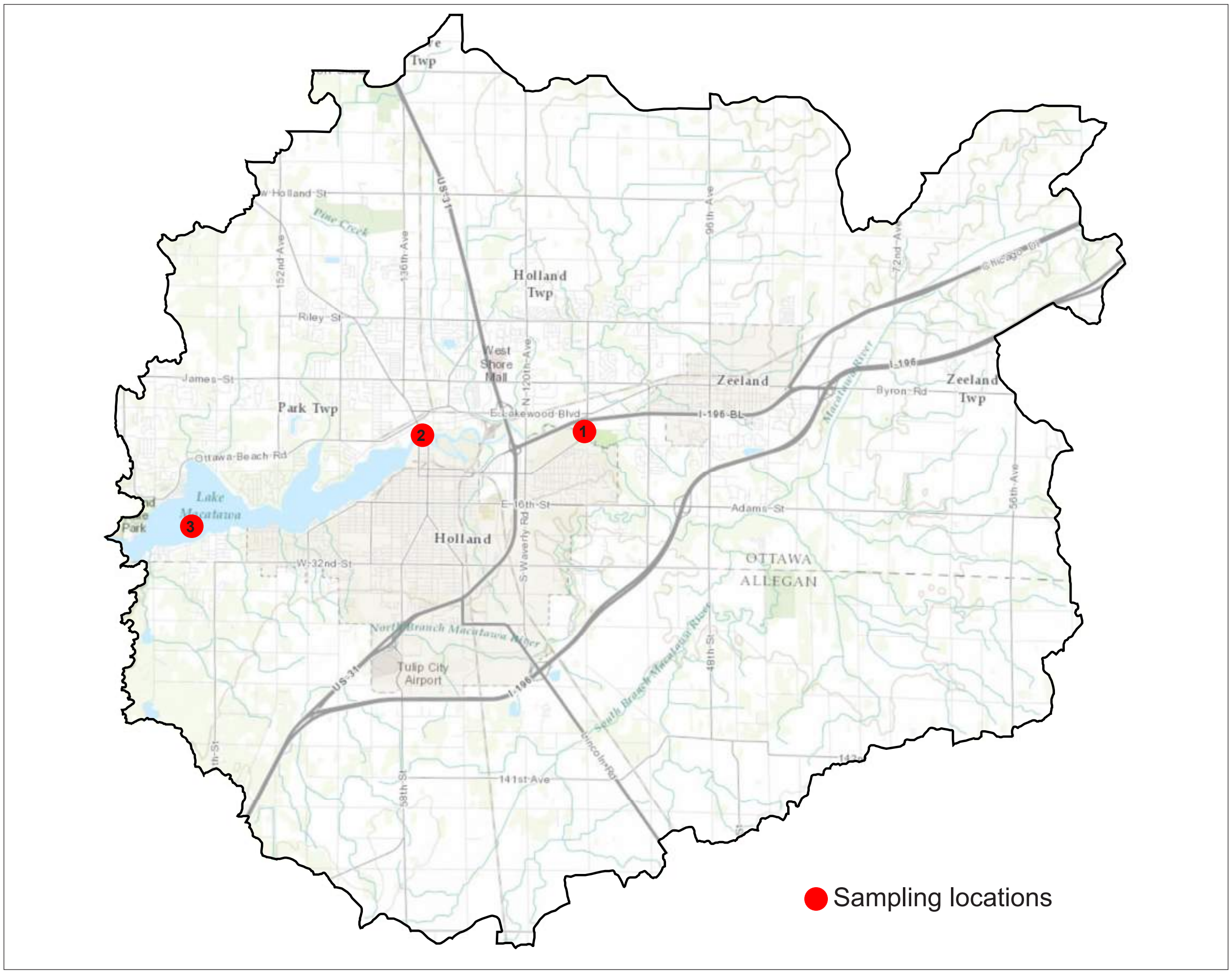

Figure 12. Jar testing sampling location map.

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[1] Jar tests can be used to evaluate alum effectiveness at removing pollutants. In the jar tests for Macatawa, test doses of alum were added to the jar test samples while the sample was stirring. Stirring of the sample continued for 60 seconds. The samples were allowed to settle under quiescent conditions for 24 hours, and the supernatant was siphoned off for laboratory analyses. pH of the treated water was measured before dosing and at the following intervals after dosing: one minute; one hour; and 24 hours. The following parameters were measured before and 24 hours after dosing: total alkalinity, total phosphorus; and total suspended solids. pH was measured using Standard Methods procedure 4500-H. Total alkalinity was titrated using Standard Methods procedure 2320 B. Total phosphorus was analyzed using Standard Methods procedure 4500-P E. Total suspended solids was analyzed using Standard Methods procedure 2540 D.

TABLE 4
MACATAWA JAR TESTING RESULTS
pH

Sampling Site No	Dose (mg/L)[1]	As Received	60 Seconds	1 Hour	24 Hours
1	5	8.33	7.57	7.60	8.04
1	7.5	8.33	7.45	7.50	8.11
1	10	8.33	7.39	7.44	8.06
2	5	8.03	8.22	8.22	8.43
2	7.5	8.03	7.95	7.99	8.36
2	10	8.03	7.77	7.83	8.26
3	5	8.82	7.51	7.57	8.11
3	7.5	8.82	7.43	7.46	8.06
3	10	8.82	7.36	7.41	8.00

TABLE 5
MACATAWA JAR TESTING RESULTS
ALKALINITY, TOTAL PHOSPHORUS, AND TOTAL SUSPENDED SOLIDS

Sampling Site No	Dose (mg/L)[1]	Treatment Time	Total Alkalinity (mg/L as $CaCO_3$)[2]	Total Phosphorus (µg/L)[3]	Total Suspended Solids (mg/L)[1]
1	0	As received	224	59	7.6
1	5	24 Hours	219	35	4
1	7.5	24 Hours	203	31	<4
1	10	24 Hours	230	21	<4
2	0	As received	118	36	12.4
2	5	24 Hours	143	23	4.4
2	7.5	24 Hours	132	19	5.2
2	10	24 Hours	113	18	4.8
3	0	As received	217	66	25.2
3	5	24 Hours	191	34	<4
3	7.5	24 Hours	206	18	<4
3	10	24 Hours	230	14	<4

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[1] mg/L = milligrams per liter = parts per million.

[2] mg/L $CaCO_3$ = milligrams per liter as calcium carbonate.

[3] µg/L = micrograms per liter = parts per billion.

TABLE 6
MACATAWA JAR TESTING RESULTS
TOTAL PHOSPHORUS REDUCTION

		Concentration			Percent Reduction		
		Dose (mg/L)			Dose (mg/L)		
Sampling Site No	Initial	5	7.5	10	5	7.5	10
1	59	35	31	21	41%	47%	64%
2	36	23	19	18	36%	47%	50%
3	66	34	18	14	48%	73%	79%

TABLE 7
MACATAWA JAR TESTING RESULTS
TOTAL SUSPENDED SOLIDS REDUCTION

		Concentration			Percent Reduction		
		Dose (mg/L)			Dose (mg/L)		
Sampling Site No	Initial	5	7.5	10	5	7.5	10
1	7.6	4	<4	<4	47%	47%+	47%+
2	12.4	4.4	5.2	4.8	65%	58%	61%
3	25.2	<4	<4	<4	84%+	84%+	84%+

pH and alkalinity were not substantially depressed (Tables 4 and 5) indicating that alkalinity in the Macatawa watershed is sufficiently high to buffer the addition of alum. Substantial reductions in total phosphorus and total suspended solids were measured at all three alum dose rates (Table 5). At the 10 mg/L dose rate, total phosphorus concentrations were reduced 50% to 79%, (Table 6), and total suspended solids concentrations were reduced 47% to 84% (Table 7). The greatest concentrations and reductions in total phosphorus and total suspended levels were measured at the in-lake sample site (site 3). Although bacterial loading reductions were not measured, laboratory testing results from Harper (2013) suggest that decreases in bacteria levels from the upper watershed could be anticipated as well (Table 3).

Based on jar test results, flow-proportioned alum dosing downstream of the five priority watershed sub-basins could result in a substantial reduction in phosphorus and suspended solids loading depending on alum dose. However, it should be noted that laboratory jar testing creates conditions ideal for phosphorus and sediment solids removal and may not be comparable to field results. Additional jar testing with appropriate controls and replication would be required to better ascertain potential removal efficiencies.

Another consideration would be the timeframe each year when an alum injection system would need to be operational. Extrapolating USGS stream discharge data for the Macatawa River to the watershed at large, the hydraulic residence time of Lake Macatawa is about 50 days. That is, on average, the entire volume of water in Lake Macatawa is replaced by incoming waters every 50 days. However, during the high-flow period in March and April (Figure 7), the hydraulic residence time ranges from 21 to 32 days. Thus, in a typical year, if an alum injection system became operational in early April, water quality improvements in the lake would theoretically be evident by May. Pilgrim and Brezonik (2005a) noted that late-fall or early-spring treatment of runoff is not critical for lakes with short water residence time since phosphorus levels decline rapidly with treatment. In the Lake Macatawa watershed, an alum injection system may only need to be operational from April through September each year in order to realize water quality improvements during the summer months. Summer operation of an alum injection system would not only be cost-effective, but would address potential problems associated with reduced alum efficacy during cold weather conditions (Cooke et al. 2005).

