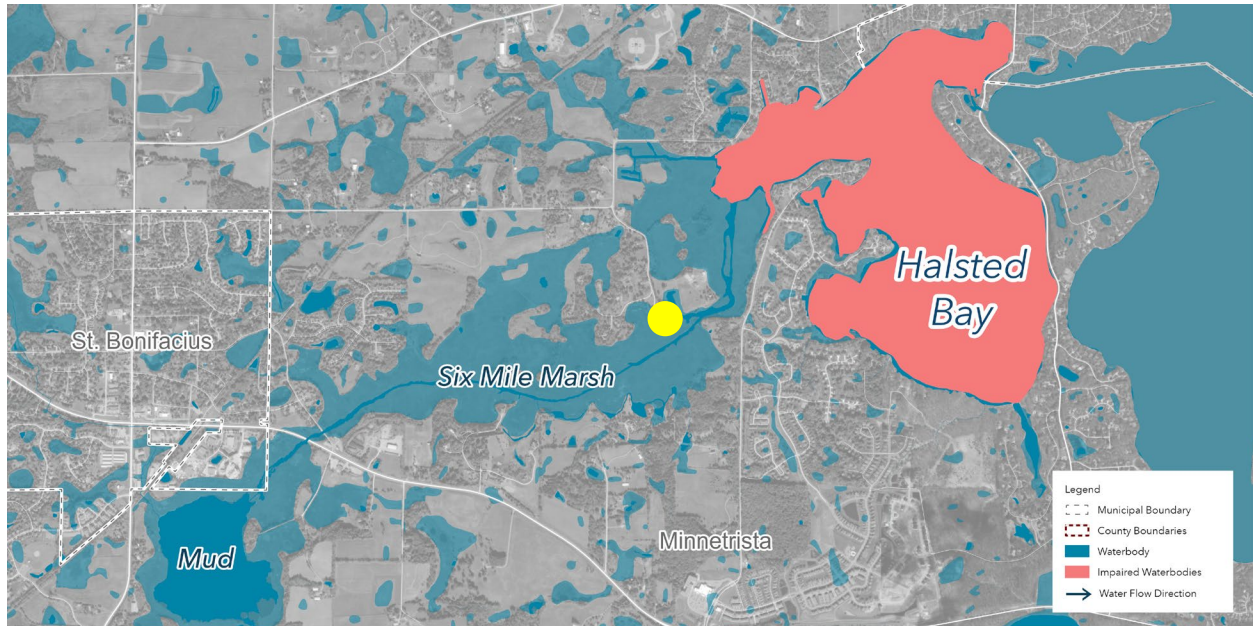




REQUEST FOR PROPOSALS

Engineering and Conceptual Design for

SIX MILE MARSH LOAD MANAGEMENT ASSESSMENT



MCWD will host an optional informational meeting for this RFP on Thursday October 1, 2026, at 12:30 pm. The meeting will be held at the MCWD office at 15320 Minnetonka Blvd, Minnetonka, MN 55345

You are encouraged to RSVP to Kailey Cermak, MCWD Planner-Project Manager (kcermak@minnehahacreek.org). Any updates relating to the project will be published on the RFP webpage: <https://minnehahacreek.org/requests-for-proposals/>

Proposals due: Tuesday, October 27, 2026



PART 1: BACKGROUND AND PROJECT OVERVIEW

Purpose

The Minnehaha Creek Watershed District (MCWD) is requesting proposals from qualified firms to evaluate the feasibility and potential value of an off-line water quality facility to address phosphorus loading from Six Mile Marsh before it enters downstream impaired Halsted Bay. To make that determination with confidence, MCWD needs to understand (1) whether the treatment approach recommended in prior feasibility work remains the best available strategy given what has changed since 2013, (2) what the overall treatment opportunity is and the associated practical limits of intercepting flow from the Six Mile Marsh, and (3) whether a facility on the District's Farmhill Circle property can technically and operationally support a meaningful portion of that treatment opportunity, and at what cost and under what conditions a project could realistically move forward. This study is intended to answer those technical questions, and its findings will serve as one of several factors informing MCWD's decision to carry the project effort forward.

Background

Halsted Bay in Minnetrista, Minnesota is impaired for nutrients and is assigned the largest required phosphorus load reduction of any waterbody in the MCWD. The Minnesota Pollution Control Agency (MPCA) has established a Total Maximum Daily Load (TMDL) for Halsted Bay requiring a phosphorus load reduction of approximately 2,000 lbs/year to meet state water quality standards.

Phosphorus loading to Halsted Bay comes from two primary sources: watershed loading conveyed through the surrounding drainage area, and internal loading released from sediments. Approximately 50% of the nutrient load to Halsted Bay is conveyed through Six Mile Marsh, a large wetland complex that drains into Halsted Bay via Six Mile Creek. A significant portion of the external phosphorus load is being exported from the wetland system itself. This loading occurs primarily in dissolved form, which cannot be effectively removed through settling. Addressing both watershed loading from Six Mile Marsh and internal loading from sediments will be necessary to achieve TMDL reduction goals.

Prior feasibility work identified an off-line chemical treatment facility as the most promising strategy for reducing watershed phosphorus loading from Six Mile Marsh. Under this concept, water would be pumped from Six Mile Creek, treated using aluminum sulfate (alum) or an alternative chemistry, and discharged back to Six Mile Creek before it enters Halsted Bay. In-lake alum treatment of Halsted Bay has also been identified as a potentially complementary strategy to address internal loading and will be evaluated by MCWD staff at a later time.

Prior feasibility work of this area includes:

- A **2013 comprehensive feasibility study (Wenck)** that calculated Halsted Bay's nutrient budget and evaluated a range of internal and watershed loading management options, including identifying an off-line alum treatment facility as the recommended approach for watershed load reduction (Appendix A).

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- A **2013 site alternatives analysis (WSB)** that assessed four potential facility locations and recommended siting the facility near the downstream end of Six Mile Marsh. The study estimated the capital cost of an off-line alum facility to be approximately \$7.7 million with the total project cost (with a 20-year present value) to be \$13.9 million (Appendix B).
- A **2017 phosphorus loading analysis (Wenck)** that characterized Six Mile Marsh as a phosphorus transformer, or a sink for particulate phosphorus inputs, but an independent source of dissolved ortho-phosphorus released from wetland sediments (Appendix C).

Since the completion of this prior work, MCWD has acquired a land parcel that corresponds with the site analysis completed in 2013, while MCWD's project implementation efforts in the Subwatershed have been focused further upstream.

Site Description

In 2017, MCWD acquired approximately 5.5 acres at 3940 Farmhill Circle in Minnetrista, Minnesota. Three Rivers Park District purchased and maintains ownership of the adjacent site to support a future trail. The MCWD property is located adjacent to Six Mile Creek toward the downstream end of Six Mile Marsh, near its discharge point toward Halsted Bay, and is consistent with the preferred siting location identified in the 2013 WSB alternatives analysis. Pre-acquisition due diligence included a Phase I Environmental Site Assessment, a massing study confirming that a treatment facility configuration could be accommodated on the property (Appendix D), a community open house, and informational meetings with Minnetrista City Council and staff.



Figure 1. 3940 Farmhill Circle

Key Considerations

- **Lot size:** The usable upland is limited (approximately 1.25 acres)
- **Residuals management:** This site and surrounding neighborhood are currently not connected to sanitary. Byproduct management should be carefully evaluated.
- **Community context:** Screening, noise attenuation, and aesthetic design measures will likely be required given proximity to residential properties. Community feedback raising these concerns was documented during a 2017 open house.

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Project Description

This feasibility study has three overarching objectives:

1. **Confirm or update the preferred watershed load management strategy for Six Mile Marsh** Assess whether the 2013 recommendation—that an off-line treatment facility is the most effective and implementable approach for reducing phosphorus loading from Six Mile Marsh—remains true given advances in treatment technology, changes in the regulatory environment, and new understanding of Six Mile Marsh phosphorus dynamics.
2. **Evaluate the technical feasibility of an off-line treatment facility at 3940 Farmhill Circle** Evaluate whether an off-line treatment facility at MCWD's property along Six Mile Marsh is technically and operationally feasible and capable of providing meaningful phosphorus reduction benefits, and assess facility type and configuration to optimize phosphorus removal performance, cost, regulatory risk, and operational practicality. This evaluation should first look to understand the maximum volume of water that could be pulled for treatment and the associated facility scale to maximize water quality benefit, independent of the physical constraints of the Farmhill Circle property, and then evaluate the merits of using the Farmhill Circle property as the location for the off-line facility.
3. **Refine project's estimated costs and phosphorus removal potential**
Develop updated and refined estimates of phosphorus load reductions and capital and lifecycle costs for viable off-line treatment facility configurations at the Farmhill Circle property to support future conversations and decision making.

The scope of work comprises three key phases of work to achieve objectives, which includes:

Kickoff & Discovery

Establish the project foundation through coordination with MCWD staff and a review of prior technical work, available data, and current conditions. This phase is intended to validate the basis for the assessment, identify any changes that may influence the analysis, and confirm the management strategy that should advance into detailed evaluation.

Feasibility Analysis

Develop and execute a comprehensive feasibility evaluation to determine whether an off-line phosphorus treatment facility represents a viable long-term strategy for reducing phosphorus loading to Halsted. Refine key assumptions related to phosphorus removal, project costs, implementation considerations, and project risks to support an informed recommendation on project advancement.

Final Report

Synthesize the findings from the feasibility evaluation into a clear, well-supported decision document that communicates project viability, compares facility alternatives, illustrates leading alternatives through conceptual layouts, and identifies a recommended path forward.

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Consultant Team Characteristics

MCWD is seeking an interdisciplinary consulting team with the technical depth and professional experience to guide our team through this process. Given the breadth of disciplines this project requires, teams should bring genuine expertise across all relevant areas and function as a cohesive unit. The nature of this project requires a team that can critically evaluate prior work, recognize where conditions or assumptions have changed, and offer an informed professional opinion on the most viable path forward. Familiarity with Minnesota water quality practices, the regulatory landscape, and the operational realities of phosphorus treatment facilities in similar settings is essential.

The selected team will be expected to work collaboratively with MCWD staff and integrate with the project team at key checkpoints throughout the scope. The consultant should expect an engaged client, not a hands-off one.

The consultant team should have demonstrated expertise in the following areas:

- Phosphorus treatment and water quality engineering
- Wetland science and hydrology
- Pumping systems and hydraulic engineering
- Wastewater and residuals management
- Regulatory and permitting expertise
- Cost estimation and lifecycle cost analysis
- Minnesota water quality context

PART 2: SCOPE OF WORK

The consultant should propose a scope and timeline including, but not limited to, the following components within a projected budget range of \$60,000-\$80,000. Rather than prescribing a specific methodology, MCWD seeks the consultant's professional judgement to describe in the proposal how the work should be structured, advanced, and coordinated with MCWD to deliver on the project's three objectives. Additional tasks or subtasks may be proposed by the consultant if deemed necessary to support the analysis.

Task 1. Kickoff and Discovery

1.1 Kickoff

- Hold a project kickoff meeting with MCWD staff to establish project schedule, communication protocols, and data transfer procedures.
- Identify key decision points or milestones that require or would benefit from MCWD staff input prior to advancing scope tasks.

1.2 Review of Prior Studies and Management Options Assessment

Drawing on a thorough review of prior feasibility work and current knowledge, the consultant should provide a professional assessment of whether the 2013 conclusion—that an off-line chemical treatment

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facility is the preferred management strategy for addressing phosphorus loading from Six Mile Marsh—remains valid. This is not intended to replicate the 2013 analysis, but to stress-test its conclusions. This assessment should consider how the landscape may have changed since 2013, including advances in treatment technologies and BMPs, changes to the regulatory environment, updated understanding of Six Mile Marsh phosphorus dynamics, the acquisition of the Farmhill Circle property, and any technical, regulatory, or operational constraints not adequately considered at the time. The consultant is invited to identify additional factors it believes are relevant to this determination.

The consultant should articulate the level of review and effort necessary to reach its conclusion and be able to provide a professional opinion on whether the off-line treatment facility remains the most effective and implementable management strategy, or whether any other strategy warrants further investigation before advancing to detailed feasibility analysis.

Task 1 Deliverables

Management strategy assessment memo *(to be incorporated/appended as a section in the final feasibility report)*

Task 2. Feasibility Evaluation

Building on the system understanding and site familiarity developed in Task 1, the consultant shall develop and execute a feasibility evaluation that provides MCWD with the technical understanding needed to evaluate and determine whether an off-line phosphorus treatment facility represents a viable and effective long-term strategy for reducing phosphorus to downstream Halsted Bay, and whether the Farmhill Circle property can reasonably accommodate a facility of the scale and configuration needed to achieve meaningful and optimal treatment.

Evaluation Approach

The proposal should describe the consultant's recommended approach to develop, refine, evaluate, and compare facility alternatives. The proposal should also clearly demonstrate how the evaluation will progressively refine the technical understanding of viable alternatives to support updated, refined, and defensible estimates of phosphorus load reduction, capital costs, and lifecycle costs at a level of confidence appropriate to determine whether the project has merit to advance further. MCWD expects the evaluation to be iterative and collaborative, with appropriate opportunities for concurrence at key decision points, and to culminate in a clear evaluation of alternatives and a well-supported recommendation.

The evaluation should be structured as a progressive process. The evaluation should distinguish between the treatment opportunity presented by the Six Mile Marsh system and the site-specific opportunity at the Farmhill Circle property. MCWD seeks to understand the full potential for treatment

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through an off-line facility in general, before applying the physical constraints of the Farmhill Circle Property. The evaluation should ultimately be structured to answer the following questions:

- 1) What is the off-line treatment opportunity within the Six Mile Marsh? What volume of water could be intercepted? What factors establish the practical upper limit of treatment potential?
- 2) Does a facility of any configuration at the Farmhill Circle property represent a viable and meaningful approach for reducing phosphorus loading to Halsted Bay?
- 3) If so, how do alternatives compare and which concept represents the most effective and feasible implementation strategy?

The proposal should identify the key decision points or gates the consultant recommends between key stages of evaluation so the collective team can remain adaptive to findings and recalibrate subsequent analysis as needed. The feasibility evaluation should incorporate a comprehensive understanding of the opportunities, constraints, tradeoffs, and uncertainties associated with the proposed alternatives. MCWD anticipates that this understanding will be informed by considering, at a minimum, the following aspects of project feasibility. The consultant's proposal should name any other aspects it recommends be considered.

- Site suitability and facility configuration
- Hydrology and operational capacity
- Residual management
- Phosphorus removal and treatment variability
- Regulatory pathway
- Construction and lifecycle costs
- Operation and maintenance demands
- Risk profile

Evaluation Framework

As part of the feasibility evaluation, the consultant is to develop an evaluation framework that documents how alternatives will be compared throughout the study. MCWD envisions this framework, in part, taking the form of an evaluation matrix that is developed early in the project, refined as the analysis progresses, and ultimately used to clearly summarize the relative strengths, limitations, tradeoffs, and distinguishing characteristics of each alternative; however, the format, metrics, and level of detail should be described in the proposal.

Task 2 Deliverables

Technical memorandum documenting the proposed alternatives, selection rationale, and any options considered but screened out *(to be incorporated as a section of the final report)*

Evaluation framework template, including categories of analysis, metrics, and comparison approach, reviewed and confirmed with MCWD staff prior to full analysis

Populated draft evaluation matrix

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Task 3: Final Report

Prepare a final report integrating and expanding on all deliverables from previous tasks. The report should be written to give MCWD staff and its board of managers a clear, well-supported picture of the feasibility landscape.

The report should include, but is not limited to, the following elements:

- **Merits of an off-line treatment facility:** Document the optimal site conditions and load reduction potential that could be reasonably achieved through an off-line facility along Six Mile Marsh, absent of the District's Farmhill Circle property. If MCWD were to maximize the load reduction to Halsted Bay through an off-line facility, what would it require? What are the controlling factors?
- **Feasibility determination:** Assess whether an off-line treatment facility of any configuration, on the Farmhill Circle property, is a viable and meaningful strategy to reduce phosphorus loading to Halsted Bay. This includes an honest evaluation of system-level limiting factors and this evaluation should be put in context of the overarching load reduction potential absent of the Farmhill Circle property. If the analysis reveals factors that would fundamentally constrain the value or viability of a facility regardless of configuration, the report should say so.
- **Alternative evaluation and recommendation:** If a facility alternative is determined to have merit, provide a clear recommendation identifying which off-line facility concept represents the best path forward, grounded in a transparent evaluation of treatment performance, total cost, operational complexity, regulatory risk, and remaining uncertainties. Where trade-offs are significant, these should be clearly described.
- **Conceptual site plan(s):** Develop high-level concept sketches for viable alternatives that provide a general understanding of the facility layout(s) and major components, such as in-take and outlet pipes, buildings, entryways, screenings, storage, and residual management. Reference Appendix D.
- **Identified unresolved questions:** Identify any questions that remain unanswered at the conclusion of the study that could materially affect whether the recommended concept is viable. For each unresolved question, provide suggested next steps to allow MCWD staff to evaluate further. This may include additional monitoring or data collection that would meaningfully inform facility design and/or viability.

Task 3 Deliverables

Draft Report

Final Report

Final Evaluation Matrix

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Expectations and Assumptions

MCWD envisions an ongoing, collaborative working relationship with the selected consultant. Proposers should reflect these expectations through their proposed methodology, schedule, and budget.

Collaboration and Coordination

- Communicate proactively with the MCWD project manager on task progress, upcoming deliverables and any issues that arise.
- Prepare monthly status updates that summarize progress and budget burn of each active task.
- Support MCWD staff in preparing materials for a Board or Committee meeting, including presentation figures and supporting technical content, and attend one Board or Committee meeting to support presentation of the findings.

Assumptions

- Raw and/or summarized hydrologic and water quality data will be provided to the consultant prior to kickoff (Appendix E).
- Proposers should identify any additional data needs from MCWD in their proposal.
- The consultant is welcome to suggest data collection efforts as part of its proposal if deemed important to achieving the project's objectives.

PART 3: INSTRUCTIONS TO PROPOSERS

Submittal requirements

Responses to the RFP should be submitted **via email to Kailey Cermak (kcermak@minnehahacreek.org) and Michael Hayman (mhayman@minnehahacreek.org) no later than 4:00pm on Tuesday, October 27, 2026.**

No page limit is imposed, however respondents will be evaluated on clarity and conciseness. Each proposal should include the following items:

1. **Cover letter:** Include a primary point of contact and contact information.
2. **Project understanding:** Describe your understanding of the scope of work, the approach to be taken, and your vision for the assessment. Identify any additional information the project partners will need to supply or obtain to enhance your understanding of the project and successfully complete the work, and any issues you anticipate in performing the work.
3. **Proposed scope of work:** Provide a detailed description of your proposed scope of work, including how you will build in check points to coordinate with MCWD staff. Include detailed descriptions of all anticipated tasks and deliverables, and any supplemental tasks, not described in the RFP, that you recommend or suggest.

Provide a spreadsheet showing:

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- Tasks, with team members, hours, schedule, and budget for each
 - Overall cost proposal
 - Overall schedule with major milestones and client check-ins
4. **Qualifications and experience:** Provide an overview of the firm(s), project team members, and qualifications, with particular attention paid to the role of each proposed team member, and the team member's experience and expertise for that role. You're invited to include descriptions of projects undertaken by the firm(s) and team members similar in nature to the one being proposed.
 5. **References:** Provide three recent project references for your proposed principal team members, including names, addresses, and phone numbers.
 6. **MCWD resources:** Provide a list of resources that you expect from MCWD, expectations that you have for MCWD contributions to the scope, and any other assumptions on which your proposal is based.
 7. **Subcontracting:** If you intend to use any subconsultant, submit the subconsultant's information, describe the intended scope and role of the subconsultant, and provide an overview of the proposed subconsultant team members.

Request for Proposal Timeline

A review committee led by the project manager, MCWD Planner-Project Manager Kailey Cermak, and composed of other select MCWD staff, will evaluate proposals and select firms to advance for interviews. Following a comprehensive review, the review committee will recommend an award to the MCWD Board of Managers.

The anticipated timeline for the proposal review process is as follows:

- **RFP issue date:** Wednesday September 23, 2026
- **Preferred date for submitting RFP questions:** Wednesday, September 30, 2026 at 4:00 pm
- **Optional Informational Meeting:** Thursday, October 1, 2026 12:30 pm (MCWD office)
- **Deadline for receipt of proposals:** Tuesday, October 27, 2026 at 4:00pm
- **Expected dates for interviews:** Thursday, November 12, 2026 (backup November 16, 2026)
- **Anticipated date for contract award:** November 19, 2026 (MCWD Board of Managers meeting)

RFP questions

Any questions regarding the RFP should be directed to Kailey Cermak, Planner-Project Manager, at kcermak@minnehahacreek.org. Questions submitted by 4:00 PM on September 30, 2026, are preferred so they can be addressed at the informational meeting. Additional questions may also be asked during or submitted through the day of the informational meeting on October 1, 2026. Answers will be distributed after the meeting to attendees and those who have indicated interest by email.

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Proposal Evaluation Procedure

Methodology

- **Project understanding:** The consultant understands the scope, goals and requirements of the project.
- **Completeness and specificity:** The proposal concisely and comprehensively explains what the consultant will do to complete all facets of the project. The proposal presents a logical and clear approach to systematically advance through the work, including how alternatives will be developed, refined, and evaluated to support MCWD's project objectives and decision-making.
- **Identification of needs:** The proposal outlines what resources will be required to complete the tasks, including project partner staff time, additional information, etc.

Experience

- **Comparable experience:** Expertise and experience with comparable projects, with a focus on conducting feasibility studies that result in successful design and construction of natural resource-based projects.
- **Specialized knowledge:** The consultant possesses the characteristics described under "Consultant Team Characteristics".
- **Budget and schedule:** The project team has a proven track record of completing projects on time and within budget.

Cost

- **Fee structure:** The proposal must clearly outline the fees and costs to complete all aspects of this project. Include hourly rates for each project team member along with total hours broken out by each task.

Proposer's Budget for the Project

The requested services under this RFP will be funded by MCWD levied funds. Services will be compensated on an hourly basis with a specified not-to-exceed for the entire project. The not-to-exceed may be adjusted when the scope of work is finalized.

Addenda/Clarifications

Any changes to this RFP will be made by MCWD through a written addendum. In preparing proposals, firms should not rely on any verbal or otherwise informal MCWD statements.

Joint Offers

Where two or more proposers desire to submit a single proposal in response to this RFP, they should do so on a prime-subconsultant basis rather than as a joint venture. MCWD intends to contract with a single firm and not with multiple firms doing business as a joint venture.

Contractual Agreement

Enclosed with this RFP is the form of contract that the selected consultant and MCWD will execute (Appendix F). The MCWD may agree to non-substantive document revisions, but proposals should be based on the contract form. The proposal should identify any terms of the form of contract that are

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unacceptable. MCWD will negotiate a term where it can preserve the substantive intent of the term but reserves the right to reject a proposal that is conditioned on a material alteration of the contract form.

The proposal also should indicate any data or methods of proposer that would be used in performing the work, and that proposer considers to be instruments of service that should be excepted from the intellectual property terms of the contract form.

Payments will be based on hourly rates on certification of completion of identified tasks. The payment schedule can be negotiated and finalized through the contract after MCWD selection of a consultant.

Part 4: Disclosures

MCWD reserves the right to postpone evaluation or award for its own convenience, to accept or reject any or all proposals received in response to this RFP, to request further information from individual firms, to negotiate with more than one firm simultaneously, and to cancel the solicitation without contract award.

Each firm is solely responsible for all costs that it incurs to respond to this RFP and, if selected, to engage in the process including, but not limited to, costs associated with preparing a response or participating in any interviews, presentations or negotiations related to this RFP.

MCWD will handle proposals and related submittals in accordance with the Minnesota Data Practices Act, Minnesota Statutes §13.591, subdivision 3(b).

Appendix

- Appendix A: 2013 Feasibility Study
- Appendix B: 2013 Site Alternatives Analysis
- Appendix C: 2017 Phosphorus Loading Analysis
- Appendix D: 2018 Massing Study Concept Plan
- Appendix E: Six Mile Creek Data Availability
- Appendix F: MCWD Contract Template

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Appendix A: 2013 Feasibility Study



Halsted Bay Load Management Feasibility Project

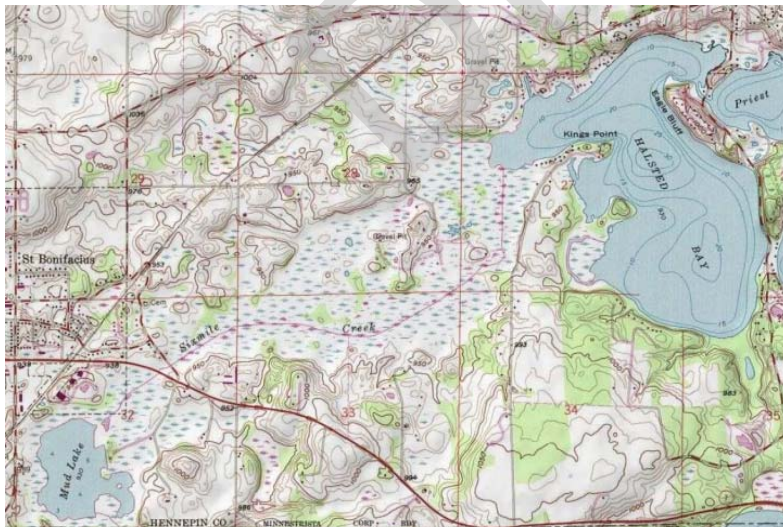


**MINNEHAHA CREEK
WATERSHED DISTRICT**

Prepared for:

MINNEHAHA CREEK WATERSHED DISTRICT

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Table of Contents

1.0	EXECUTIVE SUMMARY	1-4
2.0	INTRODUCTION	2-1
2.1	Purpose and Scope	2-1
3.0	SITE DESCRIPTION	3-1
3.1	Watershed Description	3-1
3.2	halsted bay information.....	3-1
3.2.1	Lake Morphometry.....	3-1
3.2.2	Water Quality	3-3
3.2.3	Fisheries	3-5
3.2.4	Aquatic Vegetation.....	3-7
4.0	HALSTED BAY NUTRIENT BUDGET.....	4-1
4.1	Introduction	4-1
4.2	Phosphorus Sources.....	4-1
4.2.1	Atmospheric Deposition.....	4-1
4.2.2	Groundwater	4-1
4.2.3	Watershed Runoff	4-2
4.2.3.1	Six Mile Creek Watershed	4-3
4.2.3.2	Six Mile Marsh	4-6
4.2.3.3	Watershed Phosphorus Load	4-7
4.2.4	Internal Loading	4-7
4.3	Phosphorus Budget and Load Reductions	4-8
4.3.1	Lake Phosphorus Budget.....	4-8
4.3.2	BATHTUB Model.....	4-9
4.3.3	Phosphorus Load Reductions	4-10
5.0	IDENTIFICATION OF BEST MANAGEMENT PRACTICES	5-1
5.1	Introduction	5-1
5.2	ALternatives Not Further Assessed.....	5-1
5.2.1	Abstraction by Deep Infiltration.....	5-1
5.2.2	Temporary Drawdown of Halsted Bay	5-1
5.2.3	Microtunnel Bypass from Lundsten	5-1
5.2.4	Dredging Hypolimnion Sediments.....	5-2
5.3	Alternative that Needs more Information	5-2
5.3.1	Hydrologic Restoration of Six Mile Marsh.....	5-2
5.4	Selected Alternatives – Internal Load	5-2
5.4.1	Alum Treatment of Halsted Bay	5-2
5.4.2	Hypolimnetic Aeration with Chemical Injection	5-4
5.4.3	Withdrawal, Alum Treatment, and Replacement	5-5
5.5	Selected Alternatives – External Load Control	5-8

5.5.1	Off-line Alum Treatment	5-8
5.5.2	In-line Alum Injection	5-9
5.5.3	Iron Filtration	5-9
5.6	Other Restoration Considerations	5-9
5.6.1	Vegetation Management	5-9
5.6.2	Rough Fish Management	5-10
6.0	NUTRIENT REDUCTION COST AND EFFECTIVENESS.....	6-1
6.1	Modeling Alternatives and Evaluating Cost/Benefits	6-1
6.1.1	Internal Load Reductions	6-1
6.1.2	External Load Reductions.....	6-2
6.1.3	Other Restoration Considerations	6-2
6.2	Discussion of Results.....	6-3
7.0	REFERENCES	7-1

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TABLES

Table 3-1. Physical Features of Halsted Bay.	3-1
Table 3-2. Halsted Bay Vegetation Survey Results.	3-7
Table 4-1. Six Mile Marsh sediment phosphorus release.	4-7
Table 4-2. 2005-2011 average annual internal load estimates for Halsted Bay.	4-8
Table 4-3. Numeric water quality goals for Halsted Bay.	4-10
Table 4-4. Halsted Bay TP load reductions.	4-11
Table 6-1. Physical Features of Halsted Bay.	6-1

FIGURES

Figure 3-1. Halsted Bay Watershed.	3-2
Figure 3-2. Summer average total phosphorus concentrations for Halsted Bay.	3-3
Figure 3-3. Summer average chlorophyll-a concentrations for Halsted Bay.	3-4
Figure 3-4. Summer average Secchi depth values for Halsted Bay.	3-5
Figure 3-5. Trophic group abundance based on historic MN-DNR fish survey results.	3-6
Figure 3-6. Trophic group biomass based on historic MN-DNR fish surveys.	3-6
Figure 4-1. Water budget for Halsted Bay.	4-3
Figure 4-2. Six Mile Creek TP concentrations at the outlet of Mud Lake from 1997-2012. The upper and lower edge of each box represents the 75 th and 25 th percentile of the data range for each flow zone. Error bars above and below each box represent the 95 th and 5 th percentile of the datasets. The green dash is the median DO concentration of all data collected in each flow zone.	4-4
Figure 4-3. Six Mile Creek ortho-phosphorus concentrations at the outlet of Mud Lake from 1997-2012. The upper and lower edge of each box represents the 75 th and 25 th percentile of the data range for each flow zone. Error bars above and below each box represent the 95 th and 5 th percentile of the datasets. The green dash is the median DO concentration of all data collected in each flow zone.	4-4
Figure 4-4. Six Mile Creek sampling locations.	4-5
Figure 4-5. 2013 Six Mile Creek TP data.	4-6
Figure 4-6. 2013 Six Mile Creek Ortho-phosphorus data.	4-7
Figure 4-7. Halsted Bay phosphorus budget.	4-9
Figure 4-8. Observed versus BATHTUB model-predicted total phosphorus for Halsted Bay.	4-10
Figure 5-1. Scenario 1: Alum treatment in the anoxic areas of Halsted Bay.	5-6
Figure 5-2. Scenario 2: Alum treatment in the anoxic and shallow western areas of Halsted Bay.	5-7

APPENDICES

Appendix A:	Water Surface Elevations and Flow Data
Appendix B:	Alum Dosage Considerations
Appendix C:	Lake Response Model Results
Appendix D:	Cost Estimates

1.0 Executive Summary

This report presents the results of the Halsted Bay load management feasibility study. The focus of the study is to identify alternatives to improve Halsted Bay water quality by managing its phosphorus load, both internal and external. The current average summer in-lake concentration of phosphorus is 88 µg/l. The goal is to reach the State of Minnesota's in-lake concentration of 40 µg/l. The study was completed by Minnehaha Creek Watershed District with the involvement of the City of Minnetrista. The study team consists of designated MCWD staff, Wenck, and WSB.