SYSTEM ALTERNATIVES

During the course of study, various alum injection alternatives were evaluated on a preliminary basis for the Macatawa watershed. Primary considerations in evaluating an alum injection system included facility size and location, construction and operating costs, and permitting.

Alternative 1: Centralized Offline Treatment

In order to maximize pollution loading reduction potential in the Macatawa watershed, an alum injection system would ideally be located downstream of the five high priority watershed sub-basins. To estimate treatment flow volumes in this location, the calculated 90th percentile flow was extrapolated to the priority watershed sub-basins proportionally based on the area of each basin. Based on this analysis, an alum injection system would need to have a design capacity of 325 cfs. This roughly corresponds to the design capacity of the previously discussed Apopka Beauclair Canal Nutrient Removal Facility that had a design capacity of 300 cfs, and required approximately 50 acres of land. However, in the downstream portion of the Macatawa watershed, topography and limited available upland would constrain construction of a facility of sufficient size to divert and treat offline this volume of water (Figure 13). Further, episodic storm events in the Macatawa watershed (wherein discharge greatly exceeds 325 cfs) transport a substantial portion of the pollution load and, if untreated, these high flows coupled with high phosphorus concentrations could greatly reduce the effectiveness of an alum injection system. Thus, a centralized offline system for Lake Macatawa would need to be designed and sized to accommodate storm events which would require even greater land area.

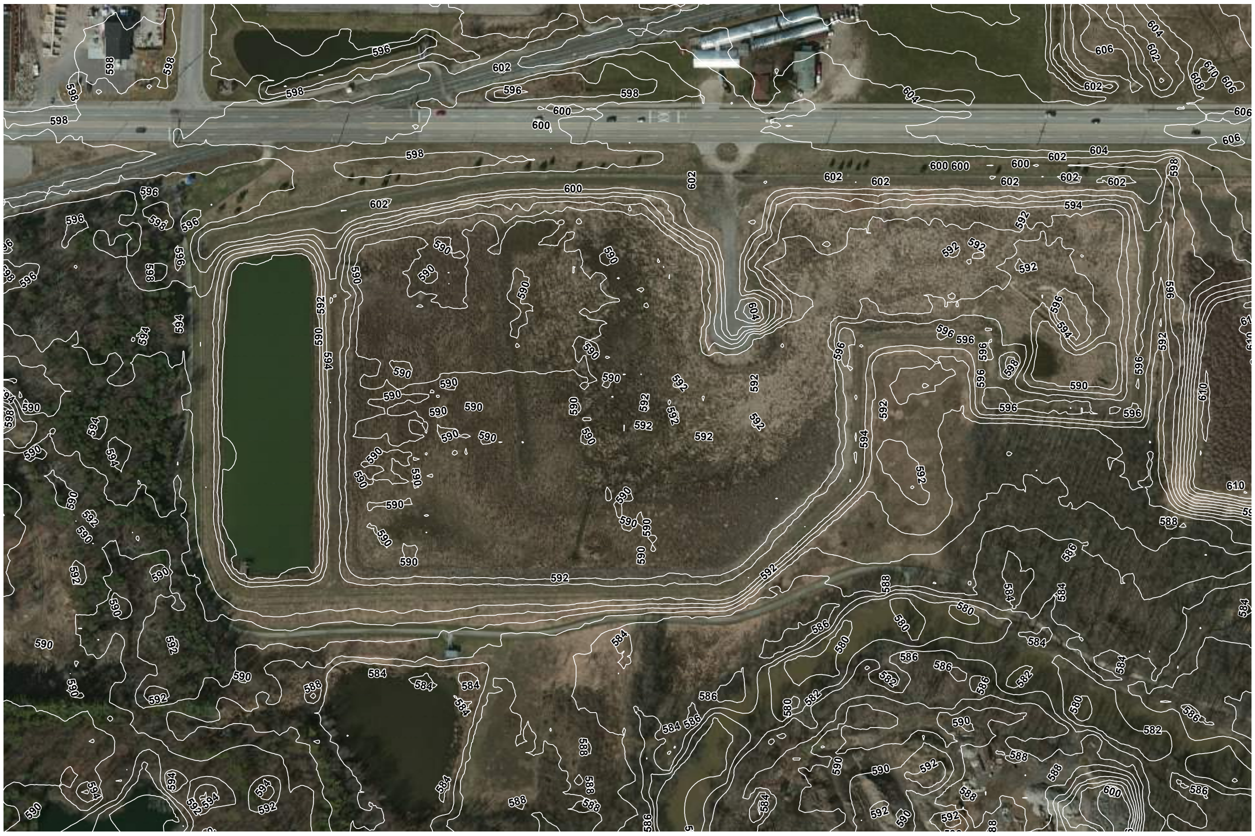

Figure 13. Topographic constraints. Pictured above is the existing dredge material disposal site used to place material dredged from Lake Macatawa's inner harbor. This site was evaluated on a preliminary basis as a potential off-line alum injection facility location. However, there is an approximate 10-foot elevation difference between the river and this site. Diversion of water in this location would require pumping or major excavation.

Alternative 2: Centralized Direct Injection Treatment at River Mouth

In lieu of offline treatment, alum could be injected directly at the river mouth. With this approach, alum storage, pumping and injection facilities would be constructed immediately downstream of the North River Avenue bridge (Figure 14). Direct injection of alum at the river mouth would allow treatment of episodic storm events and greatly enhance the pollution loading reduction potential of an alum injection system. Alum injection at the river mouth would allow treatment of all six upstream watershed sub-basins. With this approach, floc settling would occur in the inner harbor of Lake Macatawa, and periodic suction dredging would be required to remove accumulated floc. Dredged floc would be pumped to an upland location for final disposal. The existing dredge material disposal site located near the intersection of Lakewood Boulevard and Waverly Avenue (Figure 14) would be potentially suitable for this purpose. This site has been used for the past several years to place lake sediment from maintenance dredging of Lake Macatawa's inner harbor. There are several environmental factors that would need to be considered with this approach.

Figure 14. Centralized direct injection system location.

Alternative 3: Decentralized Offline Facilities

A decentralized approach would involve the construction of multiple alum injection facilities in the Macatawa watershed which may alleviate the land constraint of Alternative 1, centralized offline treatment. As previously noted with alum injection facilities, the same basic infrastructure is needed to treat a small watershed as a large watershed. Thus, the capital cost of an alum injection facility is largely independent of watershed size. Given this consideration, it would be far less costly to construct a centralized injection facility as opposed to several decentralized facilities in the Lake Macatawa watershed.

To achieve the pollution removal potential of a centralized downstream facility, decentralized facilities would need to be located at or near the lower stream stretches of each of the five priority sub-basins. In recent years, considerable urbanization of uplands has occurred in these areas, and much of the land along the riverine corridors is regulated wetland. Siting multiple facilities in these areas would be difficult. Further, diverting water offline to an alum injection facility could create a significant flood potential in areas upstream of the diversion locations. While this approach would address potential environmental problems associated with the direct injection of alum into receiving waters, it does not appear technically feasible in the Lake Macatawa watershed.

Alternative 4: Decentralized Direct Injection

While potential flooding and wetland issues could be addressed by direct injection of alum into multiple upstream locations, decentralized direct injection could potentially impact the entire downstream stretch of the Macatawa River, and would substantially complicate floc removal.

Alternative 5: Lake Alum Treatment

This alternative would involve direct injection of alum into Lake Macatawa. As previously noted, alum treatments are generally conducted to mitigate internal phosphorus release from lake sediments and, currently, internal phosphorus release is not a significant source of phosphorus loading in Lake Macatawa. Further, Lake Macatawa has a relatively short water residence time. An alum treatment of the lake would have very short-term benefits in that the alum-treated lake waters would be quickly replaced by high-nutrient river water. Thus, multiple lake alum treatments would be required to sustain improved water quality conditions in Lake Macatawa. Multiple alum treatments would result in a considerable accumulation of floc throughout the lake, and the removal of floc would require periodic dredging of the entire lake.

Recommended Alternative

Of the alternatives evaluated, direct injection of alum at the river mouth (Alternative 2) may be feasible and would maximize the pollution loading reduction potential of an alum injection system. However, while this approach may be technically feasible, it could face considerable, and perhaps insurmountable, regulatory challenges. Primary concerns would be the potential environmental impacts associated with the continuous application of alum and the temporary accumulation of floc in the lake. These issues would need to be further addressed in the preliminary design and permitting process.