Halsted Bay is a 560-acre water body located in the western most portion of Lake Minnetonka in the City of Minnetrista. The primary inflow from the 30-square-miles drainage area is from Six Mile Creek located in the northwest corner of the bay.

A large portion of the study investigates the in-lake and external or watershed sources of phosphorus. In-lake loading was documented by results of sediment samples taken as part of the study. Watershed loads are based on the recently completed diagnostic study of Six Mile Creek by MCWD in early 2013. This work was extended by an additional study of Six Mile Marsh located just upstream of the bay and downstream of Mud Lake. Based on the data collected and modeling to date, Six Mile Marsh does appear to be releasing some phosphorus, however more flow and water quality data and analysis is needed to further document this.

Lake response modeling indicates that both watershed loading and internal loading need to be aggressively pursued to reach the goal in Halsted Bay. One key factor is that 90 percent of the water comes through Mud Lake which only has a target of 60 µg/l while Halsted Bay has a target of 40 µg/l. This means additional reductions may need to be found in other parts of the watershed.

Restoration of upstream Mud and Parley Lakes will be critical in restoring Halsted Bay. Both of these lakes are very shallow and carp infested. To reach water quality goals in these lakes, the carp need to be addressed, plants reestablished in the lakes and nutrients reduced. This is an extensive undertaking.

Addressing external sources, accomplishing the goals of the Six Mile Creek Diagnostic Study, is going to be a long process with uncertain outcomes. The process could take 30 years or more and is dependent on numerous landowners. A large engineering project, such as an off-line phosphorus removal plant, provides the water quality benefits immediately however at a significant cost.

2.0 Introduction

2.1 PURPOSE AND SCOPE

Halsted Bay is a 560-acre water body located in the western most portion of Lake Minnetonka in the City of Minnetrista. The bay is very eutrophic due to high nutrient levels. The purpose of this load management feasibility study is to identify alternatives to improve Halsted Bay water quality by managing its phosphorus load, both internal and external. The current average summer in-lake concentration of phosphorus is 88 µg/l. The goal is to reach the State of Minnesota's in-lake concentration of 40 µg/l.

This study investigates the in-lake and external or watershed sources of phosphorus. In-lake loading is documented by results of sediment samples taken as part of the study. The primary external load is from the 30-square-mile Six Mile Creek drainage area located in the northwest corner of the bay. Watershed loads are based on the recently completed diagnostic study of Six Mile Creek by MCWD in early 2013. This work is extended by an additional study of Six Mile Marsh located just upstream of the bay and downstream of Mud Lake.

3.0 Site Description

3.1 WATERSHED DESCRIPTION

Halsted Bay (DNR# 27-0133-09) is the western most bay of Lake Minnetonka (DNR# 27-0133-00). The Halsted Bay drainage area covers approximately 19,489 acres in Hennepin and Carver Counties and includes portions of Mound, St. Bonifacius, Minnetrista and Victoria (Figure 3-1). The watershed was divided into four major subwatersheds for the purpose of this report: Six Mile Creek Subwatershed upstream of Mud Lake, Six Mile Creek Subwatershed downstream of Mud Lake (Six Mile Marsh drainage area), North tributary to Halsted Bay, and Halsted Bay direct subwatershed (Figure 3-1).

3.2 HALSTED BAY INFORMATION

3.2.1 Lake Morphometry

With a maximum depth of 32 feet and a littoral area of 57%, Halsted Bay is considered a deep lake by Minnesota rules and standards (Table 3-1). However the bay has a rather large littoral area suggesting that it may have several functional aspects similar to shallow lakes. Halsted Bay has a residence time of 0.8 years meaning the bay, on average flushes approximately once every 292 days. The bay has a very large watershed with a watershed to lake surface area ratio of 34:1 suggesting that the bay is sensitive to changes in watershed nutrient loading.

Table 3-1. Physical Features of Halsted Bay.

Parameter	Result
Surface Area (acres)	561
Average Depth (ft)	13.2
Maximum Depth (ft)	32
Volume (acre-feet)	7,401
Residence Time (years)	0.8
Littoral Area (acres)	318
Littoral Area (%)	57%
Watershed (acres)	19,321
Mixing Depth (ft)	8

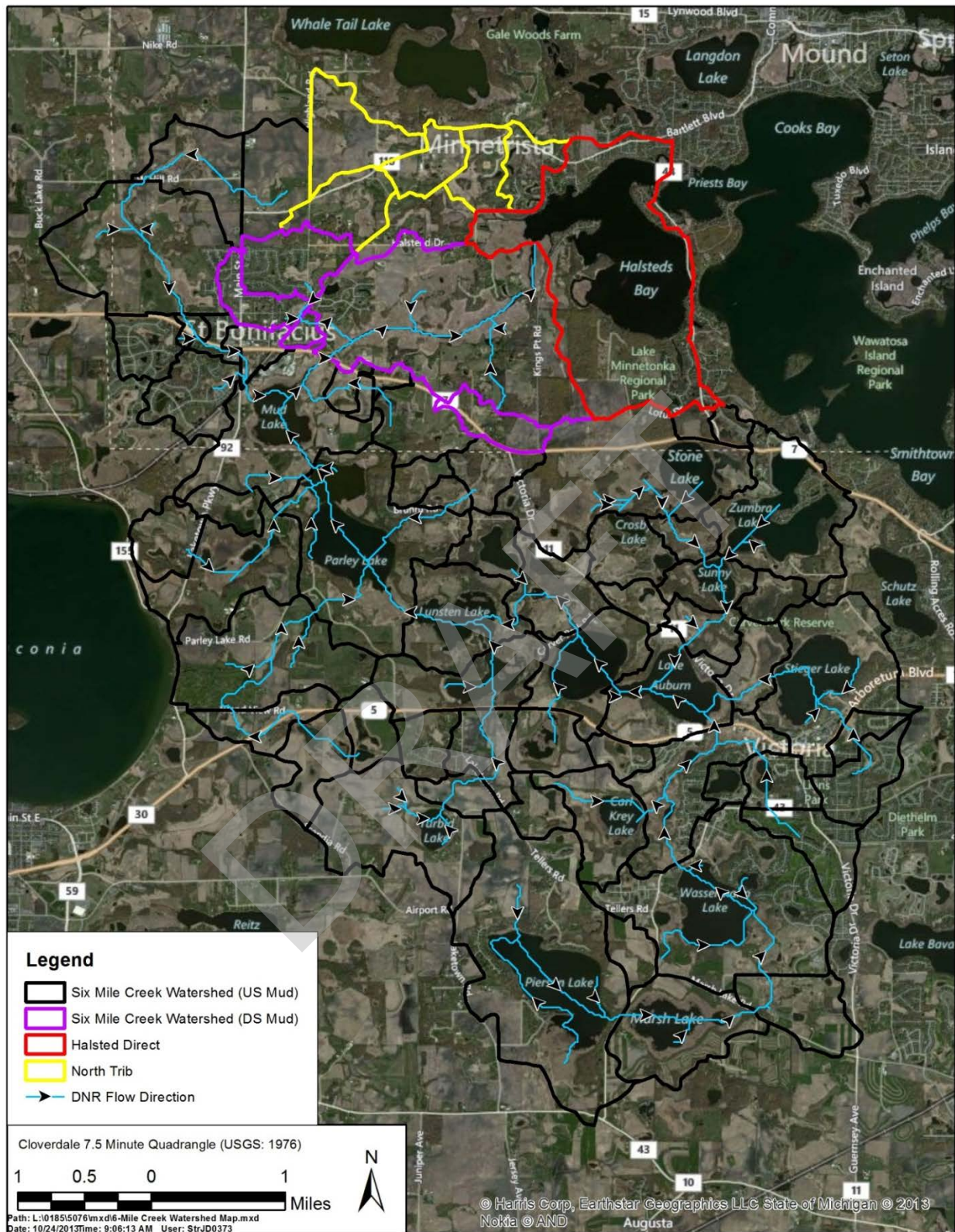


Figure 3-1. Halsted Bay Watershed.

3.2.2 Water Quality

Lake water quality is typically measured by assessing the amount of algal growth and water clarity during the summer growing season. When excess algae grow in a lake, water clarity is reduced and noxious smells can emit. These are symptoms of lake eutrophication. When lakes become hyper eutrophic (excess nutrients leading to heavy algae growth), the entire food web is affected. Changes are found in the algal community and water quality, including depletion of dissolved oxygen and decreased water clarity. A healthy lake has a balanced growth of algae supporting the base of the food chain without degrading water quality or harming biological organisms.

Lake water quality samples have been collected by Minnehaha Creek Watershed staff in Halsted Bay since 2000. In general, lake monitoring was conducted bi-weekly from May through September for Secchi depth, total phosphorus (TP) and chlorophyll-*a*, and temperature and dissolved oxygen measurements.

Phosphorus

Algal growth (measured as total chlorophyll-*a*) is typically limited by the amount of phosphorus in the water column. Therefore, TP is considered the causative factor for algal growth. Water clarity is affected by the amount of algae as well as suspended and dissolved particles in the water column. Since 2000, summer average TP concentrations have ranged from 70-130 µg/L and have exceeded the 40 µg/L NCHF deep lake standard every year (Figure 3-2).

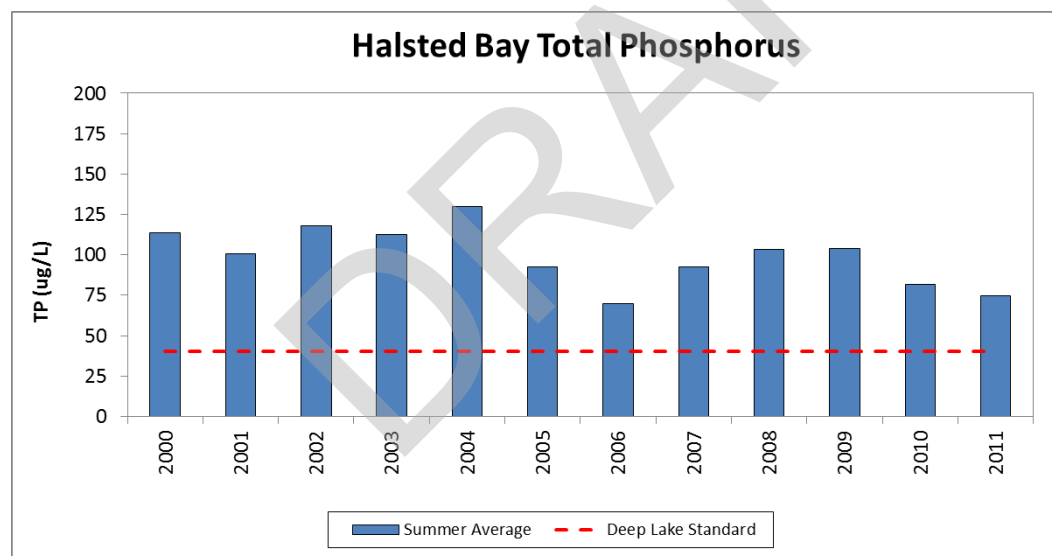


Figure 3-2. Summer average total phosphorus concentrations for Halsted Bay.

Chlorophyll-a

Chlorophyll-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Chlorophyll-*a* is a simple measurement and is often used to evaluate algal abundance rather than expensive cell counts. The greater the algal biomass and corresponding chlorophyll-*a* values, the more green and productive a lake appears with worst case scenarios including algal scum and foul odors. These conditions are considered nuisance algal blooms and are both aesthetically displeasing but also potentially bad for fish and other biological organisms. Nuisance algal

blooms cause poor smells and aesthetics and can lead to more severe problems such as summer fish kills. Ultimately, lakes should have a modest amount of algal productivity with light penetrating approximately 15 feet into the water column. Summer average chlorophyll-a concentrations in Halsted Bay have ranged from 24 µg/L to as high as 83 µg/L (Figure 3-3). Chlorophyll-a concentrations over 14 µg/L exceed state water quality standards for deep lakes in the NCHF ecoregion. Average chlorophyll-a concentrations have exceeded the state standard every year since 2000 indicating nuisance algae blooms are common in Halsted Bay during the summer months.

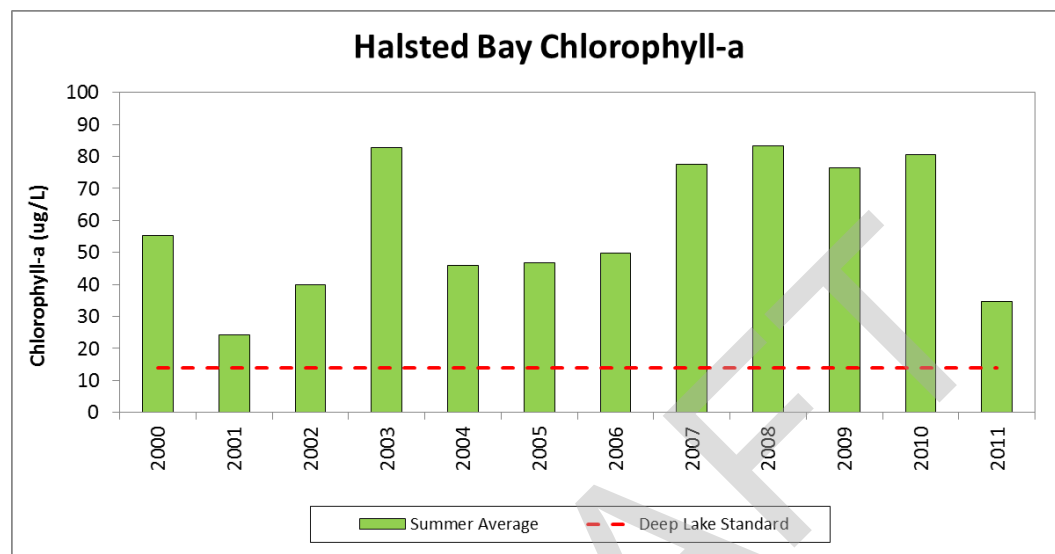


Figure 3-3. Summer average chlorophyll-a concentrations for Halsted Bay.

Water Clarity

Water clarity in lakes is typically measured using a Secchi disk. A Secchi disk is a black and white disk that is lowered into the water column until it can no longer be seen. The depth at which the disk disappears is known as the Secchi depth and is considered the depth where 90% of the light is extinguished.

Water clarity in lakes is controlled by several factors including the amount of algae in the water column as well as other suspended particles such as suspended sediment as a result of wind resuspension and bioturbation (such as carp). Since Halsted Bay is considered a deep lake, wind mixing is likely only a concern in shallow areas (<15 feet) where mixing can reach the sediments and stir up particles into the water column. Halsted Bay also has a large carp population that feeds and roots around in the sediments causing a fair amount of sediment disturbance in the shallow areas throughout the bay.

Secchi depth measurements in general follow the same trend as chlorophyll-a concentrations in Halsted Bay. Since 2000, the average summer Secchi depth has not met the 1.4 meter water quality standard for deep lakes (Figure 3-4). Mean summer values ranged from 1.2 meters to 0.5 meters between 2000-2011.

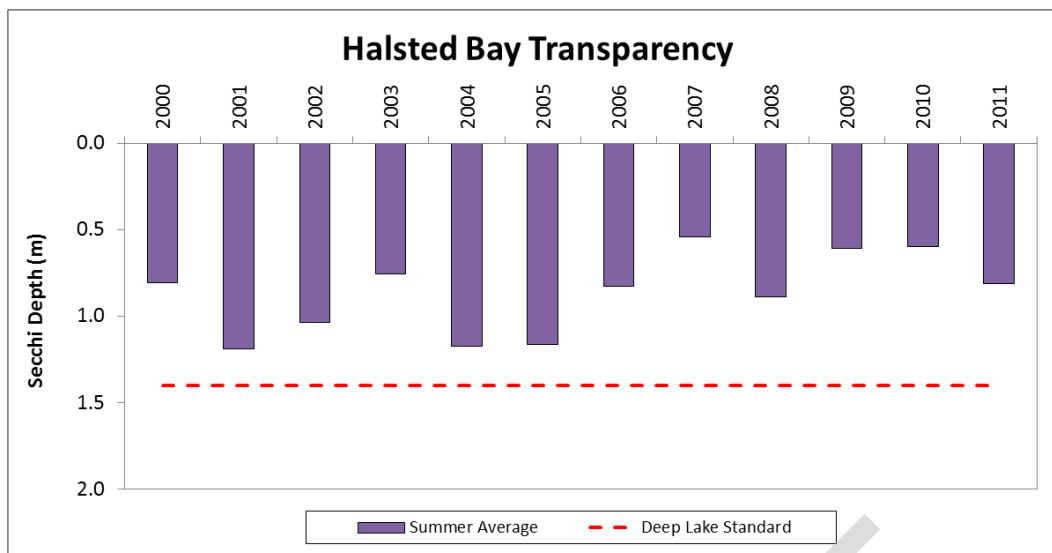


Figure 3-4. Summer average Secchi depth values for Halsted Bay.

3.2.3 Fisheries

Fish survey reports for Halsted Bay were provided by the DNR Area Fisheries Office in Shakopee, Minnesota. The first DNR fish survey conducted specifically for Halsted Bay was performed in 1992. Standard survey methods used by the DNR include gill net and trap nets. These sampling methods do have some sampling bias, including focusing on game management species (i.e., northern pike and walleye), under representing small minnow and darter species presence/abundance, and under representing certain management species such as largemouth bass. The current methods also likely under represent carp populations in lakes. However, when carp are present in a lake, the sampling methods do capture some of the population. So, although carp density is likely under represented, the methods do provide a reasonable year to year comparison.

Fish community data for Halsted Bay was summarized by trophic groups (Figures 3-5 and 3-6). Species within a trophic group serve the same ecological process in the lake (i.e., panfish species feed on zooplankton and invertebrates; may serve as prey for predators). Analyzing all the species as a group is often a more accurate summary of the fish community than analyzing individual species trends. Results indicate panfish to be the most abundant species in Halsted Bay. Total biomass in Halsted Bay appears to shift year to year between panfish and top predators. Common carp were present during both surveys and represented a sizable portion of the total catch biomass (18% in 1992 and 5% in 1997). Rough fish, particularly common carp, have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments and nutrients. These activities can lead to increased nutrients in the water column ultimately resulting in increased nuisance algal blooms.

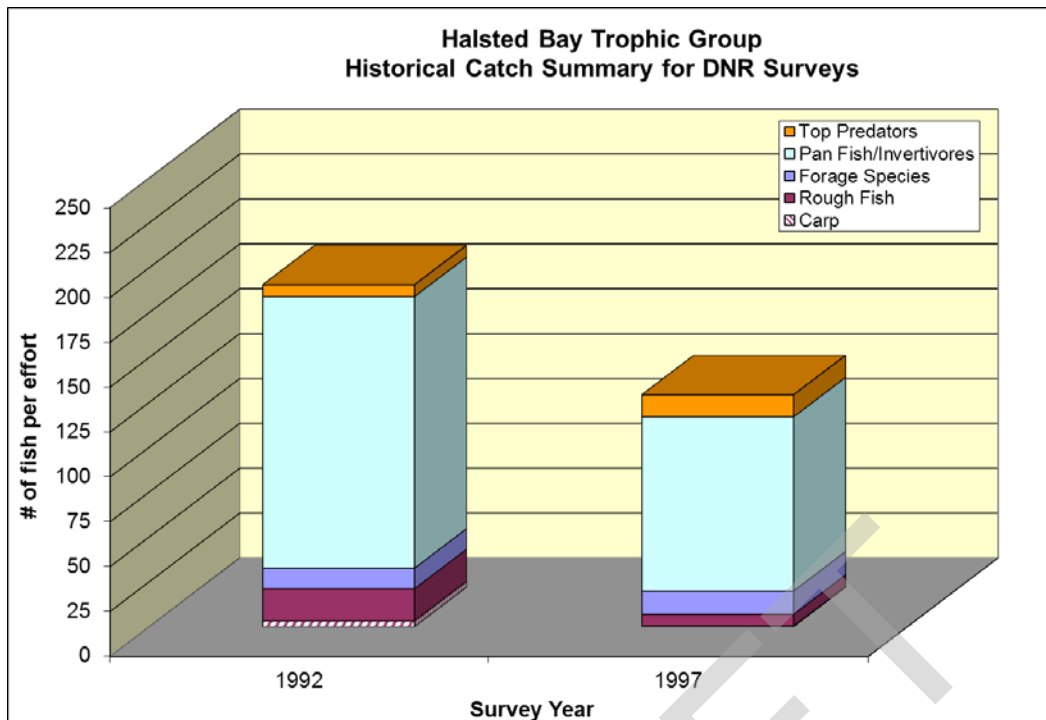


Figure 3-5. Trophic group abundance based on historic MN-DNR fish survey results.

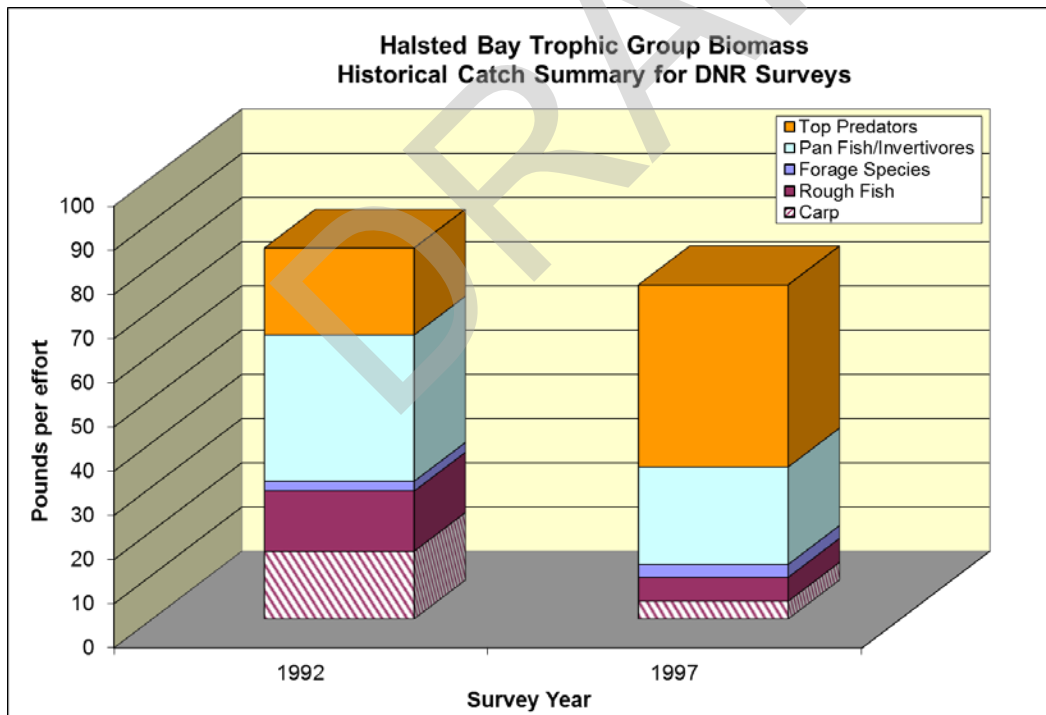


Figure 3-6. Trophic group biomass based on historic MN-DNR fish surveys.

3.2.4 Aquatic Vegetation

A point-intercept survey was conducted by Wenck staff on June 19, 2013 using methodology developed by the Minnesota Department of Natural Resources (DNR). Wenck staff identified all plant species found within a one square meter of each survey point. A weighted sampling hook attached to a rope was used to survey vegetation not visible from the surface. All vegetation species observed were identified to the species level where possible. This early summer survey was conducted specifically to estimate the distribution and abundance of curly-leaf pondweed.

Curly-leaf pondweed is a non-native plant species that can outcompete native plant species and disrupt lake ecosystems by changing the dynamics of internal phosphorus loading. Curly-leaf pondweed is a perennial submersed aquatic plant that was first noted in Minnesota around 1910. Curly-leaf pondweed has the ability to grow slowly throughout the winter, even under thick ice and snow cover. Thus by the time other species start growing in the spring, curly-leaf plants are large enough to block light penetration to the bottom. By late spring, curly-leaf pondweed can form dense surface mats which interfere with recreation activities. By mid-summer, these dense mats senesce and die back, releasing nutrients that can contribute to undesirable algae blooms. Before curly-leaf pondweed plants die back, they form hardened stem tips called turions, which serve the function of vegetative reproduction. These turions sprout in the fall and begin the plant's cycle again.

The frequency of occurrence of each species during the June 10, 2013 (near mid-season) and August 12, 2013 (late season) surveys is summarized in Table 3-2. Seven species of submerged and floating aquatic vegetation were documented at sample stations during these surveys. The most common species observed during the surveys were Eurasian water milfoil and coontail. Curly-leaf pondweed was relatively common in June, but had died off as it normally does by August. In general, species diversity and abundance was poor during both surveys and no vegetation was observed at many sample points less than 15 feet deep where submerged vegetation should grow and thrive.

Table 3-2. Halsted Bay Vegetation Survey Results.

Species	June 10, 2013 Survey (frequency of occurrence)	August 12, 2013 Survey (frequency of occurrence)
Eurasian Water Milfoil	14.5%	13.0%
Coontail	11.4%	7.2%
Curly-leaf pondweed	11.0%	0.0%
White waterlily	7.3%	13.2%
Narrowleaf pondweed group	0.4%	0.2%
Yellow waterlily	0.0%	0.4%
Sago pondweed group	0.0%	0.7%

4.0 Halsted Bay Nutrient Budget

4.1 INTRODUCTION

The first step in developing restoration options for Halsted Bay is to develop a nutrient budget for the bay along with a lake response model. A lake response model for Halsted Bay was previously developed for the Minnehaha Creek Lakes TMDL (Wenck 2013). For this study, additional data were collected including sediment cores to estimate internal phosphorus release. The lake response models were subsequently updated.

4.2 PHOSPHORUS SOURCES

One of the primary drivers for lake productivity or algal growth is phosphorus. To better understand what is driving water quality in Halsted Bay, a detailed phosphorus budget was developed to identify both the sources and magnitude of the phosphorus loading. Phosphorus sources to lakes include agricultural and stormwater runoff, internal sediment release of phosphorus, and direct atmospheric deposition of phosphorus to the lakes surface. In this section, a brief description of the potential source of phosphorus to Halsted Bay is provided.

4.2.1 Atmospheric Deposition

Precipitation picks up dust particles that contain phosphorus that can ultimately end up in Halsted Bay as a result of direct input on the basin surface or as a part of stormwater runoff from impervious surfaces in the watershed. Although they must be accounted for in development of a nutrient budget, atmospheric inputs are difficult if not impossible to control and are usually small compared to other sources (internal and external).

Atmospheric inputs of phosphorus from wet and dry deposition are estimated using rates set forth in the MPCA report “Detailed Assessment of Phosphorus Sources to Minnesota Watersheds” (Barr Engineering, 2004), and are based on annual precipitation. The values used for dry (< 25 inches), average, and wet precipitation years (>38 inches) for atmospheric deposition are 24.9, 26.8, and 29.0 kg/km²-year, respectively. These values are equivalent to 0.22, 0.24, and 0.26 pounds/acre-year for dry, average, and wet years in English units, respectively.

4.2.2 Groundwater

Groundwater flow and phosphorus load was estimated using groundwater elevations from the Hennepin County, MN Geologic Atlas published by the Minnesota Geologic Survey, 1989. Surficial geology was also interpreted from the Geologic Atlas. Elevation difference between Lake Minnetonka’s Ordinary High Water Level (929 ft) listed on the DNR LakeFinder website and the region’s surficial geology (940 ft) indicates groundwater flow to Halsted Bay. Groundwater flow to Halsted Bay was determined using the following equation:

$$Q = KiA$$

Where Q is the flow, K is the hydraulic conductivity (3.28×10^{-8} ft/s for loamy soils), i is the difference in lake surface and groundwater elevation divided by 10 feet, and A is the lake area. A mean groundwater concentration of 84 µg/L was used for the Halsted Bay lake response model as listed in Table A.17 of Baseline Water Quality of Minnesota's Principal Aquifers: Twin Cities Metropolitan Region (MPCA 1999).

4.2.3 Watershed Runoff

Phosphorus transported by agricultural runoff and urban stormwater represents some of the largest external contributors of phosphorus to surface waters in Minnesota. Ditching through crop and pasture land, impervious surfaces and storm sewer systems in the watershed improve the efficiency of runoff and phosphorus moving to streams, wetlands and lakes. Phosphorus in agricultural runoff and urban stormwater is a result of crop residue, field erosion, leaves and grass clippings, manure and fertilizers, sediments, pet waste, excessive lawn watering, automobiles, failing septic systems and illicit sanitary sewer connections. Managing agricultural runoff and stormwater is a high-priority concern for all Minnesota lakes and streams.

The first step in estimating the phosphorus load from a lake's watershed is to calculate the watershed's hydrologic budget. MCWD staff has attempted to monitor continuous flow at various locations along Six Mile Creek. Backwater conditions in Six Mile Creek upstream of Halsted Bay and other lakes throughout the watershed make it difficult to develop reliable long-term rating curves. Refer to Appendix A for more details on flow information. In 2013, Wenck Associates converted an XPSWMM model for Six Mile Creek previously developed by the District to EPA SWMM. This model predicts water elevations, runoff, flow and routing throughout the entire watershed. The EPA SWMM model was calibrated to gaged flow data collected by MCWD staff from 2001-2012 on Six Mile Creek near the outlet of Mud Lake. Using this model, Wenck was able to predict annual flow rates and volumes at various points along Six Mile Creek, including the creek's outlet to Halsted Bay. The Halsted Bay direct watershed and the tributary that enters Halsted Bay north of Six Mile Creek (Figure 3-1) were not included in the Wenck EPA SWMM model. Six Mile Creek runoff depths were used to represent the Halsted Bay direct watershed and the north tributary as it was assumed runoff from these subwatersheds is similar to Six Mile Creek.

EPA SWMM flow analysis suggests Six Mile Creek represents approximately 93% of the Halsted Bay water budget (Figure 4-1). The Six Mile Creek Watershed is approximately 17,033 acres in size and accounts for 87% of the Halsted Bay Watershed. The Halsted Bay direct watershed (1,350 acres) and the north tributary to Halsted Bay (1,106 acres) represent only 2% and 3% of the lakes overall water budget, respectively. Groundwater flow to Halsted Bay is also believed to be small and represent only 2% of the overall water budget. Direct precipitation and lake evaporation are approximately the same and there is not believed to be any net gain from the atmosphere on an annual basis.

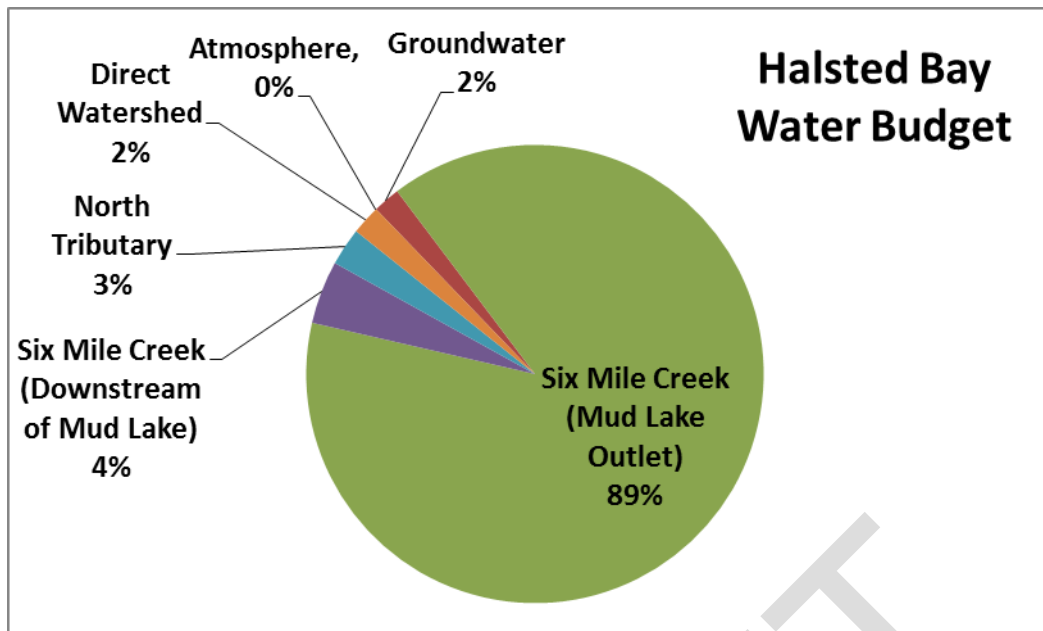


Figure 4-1. Water budget for Halsted Bay.

4.2.3.1 Six Mile Creek Watershed

MCWD staff has collected total phosphorus and ortho-phosphorus grab samples at various Six Mile Creek mainstem and tributary monitoring stations since 1997 (Figures 4-2 and 4-3). Six Mile Creek monitoring station S003-752 located near the outlet of Mud Lake is the furthest downstream Six Mile Creek station before the creek's outlet to Halsted Bay (Figure 4-4). Water quality data collected at this station from 1997-2012 indicate TP has ranged from 38 µg/L to 467 µg/L while ortho-phosphorus has ranged from less than 5 µg/L to 303 µg/L. Grouping the TP and ortho-phosphorus data based on flow conditions indicates Six Mile Creek phosphorus concentrations do not vary significantly between flow regimes.

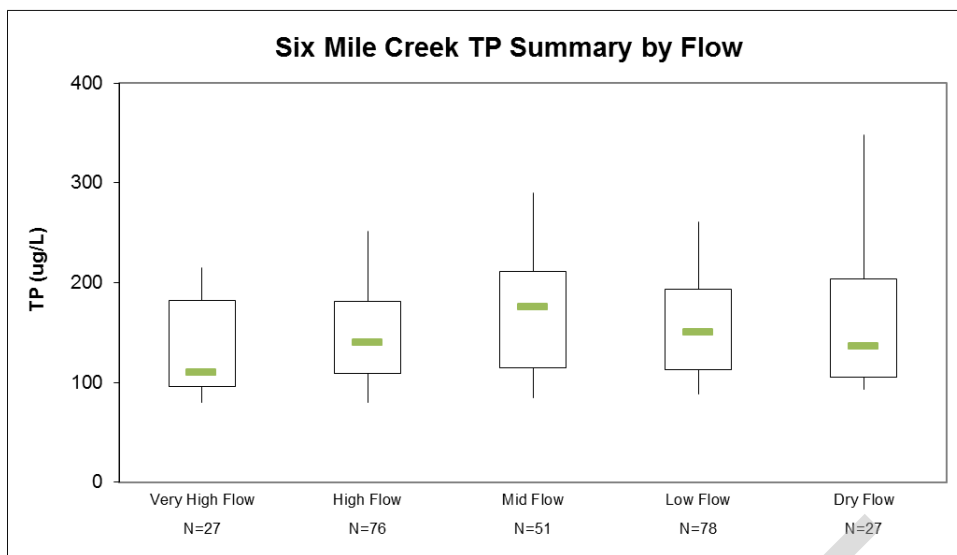


Figure 4-2. Six Mile Creek TP concentrations at the outlet of Mud Lake from 1997-2012. The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each flow zone. Error bars above and below each box represent the 95th and 5th percentile of the datasets. The green dash is the median DO concentration of all data collected in each flow zone.

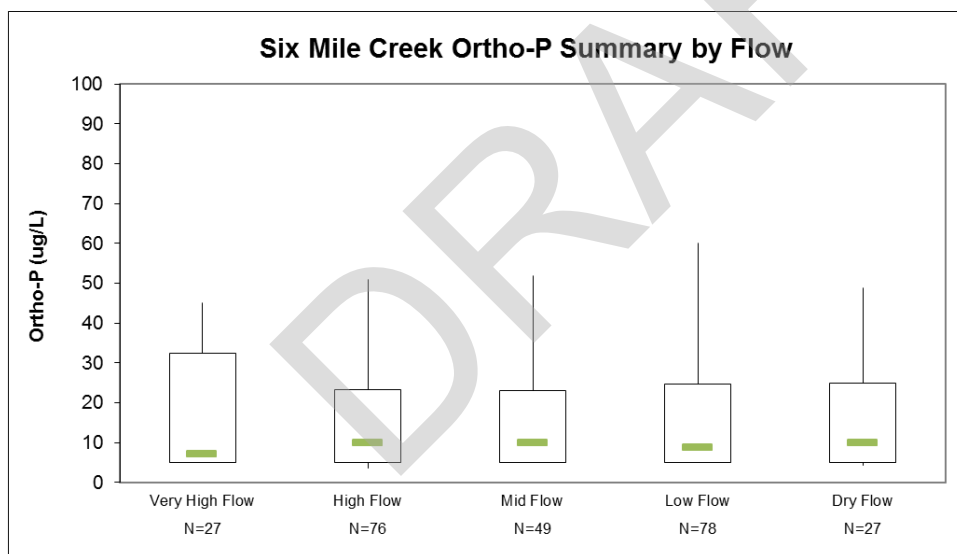
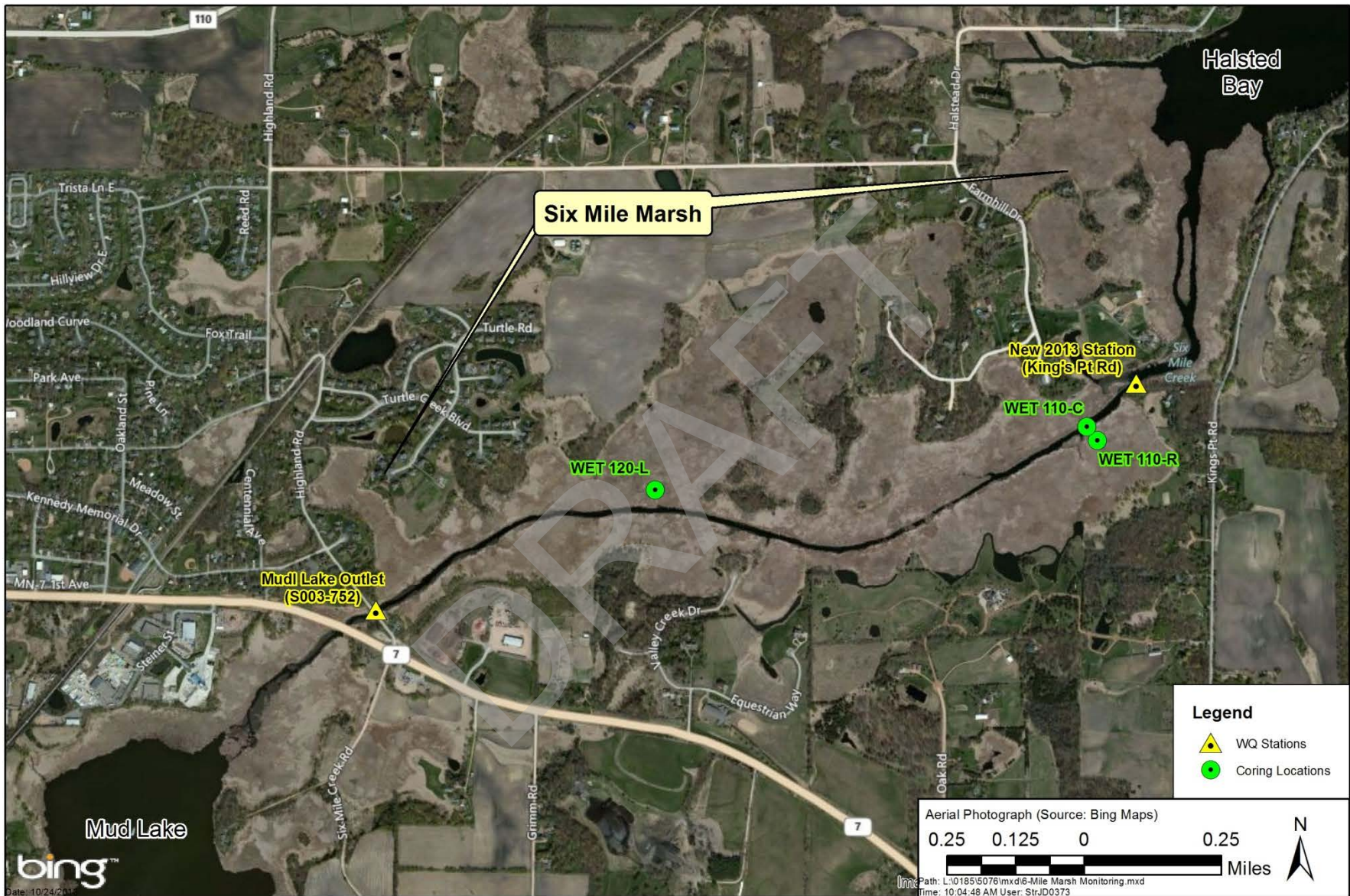


Figure 4-3. Six Mile Creek ortho-phosphorus concentrations at the outlet of Mud Lake from 1997-2012. The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each flow zone. Error bars above and below each box represent the 95th and 5th percentile of the datasets. The green dash is the median DO concentration of all data collected in each flow zone.



4.2.3.2 Six Mile Marsh

In 2013, MCWD staff began monitoring TP and ortho-phosphorus in Six Mile Creek downstream of the Mud Lake outlet station (S003-752) at King's Point Road closer to the creek's outlet to Halsted Bay (Figure 4-4). Prior to 2013, there had been no phosphorus data collected in or downstream of the area between Mud Lake and Halsted Bay referred to as Six Mile Marsh. The channel through Six Mile Marsh is ditched and straightened through a large wetland complex. Flow through this section is very slow and is often subject to backwater conditions from Halsted Bay where large areas of the wetland complex are covered in standing water. The purpose of the 2013 sampling at King's Point Road was to determine if Six Mile Marsh is a source or sink of the phosphorus release from Mud Lake. Phosphorus data was collected between mid-April and early September 2013. Early in the season (March – mid June), there was very little change in TP and ortho-phosphorus between the Mud Lake outlet station and the Six Mile Marsh station at King's Point Road. Beginning in late June, however, the outlet station was increasingly higher in both total and ortho-phosphorus suggesting that the wetland is likely acting as a phosphorus source to Halsted Bay (Figures 4-5 and 4-6). Final flow data will need to be evaluated to determine the magnitude of the phosphorus source since it appears to occur mostly during low flow periods.

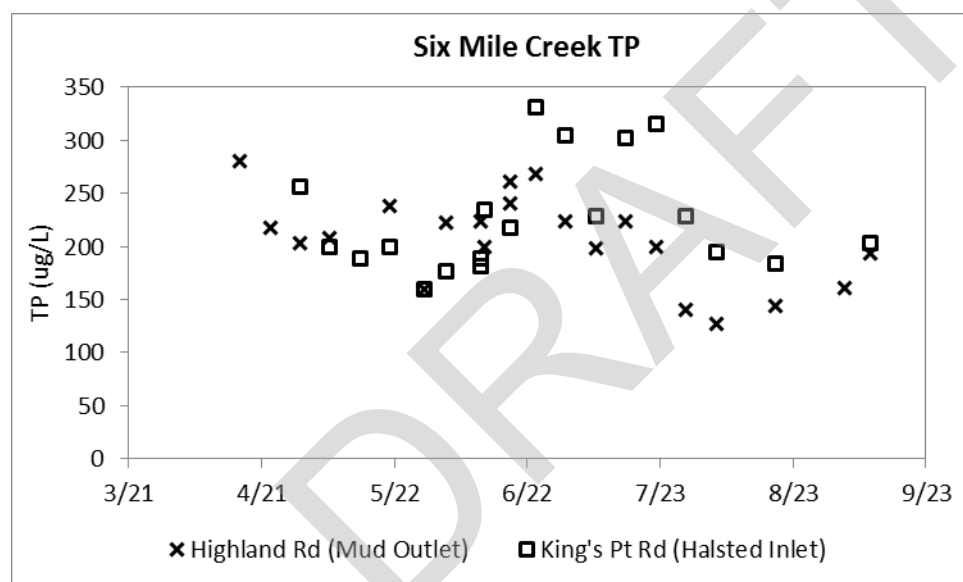


Figure 4-5. 2013 Six Mile Creek TP data.

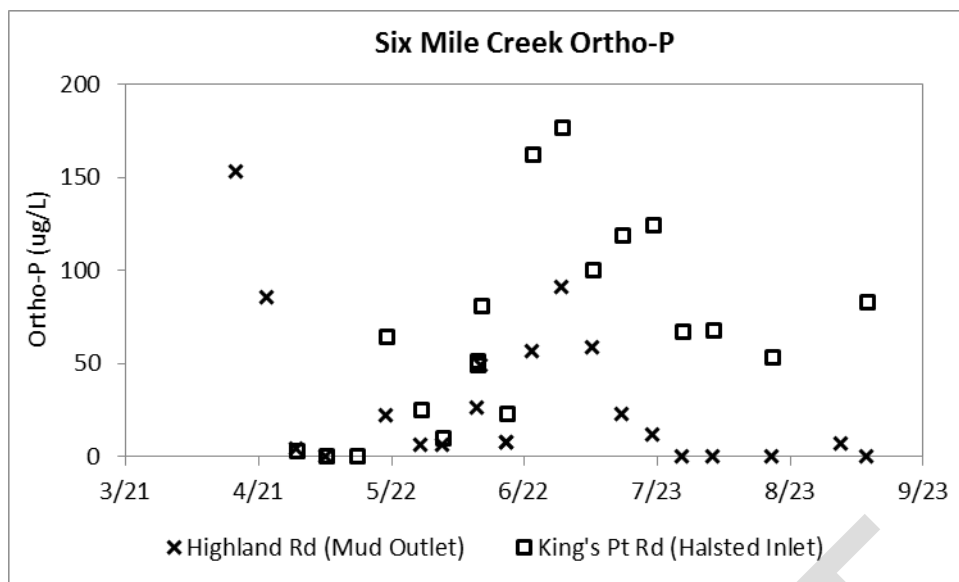


Figure 4-6. 2013 Six Mile Creek Ortho-phosphorus data.

Sediment cores were collected from the channel that flows through Six Mile Marsh in May 2013 to determine potential phosphorus release from the marsh's sediments. Results indicate moderately high phosphorus loading under both oxic and anoxic conditions further suggesting that the marsh could be a potential phosphorus source to Six Mile Creek and Halsted Bay (Table 4-1). Thus, sampling at both monitoring stations should continue to determine potential phosphorus loading from Six Mile Marsh during the late summer months when water temperatures increase and flow in Six Mile Creek is significantly lower.

Table 4-1. Six Mile Marsh sediment phosphorus release.

Site	Oxic Release (mg/m ² /day)	Anoxic Release (mg/m ² /day)
WET 110-C	5.7	5.9
WET 110-R	1.0	2.7
WET 120-L	2.9	7.2

4.2.3.3 Watershed Phosphorus Load

Phosphorus loading to Halsted Bay from Six Mile Creek was calculated by multiplying Mud Lake outlet station's annual flow weighted mean TP concentration by the modeled flow volume estimated by the XPSWMM at the outlet to Halsted Bay. No phosphorus data has been collected in the direct watershed or the tributary north of Six Mile Creek. Thus, phosphorus loads from these subwatersheds were estimated using the Mud Lake outlet flow weighted mean TP concentration and XPSWMM model runoff depths.

4.2.4 Internal Loading

Over time, basins tend to accumulate phosphorus in their bottom sediments. One of the primary bonds for phosphorus is with iron. When oxygen is depleted near the sediment surface (water concentration

less than 2.0 mg/L), phosphorus-iron bonds and other chemical bonds are broken, releasing dissolved phosphorus for transport into the water column. This phosphorus is in a dissolved form that is readily available to algae and plants.

Internal phosphorus loading from sources already in basins has been demonstrated to be an important aspect of the phosphorus budgets of basins. However, measuring or estimating internal loads can be difficult, especially in shallow lakes that mix several times throughout the year and in deep lakes that have long fetches and deep mixing depths. To estimate internal loading, an anoxic factor (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments, is estimated from the dissolved oxygen profile data. The anoxic factor is expressed in days but is normalized over the area of the lake. Once the anoxic factor has been calculated, an oxic factor may be estimated which represents the number of days the lake's sediments are well oxygenated (oxygen concentration greater than 2.0 mg/L). For Halsted Bay, the oxic factor was calculated by subtracting the length of the summer growing season (122 days) by the anoxic factor. This calculation assumes the lake's sediments shift between oxic and anoxic conditions throughout the summer growing season. The anoxic and oxic factors are then used along with anoxic and oxic sediment release rates to estimate the total phosphorus load from the sediments. Sediment release rates were estimated by collecting sediment cores in the north and south basins of Halsted Bay and incubating the sediment in the lab under oxic and anoxic conditions (James, 2012; Appendix B). The laboratory measured rate of phosphorus release from anoxic and oxic sediments for each basin are presented in Table 4-2. These rates were then multiplied by the total area of each basin to estimate the gross internal load for each basin.

Table 4-2. 2005-2011 average annual internal load estimates for Halsted Bay.

Basin	Oxic Release (mg/m ² /day)	Anoxic Release (mg/m ² /day)	Oxic Factor (days)	Anoxic Factor (days)	Total Internal Load (lbs/year)
Halsted North	3.6	11.0	87	35	2,041
Halsted South	1.6	8.0	103	19	664
Total	2.7	10.1	93	29	2,705

4.3 PHOSPHORUS BUDGET AND LOAD REDUCTIONS

The following is a description of the primary sources of phosphorus to Halsted Bay based on the phosphorus source inputs and lake response (BATHTUB) modeling.

4.3.1 Lake Phosphorus Budget

Average annual phosphorus budget for model years 2005-2011 is presented in Figure 4-7. Loading from the Halsted Bay drainage area, particularly Six Mile Creek, represents a majority of the annual TP load to the lake. Internal load from the lake's sediments represents the second largest source of TP. Internal load can play a significant role during the warm summer months when TP load from the watershed is low. Phosphorus inputs from the atmosphere and groundwater each account for only 2% of the overall budget.

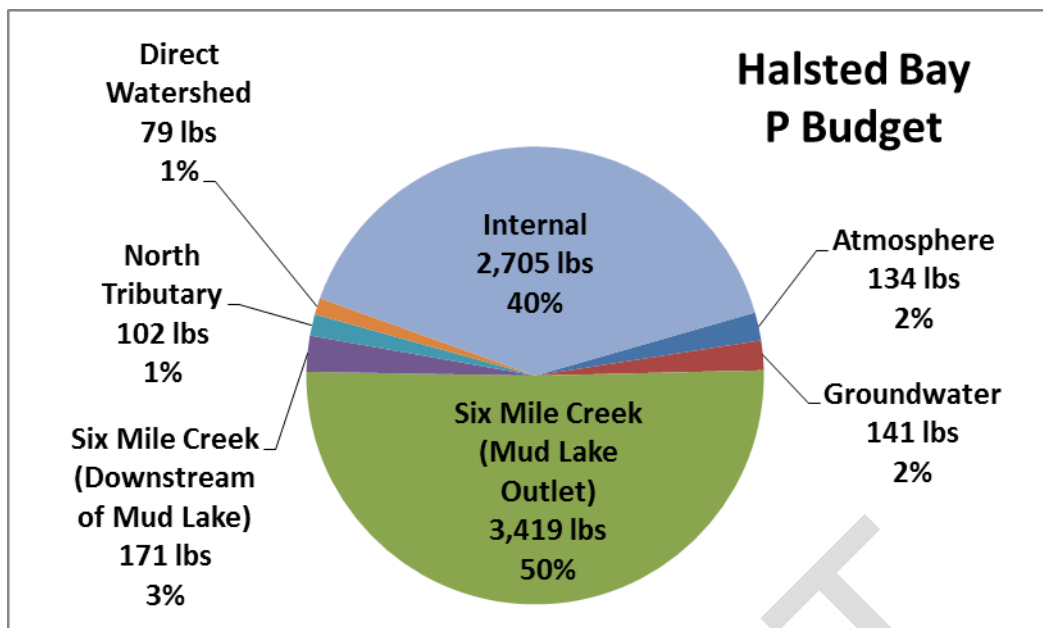


Figure 4-7. Halsted Bay phosphorus budget.