ENVIRONMENTAL CONSIDERATIONS

There have been extensive studies of the biotic impacts of conventional i.e., in-lake alum treatments (Cooke et al. 2005, Doke, et al. 1995, Gibbons et al. 1984, Narf, R.P. 1990, Gensemer and Playle 1999 Smeltzer 1999, Steinman and Ogdahl 2011) and while a few short-term adverse impacts have been observed following alum treatments, there have been no reports of large-scale mortalities nor problems with long-term toxicity or biomagnification associated with alum treatment projects (Cooke et al. 2005). Cooke at al. 2005 noted that aluminum is one of the most abundant elements in the earth’s crust, and it is naturally abundant in lake sediments. Thus, conventional alum treatments only slightly increase sediment aluminum content.

The environmental impacts of continuous alum injection on aquatic ecosystems are less thoroughly investigated. Barbiero et al. (1988) concluded that continuous application of alum could reduce or eliminate benthic invertebrates in the area directly downstream of the alum injection point due to low pH, depleted dissolved oxygen in the floc layer, and potential toxicity of intermediate forms of aluminum. Researchers speculated that continuous applications of alum may be more toxic than single dose treatments because of the continuous presence of potentially toxic transitory forms of aluminum associated with the early hydrolysis products of alum. However, in the Barbiero et al. study, no aluminum concentration data were available to substantiate this hypothesis.

Pilgrim and Brezonik (2005b) noted that the potential risk of aquatic toxicity should be negligible if treated water entering the lake has a pH greater than 6.0, and that the potential for toxicity from alum treatment increases when the pH and alkalinity of inflow water is low. (pH and alkalinity in Lake Macatawa and the Macatawa River are relatively high). They concluded that, to avoid smothering benthic organisms, the use of settling basins would be required to capture floc, and that a settling basin with a detention time of six hours should be sufficient to capture most of the floc.

Floc also has the potential to concentrate bacteria and could pose a health risk if ingested (Bulson et al. 1984).

Harvey (1990) noted that in a lake that had been receiving continuous floc injection for a number of years, floc appeared to be mixing with the superficial lake sediments rather than accumulating as a distinct surface layer. Floc accumulation rates in the lake were substantially less than laboratory tests had suggested. Water and Air Research Inc. (1999) concluded that alum injection systems may cause growth abnormalities in benthic invertebrates and/or a decline in benthic community density and diversity. However, in this study, the authors noted that factors unrelated to alum treatment (i.e., lake stratification/sediment anoxia and contaminants) may have confounded results. In a more recent study of Lake Holden in Florida, a lake that had received several in-lake alum treatments and continuous in-line alum injections for multiple years, a healthy benthic invertebrate community was found (Florida Department of Environmental Protection 2012).

Harvey (2007) reported that at alum doses typically used for treatment of urban stormwater, ranging from 5 to 10 mg/L, sludge production is equivalent to approximately 0.16% to 0.28% of treated water volume. “Sludge” included both the alum floc and solids originating in the treated stormwater. Using this estimate, alum injection at the mouth of the Macatawa River would produce approximately 52,000 cubic yards of alum floc and adhered sediment annually (assuming a 6-month period of operation and a 10 mg/L alum dose rate). If this quantity of material was evenly dispersed over a 200-acre portion of the inner harbor downstream of the injection locale, the annual accumulation rate would be approximately 2 inches. Thus, absent periodic removal, significant accumulation of alum sludge could occur over time. Better delineation of potential environmental impacts associated with continued application of alum and devising a method to effectively remove accumulated floc would be recommended prior to application for regulatory approvals for a project.

APPROVALS AND PERMITS

The construction of an alum injection system in the Lake Macatawa watershed would require approvals from multiple regulatory agencies, including the Michigan Department of Environmental Quality and the U.S. Army Corps of Engineers. While alum has been used extensively for years in water and wastewater treatment systems, and alum injection has been used in other states to treat stormwater, this technology is new in Michigan and will likely face considerable regulatory review. There are a number of issues that would need to be addressed during the approval and permit process including the method of alum injection, potential environmental impacts, and methods of floc collection and disposal.

CONSTRUCTION AND OPERATION COSTS

An alum injection system that would inject alum directly into the river (Alternative 2), would include the same basic infrastructure as the Apopka Beauclair Canal Nutrient Reduction Facility. The total cost to construct this facility was 7.2 million dollars (Appendix B). The annual operation and maintenance cost for this facility is approximately one million dollars. Although the facility for the Macatawa watershed would not necessitate the construction of floc-settling ponds, the continual removal of floc from the inner harbor would likely increase operation costs as compared to dredging floc from settling ponds (as was done at the Apopka Beauclair Canal Nutrient Reduction Facility). Given these considerations, an alum injection system for Lake Macatawa may be less costly to construct, but more expensive to operate and maintain. Estimated annual operation and maintenance costs for an alum injection system for Lake Macatawa would be 1.5 to 2 million dollars. Considering the cost of ongoing operation and maintenance, a long-term financing mechanism would need to be developed.

It should be noted that the costs for an alum injection system for Lake Macatawa could change significantly depending on land availability, permitting requirements, annual alum use, and other factors. These estimates should be used for preliminary planning purposes only.

Conclusions and Recommendations

While preliminary study findings indicate a centralized alum injection facility may provide an effective means of reducing pollutant levels in the Macatawa watershed, there are several critical obstacles that impact feasibility. Currently, there does not appear to be a site of adequate size available downstream of the priority sub-basins to effectively treat water offline. An alternative to address this issue would be to inject alum directly at the mouth of the river. However, while this alternative would maximize removal of pollutants, potential toxicity issues would need to be addressed and a method would need to be devised to continuously capture and remove floc from the inner harbor. This approach will likely face considerable regulatory scrutiny. Further, it should be recognized that alum injection is not a panacea. This technology should not be implemented in lieu of other sustainable best management practices in the Macatawa watershed. To be effective, an alum injection system would need to operate indefinitely, at considerable expense. If the facility ceased operation, the lake would quickly revert to a hyper-eutrophic condition, absent other management practices. However, given the degraded condition of Lake Macatawa, and if regulatory hurdles can be addressed, a centralized direct-injection alum system may provide a viable method to reduce pollution loading and improve conditions in Lake Macatawa.

If, based on the results of the preliminary feasible study, there is a desire to further evaluate an alum injection system for the Macatawa watershed, the following steps are recommended:

Spring and Fall of 2017

- Further evaluation of the suitability of the existing dredge material disposal site as a potential floc disposal site.
- Further evaluation of a potential floc injection site location.
- A hydro-acoustic survey of Lake Macatawa’s inner harbor to evaluate existing depths and channel morphometry.
- Hydraulic modeling of different flow scenarios to evaluate floc dispersal within Lake Macatawa’s inner harbor
- Collection of sediment cores to evaluate sediment composition within the floc dispersal area.
- Additional laboratory dose-testing of Macatawa River water with controls and replication to evaluate optimum alum dose rates, overall efficacy of treatment, transitory chemical reactions and potential aluminum toxicity, and floc-settling characteristics.
- An evaluation of existing biota and habitat conditions in the proposed floc settling-and-removal area within the inner harbor of Lake Macatawa.
- Further evaluation of methods to capture and remove alum floc from the inner harbor.
- An evaluation of alternatives to re-purpose floc-laden sediments.
- Refinement of estimates of probable cost to construct an alum injection system.

Winter 2018

- Preparation and submittal of a permit application package to the Michigan Department of Environmental Quality and U.S. Army Corps of Engineers.

Spring/Summer 2019

- Pending the results of the above work items, consideration of a mesocosm study or a field demonstration project in which alum is injected at the river mouth at a flow-proportioned rate and monitoring is conducted to evaluate pollution removal efficacy, transitory chemical reactions, floc dispersal and accumulation rates, and impacts to biota and water quality.

Given the complexity of the project, the laboratory and field testing components of the project would need to be conducted by a qualified research facility with the resources to ensure that proper monitoring design and analytical protocols are employed.

References

Baker, D.B., R.P. Richards, T.T. Loftus, and J.W. Kramer. 2004 . A New Flashiness Index: Characteristics and Applications to Midwestern Rivers and Streams. Journal of the American Water Resources Association. 40(2): 503-522.

Barbiero, R., R.E. Carlson, G.D. Cooke and A.W. Beals. 1988. The Effects of Continuous Application of Aluminum Sulfate on Lotic Benthic Invertebrates. Lake and Reservoir Management 4(2): 63-72.

Bulson, P.C., D.L. Johnstone, H.L. Gibbons, and W.H. Funk. Removal and Inactivation of Bacteria during Alum Treatment of a Lake. Applied and Environmental Microbiology 1984. p. 425–430.

Clement, D.R. and A.D. Steinman. 2016. Phosphorus loading and ecological impacts from agricultural tile drains in a west Michigan watershed, J. Great Lakes Res. http://dx.doi.org/10.1016/j.jglr.2016.10.016.

Cooke, G.D., and R.H. Kennedy. 1981. Precipitation and Inactivation of Phosphorus as a Lake Restoration Technique. EPA-600/3-81-012.