4.3.2 BATHTUB Model

Once the nutrient budget has been developed, the response of the lake to those nutrient loads must be established. The focus of the lake response modeling is on total phosphorus, chlorophyll-a and Secchi depth. For Halsted Bay, the BATHTUB model was selected to link phosphorus loads with in-lake water quality. A publicly available model, BATHTUB was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). BATHTUB has been used successfully in many lake studies in Minnesota and throughout the United States. BATHTUB is a steady-state annual or seasonal model that predicts a lake's summer (June – September) mean surface water quality. BATHTUB's time-scales are appropriate because watershed phosphorus loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. BATHTUB has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions.

Halsted Bay BATHTUB lake response model was constructed using the nutrient budget methods and results previously described in this section. In-lake phosphorus data for Halsted Bay was available from 2005-2011, therefore these years were used to validate the assumptions of the model. Several models (subroutines) are available for use within the BATHTUB model. The selection of the subroutines is based on past experience in modeling lakes in Minnesota and is focused on subroutines that were developed based on data from natural lakes. The Canfield-Bachmann natural lake model was chosen for the phosphorus model. For more information on these model equations, see the BATHTUB model documentation (Walker 1999) or the MPCA report (MPCA 2005). Halsted Bay lake response model performance is summarized in Figure 4-8. Seven years were modeled for TP and the model predicted within 2% - 17% of the in-lake monitored TP values. Lake models are included in Appendix C.

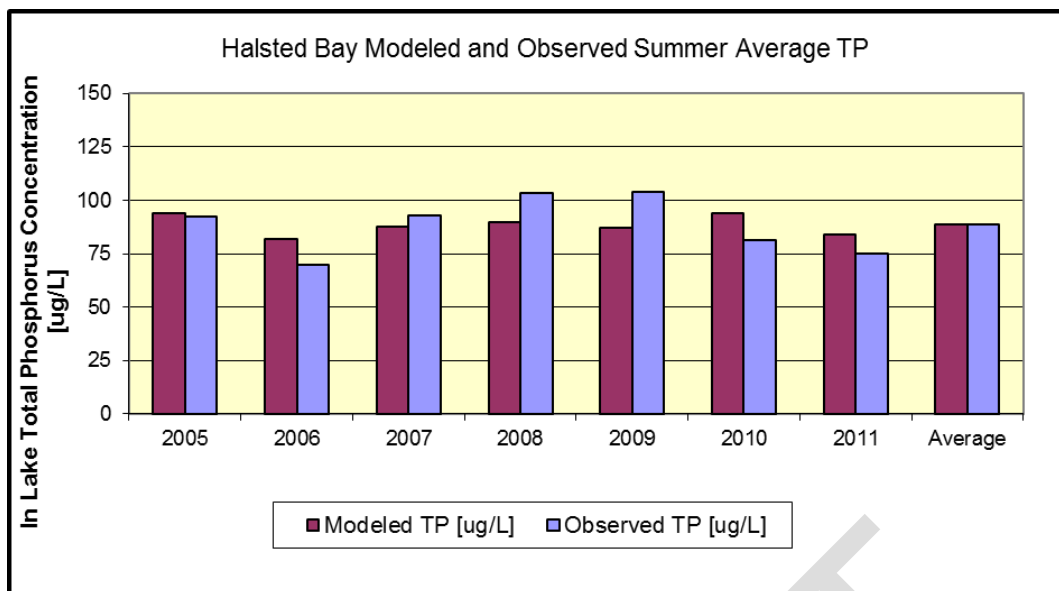


Figure 4-8. Observed versus BATHTUB model-predicted total phosphorus for Halsted Bay.

4.3.3 Phosphorus Load Reductions

To determine the required phosphorus loads to meet State water quality standards for deep lakes in the North Central Hardwood Forest Ecoregion (NCHF; Table 4-3), the average condition model run (2005-2011) phosphorus budget was used to determine the response of Halsted Bay to total phosphorus reductions.

Table 4-3. Numeric water quality goals for Halsted Bay.

Intended Use	Average June-September Values		
	Total Phosphorus (µg/L)	Chlorophyll- <i>a</i> (µg/L)	Secchi Depth (m)
Indirect Contact Recreation	≤40	≤14	≥1.4

First, internal phosphorus loading was reduced to a rate of 0.7 mg/m²/day based on other reference lakes. Then, watershed loads were reduced until the baseline lake response model predicted a summer average of 40 µg/L total phosphorus.

To meet this water quality goal, modeling suggests a total reduction of 4,459 pounds of phosphorus loading to Halsted Bay needs to occur with 2,181 pounds coming from the watershed and 2,278 pounds reduction through internal loading. The majority of watershed loading comes from Six Mile Creek through Mud Lake. Therefore, the restoration of Mud and Parley Lake is critical to the restoration of Halsted Bay. Table 4-4 breaks the watershed loading into subwatershed reduction requirements.

Table 4-4. Halsted Bay TP load reductions.

Source	Existing TP Load ¹	TP Load at 40 µg/L	Load Reduction	
	(lbs/year)	(lbs/year)	(lbs/year)	%
Drainage Areas (Six Mile Marsh, north tributary and direct watershed)	353	171	182	52%
Upstream Lakes (Mud Lake @ 60 µg/L)	3,419	1,421	1,999	58%
Atmosphere	134	134	0	0%
Groundwater	141	141	0	0%
Internal Load	2,705	427	2,278	84%
TOTAL	6,753	2,294	4,459	66%

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5.0 IDENTIFICATION OF BEST MANAGEMENT PRACTICES

5.1 INTRODUCTION

The purpose of this Feasibility Study was to assess engineering alternatives to reduce nutrient loading to Halsted Bay and ultimately improve water quality.

5.2 ALTERNATIVES NOT FURTHER ASSESSED

The first step in the process was to eliminate alternatives that are not feasible or cost effective. Four alternatives were determined to be either infeasible or too costly to implement. Those alternatives are further described below.

5.2.1 Abstraction by Deep Infiltration

Abstraction by deep infiltration requires a significant area with high infiltration and percolation capacity. This alternative was eliminated due to lack of areas in the lower part of the Halsted Bay watershed that have these characteristics.

5.2.2 Temporary Drawdown of Halsted Bay

One of the standard restoration techniques for shallow lakes to restore submerged aquatic vegetation is whole lake draw down. Drawdowns typically occur during the summer months (June through September) and expose as much sediment as feasibly possible. Winter drawdowns are also used at times; however these are more targeted at Curly Leaf Pondweed control. Halsted Bay is not a typical shallow lake (max depth >15 feet or more that 85% less than 15 feet), and will likely not respond as strongly to a drawdown as a more traditional shallow lake, although plant establishment will be necessary for long term restoration of the bay. Drawdown is also very difficult due to the large contributing watershed to the bay as well as the connection to Lake Minnetonka. Since Halsted Bay is a highly used recreational lake and the overall efficacy of drawdown appears to be limited, this option was eliminated from consideration.

5.2.3 Microtunnel Bypass from Lundsten

Microtunneling a waterway underground from Lundsten Lake to Halsted Bay was initially considered. This waterway would allow Halsted Bay inflow to bypass Parley Lake, Mud Lake, and the large wetland between Mud Lake and Halsted Bay. This would reduce phosphorus in Halsted Bay by eliminating most of the phosphorus entering the bay from Six Mile Creek. The problem with this option is that it is very costly (approximately \$23 million) and not likely feasible in terms of permitting or public approval.

5.2.4 Dredging Hypolimnion Sediments

Due to the high phosphorus concentration in the sediments of the hypolimnion, dredging the hypolimnion is an option for restoration. Dredging is enticing as it would physically remove the phosphorus, rather than suppressing the effects of high phosphorus concentration (aeration, alum dosing, alum injection). It has historically been considered for Jennings Bay, but not recommended due to the same considerations below.

The depth of the high concentration of phosphorus in the sediment is relatively unknown and may extend to depths greater than six feet. A cost estimate for eight feet of dredging results in \$30 million. In addition, the disposal of the dredged slurry becomes a significant obstacle. Setting up detention basins close to Halsted Bay would require the purchasing land for large, open basins. There would be an odor concern to the surrounding residents.

Due to cost, relatively unknown phosphorus concentration at depths greater than six feet, and the land considerations, this alternative was eliminated.

5.3 ALTERNATIVE THAT NEEDS MORE INFORMATION

5.3.1 Hydrologic Restoration of Six Mile Marsh

There is some evidence, based on historical modeling, that Six Mile Marsh may be contributing phosphorus to surface waters as water moves from Mud Lake into Halsted Bay. Recent monitoring (2013) has not validated phosphorus release from Six Mile Marsh (see Section 4.2.3.2) but the sediment did demonstrate significant phosphorus release under both oxic and anoxic conditions. Since restoring Six Mile Marsh may be a very expensive project, further data and analysis are required prior to assessing the feasibility of this project to Halsted Bay. If the marsh is verified as a significant nutrient source to surface waters, a diagnostic study needs to be completed to identify the mechanism causing the wetland to export phosphorus so that an appropriate solution can be developed. One current theory for wetlands that export phosphorus is that the hydrology of the wetland has been significantly altered such that the soil wet and dry cycles are extended increasing the phosphorus release from the soils.

The District is currently monitoring Six Mile Marsh for flow and water quality to help determine if the marsh is really a significant source of phosphorus. If the wetland is determined to be a net phosphorus exporter, further monitoring and study may be required including piezometers, groundwater wells, and other water quality monitoring to determine an appropriate solution for Six Mile Marsh.

5.4 SELECTED ALTERNATIVES – INTERNAL LOAD

Five alternatives were evaluated for internal nutrient controls.

5.4.1 Alum Treatment of Halsted Bay

Internal phosphorus loading accounts for 40% of the phosphorus budget to Halsted Bay or roughly 2,705 pounds. An 84% reduction (2,278 pounds) is targeted for internal load reduction for Halsted Bay to meet water quality goals. It is important to note that internal nutrient load reductions alone will not achieve water quality goals for Halsted Bay.

One approach to reduce or eliminate internal phosphorus loading in lakes is chemical addition to permanently bind phosphorus in a form unavailable for algal uptake. Currently, the most common chemical used to permanently bind phosphorus is aluminum sulfate or alum. The alum phosphorus bond is insensitive to sediment redox processes keeping the phosphorus from releasing into the water column even if sediment becomes anoxic. Furthermore, research demonstrates that the longer the alum is in the lake sediment, the more stable it becomes, assuring the long term viability of phosphorus sequestration.

The process of applying alum to a lake typically includes injection of liquid alum just below the surface of the lake. The alum quickly forms a floc and settles to the bottom of the lake, forming a sediment seal while stripping phosphorus from the water column on the way down to the sediments. The undisturbed floc provides a sediment barrier that binds any phosphorus released from the sediment, essentially eliminating internal phosphorus loading from that portion of the lake.

To evaluate the appropriateness and cost of an alum treatment in Halsted Bay, Wenck, in conjunction with the University of Wisconsin-Stout, collected sediment cores from numerous locations in Halsted Bay. The cores were transported back to the University's lab and analyzed for sediment chemistry, phosphorus release under both anaerobic and aerobic conditions, and alum binding efficiency (UW-Stout 2013). More details on the methods used for alum dosage calculations can be found in Appendix B.

Two scenarios were evaluated for alum treatment to Halsted Bay including Scenario 1 where only the area of the lake that experiences anoxia is treated (Figure 5-1), and Scenario 2 where additional areas of aerobic phosphorus release is high are also treated (Figure 5-2). Scenario 1 is the more traditional approach with alum that targets the areas of the lake that have the potential to go anoxic. This approach can reduce internal loading by approximately 1,308 pounds, only a little more than half of the target reduction. This is because the shallower areas demonstrated a relatively high oxic (aerobic) release rate. If the shallow western areas (6 to 14 feet) are also targeted for alum, an additional 599 pound reduction can be achieved. The long term effectiveness in the shallower areas will likely be less than the deeper areas due to fish activity and wind resuspension (5 to 10 years). However, the treatment may help establish submerged aquatic vegetation that will stabilize and protect sediments from mobilization lengthening the benefits of the alum treatment. The ability to treat the shallow areas of the lake presents a stark advantage over other internal load approaches that only address the anoxic areas of the lake.

Multiple treatments of lower alum concentrations over a period of years (i.e., 1-2 year intervals) have been successful (Tiefwareensee, Germany) and have merit as a viable treatment schedule for Halsted Bay. First, splitting the overall alum dosage into 2 or 3 years would ensure that application does not lower pH temporarily to < 6.0. Second, costs are spread out over a period of several years and may be easier to finance. Third, since each incremental dosage is low relative to the final target dose, the alum floc has a greater chance of becoming saturated with sediment phosphorus immediately after application. Other research has suggested that alum binding efficiency for phosphorus declines with time as the alum reacts to form more orderly $Al^{+}(OOH)$ polymer chains (Berkowitz et al. 2005, de Vicente et al. 2008). Sediment redox-phosphorus and aluminum-bound phosphorus could be monitored after each application for effectiveness in control of sediment phosphorus. Subsequent alum applications might ultimately be lower if previously applied alum flocs have efficiently inactivated most of the redox-phosphorus in the surface sediment layers, resulting in overall cost savings. To ensure this

approach can be considered, we used a 7% mobilization cost that should be sufficient to cover multiple applications.

Regulatory Considerations

Currently, there are no required permits to conduct an alum treatment on a lake in Minnesota; however the Minnesota Pollution Control Agency does request a letter outlining the project details for their review. The MPCA requests that the letter address the prescribed alum dose, pH considerations and other projects being considered to address external loading as well as internal loading. The MPCA continues to work toward developing a permitting process for alum treatments in Minnesota.

5.4.2 Hypolimnetic Aeration with Chemical Injection

Lake hypolimnetic aeration controls internal loads by aerating hypolimnetic waters (cold, dense water trapped at the bottom of a deep lake) to maintain oxic (oxygenated) conditions in the hypolimnion and sediment surface. It is the anoxic (no dissolved oxygen) condition of the hypolimnetic sediments which contribute to the internal phosphorus load. Hypolimnetic aeration only aerates water of the hypolimnion without causing it to mix with the epilimnion. This prevents the lake from destratifying and limits the amount of water to be aerated.

For this alternative, various aeration units would be placed throughout the bay. Diffused air would be introduced at the bottom of the aerator in the hypolimnion. The buoyancy of the air-water mixture lifts the water through the central pipe to the top of the aerator. The air bubbles leave the water and are vented to the water surface, while the oxygenated water returns to the hypolimnion by sinking through the external tube.

Addition of ferric chloride (an iron salt) solution may be necessary if iron becomes the limiting constituent in the deactivation of soluble phosphorus release. Therefore, both aeration and ferric chloride lines (other chemicals can be used too) would be installed in the lake during the initial construction.

Some additional implementation and design issues would need to be considered. For instance, the location and number of aeration units would need to be refined through further analysis. Also, the project team would need to determine if the aeration could take place year round. If aeration is used through the winter, it has the disadvantage of destroying ice cover or causing open water, posing a hazard for winter bay use. If year-round aeration is not an option, storage of the aeration units would need to be investigated. Therefore, additional safety measures or an increase of operation and maintenance practices will have to be factored into the final design.

Regulatory Considerations

A hypolimnetic aeration project would likely require review and comment from several local and state agencies. Two permits are required from the Minnesota DNR for a hypolimnetic aeration project. The first is from the Division of Fisheries. The second is the General Work in Public Waters Permit. The typical timeframe to acquire a General Work in Public Waters permit is 60 days. However, depending on the complexity of the project and the potential for controversy with the lake shore residents and/or general public the permitting process could take considerably longer. Typical processes for obtaining these permits can last from a period of many months to many years and involve a technical advisory

committee to approve final design. DNR shoreline set-back requirements may apply to certain aspects of the project construction. The MPCA would also need to review the project in conjunction with the DNR permit.

5.4.3 Withdrawal, Alum Treatment, and Replacement

Hypolimnetic withdrawal is where anoxic bottom water is removed from the lake and either discharged downstream or treated and returned to the lake. In this alternative the water would be returned to the lake to minimize an overall decrease in lake water volume. Water would be pumped out of the hypolimnion into a pump house constructed on shore. A force main would be laid on the bottom of the lake with a screen at the intake.

Once water reaches the pump house, it is aerated over a cascade of concrete weirs into a basin. The water in the hypolimnion of Halsted Bay likely contains hydrogen sulfide (H_2S) and the aeration process releases hydrogen sulfide (H_2S) gas into the air, creating a very potent “rotten egg” smell. Due to the close proximity of residential neighborhoods, the hydrogen sulfide gas would need to be reduced to a suitable level before leaving the pump house. To reach this level, a series of air filters will be required. Along with the air filters in the pump house building, air monitoring equipment will also be required because even at low concentrations, hydrogen sulfide is potentially dangerous to maintenance personnel working in the building.

Dosing for this option will vary from the amounts calculated in Section 5.4.1 as the dosages for this option are based on water quality and not soil chemistry. More detailed methods including bench testing should be used to develop specification if Withdrawal and Alum Treatment is the internal load reduction option selected. Also, in-lake alkalinity and pH would need to be examined on a detailed level. If an inappropriate alum dose is used and the pH of Halsted Bay drops below 6.0, aquatic toxicity may occur which would be harmful to aquatic life. Application of a buffer solution, such as liquid sodium aluminate, may be required to keep pH levels above the toxicity threshold.

The long-term effectiveness of this method of alum treatment is determined by several factors including depth of treatment, presence of rough fish, long term storage and release of phosphorus in sediments, external loading rates, and application or injection techniques.

Regulatory Considerations

Hypolimnetic withdrawal implementation would require a General Work in Public Waters permit. The typical time frame to acquire a General Work in Public Waters permit is 60 days. However, depending on the complexity of the project and the potential for controversy with the lake shore residents and/or general public the permitting process could take considerably longer. Typical processes for obtaining these permits can last from a period of many months to many years and involve a technical advisory committee to approve final design. DNR shoreline set-back requirements may apply to certain aspects of the project construction. The MPCA would also need to review the project in conjunction with the DNR permits.

Additionally, a Water Appropriations permit will be necessary for the withdrawal of water, even if the water is being pumped back into the bay. However, a permit through the Minnesota DNR’s Division of Fisheries for a Partial Drawdown Waters Work permit will not be necessary.

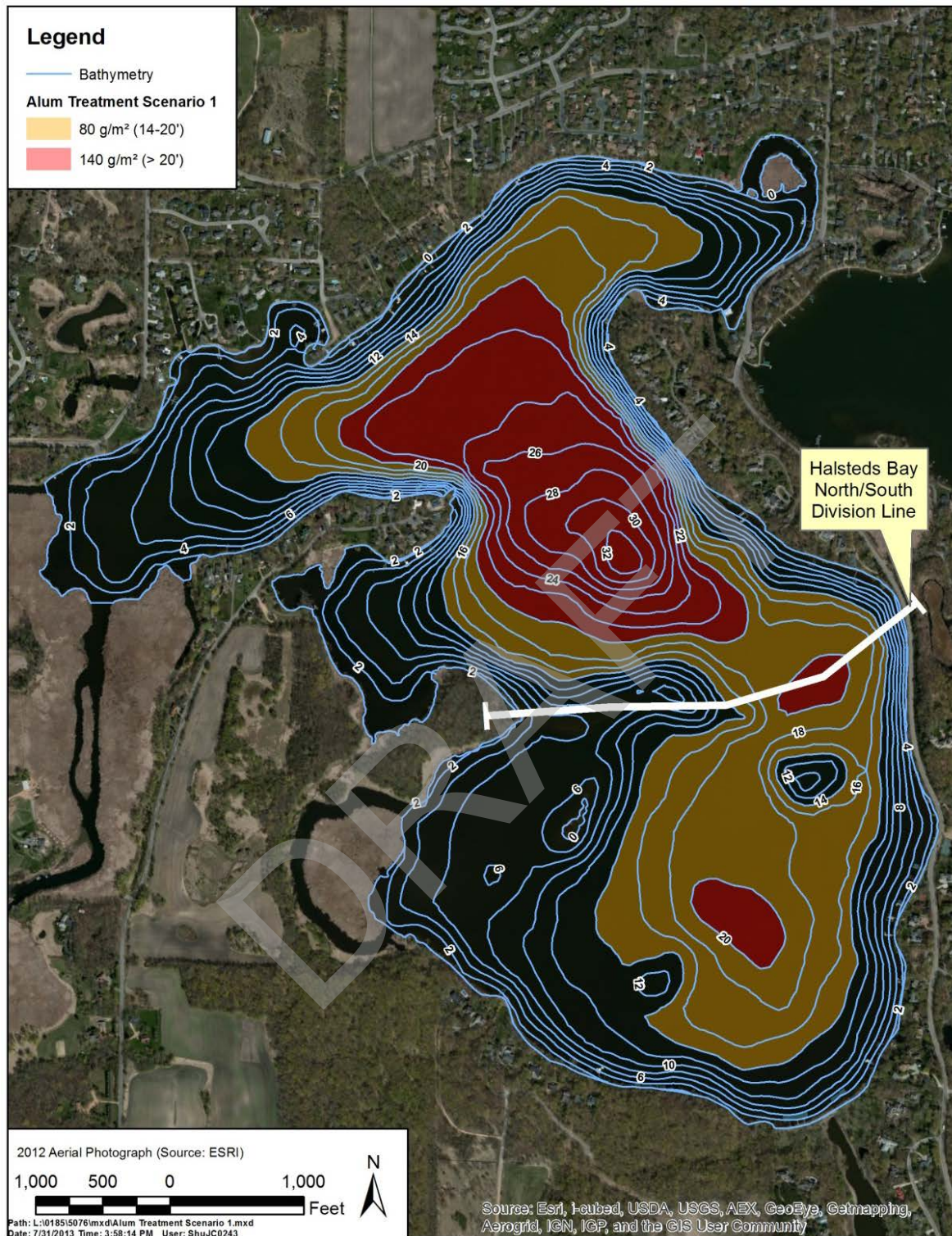


Figure 5-1. Scenario 1: Alum treatment in the anoxic areas of Halsted Bay.

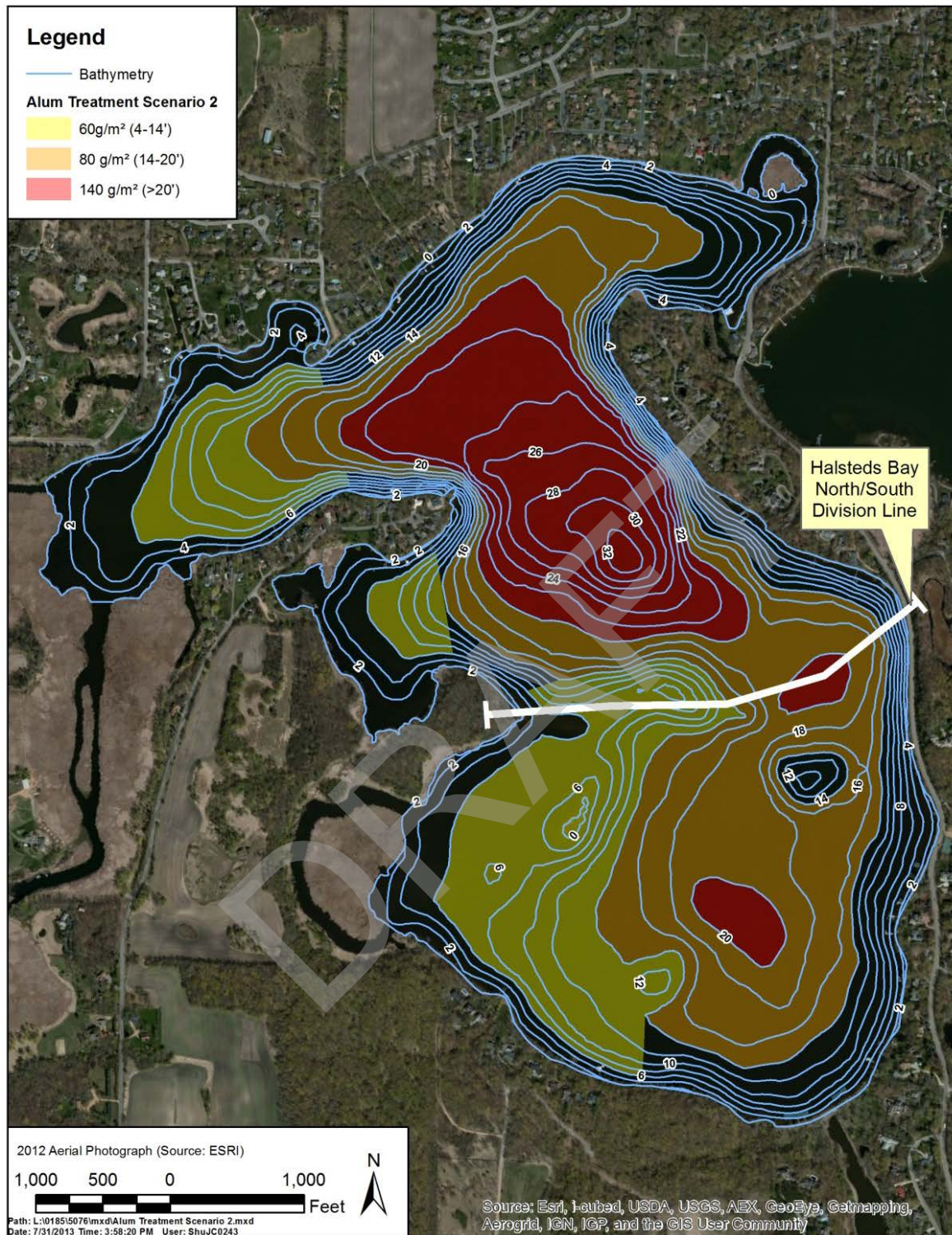


Figure 5-2. Scenario 2: Alum treatment in the anoxic and shallow western areas of Halsted Bay.

5.5 SELECTED ALTERNATIVES – EXTERNAL LOAD CONTROL

5.5.1 Off-line Alum Treatment

The off-line treatment alternative consists of a clarification system designed to remove phosphorus from the creek water entering Halsted Bay. The phosphorus is removed through the addition of a flocculant (alum) to the influent creek water to create large particles (floc) containing the phosphorus. The influent travels through the clarifier where the floc settles to the bottom, leaving cleaner water (effluent) near the top of the clarifier. The effluent is then discharged into Halsted Bay while the floc is disposed of through a sanitary sewer or to holding ponds.

For this alternative, raw water would be drawn from an intake structure placed at the bottom of Six Mile Creek. The water would be pumped to a splitter box which would control the flow rate to two 48-foot diameter clarifiers. Each clarifier would be equipped with a perimeter rake on the bottom of the structure and perimeter skimmer on the top of the water. The rake assists with the sludge disposal while the surface skimmer removes surface floc and prevents it from being discharged to Halsted Bay.

The plant would be designed for a flow rate of 5 cfs (2,250 GPM). At this rate, it is estimated that approximately 11,000 gpd of sludge would be generated. The sludge discharge rate from the clarifier is greater than the capacity of the two lift stations and therefore, two equalization tanks would be used to temporarily store sludge flow. The sludge would then be discharge to a sanitary sewer or to holding ponds.

Regulatory Considerations

The City of Minnetrista owns and operates the local wastewater collection system, but ultimately conveys its wastewater to MCES interceptor sewers that transport wastewater to regional treatment plants for final disposal. MCES requires an industrial discharge permit for all facilities using water in its treatment process and one would be required for this system. Historically, MCES has granted industrial discharge permits for similar facilities, but as phosphorus limits are reduced at their regional treatment facilities, there is a strong possibility permits will not be granted in the future. Additionally, industrial discharge permits are reviewed on a regular basis and MCES can revoke the permit in the future.

In the event MCES does not authorize an industrial discharge permit, a sludge holding pond system would need to be utilized. Sludge ponds would be designed to hold the sludge and allow drying. The ponds would need to be dredged as sludge builds up over time.

The treatment facility would withdraw water from and return it to public water; therefore a National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) permit will be required from the MPCA. Similar facilities have been permitted in the past, and water quality monitoring may be required by the permit (WSB & Associates, 2013).

5.5.2 In-line Alum Injection

In-line alum injection line is very similar to the off-line alum injection, except that it eliminates the need for clarifiers and an intake structure with associated pumps. The in-line injection system would introduce alum to the high-phosphorus concentrated Six Mile Creek flow. The alum would mix with the phosphorus and settle to the bottom of Halsted Bay.

A pump house would still be necessary for this alternative to house the injection pumps and the alum storage tanks, but it would have a much smaller footprint than the off-line alum injection alternative.

Regulatory Considerations

Permitting of in-line alum injection is very doubtful. It will be difficult to convince regulators that continuous injection of alum will not cause environmental impacts downstream.

5.5.3 Iron Filtration

Iron filtration involves passing phosphorus rich water through a sand and iron particle filter. Iron reacts with the phosphorus and removes it from the water. For this alternative, it is assumed 15 cfs of water from Six Mile Creek is pumped to a 15-acre lined, sand/iron filtration area. Once the water has passed through the filter it is collected in an under drain and routed back to the creek. The cost effectiveness is based on 85 percent removal efficiency.

Regulatory Considerations

Iron filtration is a relatively new best management practice, but it has been used in several locations in the metro area. There are no significant regulatory issues beyond that fact that this system is relatively large. The size may result in local concerns related to its appearance and possible odor.

5.6 OTHER RESTORATION CONSIDERATIONS

The projects evaluated in this report are focused on phosphorus reductions since these will have the greatest impact on water quality in Halsted Bay. However, several other factors need to be considered for these projects to be effective and sustainable for the long term. Following is a description of these factors.

5.6.1 Vegetation Management

Submerged aquatic vegetation (SAV) play a critical role in water quality especially in shallow areas of lakes. Submerged aquatic vegetation provide habitat for fish, stabilize sediments preventing wind resuspension and turbid water, and represent a food source and habitat for macroinvertebrates. Halsted Bay lacks a robust SAV population which may inhibit good water quality in the Bay.

Restoration of SAV typically involves whole-lake drawdown to consolidate sediments and invigorate the native seed bank. However, whole lake draw down is not feasible in Halsted Bay due to its littoral depth, large watershed, and recreational uses. Consequently, the best approach for restoring native

vegetation is to improve water clarity and control invasive vegetation so that the native vegetation can establish.

One approach to increasing water clarity is the addition of alum (see Section 5.4.1). The increased water clarity will help the native plants establish, although Curly Leaf Pondweed and Eurasian Water Milfoil will respond too. A vegetation management plan should be developed prior to implementing water quality projects expected to have immediate impacts on water clarity. The invasive plants need to be controlled or they will choke out the natives, decreasing the value of the SAV in the lake. The increased water clarity and SAV abundance may also lead to some recreational constraints for swimming and boat access.

From a water quality perspective, only Curly Leaf Pondweed poses a major threat because it senesces mid-summer exposing sediments for release and resuspension. Management should focus on Curly Leaf Pondweed to protect the investment in the alum application or other internal control measures. There are other reasons to manage Eurasian Water Milfoil, including improved habitat and recreational access, although it is not critical for water quality. This report focuses on the management of Curly Leaf Pondweed.

The two most common approaches for managing vegetation include herbicide applications and mechanical removal. Typically, the most effective approach is a mix of mechanical removal and herbicide application.

5.6.2 Rough Fish Management

One of the keys to restoring Halsted Bay is the restoration of Parley and Mud Lakes as well as ensuring Six Mile Marsh is not discharging phosphorus. Almost 90% of the water entering Halsted Bay comes through Parley and Mud Lakes, exerting a large influence on Halsted Bay.

One of the key considerations for restoring Mud and Parley Lake is the removal and control of carp in the lakes. Carp cause significant damage in shallow lakes, uprooting submerged vegetation, stirring up sediments, and ultimately driving the lake into a turbid state. Carp likely migrate up into Mud and Parley Lake from Halsted Bay through Six Mile Marsh. Consequently, a carp barrier between Halsted Bay and Six Mile Marsh may need to be considered for the long term restoration of Mud and Parley Lakes. However, it is important to note that carp could still move down from the upper watershed through Lundsten Lake. So, restoration needs to focus on both sources.

Wenck reviewed locations for a potential carp barrier between Halsted Bay and Six Mile Marsh. The best location occurs just west of Halsted Bay where a constriction of the creek occurs (see location of new King's Point Road water quality station in Figure 4.4). Another area just north of this constriction may need to be considered for a fish barrier depending on water depths and fish movement potential.

The University of Minnesota is currently working with the District to develop a watershed-wide carp management plan for the Six Mile Creek Watershed. This study will evaluate the long term viability of controlling carp in the watershed and ultimately determine whether there is a need for a carp barrier between Halsted Bay and Six Mile Marsh. However, carp management is critical to restoring Mud and Parley Lake and ultimately Halsted Bay.

6.0 Nutrient Reduction Cost and Effectiveness

6.1 MODELING ALTERNATIVES AND EVALUATING COST/BENEFITS

Table 6-1 provides a summary of the costs related to the selected alternatives presented in this report. Refer to Appendix D for more details on cost estimates.

Table 6-1. Physical Features of Halsted Bay.

Alternative Description	Capital Cost	20-Yr Life Cost	Phosphorus Removal	
			(lbs/yr)	(\$/lb-yr)
Internal Alternatives (2,278 lb Annual P Reduction Goal)				
Alum Treatment of Halsted Bay - Scenario 1	\$1,046,000	\$1,054,000	1,308	\$40
Alum Treatment of Halsted Bay - Scenario 2	\$1,134,000	\$1,142,000	1,907	\$30
Hypolimnetic Aeration with Chemical Injection	\$1,112,000	\$2,672,000	1,308	\$102
Hypolimnetic Withdrawal, Alum Treatment, and Replacement	\$8,277,000	\$11,577,000	1,308	\$443
Hypolimnetic Alum Circulation	\$1,663,000	\$4,363,000	1,308	\$167
External Alternatives (2,278 lb Annual P Reduction Goal)				
Off-line Alum Injection	\$7,728,000	\$13,932,568	1,617	\$431
In-line Alum Injection	\$851,000	\$1,060,000	1,396	\$38
Iron Filtration	\$4,789,000	\$5,490,000	900	\$305
Other Restoration Considerations				
Fish Migration Barrier	\$109,000	\$204,000	Does not remove P, but is necessary for lake restoration.	
Vegetation Management	\$0	\$396,000		

6.1.1 Internal Load Reductions

The most cost effective approach for reducing sediment phosphorus release from Halsted Bay is sediment phosphorus inactivation using alum. The treatment of hypolimnetic water through an alum injection plant is very expensive and requires significant operation and maintenance over a 20 year life cycle. Hypolimnetic circulation with alum microfloc addition can achieve similar results as an alum treatment, but requires significant long term operation and maintenance costs versus an alum treatment. The only advantage to this approach is that the certainty of eliminating phosphorus flux to the epilimnion is much higher because you are continually dosing the hypolimnion and stripping phosphorus out of the water column. However, treating the sediments with alum provides the advantage of treating the shallow areas that demonstrated significant phosphorus release. Also, even of the alum treatment needs to be repeated at year 10 at the full dose (which is unlikely), the overall treatment cost is still significantly less than the microfloc addition. Alum treatment of sediments including identified shallow areas appears to provide the best long term control of internal phosphorus release at the lowest cost.

6.1.2 External Load Reductions

Of the three external load reductions alternatives, only off-line alum treatment and iron filtration are likely to get a permit. In-line alum treatment appears to be very cost effective, but there are too many unknown environmental impacts at this point in time.

In comparison to internal load reduction alternatives, external load reduction alternatives are significantly more expensive. These alternatives rely on facilities that are costly and require significant operation and maintenance costs.

Off-line alum treatment may have higher cost effectiveness, but has the advantages of a higher removal capacity and significantly smaller footprint. It should also be noted that the infrastructure required for off-line alum treatment may be used for some of the internal load reduction alternatives as well. The costs in Table 6-1 assume each alternative is separate. If the treatment required in hypolimnetic withdrawal, treatment, and replacement is done in conjunction with off-line alum treatment, the overall cost can be greatly reduced. Only one treatment facility is needed. There will be additional processes to add to accommodate both alternatives in one facility, but these costs are small relative to cost of the building.

6.1.3 Other Restoration Considerations

To restore Halsted bay, two ecological factors must be considered including carp and vegetation management. It is unclear if carp are impacting Halsted Bay currently, but the Bay is devoid of submerged aquatic vegetation, a key component to maintaining good water quality. For Halsted Bay to be ecologically healthy, a healthy submerged vegetation population needs to be established in areas less than 15 feet in depth. The presence of carp can hinder plant establishment and long term establishment of submerged vegetation. Furthermore, the long term restoration of Halsted Bay requires that both Parley and Mud Lake meet water quality standards which are nearly impossible with the current carp populations. Carp can also impact the long term effectiveness of alum in shallower areas because they stir up sediments which can bring phosphorus rich sediment to the surface. Overall, carp management will be critical in establishing long term internal phosphorus load control. To that end, the District is working with the University of Minnesota to evaluate carp in the Six Mile Creek Watershed to identify long term management strategies.

Another factor that must be considered is the presence of invasive species in Halsted Bay including Curly Leaf pondweed and Eurasian Water Milfoil. Curly Leaf Pondweed can have long term negative impacts on water quality in shallow lakes because it senesces in midsummer leaving sediments exposed of phosphorus release and resuspension. Furthermore, as the water clarity is increased through the implementation of nutrient reduction projects, both of the invasive species can be expected to respond with aggressive increases in abundance. Controls should be in place prior to implementing the nutrient reduction projects.

Table 6.1 provides some estimated costs associated with both carp control (if a barrier is needed) and Curly Leaf Pondweed maintenance. Vegetation management is assumed to be chemical and mechanical control of Curly Leaf Pondweed. Costs included for carp management just include the cost of a carp barrier at the outlet of Six Mile Creek if one is determined to be needed. However, long term costs for

removal and management may be necessary. These costs will be much clearer once the University of Minnesota completes their carp study on Six Mile Creek.

6.2 DISCUSSION OF RESULTS

Lake response modeling indicates that both watershed loading and internal loading need to be aggressively pursued to reach the goal in Halsted Bay. One key factor is that 90 percent of the water comes through Mud Lake which only has a target of 60 µg/l while Halsted Bay has a target of 40 µg/l. This means additional reductions may need to be found in other parts of the watershed.

Restoration of upstream Mud and Parley Lakes will be critical in restoring Halsted Bay. Both of these lakes are very shallow and carp infested. To reach water quality goals in these lakes, the carp need to be addressed, plants reestablished in the lakes and nutrients reduced. This is an extensive undertaking.

Addressing external sources, accomplishing the goals of the Six Mile Creek Diagnostic Study, is going to be a long process with uncertain outcomes. The process could take 30 years or more and is dependent on numerous landowners. A large engineering project, such as an off-line phosphorus removal plant, provides the water quality benefits immediately however at a significant cost.

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Appendix

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Appendix A

Water Surface Elevations and Flow Data

Monitoring Locations and Equipment

The water surface elevations were monitored at three locations as shown in Figure A-1. Continuous flow data was also recorded at the Mud Lake Outlet location. The monitoring equipment used at Halsted Bay and Kings Point Road was a BaroTROLL by In-Situ Inc. The monitoring equipment used at Mud Lake Outlet was a SonTek-IQ ADV.



Figure A-1. Monitoring Locations.

Water Surface Survey Data

The change in water surface elevation between the monitoring locations is small. Six Mile Creek between Halsted Bay and Mud Lake (and even Parley just upstream) act as an extension of Halsted Bay. The surrounding lakeshore and marsh are very flat. The data collection systems at Halsted Bay and Kings Point Road require that the data loggers be removed to download information. As a result, offsets occurred in the collected water surface data between each collection period. To correlate, compare, and correct the data collected at the three monitoring locations, multiple survey points were taken to determine the water surface elevation at each location. All three locations were surveyed on the same

day and the average of the survey points was used as the water surface elevation. The surveyed water surface elevations are detailed in Table A-1. Using the time stamps associated with the survey points, the water surface elevation data were matched to the surveyed elevations and corrected for any offsets that occurred in the data during downloads.

Table A-1. Survey data collected on July 23, 2013.

Location	Water Surface Survey Elevation (ft)					Approximate Time Stamp
	Point 1	Point 2	Point 3	Point 4	Average	
Halstead Bay	930.35	930.13	-	-	930.24	2:37pm
Kings Point Road	930.31	930.20	930.22	-	930.24	3:36pm
Mud Lake Outlet	930.39	930.17	930.40	930.27	930.31	3:07pm

Flow Data

Continuous water surface elevation data was collected every 15 minutes at the three monitoring locations. Figure A-2 shows the water surface elevations at the three monitoring locations throughout the monitoring duration. Continuous flow data was also measured every 15 minutes at the Mud Lake Outlet monitoring location using the SonTek-IQ ADV. While collecting measurements, the ADV was unable to collect flow measurements during the period of time from 6/21/2013 through 7/12/2013 because the depth of flow exceeded the limits of the channel geometry input into the ADV. It was also noticed that the SonTek-IQ did not report flow measurements when the mean channel velocity was within the range of approximately 0.1 ft/s to -0.1 ft/s. Within this range, the velocity results were reported as 0 ft/s and the corresponding flow was also 0 cfs. As a result, a low reverse flow could have occurred over periods of time where 0 cfs was reported if the flow did not reach the measureable limits of the ADV.

There is also an inconsistency in the Mud lake Outlet data over the period of time from 5/23 to 6/2 likely due to debris that affected the ADV measurements. The large variations in the Halsted Bay data over the period of time from 6/23 to 7/6 were likely caused by an interference with the measuring instrument. Reverse flow was measured at several different periods of time during monitoring. Precipitation data from the MSP airport was compared to the flow data at Mud Lake Outlet, and it is clear that reverse flow conditions correlate with large precipitation events which can be seen in Figure A-3.

Figure A-4 compares the water surface elevation with measured reverse flow conditions and there is a correlation between abrupt increases in the water surface elevation and measured reverse flow conditions. During the later months of the summer when precipitation was less frequent, the base flow rate lowered to less than 10 cfs and the mean channel velocity dropped to within the range that the ADV did not report velocities and flow rates. During that time, many of the periods of time that report 0 cfs and no measured reverse flows do not indicate the potential of reverse flow. This is especially true if the period of time does not correlate with a precipitation event.

Figure A-5 shows the difference between the water surface elevations at the monitoring stations in Six Mile Creek with the water surface elevations at Halsted Bay. Figures A-6a and A-6b are examples that show the difference in the water surface elevation minimizes during times of reverse flow.

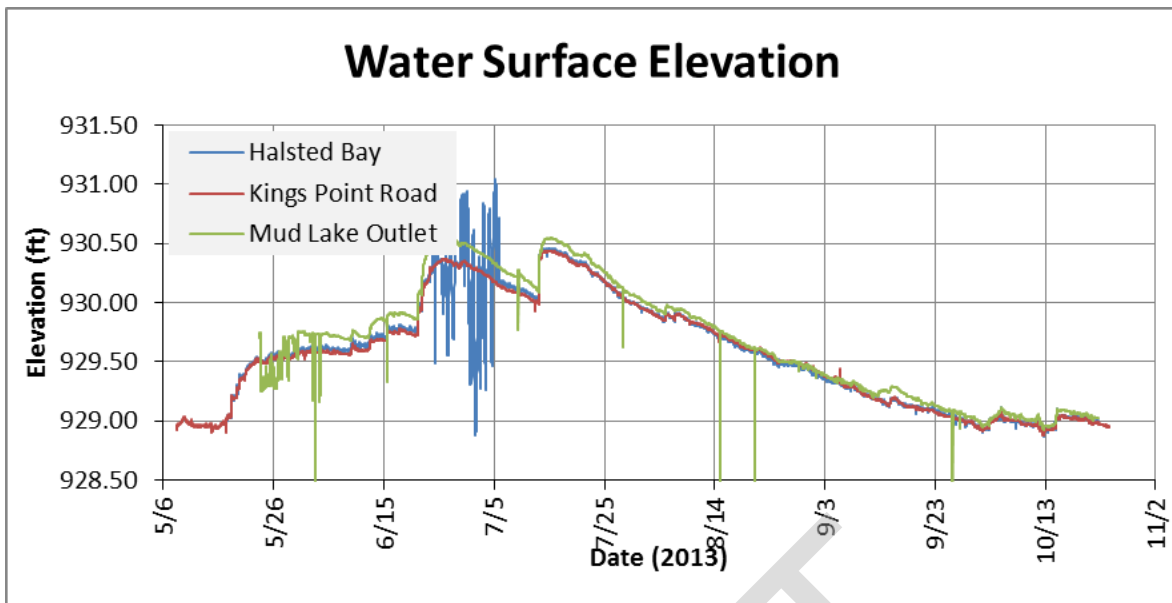


Figure A-2. Water surface elevation comparison.

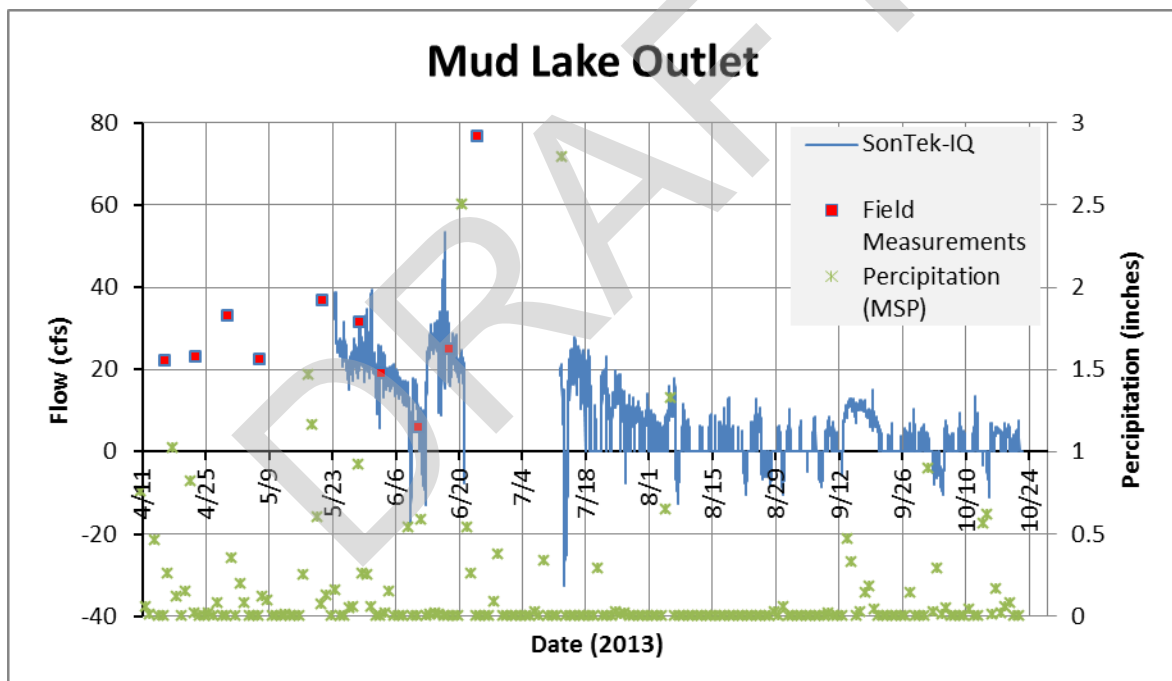


Figure A-3. Mud Lake Outlet flow measurements and precipitation comparison.

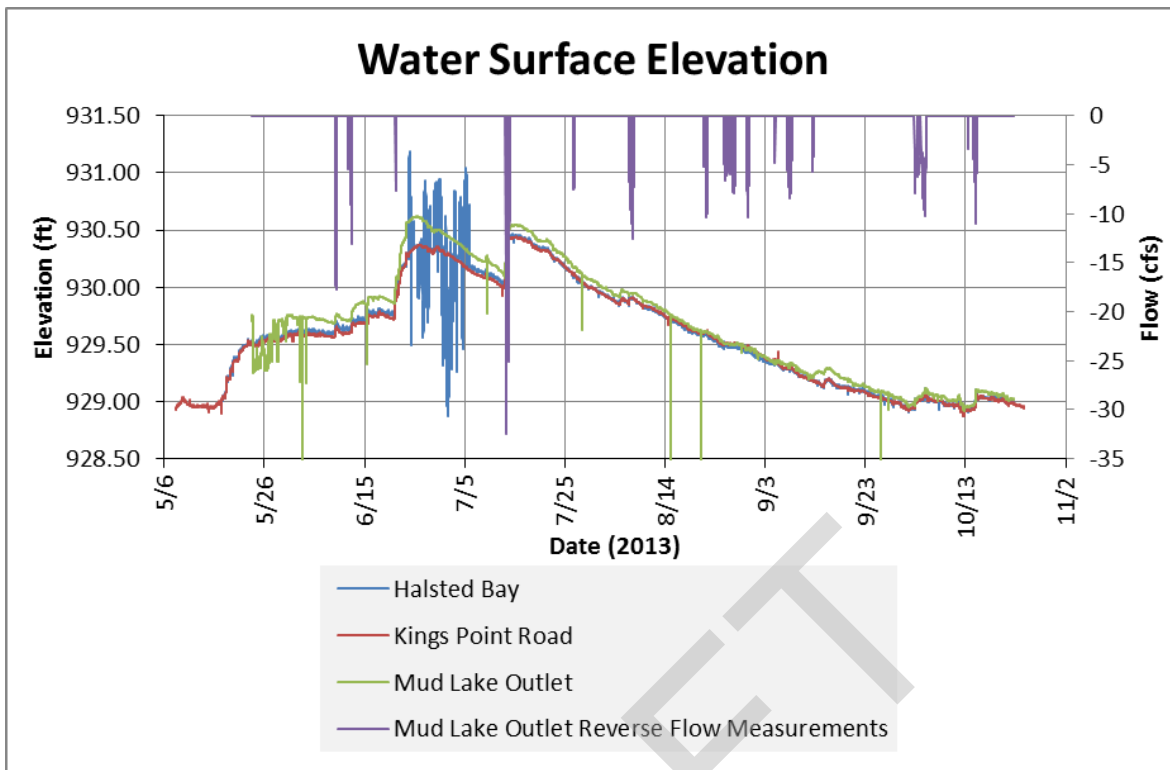


Figure A-4. Water surface elevations compared to measured reverse flow conditions.

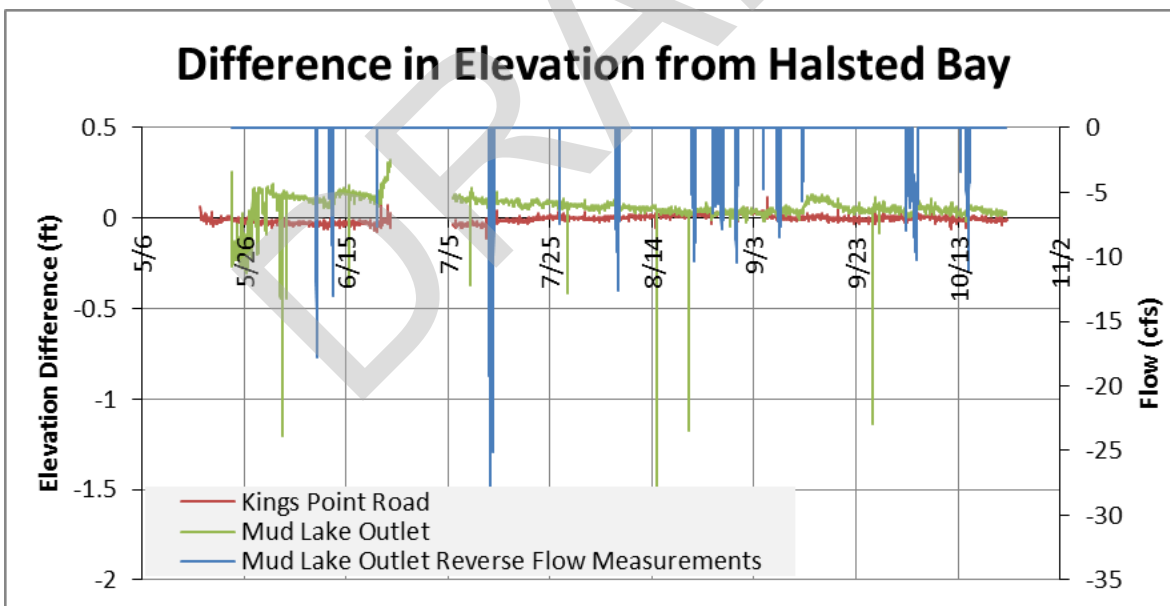


Figure A-5. Difference in Elevation from Halsted Bay.

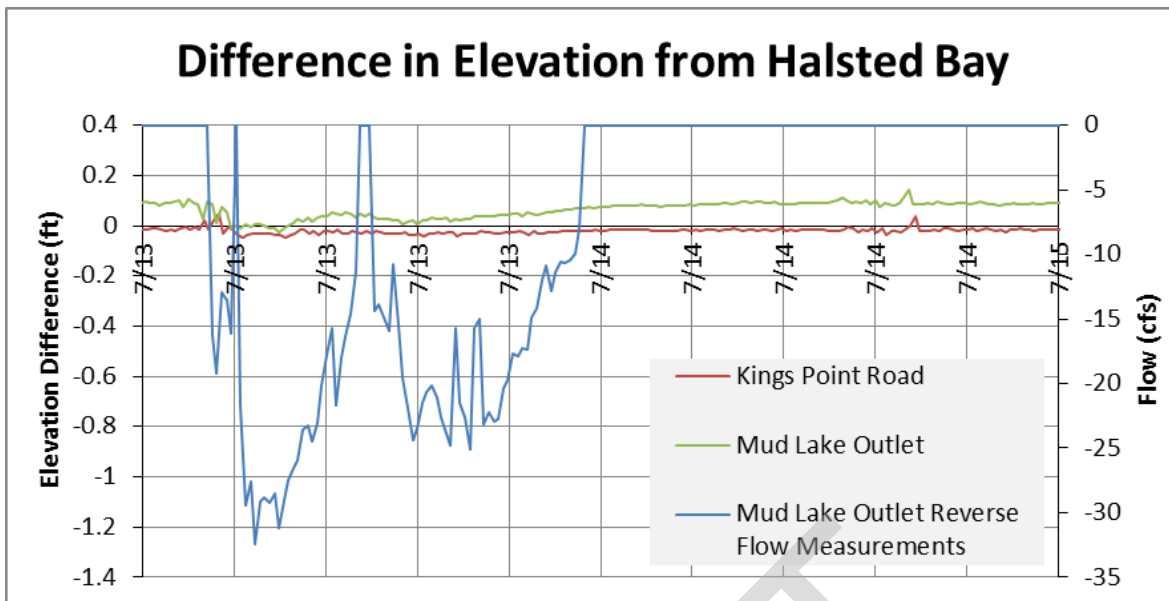


Figure A-6a. The differences in the water surface elevation minimizes during periods when reverse flow was measured.

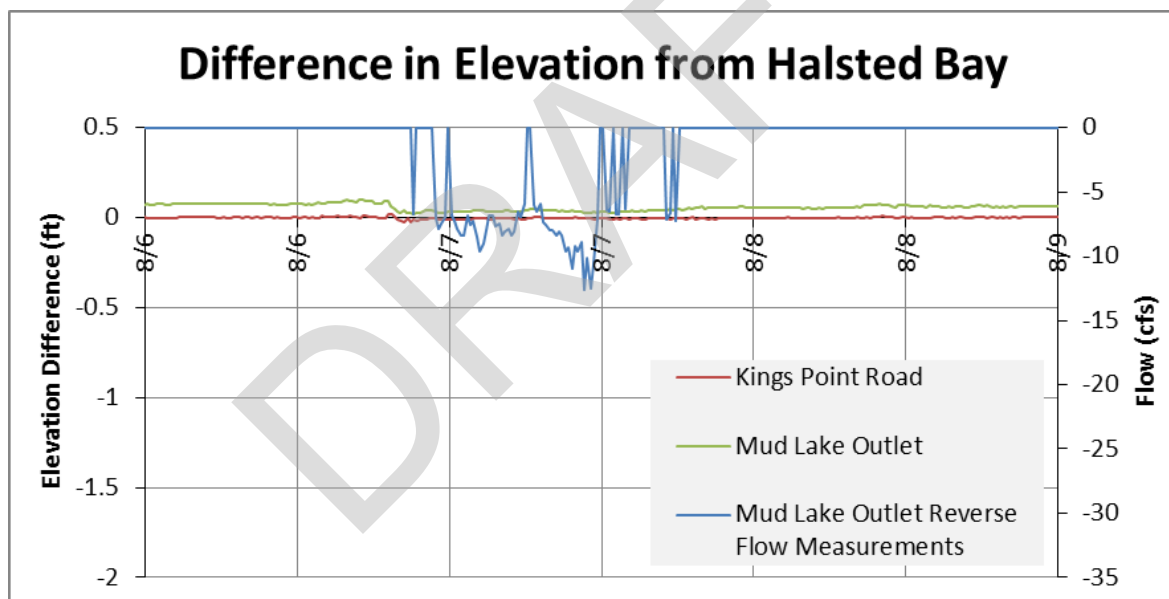


Figure A-6b. The differences in the water surface elevation minimizes during periods when reverse flow was measured.