Cooke, G.D., E.B. Welch, S.A. Peterson, and S.A. Nichols. 2005. Restoration and Management of Lakes and Reservoirs, 3rd Edition.

Doke, J.L., W.H. Funk, S.T.J. Juul, and B.C. Moore. 1995. Habitat availability and benthic invertebrate population changes following alum treatment and hypolimnetic oxygenation in Newman Lake, Washington. Journal of Freshwater Ecology. 10(2): 87–102.

Faasen, C.V., J. Soukhome, and G. Peaslee. 2008. An Environmental History of the Lake Macatawa Watershed. Holland Litho, Holland, MI.

Fongers, D. 2009. Macatawa Watershed Hydrologic Study. Hydrologic Studies Unit. Land and Water Management Division. Michigan Department of Environmental Quality.

Gensemer R.W. and R.C. Playle. 1999. The Bioavailability and Toxicity of Aluminum in Aquatic Environments, Critical Reviews in Environmental Science and Technology, 29:4, 315-450, DOI: 10.1080/10643389991259245

Gibbons, M.V., F.D. Woodwick, W.H. Funk, and H.L. Gibbons.1984. Effects of multiphase restoration, particularly aluminum sulfate application, on the zooplankton community of a eutrophic lake in eastern Washington. Journal of Freshwater Ecology. 2(4): 393–404

Harper, H.H. 2013. Control of Watershed Loadings Using Chemical Treatment. Lakeline, Fall 2013. pp. 19-22.

Harper, H.H., J.L. Herr, and E.H. Livingston. 1999, Alum Treatment of Stormwater: The First Ten Years. New Applications in Modeling Urban Water Systems – Monograph 7.

Hassett, M., M. Oudsema, and A. Steinman. 2016. Project Clarity: 2015 Annual Monitoring Report. Annis Water Resources Institute Grand Valley State University, Muskegon, MI.

Holden, S. 2014. Monthly Water Quality Assessment of Lake Macatawa and its Tributaries, April – September 2012. MDEQ Report No. MI/DEQ/WRD-14/005.

Hope College, Outdoor Discovery Center Macatawa Greenway, and Macatawa Area Coordinating Council. 2011. Lake Macatawa Water Quality Research Project: Phase 1 Report.

Macatawa Watershed Project. 2012. Macatawa Watershed Management Plan. Macatawa Area Coordinating Council, Holland, Michigan.

Narf, R.P. 1990. Interactions of Chironomidae and Chaoboridae (Diptera) with aluminum sulfate treated lake sediments. Journal of Lake and Reservoir Management. 6(1): 33–42.

Pilgrim, K.M. and P.L. Brezonik. 2005a Treatment of lake inflows with alum for phosphorus removal. Lake and Reservoir Management. Volume 21(1): 1-9.

Pilgrim, K.M. and P.L. Brezonik. 2005b Evaluation of the potential adverse effects of lake inflow treatment with alum, Lake and Reservoir Management. Volume 21(1): 77-87.

Progressive AE. 2014. Byram Lake 2013 Water Quality Monitoring Report. Grand Rapids, Michigan.

Smeltzer, E. R.A. Kirn, and S. Fiske. 1999. Long-term water quality and biological effects of alum treatment of Lake Morey, Vermont. Journal of Lake and Reservoir Management. 15(3): 173–184.

Steinman, A., and M. Ogdahl. 2011. Internal Phosphorus Loading in Spring Lake 5 Years Following Alum Treatment. Annis Water Resources Institute, Muskegon, Michigan.

Steinman, A. D. and R. Rediske. 2005. Internal Phosphorus Loading Estimate for Lake Macatawa. Annis Water Resources Institute, Muskegon, Michigan.

Walterhouse, M. 1998. Phosphorous Loading Assessment for Lake Macatawa, 1995 through 1997. MDEQ Report No. MI/DEQ/SWQ-98/015.

Walterhouse, M. 1999. Total Maximum Daily Load (TMDL) for Phosphorus in Lake Macatawa.

Water and Air Research Inc. 1999. Investigation of the Effect of Alum Treatment on Benthic Invertebrate Communities of Florida Lakes. Special Publication SJ2000-SP6.

Williams, T. 2012. Project Clarity: Restoring the Macatawa Watershed. Outdoor Discovery Center Macatawa Greenway, 20 pp.

Appendix A

Current Research and Trends in Alum Treatment of Stormwater Runoff

CURRENT RESEARCH AND TRENDS IN ALUM TREATMENT OF STORMWATER RUNOFF

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ABSTRACT

Alum treatment of runoff has been used as a stormwater retrofit option for the past 20 years. This technology has evolved from the initial demonstration research projects to a viable retrofit option for urban areas. A considerable amount of data has now been collected on the water quality and ecological impacts of alum treatment systems. Alum treatment of stormwater consistently provides removal efficiencies of 85-95% for total phosphorus, >95% for total suspended solids (TSS), 35-70% for total nitrogen, 60-90% for metals, and 90->99% for total and fecal coliform bacteria.

Although only positive chemical and ecological impacts have been reported in waterbodies receiving alum floc, current state policies require collection and disposal of the generated floc, and this issue has received considerable attention in recent years. A variety of floc collection and disposal techniques have been evaluated, including settling ponds, in-lake floc traps, underground vaults, and CDS units. Current floc disposal techniques include disposal to sanitary sewer systems and drying ponds. Chemical characterization of floc suggests that the material can be used as fill or applied to soil surfaces to reduce release of phosphorus, metals, and organics under flooded conditions.

System reliability has been substantially enhanced in recent years, but commitment to long-term maintenance is a concern with many systems. However, in spite of the additional costs associated with floc disposal and maintenance, alum treatment continues to provide pollutant removal at a substantially lower unit cost ($/kg removed) than traditional treatment systems such as ponds.

INTRODUCTION

Aluminum is the most abundant metallic element in the lithosphere and the third most abundant element in the earth, comprising approximately 8% of the earth's crust (Hem, 1986). The soil represents the largest pool of aluminum at the earth's surface. The chemistry of aluminum in natural waters is quite complex. Aluminum has a high ionic charge and a small crystalline radius which combine to yield a level of reactivity which is unmatched by any other soluble metal.

Since at least Roman times, salts of aluminum have been added to drinking water and surface water to reduce turbidity and improve appearance. Aluminum compounds have been used extensively as flocculating agents in the treatment of wastewater for over 100 years. The most commonly used aluminum coagulant is aluminum sulfate,

$Al_2(SO_4)_3 \bullet nH_2O$, which is commonly referred to as alum. Liquid alum is manufactured by dissolving aluminum bauxite ore in sulfuric acid. Commercial-grade alum is a clear, viscous, light green to yellow solution which is 48.5% aluminum sulfate by weight and has a specific gravity of 1.34.

The addition of alum to water results in the production of chemical precipitates which remove pollutants by two primary mechanisms. Removal of suspended solids, algae, phosphorus, heavy metals and bacteria occurs primarily by enmeshment and adsorption onto aluminum hydroxide precipitate according to the following net reaction:

$$Al^{+3} + 6H_2O \rightarrow Al(OH)_{3(s)} + 3H_3O^+$$

This reaction occurs rapidly and is generally complete within 30-45 seconds. The aluminum hydroxide precipitate, $Al(OH)_3$, is a gelatinous floc which attracts and adsorbs colloidal particles onto the growing floc, thus clarifying the water.

Removal of additional dissolved phosphorus occurs as a result of direct formation of $AlPO_4$ by:

$$Al^{+3} + HnPO_4^{n-3} \rightarrow AlPO_{4(s)} + nH^+$$

The alum precipitate formed during coagulation of stormwater can be allowed to settle in receiving waterbodies or collected in small settling basins. Alum precipitates are exceptionally stable in sediments and do not re-dissolve due to changes in redox potential or pH under conditions normally found in surface waterbodies. Over time, the freshly precipitated floc ages into more stable complexes, eventually forming gibbsite. The solubility of dissolved aluminum in the treated water is regulated primarily by the ambient pH level. Minimum solubility for dissolved aluminum occurs in the pH range of 5.5-7.5. As long as the pH of the treated water is maintained within the range of 5.5-7.5, dissolved aluminum concentrations will be minimal. In many instances, the concentration of dissolved aluminum in the treated water will be less than the concentration in the raw untreated water due to adjustment of pH into the range of minimum solubility.

There are numerous advantages associated with the use of alum for coagulation of stormwater runoff. First, alum coagulation provides rapid, highly efficient removal of solids, phosphorus, and bacteria. Liquid alum is relatively inexpensive, resulting in low unit costs per mass of pollutant removed. Unlike iron compounds, alum does not deteriorate under long-term storage. Due to the quality of the raw materials used for manufacture of alum, liquid alum contains substantially less heavy metal contamination than other metal coagulants. Alum floc is chemically inert and is immune to dissolution from normal fluctuations in pH and redox potential in surface waterbodies. In contrast, iron floc is only inert under oxidized conditions and at relatively elevated pH levels.