Appendix B

Alum Dosage Considerations

DRAFT

Alum Dosage Considerations for Halsted Bay, Lake Minnetonka, Minnesota



12 July, 2013

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OBJECTIVES

The objectives of these investigations were to examine rates of phosphorus (P) flux from sediments located in the wetland inlet and in Halsted Bay (Lake Minnetonka, Minnesota) and to estimate the aluminum sulfate dosage required to control sediment anaerobic internal phosphorus (P) loading in the bay. The specific outcomes and deliverables of this research were to,

1. determine rates of P flux from intact sediment cores under laboratory-controlled temperature and redox (i.e., aerobic and anaerobic) conditions,
2. examine vertical variations in biologically-labile (i.e., subject to recycling via Eh, pH, and bacterially-mediated reactions in the sediment; loosely-bound, iron-bound, and labile organic P) and refractory (i.e., relatively inert to recycling and subject to burial) phosphorus fractions from various stations in the bay to estimate the thickness of the sediment layer potentially active in sediment anaerobic internal P loading,
3. estimate aluminum sulfate (as aluminum; Al) dosage for binding redox-sensitive P (i.e., the loosely-bound and iron-bound P fractions) in the upper sediment layer, and,
4. provide a cost estimate for Al treatment based on treatment areas in the bay.

APPROACH

Sediment coring stations and gravity coring methodology

Sediment coring stations in the wetland inlet and Halsted Bay, along with numbers of replicate cores collected, are identified in Table 1 and Figure 1. Three replicate intact sediment cores were collected in the deep north and south basins of Halsted Bay (stations HB 20 and HB 30) for determination of rates of P flux under anaerobic conditions (Figure 2). Stratified conditions and hypolimnetic anoxia develop in the summer at these sites. At the shallow littoral stations HB 40 and 50, triplicate sediment cores were

collected to measure rates of P flux under aerobic conditions. These representative stations were chosen for determination of P release under aerobic conditions because oxygenated conditions generally occur in the epilimnion and at depths < 12 ft throughout the bay during the summer period. Intact sediment cores were also collected in the wetland tributary channel (WET 110-C) and in the wetland complex (WET 110-R and WET 120-L) for P flux measurements.

For evaluation of spatial variations in sediment textural characteristics and biologically labile and refractory P fractions, sediment cores (i.e., one at each station) were collected at all stations in the wetland inlet and Halsted Bay for sectioning in the laboratory. For wetland sediment cores, the upper 10-cm section was examined for sediment constituents listed in Table 2. Halsted Bay sediment cores were sectioned at 5-cm intervals over the upper 10-cm for determination of the same constituents (Table 2).

Sediment cores collected at HB 10, HB 20, and HB 30 were sectioned vertically over the upper 20-cm layer to evaluate the thickness of the active sediment layer associated with internal P loading. Cores were sectioned at 1-cm intervals over the first 4 cm, 2-cm intervals between 4 and 10 cm, 2.5-cm intervals between 10 and 15 cm, and 5-cm intervals thereafter (Table 2). The upper 5-cm section of an additional core collected at each of these stations was used for estimation of Al dosage required to control internal P loading.

A gravity sediment coring device (Aquatic Research Instruments, Hope ID) equipped with an acrylic core liner (6.5-cm ID and 50-cm length) was used to collect sediment in May, 2013. The core liners, containing both sediment and overlying water, were immediately sealed using rubber stoppers and stored in a covered container in a cool location until analysis. Additional lake water was collected for incubation with the collected sediment. Sediment cores were sectioned within 24 hours of collection. Fresh sediment sections were stored in heavy-duty quart freezer bags and refrigerated until analysis.

Rates of phosphorus flux from sediment

Intact sediment cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from the bay was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 to 25 °C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling air (oxic) or nitrogen (anoxic) through an air stone placed just above the sediment surface in each system. Bubbling action insured complete mixing of the water column but did not disrupt the sediment.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of P release from the sediment ($\text{mg/m}^2 \text{d}^{-1}$) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry

A known volume of sediment was dried at 105 °C for determination of moisture content and bulk density and burned at 500 °C for determination of loss-on-ignition

organic matter content (Håkanson and Jansson 2002). Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), and sodium hydroxide-extractable P (i.e., aluminum-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P.

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that lead to desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988; Table 2). The sum of the loosely-bound and iron-bound P fraction represents redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions; redox-P). In addition, labile organic P can be converted to soluble P via bacterial mineralization (Jensen and Andersen 1992) or hydrolysis of bacterial polyphosphates to soluble phosphate under anaerobic conditions (Gächter et al. 1988, Gächter and Meyer 1993, Hupfer et al. 1995). The sum of redox-P and labile organic P collectively represent biologically-labile P. This fraction is active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column and potential assimilation by algae. In contrast, aluminum-bound, calcium-bound, and refractory organic P fractions are more chemically inert and subject to burial rather than recycling.

Al dosage determination

Mixed sediment from the upper 5-cm section of an additional sediment core collected at HB 10, HB 20, and HB 30 was subjected to a range of aluminum sulfate (as Al) concentrations to determine the dosage required to inactivate the redox-P fraction (Rydin and Welch 1999). Alum (as aluminum sulfate; $\text{Al}_2(\text{SO}_4)_3 \cdot 18 \text{H}_2\text{O}$) was combined with 0.1 M sodium bicarbonate (NaHCO_3) to a concentration of 0.7 g Al/L to form an

aluminum hydroxide (Al(OH)₃) floc. Aliquots of this solution, diluted to a final volume of 10 mL with distilled water, were added to centrifuge tubes containing the equivalent of 0.025 g dry weight (DW) of fresh sediment to obtain Al concentrations ranging from 0 (i.e., control) to ~ 50 mg Al/g DW sediment. The assay tubes were shaken for a minimum of 2 hours at 20 °C in a darkened environmental chamber, centrifuged at 500 g to concentrate the sediment, and decanted for redox-P determination (see *Sediment chemistry* above).

Al dosage was estimated as the concentration (g/m²) required to bind at least 90% of the redox-P. The dry mass concentration of redox-P (mg/g) was converted to an areal concentration (g/m²) as,

$$\text{Redox-P (g/m}^2\text{)} = \text{Redox-P (mg/g)} \cdot \rho \text{ (g/cm}^3\text{)} \cdot \theta \cdot h \text{ (m)} \cdot 1,000,000 \text{ (cm}^3\text{/m}^3\text{)} \cdot 0.001 \text{ (g/mg)} \quad 1)$$

where, ρ is sediment bulk density (g/cm³), θ is the percentage of sediment solids (100 – percent moisture content; dimensionless), and h is sediment thickness (m). The Al concentration (g/m²) was estimated as,

$$\text{Al (g/m}^2\text{)} = \text{Redox-P (g/m}^2\text{)} \cdot \text{Al:P}_{90\%} \quad 2)$$

where, Al:P_{90%} is the binding ratio required to adsorb at least 90% of the redox-P in the sediment.

Maximum allowable Al dosage based on alkalinity and pH in the bay

Addition of aluminum sulfate to a lake leads to hydrolysis and the liberation of hydrogen ions which lowers the pH of the water column. Since Al toxicity to the biota can occur if the pH falls below ~4, maintaining a pH ≥ 6.0 as a margin of safety should also be considered in dose determination (Cooke et al. 2005). For situations where alkalinity is low or the required dosage exceeds the maximum allowable dosage to maintain pH ≥ 6.0, a buffered aluminum sulfate-sodium aluminate treatment will be

needed to maintain pH near neutrality. Surface water collected from the lake was analyzed for total alkalinity and pH according to APHA (2005). A titration procedure was used to determine the maximum allowable dosage of aluminum sulfate that can be added and yet maintain pH above 6.0 (Cooke et al. 2005). A 1.25 g Al/L solution of $\text{Al}_2(\text{SO}_4)_3 \cdot 18 \text{H}_2\text{O}$ was used as the titrant and 1.0 mL additions to 500 mL of lake water were each equivalent to 2.5 mg Al/L. Lake water was titrated with the Al solution until an endpoint of pH 6 was reached. A 1.0 mL aliquot of this solution added to 500 mL of lake water is equivalent to 2.5 mg Al/L. The total volume of Al solution needed to titrate lake water to pH 6 was multiplied by 2.5 mg Al/L to estimate the maximum allowable concentration. This calculation was then compared with estimates based on sediment redox-P to ensure that the latter was at or below the maximum allowable dosage. Caution needs to be used because a vertical alkalinity and pH profile over the entire vertical water column needs to be estimated in order to more accurately evaluate the maximum allowable dosage.

RESULTS AND INTERPRETATION

Halsted Bay

Sediment phosphorus fluxes

Phosphorus mass and concentration increased linearly in the overlying water column under anaerobic conditions in replicate incubation systems collected in the north and south basins of Halsted Bay (i.e., stations HB 20 and HB 30; Figure 3). Mean SRP concentrations in the overlying water column at the end of the incubation period were high at 1.467 mg/L (± 0.329 standard error; SE) and 0.984 mg/L (± 0.088 SE) for HB 20 and HB 30, respectively. The mean rate of P release under anaerobic conditions was greatest at the deeper HB 20 ($10.9 \text{ mg/m}^2 \text{ d} \pm 1.6 \text{ SE}$) versus HB 30 ($8.0 \text{ mg/m}^2 \text{ d} \pm 0.9 \text{ SE}$; Table 3). When compared to linear regression relationships developed between iron-bound P or redox-P versus the anaerobic P release rate for other lakes in the region, Halsted Bay fell within the overall range of values (Figure 4), suggesting that iron-

phosphorus chemistry was playing a role in anaerobic P release. Overall, the higher mean anaerobic P release rate at HB 20 coincided with higher iron-bound P and redox-P in the sediment versus HB 30.

Soluble phosphorus accumulation in the overlying water column was much more variable for sediment cores collected at shallow littoral sites in Halsted Bay (i.e., HB 40 and HB 50) and incubated under aerobic conditions (Figure 5). Phosphorus concentrations generally increased in a linear pattern starting near ~ day 5 then leveled off to constant values near the end of the incubation period. Mean rates of P release under aerobic conditions were lower at these shallow stations versus rates under anaerobic conditions determined at the deeper stations. Nevertheless, aerobic P release rates were relatively high at $3.6 \text{ mg/m}^2 \text{ d}$ ($\pm 1.4 \text{ SE}$) and $1.6 \text{ mg/m}^2 \text{ d}$ ($\pm 0.7 \text{ SE}$) for HB 40 and HB 50, respectively (Table 3). The maximum P concentration attained in the overlying water column toward the end of the incubation period was a mean 0.310 mg/L ($\pm 0.046 \text{ SE}$) for HB 40 and 0.254 mg/L ($\pm 0.031 \text{ SE}$) for HB 50 aerobic incubation systems, which was moderately high and could represent an important available P source for assimilation by algae.

Sediment vertical phosphorus profiles

Patterns in sediment physical-textural characteristics were similar at the three vertical profile stations (Figure 6). At HB 10 and HB 20, moisture content was greater than 90% over the upper 6 cm and declined steadily to ~83% below that depth. This vertical pattern is common and related to compaction of deeper sediment layers as new sediment accumulates over time. In particular, moisture content was greater than 92% in the upper 3 cm layer, indicating very flocculent, fine-grained sediment. Wet bulk density was less than 1.04 g/cm^3 within this layer due to high porosity (i.e., high interstitial volume). HB 30, located in the shallower south basin (>20 ft), exhibited a similar vertical pattern in moisture content. Sediment organic matter content at these stations was moderate, ranging between 21 and 27%. It was generally highest in the upper 4-6 cm sediment layer

and declined linearly at deeper depths, a pattern resulting from the gradual anaerobic decomposition of organic matter by microbial communities residing in the sediment.

Although loosely-bound P accounted for < 25% of the biologically-labile P, concentrations were unusually high at 0.08 to 0.15 mg/g at HB 10-30 and nearly constant throughout the vertical profile (Figure 7). In contrast, iron-bound and labile organic P co-dominated the biologically-labile P fraction. Iron-bound P concentrations were usually highest in the upper 8-cm sediment layer and declined in concentration below that depth. In the upper sediment layer, iron-bound P concentrations were highest at the deeper stations HB 20 and HB 30, ranging between 0.30 and 0.38 mg/g. Labile organic P concentrations were also greatest in the upper sediment layer and declined with increasing depth below the sediment-water interface. Indeed, labile organic P exceeded iron-bound P in the surface sediment layer at station 10, versus the other stations where concentrations of these constituents were similar.

Overall, biologically-labile P exhibited peak concentrations near the sediment-water interface and declined to nearly constant concentrations below ~ 10-cm depth (Figure 8). Typically, biologically-labile P concentrations are elevated and exhibit a distinct maxima in the upper layer versus deeper layers of eutrophic lake sediments due to accumulation of sediment P that is recycled in excess of burial and diagenesis (Carey and Rydin 2011). Most or all of this excess P can be mobilized during summer hypolimnetic anoxia and generally represents the internal P load to lake systems (Rydin et al. 2011). Biologically-labile P in excess of background concentrations occurred over the upper 5 cm at station 10. Excess concentrations at this station declined to background levels at the 5-cm depth and then increased slightly below that depth. At stations 20 and 30, excess biologically labile P concentrations occurred over the upper 8 cm.

Spatial variations in sediment phosphorus

Surface sediments (upper 5 cm) at various stations in Halsted Bay typically exhibited high moisture content and low dry bulk density indicative of flocculent sediment with

high porosity (Table 4). Organic matter content was greatest for sediment located in the shallow littoral zone (i.e., stations 40 and 50) and percentages were high at ~ 48 to 60%. It was more moderate at ~ 21 to 33% for sediment located at deeper depths in the north and south basins.

Labile organic P tended to account for a major portion of the biologically-labile P fraction at most stations followed by iron-bound P (Table 5 and Figure 9). Overall, redox-P and labile organic P each represented ~ 50% of the biologically-labile P fraction (Table 5). Highest mean concentrations of biologically-labile P fractions occurred in the deep north and south basins with a trend of declining means as a function of decreasing depth, when values within various depth contours were averaged (Table 6). This spatial pattern is typical in lake basins and attributable to processes that result in the focusing of fine-grained, more nutrient-rich sediments, from shallow erosional regions to deeper zones of sediment accumulation. For instance, mean iron-bound P concentrations ranged between 0.105 mg/g at depths < 15 ft to 0.219 mg/g at depths > 20 ft. Estimated mean anaerobic P release rates, predicted from redox-P (Figure 4), varied from 3.4 mg/m² d at shallow, littoral sites to ~ 8.0 mg/m² d at the deep basin sites. Mean labile organic P concentrations followed a similar pattern of increasing concentration as a function of increasing depth.

Aluminum sulfate dosage and cost

The Al:P ratio (i.e., parts of Al required to bind one part of redox-sensitive P), used to calculate the Al dosage needed to inactivate sediment P (*see* equation 1 in APPROACH), was estimated from assays that examined the binding of iron-bound P onto precipitated Al(OH)₃ floc as a function of Al concentration (Figure 10). I did not include the loosely-bound P fraction in the Al:P ratio determination because it was unusually high for Halsted Bay sediments and leads to underestimation of the ratio and Al dose needed to bind the iron-bound P (i.e., results in a lower than predicted ratio; James unpublished data). Binding of the loosely-bound P fraction was, however, factored into the overall Al dosage estimation for Halsted Bay. In general, iron-bound P declined exponentially as a

function of increasing Al concentration due to binding onto the $\text{Al}(\text{OH})_3$ floc (Figure 10). Loosely-bound P declined very rapidly at relatively low Al doses. The measured Al:P ratios required to bind 90% of the iron-bound P for various stations in Halsted Bay fell within regression relationships developed from several lakes in the region (Figure 11).

To calculate Al dosage for the bay, an Al:P ratio was estimated for each lake station from regression relationships developed between iron-bound P and the Al:P ratio (Figure 12). The thickness of the sediment layer to be inactivated was set at 8 cm for sediment located at depths > 20 ft, based on excess biologically-labile P (Figure 8). For sediments located at depths < 20 ft, I assumed a sediment thickness of 5 cm in the dosage calculation, based on vertical trends in excess biologically-labile P at station 10. The Al dosage was $\sim 60 \text{ g/m}^2$, 80 g/m^2 , and 140 g/m^2 for sediments < 15 ft, between 15 and 20 ft, and > 20 ft, respectively (Table 6).

Al dosage and cost scenario is shown in Table 7. The sediment area located at depths > 14 ft was chosen for treatment because this contour represents the maximum extent of summer anoxia in the hypolimnion and, thus, the potential of anaerobic P release from sediments. Sediment between the 14- and 20-ft depth contours would be treated with 80 g Al/m^2 while sediments deeper than 20 ft would be treated with an Al dosage of 140 g/m^2 to control internal P loading. Total cost, including a generic setup fee of \$10,000 was \$761,471.

Shallow sediments (i.e., between ~ 5 and 14 ft), particularly along the western shoreline and near the wetland inlet region, might also be considered for Al treatment because rates of P release under aerobic conditions were relatively high in this region of the bay. This internal P loading source could subsidize algal productivity and slow recovery. The effectiveness and benefits of an Al treatment in shallow regions can be problematic if sediment resuspension and focusing occurs. Under these conditions, the Al floc may be eroded to deeper accumulation zones during periods of high winds and overturn (Huser 2012). However, since the western littoral region of the bay has a much shallower slope and is more protected from northern and western winds than the steeper

east littoral zone, the Al floc might be less susceptible to transport. In addition, sediment moisture content was relatively high, while wet bulk density was low, at HB 40 and HB 50 (Table 4). These patterns indicated that sediments were likely composed of fine-grained sediments, suggesting a lower erosion potential in this area of the bay. Since the Al floc is typically denser than surface sediments with high moisture content, it would likely sink several cm and further consolidate the sediment from erosion.

The proposed hypolimnetic Al dosage for Halsted Bay, based on the weighted average dose of the two sediment areas, was 105 g Al/m^2 . Recent lake Al treatments that have resulted in very effective and successful control of sediment internal P loading and improved water quality have generally ranged between $\sim 95 \text{ g Al/m}^2$ and $\sim 140 \text{ g Al/m}^2$ (Table 8). These more recent Al dosage ranges are generally higher compared to historical ranges (Huser 2012) and were targeted toward inactivation of the excess P pool in the sediment. The proposed Al dosages for Halsted Bay fall within these recent ranges reported in the literature.

Al dosage estimation for Halsted Bay accounted for binding of the more rapidly mobilized redox-sensitive P and did not account for gradually released labile organic P and slower P diffusion upward from deeper sediments or downward from sediment freshly deposited on top of the Al floc. There is currently some uncertainty regarding whether simply increasing Al dosage to account for these future P sources will result in the desired longer-term control. de Vicente et al. (2008) showed that aging of the Al(OH)_3 floc without previously sorbed PO_4^{3-} could result in substantially reduced future binding efficiency (up to 75% reduction in adsorption capacity over 90 d) due to changes in crystalline structure of the floc (Berkowitz et al. 2005). They suggested that smaller doses spread out over several years, versus one large dose, might maintain higher binding efficiencies for these future P sources. For Halsted Bay, Al dosage could be adjusted to account for these potential additional sources of P, but more research is needed to clarify both dosage estimation and application strategies for longer-term control of labile organic P and P diffusion from adjacent sediment layers. However, the overall Al dosage

proposed for Halsted Bay should be more than sufficient to bind these future, more gradually released, P sources because the initial Al:P ratio is high.

The total alkalinity for Halsted Bay was relatively high at 139 mg CaCO₃/L, suggesting a high buffering capacity for moderating pH during alum application. Al binding of P is most efficient within a pH range of 6 to 8. As pH declines below 6, Al becomes increasingly soluble (as Al³⁺) and toxic to biota. The maximum allowable Al dosage for Halsted Bay, determined via jar tests (Cooke et al. 2005), was high at 18.75 mg Al/L (Table 9). Cooke et al. (2005) reported that treatment longevity (i.e., years of successful P control) generally coincided with Al dosages greater than ~ 12 to 18 g/m³ for stratified lakes (range = 11.7 to 30 g/m³; Table 9). The overall estimated volume-based Al dosage of 17 mg/L for Halsted Bay fell well within that reported finding. However, treatment with the proposed areal Al dosages of 80 and 140 g/m² would be equivalent to volumetric dosages of 19 mg/L at depths > 20 ft. Thus, Al dosage is at the maximum allowable for depths > 20 ft and there would be potential concerns regarding low pH during application. This concern could be alleviated by splitting the application into at least 2 years (see below). An additional alkalinity-pH vertical profile would need to be examined during the spring to early summer period to verify and refine the maximum allowable Al dose.

Aluminum sulfate treatment schedule considerations

Multiple treatments of lower Al concentrations over a period of years (i.e., 1-2 year intervals) have been successful (Tiefwareensee, Germany) and have merit as a viable treatment schedule for Halsted Bay. First, splitting the overall Al dosage into 2 or 3 years would ensure that application does not lower pH temporarily to < 6.0. Second, costs are spread out over a period of several years and may be easier to finance. Third, since each incremental dosage is low relative to the final target dose, the Al floc has a greater chance of becoming saturated with sediment P immediately after application. Other research has suggested that Al binding efficiency for P declines with time as the Al reacts to form more orderly Al~(OOH) polymer chains (Berkowitz et al. 2005, de Vicente et al. 2008).

Sediment redox-P and aluminum-bound P could be monitored after each application for effectiveness in control of sediment P. Subsequent Al applications might ultimately be lower if previously applied alum flocs have efficiently inactivated most of the redox-P in the surface sediment layers, resulting in overall cost savings.

Wetland Inlet

Anaerobic and aerobic phosphorus release rates

Under anaerobic conditions, P mass and concentrations generally increased rapidly and linearly over most of the incubation period (Figure 13). An exception occurred in one of the WET120-L systems where P was essentially undetectable in the overlying water column throughout the incubation. Anaerobic P release rates were relatively at all the wetland stations (Table 10) with no readily apparent pattern as a function of sampling location. For instance, the anaerobic P release rates were high both in the wetland channel at WET100-C and at both off-channel sites. Maximum overlying water concentrations were also elevated at the end of the incubation period, ranging between 0.875 mg/L (± 0.010 SE) For WET110-C and ~ 0.350 mg/L to 0.391 mg/L for WET110-R and WET120-L, respectively. In particular, wetland sediments can rapidly become anaerobic under low flow and stagnant conditions and, thus, represent a potentially important P source to the Bay during storm inflows and flushing. P mass and concentration also increased rapidly and linearly in the overlying water column of systems incubated under oxic conditions (Figure 14). Aerobic rates of P release were substantial, ranging between a mean 1.0 and 5.7 mg/m² d (Table 10).

Wetland sediment chemistry

Aerobic and anaerobic P release from wetland sediments was probably driven more by microbial breakdown and transformation of organic matter versus iron-phosphorus chemistry as iron-bound P concentrations were moderate relative to the magnitude of P release. Wetland sediment both in the thalweg and off channel exhibited very high

moisture content and low wet and dry bulk density (Table 11). Organic matter content was greater than 50% at all stations and exceeded 80% at many stations. High organic matter content was related to extensive thick root mass and accumulated detritus. Labile organic P, which can be recycled via microbial transformations, dominated the biologically-labile P pool in the sediment at 45% to 70% (Table 12 and Figure 15). In contrast, iron-bound P accounted for only 17% to 36% of this pool. Loosely-bound P concentrations were also notably high at 0.049 mg/g to 0.096 mg/g and could represent an important P pool for nutrient flux from sediment.

Implications for Phosphorus Management

Overall recommendations for aluminum sulfate treatment of Halsted Bay

Laboratory-based rates of P release under anaerobic conditions are high in the two deep basins of Halsted Bay and indicative of eutrophic conditions. I recommend that the Al treatment scenario presented in Table 7 to control this internal P load be split into at least two applications to minimize concerns over low pH during application and to increase the sediment P binding efficiency (i.e., attempt to completely saturate binding sites with sediment P with each application). Aluminum sulfate applications could be conducted during consecutive years or during year 1 and 3. It should be noted that internal P loading reduction will not be completely reduced during the first year of application due to the split dosage scenario, and will not be completely controlled until the final Al application. Ideally, each application should occur in May or early June, before the onset of P accumulation in the hypolimnion and when P concentrations in the water column are relatively low. The goal of the aluminum sulfate treatment is to primarily bind sediment P on the $\text{Al}(\text{OH})_3$ floc and minimize filling of these binding sites with P originating from the water column.

Aerobic rates of P release were also relative high for sediment cores collected in the shallow, littoral portion of the bay and could subsidize algal productivity after Al treatment. Potential contributions from this sediment source should be incorporated into

the P budget for Halsted Bay for evaluation. It is more difficult to manage shallow sediments with Al because the floc tends to focus to deep accumulation zones (Huser 2011). However, application of 60 g Al/m² might be considered for shallow sediments located along the western shoreline of the bay between ~ 5- and 14-ft depth contours to temporarily control sediment P flux at locations near the wetland inlet (Table 6). A desirable management outcome would be improved underwater light penetration and re-establishment of native submersed macrophyte communities in this region of the bay to ultimately stabilize the Al floc for continued control of aerobic P release, reduce sediment resuspension, and promote habitat for invertebrates, fish larvae, and young of the year fish.

Wetland sediment phosphorus contributions to Halsted Bay

Similar to the shallow, littoral sediments in Halsted Bay, sediments located in the wetland inlet appear to be a potential source of internal P loading and may subsidize algal blooms. Although the mechanism of P release is not precisely known (i.e., may be driven more by microbial breakdown), rates are, nevertheless, relatively high under both aerobic and anaerobic conditions. More information is needed to better understand P contributions and fluxes from these sources in order to develop sound management decisions. Studies include:

1. quantifying hydrological conditions, water level stages, and flows in the wetland complex to determine periods of wetland soil flooding, desiccation, and potential P fluxes,
2. quantifying the role of vegetation breakdown in P recycling and flux to the bay, and
3. continuously monitoring temperature, dissolved oxygen, and pH at various locations in the wetland complex to determine periods of anoxia for more accurate sediment P flux determination.

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Table 1. Station identification labels (HB = Halsted's Bay; WET = wetland inlet; L = north side of wetland tributary, C = center of wetland tributary channel, R = south side of wetland tributary) and numbers of sediment cores collected for determination of rates of phosphorus (P) flux under aerobic or anaerobic conditions, biologically-labile and refractory P fractions (see Table 1), and the dosage of aluminum (Al) required to bind redox-sensitive P.

Station	P Flux		P fractions		Al dosage
	Aerobic	Anaerobic	upper 5 to 10 cm	Vertical profile	
HB 10			1	1	1
HB 20		3	1	1	1
HB 30		3	1	1	1
HB 40	3		1		
HB 50	3		1		
HB 60			1		
HB 70			1		
HB 80			1		
HB 90			1		
WET 100-L			1		
WET 100-C			1		
WET 100-R			1		
WET 110-L			1		
WET 110-C	2	2	1		
WET 110-R	2	2	1		
WET 120-L	2	2	1		
WET 120-C			1		
WET 120-R			1		

Table 2. Sediment physical-textural characteristics, phosphorus species, and metals variable list.	
Category	Variable
Physical-textural	Moisture content Wet and dry sediment bulk density organic matter content
Phosphorus species	Loosely-bound P Iron-bound P Labile organic P Aluminum-bound P Calcium-bound P Refractory organic P Total P
Metals	Iron ¹ Aluminum ²

¹For the surface 5-cm section from all stations

²For vertical sections collected at HB 10, HB 20, and HB 30

Table 3. Mean (1 standard error in parentheses; n = 3) rates of phosphorus (P) release under oxic (aerobic) and anoxic (anaerobic) conditions for sediments collected in Halsted's Bay.

Station	Diffusive P flux	
	Oxic (mg m ⁻² d ⁻¹)	Anoxic (mg m ⁻² d ⁻¹)
HB 20		10.9 (1.6)
HB 30		8.0 (0.9)
HB 40	3.6 (1.4)	
HB 50	1.6 (0.7)	

Table 4. Textural characteristics in the upper sediment layer for various stations in Halsted's Bay.

Station	Moisture Content (%)	Wet Bulk Density (g/cm ³)	Dry Bulk Density (g/cm ³)	Organic Matter (%)
HB 10	90.6	1.045	0.099	25.5
HB 20	90.5	1.046	0.100	24.3
HB 30	89.2	1.054	0.115	22.8
HB 40	93.1	1.018	0.072	59.5
HB 50	91.5	1.028	0.089	48.4
HB 60	91.7	1.036	0.087	33.0
HB 70	89.9	1.049	0.108	25.6
HB 80	90.9	1.044	0.096	25.2
HB 90	88.3	1.060	0.126	21.2

Table 5. Concentrations of biologically labile and refractory P in the upper 5-cm sediment layer for various stations in Halsted's Bay. DW = dry mass, FW = fresh mass.

Station	Redox-sensitive and biologically labile P				Refractory P		
	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (ug/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Calcium-bound P (mg/g DW)	Refractory organic P (mg/g DW)
HB 10	0.127	0.161	15	0.306	0.070	0.122	
HB 20	0.106	0.308	29	0.303	0.085	0.131	
HB 30	0.096	0.188	20	0.301	0.067	0.329	
HB 40	0.042	0.095	7	0.248	0.091	0.077	
HB 50	0.088	0.115	10	0.300	0.074	0.107	
HB 60	0.114	0.162	14	0.336	0.083	0.149	
HB 70	0.124	0.141	14	0.262	0.065	0.165	
HB 80	0.089	0.259	24	0.299	0.079	0.100	
HB 90	0.112	0.167	20	0.258	0.065	0.134	

Table 6. Predicted anaerobic phosphorus (P) release, loosely-bound P, iron-bound P labile organic P, redox-P biologically-labile P, the estimated aluminum:phosphorus (Al:P) binding ratio, estimated thickness of the excess sediment P layer to be treated with aluminum sulfate (as aluminum; Al), and the areal Al dosage estimate for various stations in Halsted's Bay. Means for these variables are presented at the bottom of the table for depths < 15 ft, between 15 and 20 ft, and > 20 ft.

Depth contour	Station	Predicted anaerobic P release	Loosely-bound P	Iron-bound P	Labile organic P	Redox-P	Biologically-labile P	Estimated Al:P ratio ¹	Treated sediment thickness	Al dose
(ft)		(mg/m ² d)	(mg/g)	(mg/g)	(mg/g)	(mg/g)	(mg/g)		(cm)	(g/m ²)
<15	HB 40	2.9 ²	0.042	0.095	0.248	0.137	0.385	104	5	50
<15	HB 50	3.9 ²	0.088	0.115	0.300	0.203	0.503	76	5	67
15-20	HB 60	4.6 ²	0.114	0.162	0.336	0.276	0.612	59	5	70
15-20	HB 70	5.2 ²	0.124	0.141	0.262	0.265	0.527	61	5	86
15-20	HB 80	5.8 ²	0.089	0.259	0.299	0.348	0.647	49	5	80
15-20	HB 90	6.0 ²	0.112	0.167	0.258	0.279	0.537	58	5	101
>20	HB 10	5.2 ²	0.127	0.161	0.306	0.288	0.594	57	8	128
>20	HB 30	8.0 ³	0.096	0.188	0.301	0.284	0.585	57	8	138
>20	HB 20	10.9 ³	0.106	0.308	0.303	0.414	0.717	42	8	148
< 15	Average	3.4	0.065	0.105	0.274	0.170	0.444	90	5	59
15-20	Average	5.4	0.110	0.182	0.289	0.292	0.581	57	5	84
> 20	Average	8.0	0.110	0.219	0.303	0.329	0.632	52	8	138

¹Based on the regression equation shown in Figure 12 but substituting the redox-P concentration into the calculation.

²Estimated from regression relationships between redox-P and the anaerobic P release rate (Figure 4).

³Measured mean anaerobic P release rate from Table 3.

Table 7. Approximate cost scenario to treat two sediment areas with different concentrations of aluminum sulfate.		
Variable	Sediment area	
	14-20 ft contour	> 20 ft contour
Acres	167	100
Al dosage (g/m ²)	80	140
Alum (\$)	\$366,435	\$385,036
Setup (\$)	\$10,000	
Total (\$)	\$761,471	

Table 8. Recent and proposed alum (as Al) dosages for various lakes. An asterisk denotes a future treatment.		
Lake	Al Dose (g Al m ⁻²)	Reference
Halsted's Bay ¹	105	Present study
Tiefwareensee, Germany	137	Wauer et al. (2009)
East Alaska, Wisconsin	132	Hoyman (2012)
Squaw, Wisconsin*	120	James (unpubl. Data)
Cedar, Wisconsin ²	116	James (unpubl. Data)
Half Moon, Wisconsin ³	115	James (2011)
Susser See, Germany	100	Lewandowski et al. (2003)
Green, Washington	94	Dugopolski et al. (2008)

¹Average of a stratified treatment at 140 and 80 g/m²

²Average of a stratified treatment at 130 and 100 g/m²

³West and east arm dosages were 150 and 75 g/m², respectively

Table 9. A comparison of the maximum allowable Al dose, based on a titration assay (Cooke et al. 2005) and the the areal sediment redox-P based Al dosage converted to a concentration for Halsted Bay. Al dosages and longevity for other unstratified and stratified lakes are from Cooke et al (2005).

Lake		Al Dose (g Al/m ³)	Observed Longevity (years)
Halsted's Bay	Maximum allowable	18.8	
	140 g Al/m ² below 20-ft contour	19.1	
	80 g Al/m ² between the 14 and 20 ft contour	15.3	
	Combined Al concentration below the 14-ft depth contour	17.1	
Unstratified lakes	Long Kitsap County	5.5	11
	Pickerel	7.3	<1
	Long Thurston County North	7.7	>8
	Pattison North	7.7	7
	Wapato	7.8	<1
	Erie	10.9	>8
	Campbell	10.9	>8
Stratified lakes	Eau Galle	4.5	<2
	Morey	11.7	8
	Cochnewagon	18	6
	Dollar	20.9	18
	Annabessacook	25	13
	West Twin	26	18
	Irondquoit Bay	28.7	5
	Kezar	30	9

Table 10. Mean (1 standard error in parentheses; n = 2) rates of phosphorus (P) release under oxic (aerobic) and anoxic (anaerobic) conditions for sediments collected in the wetland inlet.

Station	Diffusive P flux	
	Oxic (mg m ⁻² d ⁻¹)	Anoxic (mg m ⁻² d ⁻¹)
WET110-C	5.7 (1.2)	5.9 (<0.1)
WET110-R	1.0 (<0.1)	2.7 (0.3)
WET120-L	2.9 (0.7)	7.2 ¹

¹n = 1; undetected rate for the other rep

Table 11. Textural characteristics in the upper sediment layer for various stations in the wetland Inlet.

Station	Moisture Content (%)	Wet Bulk Density (g/cm ³)	Dry Bulk Density (g/cm ³)	Loss-on-ignition (%)
WET100-L	91.7	1.011	0.087	78.0
WET00-C	92.4	1.018	0.079	62.3
WET100-R	92.5	1.011	0.078	76.7
WET110-L	92.8	1.008	0.075	83.2
WET110-C	90.8	1.024	0.096	57.8
WET110-R	92.5	1.012	0.078	73.9
WET120-L	91.3	1.010	0.090	81.3
WET120-C	92.7	1.019	0.076	58.3
WET120-R	92.7	1.006	0.736	98.3

Table 12. Concentrations of biologically labile and refractory P in the upper 10-cm sediment layer for various stations in wetland inlet. DW = dry mass, FW = fresh mass.

Station	Redox-sensitive and biologically labile P				Refractory P		
	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (ug/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Calcium-bound P (mg/g DW)	Refractory organic P (mg/g DW)
WET100-L	0.089	0.172	6	0.405	0.126	0.107	
WET00-C	0.096	0.167	7	0.351	0.125	0.144	
WET100-R							
WET110-L							
WET110-C	0.049	0.066	5	0.266	0.099	0.048	
WET110-R							
WET120-L							
WET120-C	0.091	0.176	7	0.217	0.104	0.074	
WET120-R							

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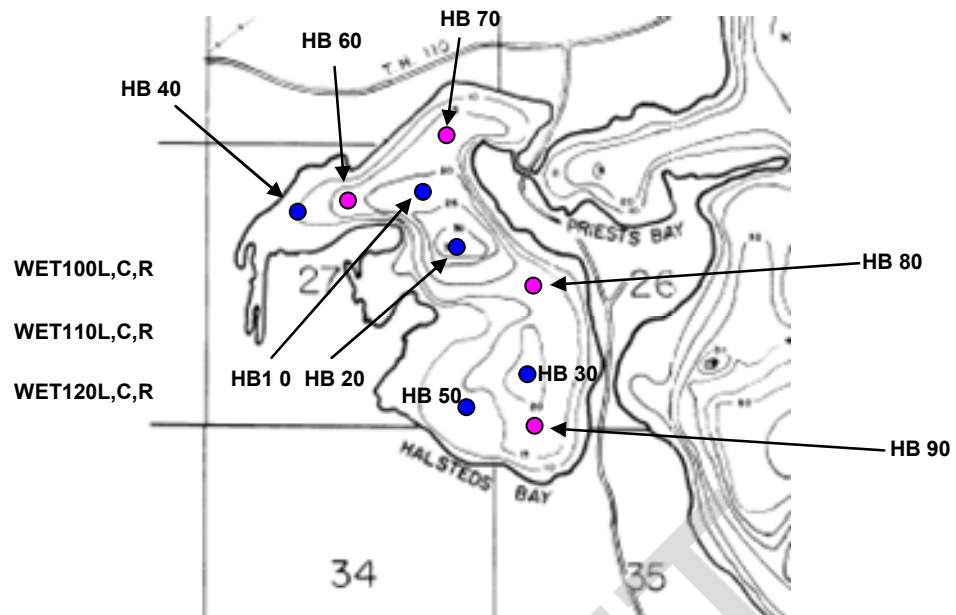


Figure 1. Sediment core station identification and location.

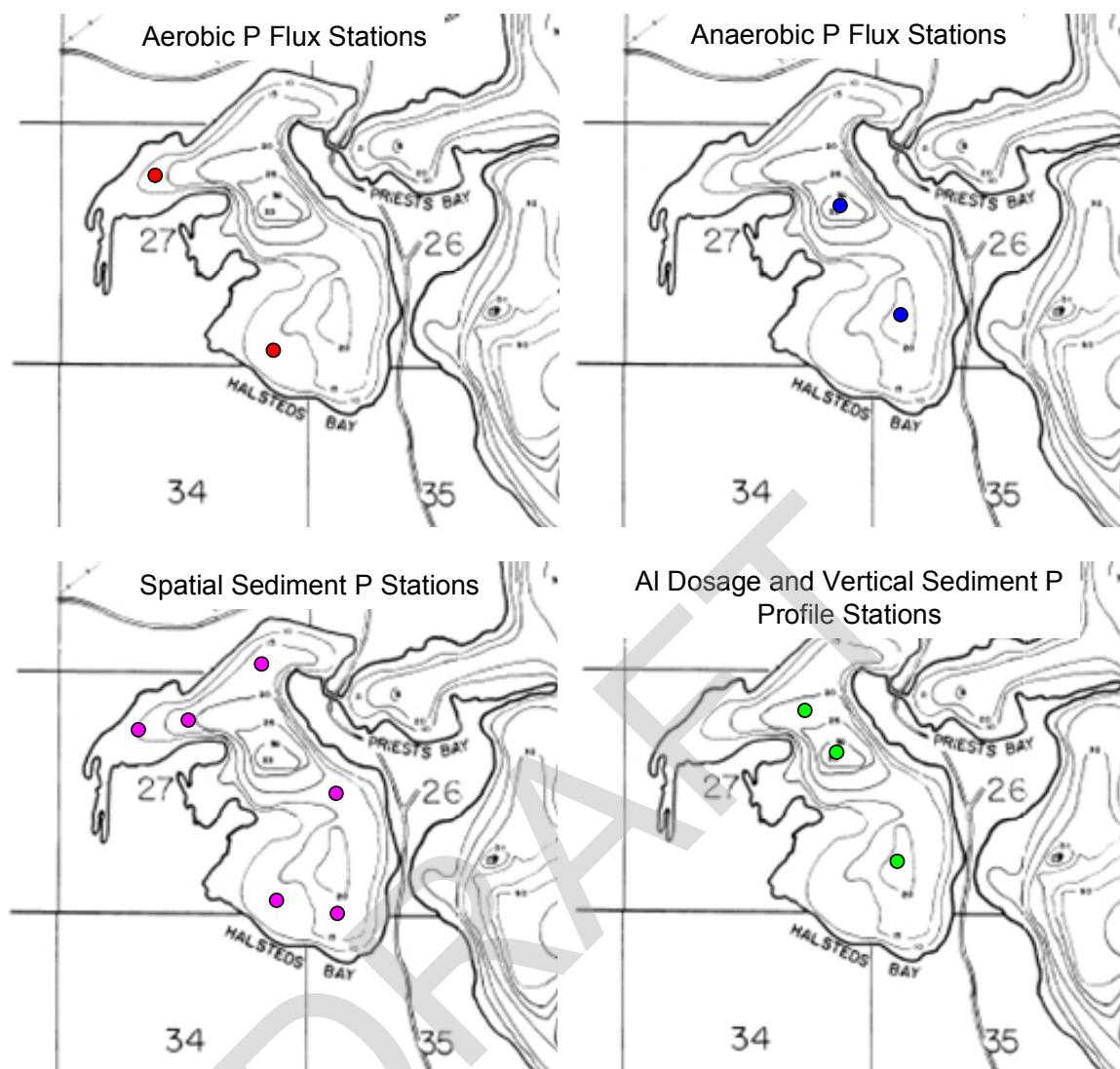


Figure 2. Locations of sediment coring stations for the various studies. Upper left – location of shallow, littoral stations for determination of phosphorus (P) release from sediment under aerobic conditions, Upper right – stations for determination of anaerobic P release from sediment, Lower left – stations for determination of spatial variations in sediment physical-textural and chemical characteristics, Lower right - stations for determination of aluminum (Al) sulfate dosage and vertical variations in sediment physical-textural and chemical characteristics.

Anaerobic P Release Rate

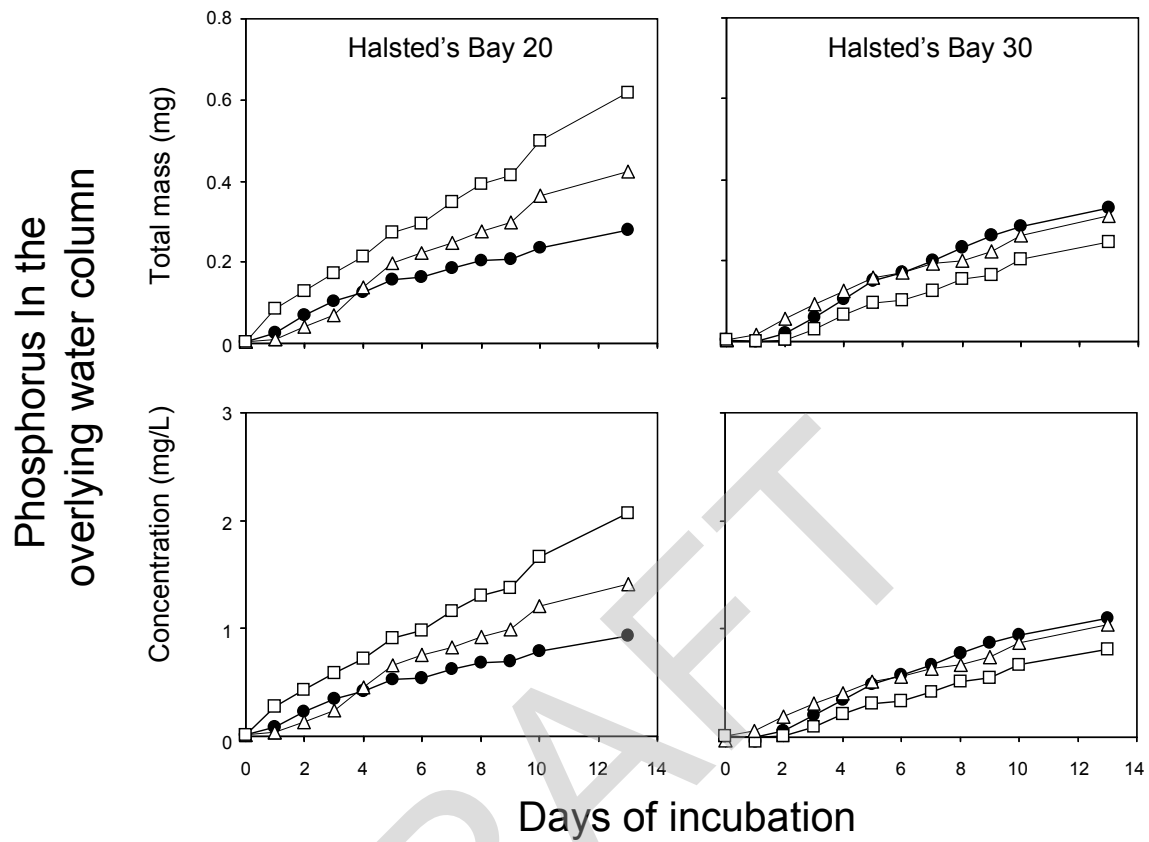


Figure 3. Changes in soluble reactive phosphorus mass (upper panels) and concentration (lower panels) in the overlying water column under anaerobic conditions versus time for sediment cores collected in Halsted Bay.

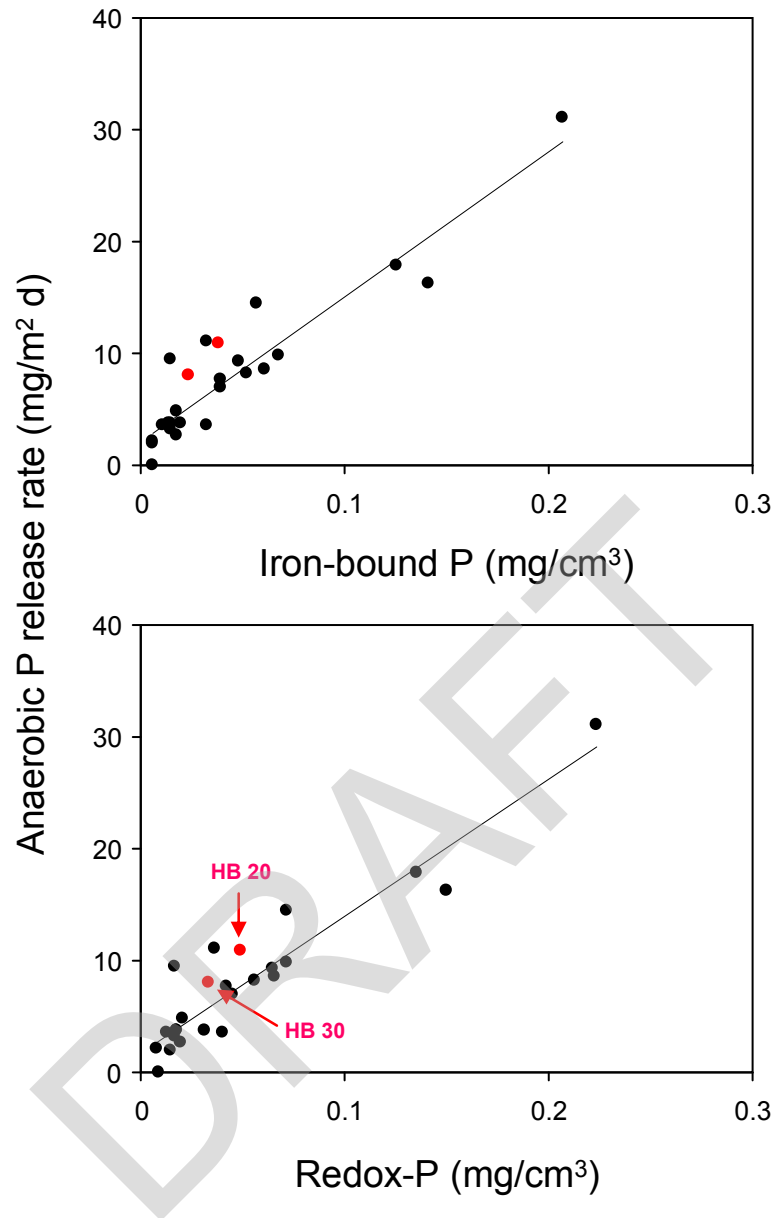


Figure 4. Relationships between iron-bound phosphorus (P; mg/cm^3 dry bulk density) and rates of P release from sediments under anaerobic conditions for various lakes in the region.

Aerobic P Release Rate

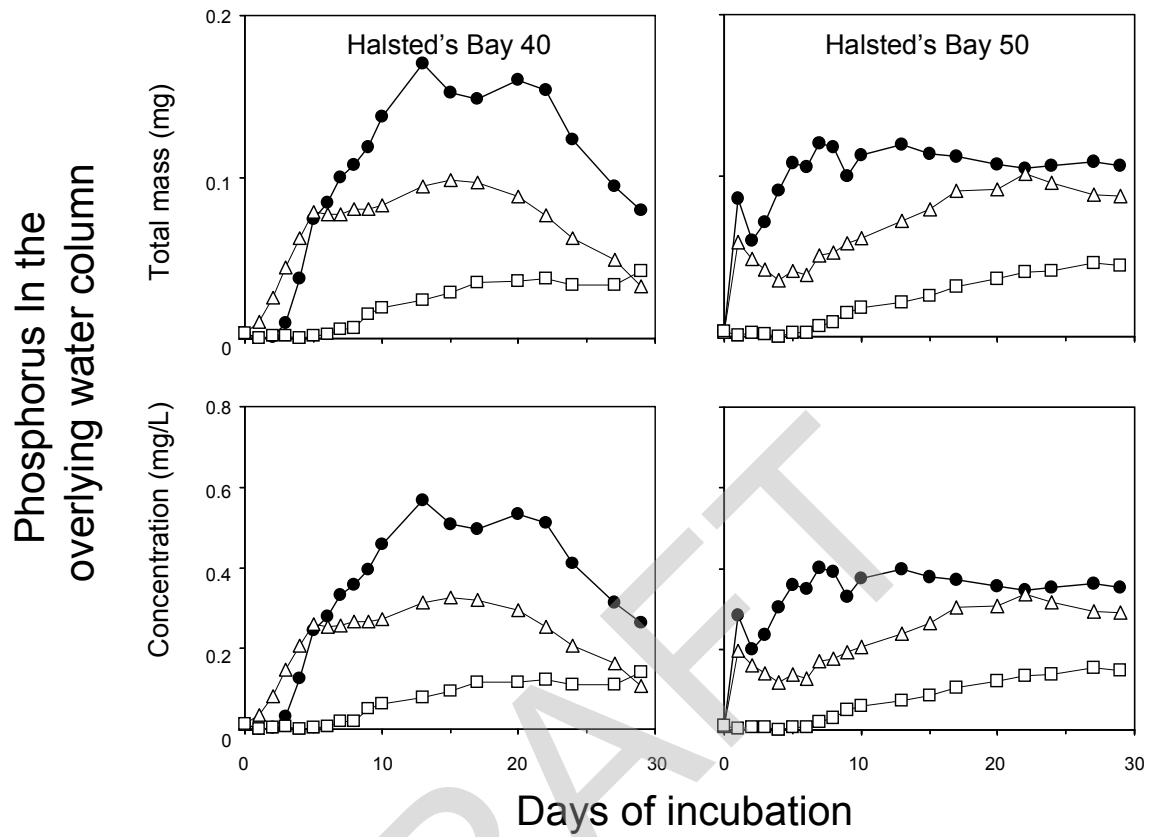


Figure 5. Changes in soluble reactive phosphorus mass (upper panels) and concentration (lower panels) in the overlying water column under aerobic conditions versus time for sediment cores collected in Halsted Bay.

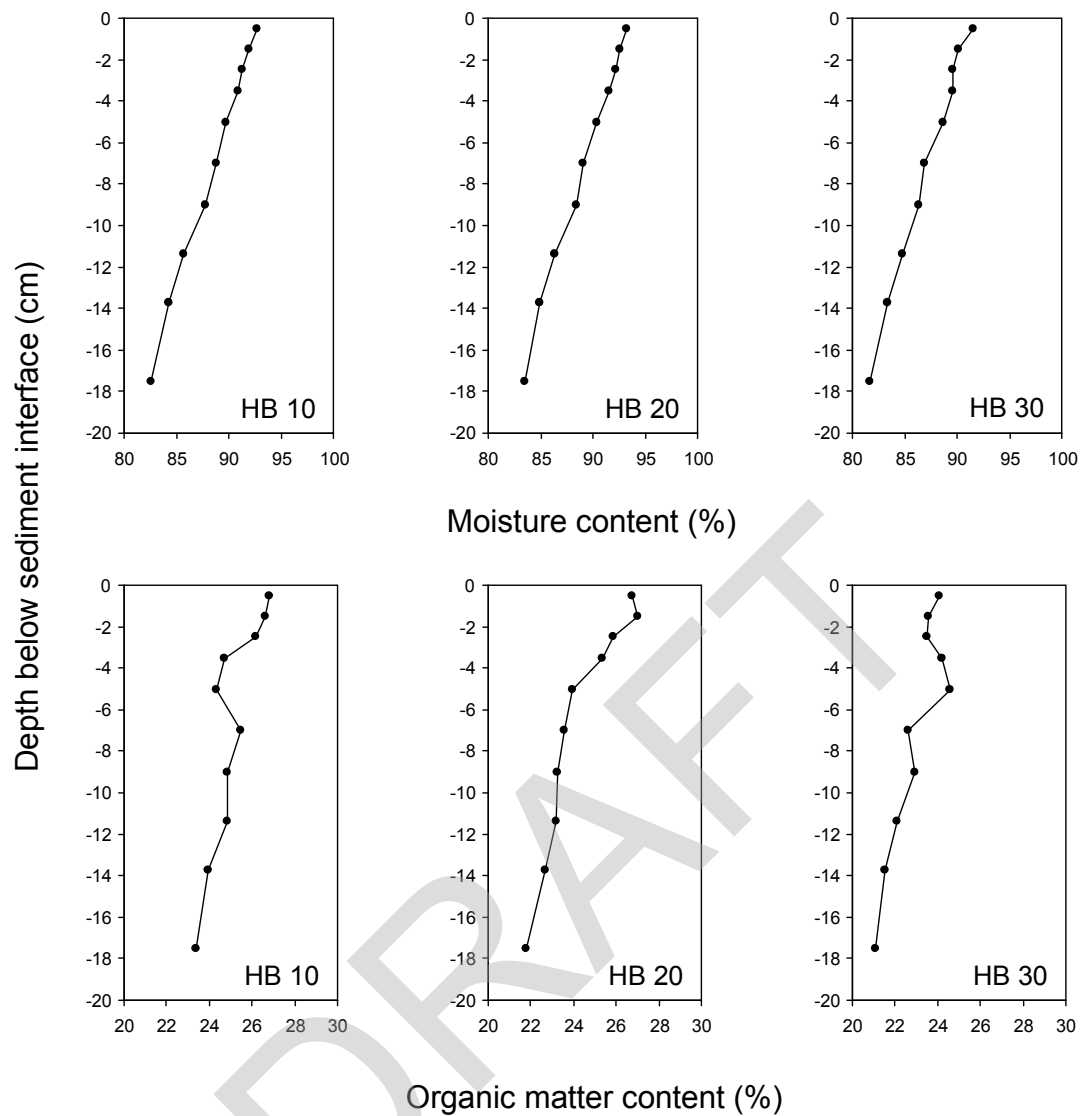


Figure 6. Vertical variations in sediment moisture (upper panels) and organic matter content (lower panels) at Halsted Bay (HB) stations HB 10, HB 20, and HB 30.