In 1985, a lake restoration project was initiated at Lake Ella, a shallow 13.3 acre hypereutrophic lake in Tallahassee, Florida, which receives untreated stormwater runoff from approximately 163 acres of highly impervious urban watershed areas through 13 separate stormsewers. Initially, conventional stormwater treatment technologies, such as retention basins, exfiltration trenches and filter systems, were considered for reducing available stormwater loadings to Lake Ella in an effort to improve water quality within the lake. Since there was little available land surrounding Lake Ella that could be used for construction of traditional stormwater management facilities, and the cost of purchasing homes and businesses to acquire land for construction of these facilities was cost-prohibitive, alternate stormwater treatment methods were considered.

Chemical treatment of stormwater runoff was evaluated using various chemical coagulants, including aluminum sulfate, ferric salts and polymers. Aluminum sulfate (alum) consistently provided the highest removal efficiencies and produced the most stable floc. In view of successful jar test results on runoff samples collected from the Lake Ella watershed, the design of a prototype alum injection stormwater system was completed. Construction of the Lake Ella alum stormwater treatment system was completed in January 1987, resulting in a significant improvement in water quality.

Since the Lake Ella system, more than 50 additional alum stormwater treatment systems have either been constructed or are currently being evaluated, with most located within the State of Florida. Alum treatment of stormwater runoff has now been used as a viable stormwater treatment alternative in urban areas for over 20 years. Over that time, a large amount of information has been collected related to optimum system configuration, water chemistry, sediment accumulation and stability, construction and operation costs, comparisons with other stormwater management techniques, and floc collection and disposal (Livingston, Harper, and Herr, 1994; Harper and Herr, 1992; Harper, Herr, and Livingston, 1997, 1998a, and 1998b; Harper, 1990, 1991, 1992, 1999, and 2005).

SYSTEM CONFIGURATION

Once alum has been identified as an option for stormwater treatment, extensive laboratory testing must be performed to verify the feasibility of alum treatment and to establish process design parameters. The feasibility of alum treatment for a particular stormwater stream is typically evaluated in a series of laboratory jar tests conducted on representative runoff samples collected from the project watershed area. This laboratory testing is an essential part of the evaluation process necessary to determine design, maintenance, and operational parameters such as the optimum coagulant dose required to achieve the desired water quality goals, chemical pumping rates and pump sizes, the need for additional chemicals to buffer receiving water pH, post-treatment water quality characteristics, floc formation and settling characteristics, floc accumulation, annual chemical costs and storage requirements, ecological effects, and maintenance procedures. In addition to determining the optimum coagulant dose, jar tests can also be used to evaluate floc strength and stability, required mixing intensity and duration, and determine design criteria for floc collection systems.

In a typical alum stormwater treatment system, alum is injected into the stormwater flow on a flow-proportioned basis so that the same dose of alum is added to the stormwater flow regardless of the discharge rate. A variable speed chemical metering pump is typically used as the injection pump. The operation of the chemical injection pump is regulated by a flow meter device attached to the incoming stormwater line to be treated. Mixing of the alum and stormwater occurs as a result of turbulence in the stormsewer line. If sufficient turbulence is not available within the stormsewer line, artificial turbulence can be generated using aeration or physical stormsewer modifications.

Mechanical components for the alum stormwater treatment system, including chemical metering pumps, stormsewer flow meters, electronic controls, and an alum storage tank, are typically housed in a central facility which can be constructed as an above-ground or below-ground structure. Alum feed lines and electrical conduits are run from the central facility to each point of alum addition and flow measurement. Alum injection points can be located as far as 3000 ft or more from the central pumping facility. The capital costs of constructing an alum stormwater treatment system do not increase substantially with increasing size of the drainage basin which is treated. As a result, alum treatment has become increasingly popular in large regional treatment systems.

The largest alum stormwater treatment system is located along the Apopka-Beauclair Canal which extends between Lake Apopka and Lake Beauclair in Central Florida. This canal carries discharges from Lake Apopka, a 30,000-acre shallow hypereutrophic lake, into Lake Beauclair which forms the headwaters of the Harris Chain-of-Lakes. Inflow from the Apopka-Beauclair Canal into Lake Beauclair is thought to be the single largest source of phosphorus loadings to the Harris Chain-of-Lakes. The Apopka-Beauclair Canal Nutrient Reduction Facility (NuRF) is designed to provide alum treatment for the canal discharges prior to reaching Lake Beauclair. A schematic of the NuRF Facility is given on Figure 1. Discharge rates and water level elevations in the Apopka-Beauclair Canal are regulated by the Apopka-Beauclair Canal lock and dam. The NuRF Facility uses the difference in water level elevations between upstream and downstream portions of the canal to force the canal water into two parallel treatment basins. Liquid alum is added upstream of the point of inflow into the treatment basin, and the generated floc settles onto the bottom of the basins. These basins are designed to allow treatment of up to 300 cfs while still providing a minimum detention time of three hours for capture of the floc material. Treated discharges from the ponds enter a small canal which conveys the treated water downstream of the lock and dam structure where it ultimately reaches Lake Beauclair. Flow in excess of 300 cfs, which rarely occurs, will be allowed to bypass the treatment system.

Approximately 1-2 times each year, depending upon treated flow rates, floc removal will be necessary from the two settling ponds. This removal will be achieved using an automated dredging system constructed as part of these ponds. This system will automatically dredge the accumulated floc from the bottom of the pond and pump the dredge slurry to a large centrifuge located in the adjacent floc processing building. The centrifuge will decrease the water content of the sludge to approximately 40%, so that it can be hauled to the adjacent floc drying area. The floc drying area consists of an elevated area constructed on permeable soils where the floc will continue to dry naturally.

It is anticipated that the dry floc will be used either as landfill cover or by the St. Johns River Water Management District as a soil amendment for various Lake Apopka restoration projects. The alum floc still contains considerable uptake capacity for phosphorus and other species and can be used to reduce phosphorus release from flooded farm lands which are converted to water quality treatment areas. The NuRF Facility contains storage capabilities for approximately 124,000 gallons of alum to meet chemical demand under high flow conditions. At the maximum design treatment rate of 300 cfs, the facility will utilize approximately eight tanker loads (4500 gallons) of alum each day.

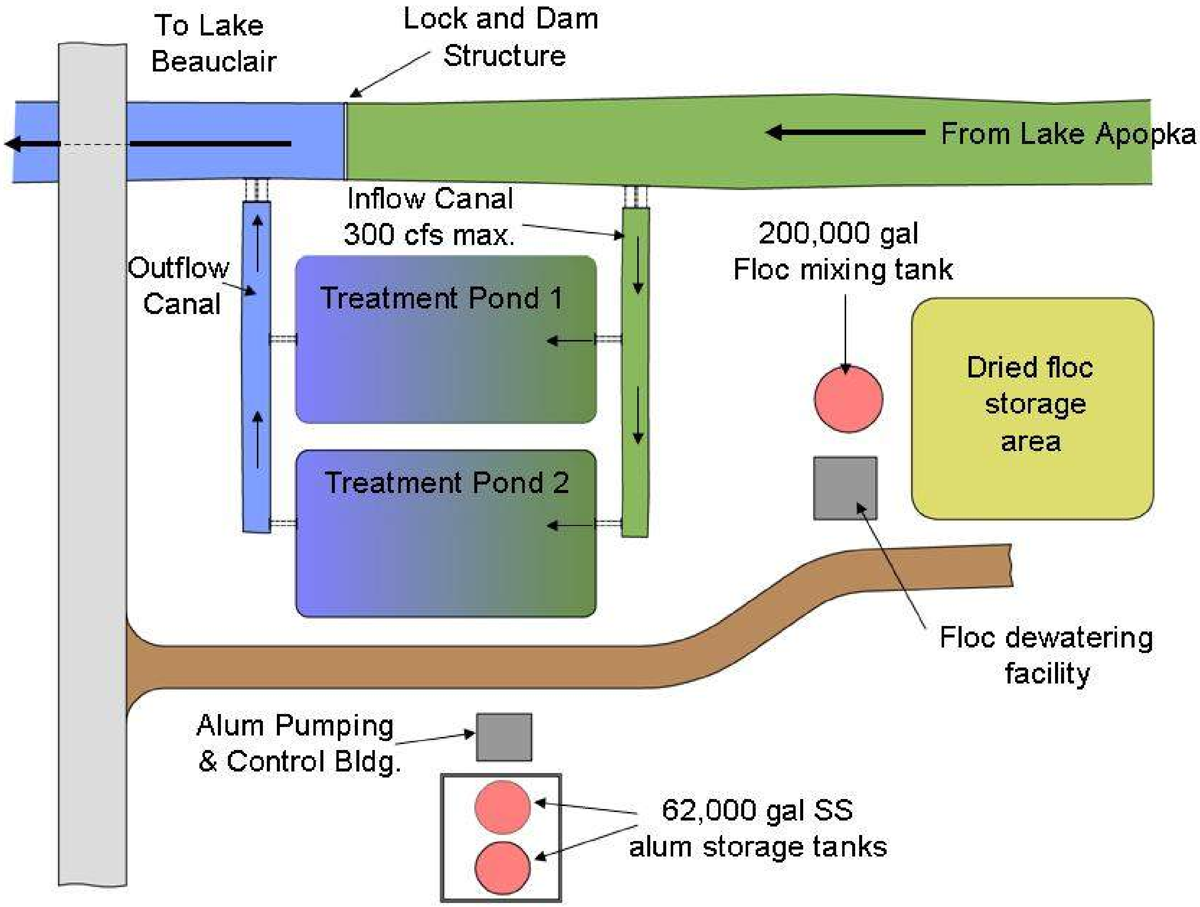

Figure 1. Schematic of Lake County NuRF Facility.

PERFORMANCE EFFICIENCY

Over the past 20 years, literally hundreds of laboratory jar tests have been performed to evaluate the effectiveness of alum for reducing pollutant concentrations in urban runoff. Typical alum doses required for treatment of urban runoff have ranged from 5-10 mg Al/liter. Although pollutant reductions have been observed at alum doses less than 5 mg Al/liter, floc formation and settling patterns are often too slow to be useful for treatment of urban runoff where floc collection is required.

A summary of typical removal efficiencies for alum treated urban runoff is given in Table 1. Mean removal efficiencies are listed for alum treatment of urban runoff at doses of 5, 7.5, and 10 mg Al/liter. Comparative removals are also provided for runoff settled for 24 hours without alum addition. In general, settling of alum floc generated by treatment of urban runoff is approximately 90% complete in 1-3 hours, with additional settling occurring over a period of 12-24 hours. Alum treatment of urban runoff has consistently achieved a 90% reduction in total phosphorus, 50-90% reduction in heavy metals, and >99% reduction in fecal coliform. Removal efficiencies typically increase slightly with increasing alum dose. In general, removal patterns and efficiencies for phosphorus species, turbidity, TSS, heavy metals, and coliform bacteria are predictable and consistent for virtually all types of stormwater runoff. However, alum treatment removal efficiencies for nitrogen can be highly variable. In general, alum treatment has only a minimal effect on concentrations of ammonia and virtually no impact on concentrations of NO_x in stormwater runoff. Removal of dissolved organic nitrogen species can also be highly variable, depending upon molecular size and structure of the organic compounds. The only nitrogen species which can be removed predictably is particulate nitrogen. As a result, removal efficiencies for total nitrogen are highly dependent upon the nitrogen species present, with higher removal efficiencies associated with runoff containing large amounts of particulate and organic nitrogen and lower removal efficiencies for runoff flows which contain primarily inorganic nitrogen species. Selection of the "optimum" dose often involves an economic evaluation of treatment costs vs. desired removal efficiencies.

In general, removal efficiencies achieved with alum stormwater treatment meet or exceed removal efficiencies obtained using dry retention or wet detention stormwater management systems. A comparison of treatment efficiencies for common stormwater management systems is given in Table 2 (Harper and Baker, 2007). Removal efficiencies achieved with alum treatment are similar to removal efficiencies achieved with dry retention and appear to exceed removal efficiencies which can be obtained using wet detention, wet detention with filtration, dry detention, or dry detention with filtration.

Alum stormwater treatment has been shown to provide highly competitive mass removal costs compared with traditional stormwater treatment techniques such as wet detention and wetland treatment. The smaller land area required for alum treatment, combined with high removal efficiencies, results in a lower life-cycle cost per mass of pollutant removed. A comparison of life-cycle costs per mass of pollutant removal for similar large-scale stormwater retrofit projects is given in Table 3. Life-cycle costs are calculated using the initial capital costs and 20 years of operation and maintenance. Based upon this analysis, the cost per mass removal for total phosphorus and total nitrogen by alum treatment is substantially less than mass removal costs for large regional wet detention systems.

TABLE 1

TYPICAL PERCENT REMOVAL EFFICIENCIES FOR ALUM TREATED STORMWATER RUNOFF

PARAMETER	SETTLED WITHOUT ALUM	ALUM DOSE (Dose in mg Al/liter)		
		5	7.5	10
Dissolved Organic Nitrogen	20	51	62	65
Particulate Nitrogen	57	88	94	96
Total Nitrogen	20*	65*	71*	73*
Dissolved Orthophosphorus	17	96	98	98
Particulate Phosphorus	61	82	94	95
Total Phosphorus	45	86	94	96
Turbidity	82	98	99	99
TSS	70	95	97	98
BOD	20	61	63	64
Total Coliform	37	80	94	99
Fecal Coliform	61	96	99	99

* Depending on types of nitrogen species present

TABLE 2

COMPARISON OF TREATMENT EFFICIENCIES FOR COMMON STORMWATER MANAGEMENT SYSTEMS

TYPE OF SYSTEM	ESTIMATED REMOVAL EFFICIENCIES (%)			
	TOTAL N	TOTAL P	TSS	BOD
Dry Retention (0.50-inch runoff)	40-80[1]	40-80	40-80	40-80
Wet Detention[2]	20-30	60-70	75-85	65-70
Wet Detention with Filtration	20-30	60	> 90	80
Dry Detention	0-30	0-40	60-80	0-50
Dry Detention with Filtration	0-30	0-40	60-90	0-50
Alum Treatment	40-70	> 90	> 95	60-75

1. Varies according to project characteristics and location
2. Based on 14-day wet season residence time

TABLE 3

COMPARISON OF LIFE-CYCLE COST PER MASS POLLUTANT REMOVED FOR SIMILAR STORMWATER RETROFIT PROJECTS

PROJECT	LIFE-CYCLE COSTS ($)	COST PER MASS REMOVED ($/kg)		
		TOTAL P	TOTAL N	TSS
Alum Treatment				
Largo Regional STF	2,044,780	5,061	1,293	79
Lake Maggiore STF	4,086,060	3,583	1,268	37
Gore Street Outfall STF	1,825,280	1,736	314	16
East Lake Outfall TF	1,223,600	2,707	334	21
Lake Howard	596,359	74	32	2.21
Wet Detention				
Melburne Blvd.	1,069,000	7,985	2,498	36
Clear Lake Ponds	1,091,600	10,496	4,166	30

FLOC PRODUCTION

After initial formation, alum floc consolidates rapidly for a period of approximately 6-8 days, compressing to approximately 5-10% of the initial floc volume. Additional gradual consolidation appears to occur over a period of approximately 30 days, after which sludge volumes appear to approach maximum consolidation (Harper, 1991).

Estimates of maximum anticipated sludge production, based upon the results of hundreds of laboratory tests involving coagulation of urban stormwater runoff with alum at various doses and a consolidation period of approximately 30 days, are given in Table 4 (Harper, 1991). At alum doses typically used for treatment of urban stormwater runoff, ranging from 5-10 mg Al/liter, sludge production is equivalent to approximately 0.16-0.28% of the treated runoff flow. Sludge production values listed in Table 4 reflect the combined mass generated by alum floc as well as solids originating from the stormwater sample.

Actual accumulation rates of alum floc have been monitored in waterbodies receiving alum treated inputs. In most cases, the observed field accumulation rates are substantially lower than would be expected based on the predicted accumulation rates summarized in Table 4. The reduced observed accumulation rates are thought to be a result of additional floc consolidation over time and incorporation of alum floc into the existing sediments.

TABLE 4

ANTICIPATED PRODUCTION OF ALUM SLUDGE FROM ALUM TREATMENT OF URBAN STORMWATER AT VARIOUS DOSES

ALUM DOSE (mg/l as Al)	SLUDGE PRODUCTION[1]	
	AS PERCENT OF TREATED FLOW	PER AC-FT OF RUNOFF TREATED
5	0.16	69.7 ft^3
7.5	0.20	87.1 ft^3
10	0.28	122 ft^3

[1] Based on a minimum settling time of 30 days

FLOC COLLECTION AND DISPOSAL

Early alum stormwater treatment systems provided for floc settling directly in receiving waterbodies. Extensive laboratory testing was conducted by Harper (1991) to evaluate the long-term stability of phosphorus and heavy metals contained in alum floc generated as a result of alum stormwater treatment. These evaluations were conducted by collecting accumulated alum floc from the bottom of various receiving waterbodies and using an incubation apparatus to evaluate the influence of pH and redox potential on the stability of alum treated sediments. These experiments indicated that phosphorus and heavy metals combined into alum floc are extremely stable under a wide range of pH conditions and redox potentials ranging from highly oxidized to highly reduced. The stability of heavy metals within the sediments under post-treatment conditions was found to be substantially greater than the observed under pre-development conditions. As alum floc ages, the freshly precipitated $Al(OH)_3$ forms into a series of ringed structures which are extremely stable and which tightly bind phosphorus and heavy metals in a crystalline lattice network. These phosphorus and metal associations are inert to changes in pH and redox potential normally observed in a normal lake system. Introduction of alum floc into polluted sediments has been shown to reduce poor water concentrations for phosphorus and all evaluated heavy metals.

Although only beneficial aspects of alum floc accumulation have been observed to date, the Florida Department of Environmental Protection (FDEP) has determined that the floc generated by treatment of stormwater runoff must be collected and can no longer be discharged directly to State waters. This requirement is based primarily upon language contained in Chapter 403 of the Florida Administrative Code (FAC) which prohibits treatment of stormwater in “Waters of the State”. As a result, current alum treatment system designs emphasize collection and disposal of floc rather than allowing floc accumulation within surface water systems.

Several innovative designs have been developed for floc collection and disposal. Where possible, sump areas have been constructed to provide a basin for collection and accumulation of alum floc. The accumulated floc can then be pumped out of the sump area on a periodic basis, using either manual or automatic techniques. Most current treatment systems provide for automatic floc disposal into the sanitary sewer system at a slow controlled rate. Since alum floc is inert and has a consistency similar to that of water, acceptance of alum floc on a periodic basis poses no operational problem for wastewater treatment facilities. Many operators have reported that introduction of the alum floc improves the performance efficiency of their treatment system due to the residual uptake capacity within the alum floc for adsorption of additional phosphorus and heavy metals. Floc collection has also been achieved using fabric mesh which traps the floc.

A dedicated manually operated dredging system has recently been designed for use in alum treatment projects within Pinellas County. This unit consists of a manually operated portable dredge with a rotary cutter head that can be raised or lowered to desired depths within the pond. The dredge is powered by a 40-HP outboard motor. The operator controls both the movement of the dredge and the position of the cutter head within the floc layer. The dredge is capable of removing approximately 2-3 ft of floc material with each pass. The pumping system for the dredge has been specially designed to provide an output of approximately 300-400 gallons per minute (gpm) which is suitable for discharge into either a sanitary force main or gravity sanitary sewer. The dredged floc material typically contains between 1-3% solids.

During 2003, ERD evaluated the feasibility of utilizing a hydrodynamic separator (CDS Unit) to collect alum floc generated as a result of treatment of the Lettuce Creek tributary which discharges into Lake Okeechobee. To enhance the speed of the settling process, a relatively high polymer dose was added in addition to the alum. The polymer caused rapid floc formation with virtually complete settling in approximately 2-3 minutes, corresponding to the detention time available within the CDS unit. However, subsequent field testing indicated that the capture rate for the unit was relatively small, probably due to turbulent conditions within the unit which impacted the ability of the floc to settle out. This study concluded that hydrodynamic separators are not feasible alternatives for collection of alum floc.

A long linear treatment basin and settling area has recently been designed for the Lake Seminole alum treatment project in Pinellas County. A schematic of this treatment system is given in Figure 2. The treatment area consists of a linear trough, approximately 25.5 ft in width and 600 ft in length, with a water depth of approximately 17 ft. Water is pumped into this system at a constant rate of 10 cfs with an added alum dose of 7.5 mg/l. The generated floc settles onto the sloped bottom area of the system and accumulates into a small central sump area. The sump area contains 6-inch diameter perforated pipe which is divided into eight separate zones. Floc removal from the system occurs on a daily basis, with each of the eight zones pumped for approximately 21 minutes each at a flow rate of approximately 300 gpm into the adjacent sanitary lift station. This unit is the first alum system which is totally automated for the chemical treatment, floc collection, and disposal processes, although the operation of the system must still be monitored on a frequent basis.

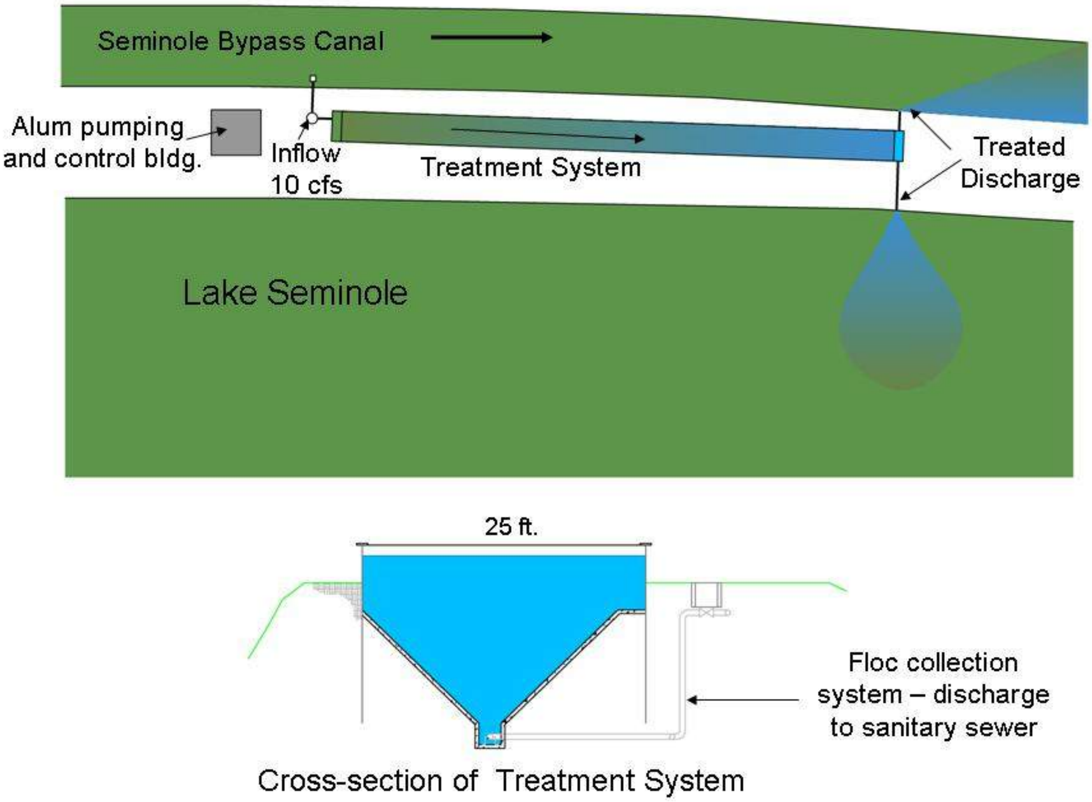

Figure 2. Schematic of Lake Seminole Bypass Canal Treatment System.

Several current alum treatment systems utilize on-site drying beds for floc dewatering. These drying beds are constructed similar to a wastewater sludge drying bed, with an underdrain system constructed beneath a permeable sand layer. The alum floc is deposited onto the drying area, and the leachate is returned to the settling pond. Drying characteristics for alum sludge are similar to a wastewater treatment plant sludge. A drying time of approximately 30 days is sufficient to dewater and dry the sludge, with a corresponding volume reduction of 80-90%.

A summary of the chemical characteristics of the dried alum residual from the NuRF pilot studies is given in Table 5. The alum sludge evaluated during this study was generated by chemical coagulation of thousands of gallons of water collected from the Apopka-Beauclair Canal. The generated floc was captured, placed onto a drying bed, and allowed to dewater. A photograph of the alum sludge during the dewatering process is given in Figure 3. After the sludge has dried, chemical characteristics of the sludge were evaluated and compared with Clean Soil Criteria, outlined in Chapter 62-777 FAC, to assist in identifying disposal options. As seen in Table 5, the measured chemical characteristics from the alum residual are substantially less than the applicable Clean Soil Criteria, based upon direct residential exposure which is the most restrictive soil criteria. Based upon this analysis, the dried alum residual easily meets the criteria for use as fill material for daily landfill cover.

TABLE 5

CHEMICAL CHARACTERISTICS OF DRIED ALUM RESIDUAL FROM THE NURF PILOT STUDIES[1]

PARAMETER	UNITS	VALUE	CLEAN SOIL CRITERIA[2] (Chap. 62-777 FAC)
Aluminum	µg/g	51,096	72,000
Antimony	µg/g	< 6.3	26
Barium	µg/g	< 21	110
Beryllium	µg/g	< 0.53	120
Cadmium	µg/g	0.5	75
Calcium	µg/g	1,564	None
Chromium	µg/g	65.0	210
Copper	µg/g	31.6	110
Iron	µg/g	764	23,000
Lead	µg/g	0.7	400
Magnesium	µg/g	96.8	None
Manganese	µg/g	12.3	1,600
Mercury	µg/g	< 0.091	3.4
Nickel	µg/g	2.3	110
Zinc	µg/g	50.6	23,000
NO_x	µg/g	0.773	120,000
Total N	µg/g	2,054	None
SRP	µg/g	< 1	None
Total P	µg/g	166	None
pH	s.u.	6.17	None

1. Residual sample air-dried and screened using an 0.855 mm sieve
2. Based on residential direct exposure criteria.

Figure 3. Alum Floc Drying Process.

CONCLUSIONS

Alum treatment of stormwater runoff has emerged as a viable and cost-effective alternative for providing stormwater retrofit in urban areas. Recent research in alum stormwater treatment indicate:

1. In general, removal efficiencies obtained with alum stormwater treatment are similar to removals obtained using a dry retention stormwater management facility.
2. Unit costs per mass of pollutant removal using alum treatment are less than mass removal costs for wet detention systems.
3. Several innovative designs have recently been developed for collection of alum floc in sump areas and containment areas, with floc disposal to sanitary sewer or adjacent drying beds.
4. Dried alum floc has no restrictions for use as fill material or cover.
5. Recent designs continue to automate the treatment process to improve overall efficiency and reduce costs.

REFERENCES

Harper, H.H. (1987). "Feasibility of Alum Treatment for Nutrient Reductions in Surface Water Discharges." Presented to the Lake County Board of County Commissioners/Lake County Pollution Control Board.

Harper, H.H. (1990). “Restoration of Lake Dot Using an Improved Alum Stormwater Treatment Process.” In Proceedings of the Stormwater Quality Short Course, Orlando, FL.

Harper, H.H. (1991). "Long-Term Performance Evaluation of the Alum Stormwater Treatment System at Lake Ella, Florida." Final Report submitted to the Florida Department of Environmental Regulation for Project WM339.

Harper, H.H. (1992). “Long-Term Evaluation of the Use of Alum for Treatment of Stormwater Runoff.” In Proceedings of the First Annual Southeastern Lakes Management Conference, Marietta, GA, March 19-21, 1992.

Harper, H.H. (October 1995). "Pollutant Removal Efficiencies for Typical Stormwater Management Systems in Florida." In Proceedings of the 4th Biennial Stormwater Research Conference (Sponsored by the Southwest Florida Water Management District), pp. 6-17, Clearwater, FL.

Harper, H.H. (2003). "Chemical and Ecological Impacts of Alum Coagulation." In Proceedings of the 12th Annual Southeast Lakes Management/NALMS/FLMS Conference, Orlando, FL, June 2-5, 2003.

Harper, H.H. (2005). "Use of Alum in Lake Management: Managing the Associated Risks." Lakeline 25, No. 3, pp. 13-16.

Harper, H.H., and Baker, D.M. (2007). "Evaluation of Current Stormwater Design Criteria within the State of Florida." Final Report submitted to the Florida Department of Environmental Protection for Contract No. SO108.

Harper, H.H., and Herr, J.L. (1992). "Stormwater Treatment Using Alum." Public Works Magazine 123, pp. 47-49 and 89, September 1992.

Harper, H.H.; Herr, J.L.; and Livingston, E.H. (1997). "Alum Treatment of Stormwater – The First Ten Years: What Have We Learned and Where Do We Go From Here?" In Proceedings of the 5th Biennial Stormwater Research Conference, Southwest Florida Water Management District, Tampa, FL, November 5-7, 1997.

Harper, H.H.; Herr, J.L.; and Livingston, E.H. (1998a). "Alum Treatment of Stormwater: The First Ten Years." In New Applications in Modeling Urban Water Systems – Monograph 7 – Proceedings of the Conference on Stormwater and Related Modeling: Management and Impacts, Toronto, Canada, February 19-20, 1998.

Harper, H.H.; Herr, J.L.; and Livingston, E.H. (1998b). "Alum Treatment of Stormwater: An Innovative BMP for Urban Runoff Problems." In Proceedings of the National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments, Chicago, IL, February 11, 1998. EPA/625-R-99/002 (July 1999).

Hem, H.D. (1986). "Geochemistry and Aqueous Chemistry of Aluminum." In Kidney International, p. 29, Edited by J.W. Coburn and A.C. Alfrey. New York: Springer-Verlag.

Herr, J.L., and Harper, H.H. (1997). "The Evaluation and Design of an Alum Stormwater Treatment System to Improve Water Quality in Lake Maggiore, St. Petersburg, Florida." In Proceedings of the ASCE Florida/South Florida Section Annual Meeting, Clearwater, FL, September 18-20, 1997.

Livingston, E.H.; Harper, H.H.; and Herr, J.L. (1994). "The Use of Alum Injection to Treat Stormwater." In Proceedings of the 2nd Annual Conference on Soil and Water Management for Urban Development, Sydney, Australia, September 1994.

Appendix B

Apopka Beauclair Canal Nutrient Reduction Facility Cost Breakdown

ATTACHMENT - PHOSPHORUS REMOVAL/REDUCTION FACILITY RFP

Pay Item #	Description	Quantity	Unit	Unit Price	Bid Total
1	MOBILIZATION	1	LS	$604,030	$604,030
2	CLEARING & GRUBBING	1	LS	$93,073	$93,073
3	EARTHWORK	1	LS	$1,120,336	$1,120,336
4	SEED & MULCH	1	LS	$53,602	$53,602
5	SODDING	1	LS	$249,380	$249,380
6	CRUSHED CONCRETE ACCESS ROAD	1	LS	$132,556	$132,556
7	CONCRETE RUBBLE RIPRAP	1	LS	$227,592	$227,592
8	STAKED SILT FENCE	1	LS	$14,831	$14,831
9	FLOATING TURBIDITY BARRIER	1	LS	$2,000	$2,000
10	CONCRETE ENDWALL S-1	1	LS	$11,000	$11,000
11	CONCRETE ENDWALL S-2	1	LS	$11,000	$11,000
12	CONCRETE ENDWALL S-3	1	LS	$11,000	$11,000
13	CONCRETE ENDWALL S-4	1	LS	$11,000	$11,000
14	CONCRETE ENDWALL S-5	1	LS	$11,000	$11,000
15	CONCRETE ENDWALL S-6	1	LS	$11,000	$11,000
16	CONCRETE ENDWALL S-7	1	LS	$11,000	$11,000
17	CONCRETE ENDWALL S-8	1	LS	$11,000	$11,000
18	CONCRETE ENDWALL S-9	1	LS	$11,000	$11,000
19	CONCRETE ENDWALL S-10	1	LS	$11,000	$11,000
20	CONCRETE ENDWALL S-11	1	LS	$11,000	$11,000
21	CONCRETE ENDWALL S-12	1	LS	$11,000	$11,000
22	TYPE "C" INLETS	1	LS	$3,867	$3,867
23	TYPE "E" INLETS	1	LS	$10,914	$10,914
24	TYPE "E" INLET CONTROL STRUCTURE	1	LS	$5,191	$5,191
25	MITERED END SECTIONS	1	LS	$7,876	$7,876
26	6' DIAMETER ALUMINUM RISER	1	LS	$51,985	$51,985
27	S-1 & S-12 INSERTS	1	LS	$20,604	$20,604
28	12" HDPE	1	LS	$3,157	$3,157
29	18" HDPE	1	LS	$17,954	$17,954
30	24" HDPE	1	LS	$59,488	$59,488
31	36" HDPE	1	LS	$0	$0
32	6' X 8' CONCRETE BOX CULVERTS	1	LS	$155,353	$155,353
33	DOUBLE 6' X 8' CONCRETE BOX CULVERTS	1	LS	$225,464	$225,464
34	6' X 8' SLUICE GATES	1	LS	$85,999	$85,999
35	6' X 8' WEIR GATES	1	LS	$85,999	$85,999
36	4" X 2" DOUBLE-WALL HDPE ALUM FEED LINE	1	LS	$48,488	$48,488
37	2" PP AIR LINE	1	LS	$40,635	$40,635
38	3" PP ALUM TANK FILL LINE	1	LS	$6,519	$6,519
39	6" PVC FLOC DISCHARGE LINE	1	LS	$48,460	$48,460
40	4" & 6" PVC DRAIN LINES & 4" PLUG VALVES	1	LS	$8,523	$8,523
41	8" PVC OVERFLOW DRAIN FROM FLOC TANK	1	LS	$9,410	$9,410
42	10" PVC DRAIN LINE	1	LS	$25,734	$25,734
43	6" DIP FIRE MAIN & DRY HYDRANT	1	LS	$6,871	$6,871
44	WELL/ WATER SERVICE	1	LS	$40,279	$40,279
45	SEPTIC TANK & DRAIN FIELD	1	LS	$7,226	$7,226
46	PUMP BUILDING	1	LS	$60,435	$60,435
47	BUILDING PIPING, VALVES & APPURTENANCES	1	LS	$25,353	$25,353
48	ALUM STORAGE TANKS	1	LS	$211,091	$211,091
49	STORMWATER FLOW & LEVEL METERS	1	LS	$6,524	$6,524
50	ALUM PUMPS & CONTROL PANELS	1	LS	$250,675	$250,675
51	DEWATERING BUILDING	1	LS	$374,627	$374,627
52	FLOC DEWATERING SYSTEM	1	LS	$1,276,206	$1,276,206
53	FLOC STORAGE TANK	1	LS	$105,831	$105,831
54	REMOTE CONTROL DREDGES	1	LS	$569,290	$569,290
55	AIR COMPRESSOR/ VALVE	1	LS	$20,033	$20,033
56	ELECTRICAL & MECHANICAL	1	LS	$766,539	$766,539
	BID TOTAL	**1**	**LS**	**$7,272,000**	**$7,272,000**