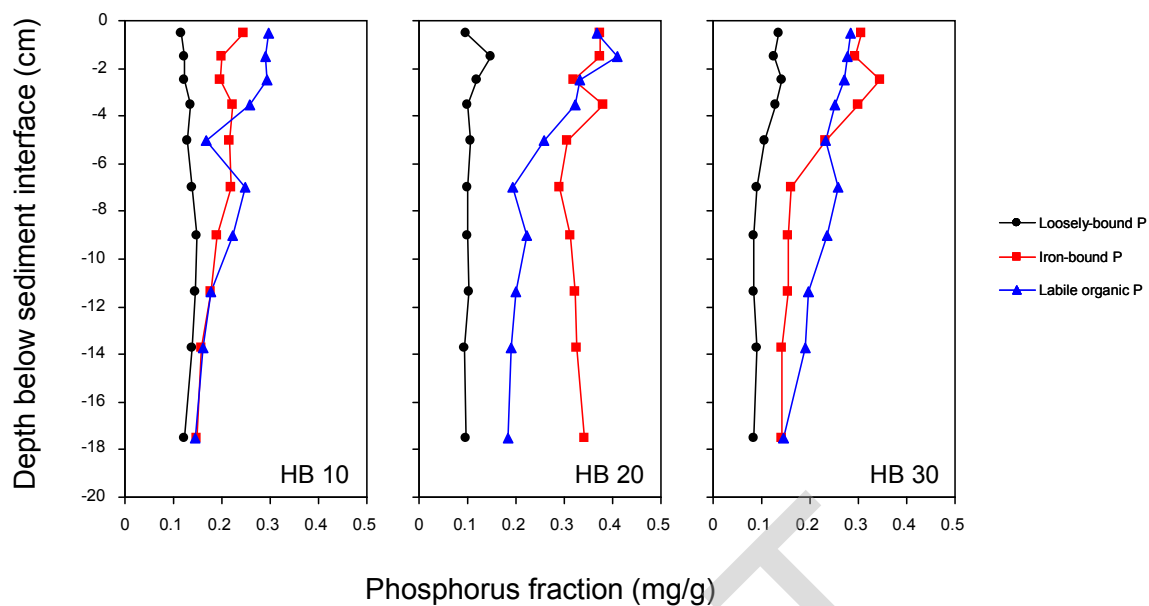


Figure 7. Vertical variations in loosely-bound phosphorus (P), iron-bound P, and labile organic P concentrations at Halsted Bay (HB) stations HB 10, HB 20, and HB 30.

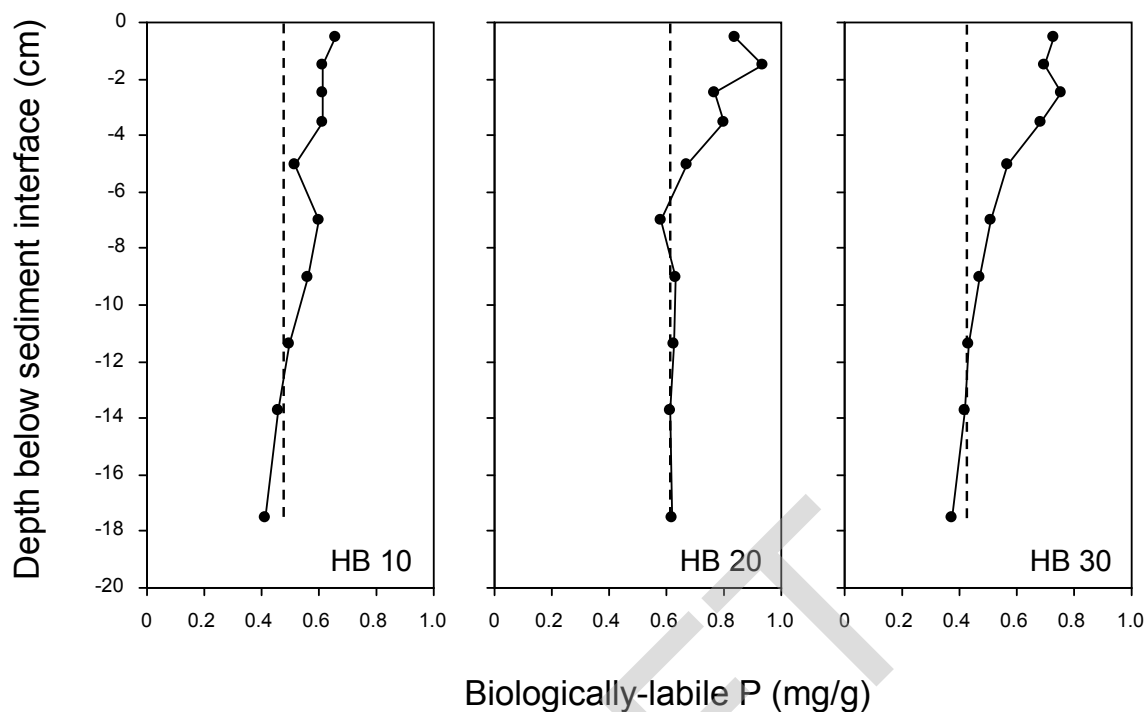


Figure 8. Vertical variations in biologically-labile phosphorus (P; i.e., the sum of loosely-bound, iron-bound P, and labile organic P concentration) and thickness of the sediment layer with excess P (above background concentrations) that is subject to diffuse P flux into the overlying water column under anaerobic conditions.

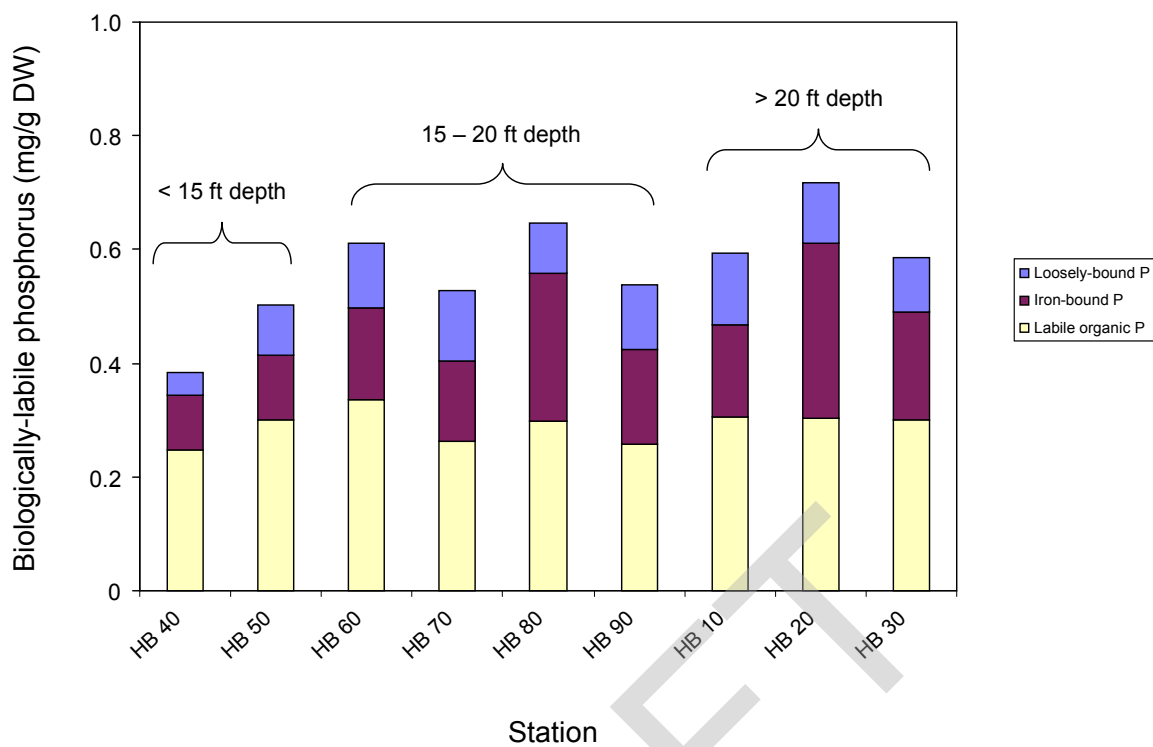


Figure 9. Composition of the biologically-labile phosphorus (P) pool in the upper 5-cm sediment layer at various stations in Halsted Bay. Depth brackets represent various depth contour strata in the bay.

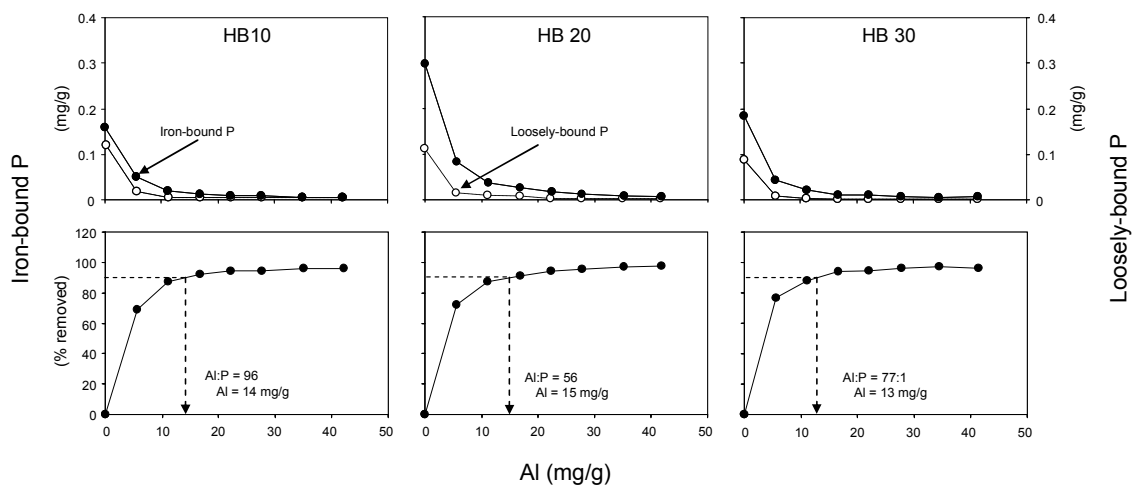


Figure 10. Variations in the concentration of loosely-bound and iron-bound phosphorus (P; upper panels) and percent removed or adsorbed to the aluminum (Al) floc (lower panels) as a function of increasing Al concentration.

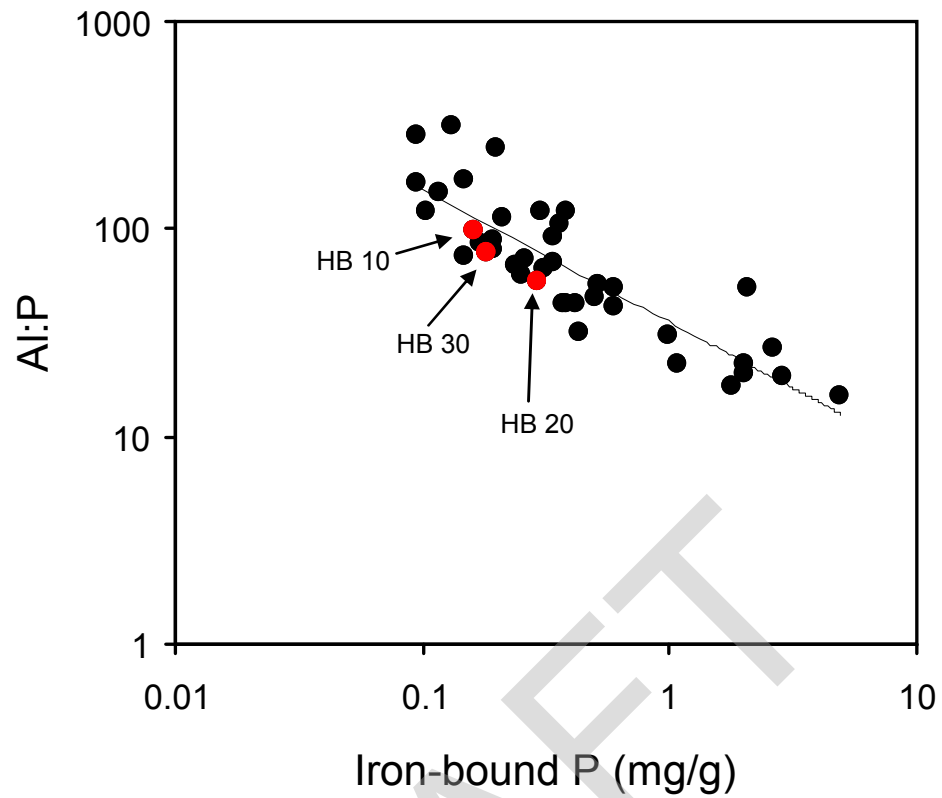


Figure 11. Regression relationships between iron-bound phosphorus (P) concentration and the aluminum:phosphorus (Al:P) ratio for Halsted Bay sediments and sediments collected from various lakes in the region.

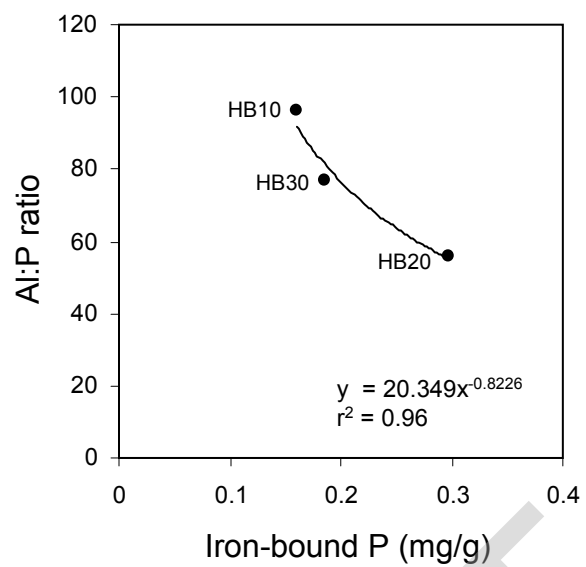


Figure 12. Regression relationships between iron-bound phosphorus (P) concentration and the aluminum:phosphorus (Al:P) ratio for Halsted Bay sediments.

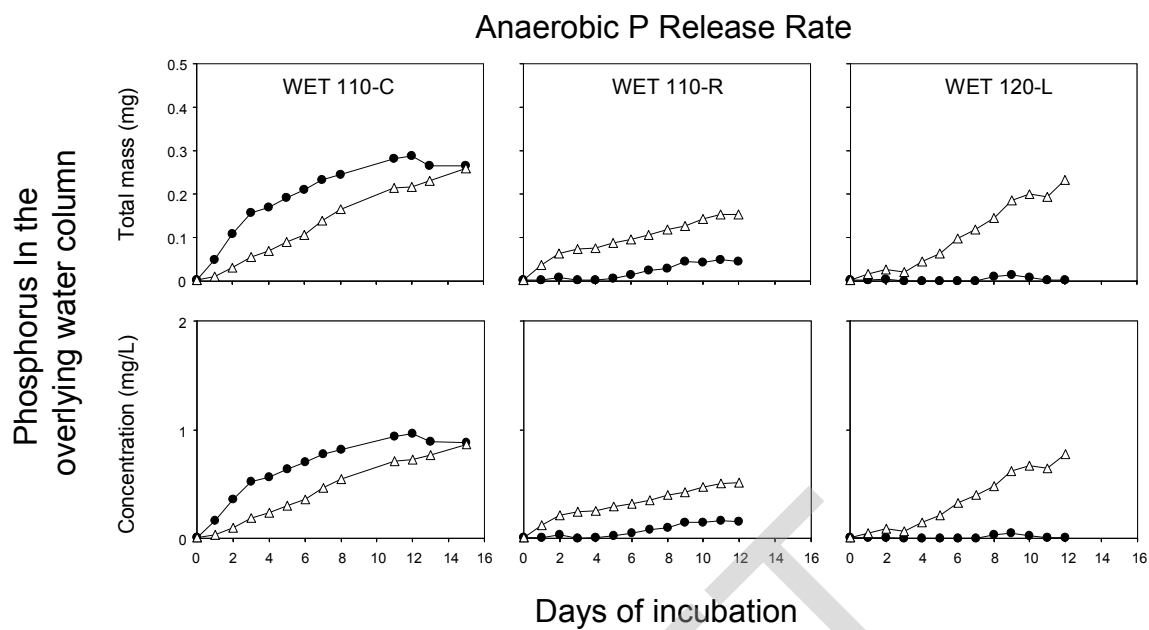


Figure 13. Changes in soluble reactive phosphorus mass (upper panels) and concentration (lower panels) in the overlying water column under anaerobic conditions versus time for sediment cores collected in the wetland inlet.

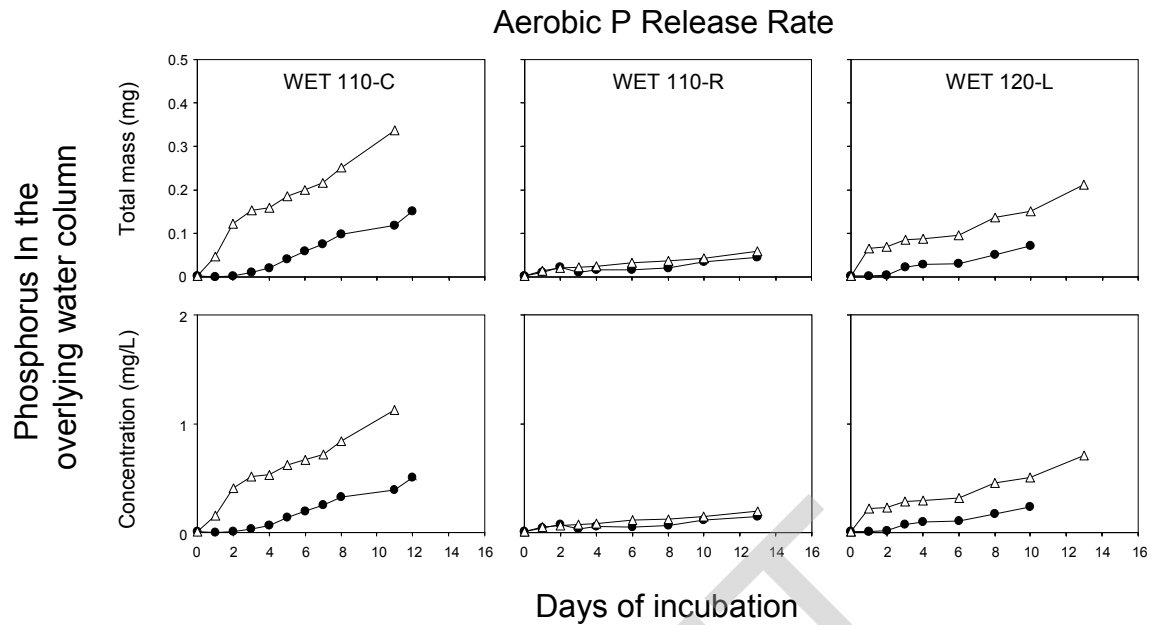


Figure 14. Changes in soluble reactive phosphorus mass (upper panels) and concentration (lower panels) in the overlying water column under aerobic conditions versus time for sediment cores collected in the wetland inlet.

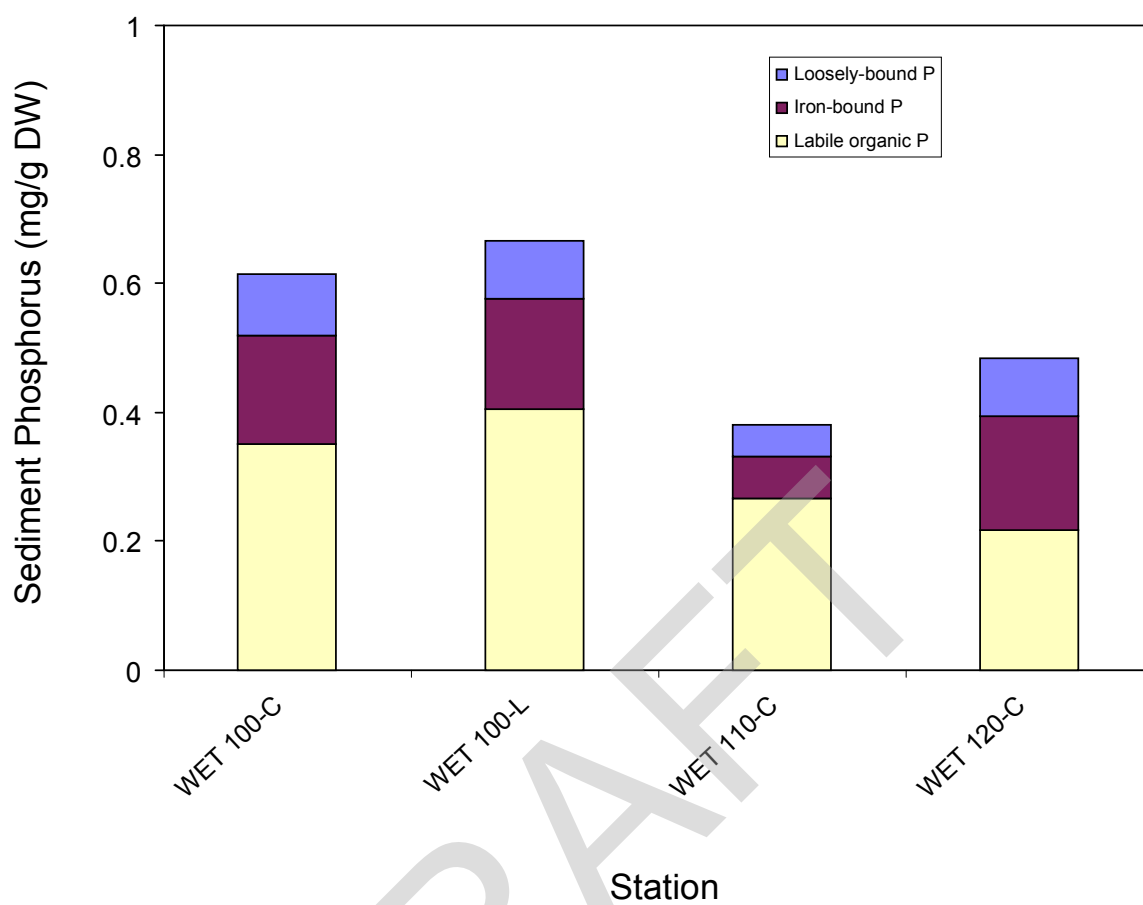


Figure 15. Composition of the biologically-labile phosphorus (P) pool in the upper 10-cm sediment layer at various stations in the wetland inlet.

Appendix C

Lake Response Model Results

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2005 Loading Summary for Halsted Bay							
Water Budgets				Phosphorus Loading			
Inflow from Drainage Areas							
Drainage Area			Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load
Name	[km ²]	[m/yr]	[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1 Direct (Halsted's)	3.2	0.10	0.330	160	1.0	53.0	
2 6-Mile Creek (DS of	6.9	0.10	0.712	160.4	1.0	114.2	
3 North Trib	4.1	0.10	0.425	160.4	1.0	68.2	
4					1.0		
5					1.0		
Summation	14	0	1			235.3	
Point Source Dischargers							
			Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load	
Name			[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1					1.0		
2					1.0		
3					1.0		
4					1.0		
5					1.0		
Summation			0.000			0.0	
Failing Septic Systems							
Name	Total Systems	Failing Systems	Discharge	Failure [%]		Load	
			[10 ⁶ m ³ /yr]			[kg/yr]	
1							
2							
3							
4							
5							
Summation	0	0	0.0			0.0	
Inflow from Upstream Lakes							
			Discharge	Estimated P Concentration	Calibration Factor	Load	
Name			[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1 Mud Lake			14.53	160.5	1.0	2,330.95	
2				-	1.0		
3				-	1.0		
Summation			14.53	160.5		2,331	
Atmosphere							
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load	
[km ²]	[m/yr]	[m/yr]	[10 ⁶ m ³ /yr]	[kg/km ² -yr]	[--]	[kg/yr]	
2.27	1.08	1.08	0.00	29.00	1.0	65.8	
Dry-year total P deposition =				24.9			
Average-year total P deposition =				26.8			
Wet-year total P deposition =				29.0			
(Barr Engineering 2004)							
Groundwater							
Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load	
[km ²]	[m/yr]		[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
2.27	0.3		0.76	84	1.0	64	
Internal							
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load	
[km ²]	[days]			[mg/m ² -day]	[--]	[kg/yr]	
2.27	95.7		Oxic	2.7	1.0	584	
2.27	26.3		Anoxic	10.2	1.0	608	
Summation						1,191	
Net Discharge [10 ⁶ m ³ /yr] =			16.76	Net Load [kg/yr] = 3,888			

NOTES

¹ Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2005 Lake Response Modeling for Halsted Bay			
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)	
		C _P =	1.04 [-]
		C _{CB} =	0.162 [-]
		b =	0.458 [-]
		W (total P load = inflow + atm.) =	3,888 [kg/yr]
		Q (lake outflow) =	16.8 [10 ⁶ m ³ /yr]
		V (modeled lake volume) =	9.1 [10 ⁶ m ³]
		T = V/Q =	0.55 [yr]
		P _i = W/Q =	232 [ug/l]
Model Predicted In-Lake [TP]			94.1 [ug/l]
Observed In-Lake [TP]			92.6 [ug/l]

2006 Loading Summary for Halsted Bay						
Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Drainage Area		Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load
Name	[km ²]	[m/yr]	[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]
1 Direct (Halsted's)	3.2	0.07	0.233	124	1.0	28.9
2 6-Mile Creek (DS of	6.9	0.07	0.503	123.8	1.0	62.3
3 North Trib	4.1	0.07	0.301	123.8	1.0	37.2
4					1.0	
5					1.0	
Summation		14	0	1		128.4
Point Source Dischargers						
		Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load	
Name		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
1					1.0	
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation			0.000		0.0	
Failing Septic Systems						
Name	Total Systems	Failing Systems	Discharge	Failure [%]	Load	
			[10 ⁶ m ³ /yr]		[kg/yr]	
1						
2						
3						
4						
5						
Summation		0	0	0.0	0.0	
Inflow from Upstream Lakes						
		Discharge	Estimated P Concentration	Calibration Factor	Load	
Name		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
1 Mud Lake		9.94	123.9	1.0	1,231.78	
2			-	1.0		
3			-	1.0		
Summation			9.94	123.9	1,232	
Atmosphere						
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
[km ²]	[m/yr]	[m/yr]	[10 ⁶ m ³ /yr]	[kg/km ² -yr]	[-]	[kg/yr]
2.27	0.68	0.68	0.00	26.80	1.0	60.9
Dry-year total P deposition =				24.9		
Average-year total P deposition =				26.8		
Wet-year total P deposition =				29.0		
(Barr Engineering 2004)						
Groundwater						
Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
[km ²]	[m/yr]		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]
2.27	0.3		0.76	84	1.0	64
Internal						
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
[km ²]	[days]			[mg/m ² -day]	[-]	[kg/yr]
2.27	97.8		Oxic	2.7	1.0	597
2.27	24.2		Anoxic	10.2	1.0	561
Summation						1,158
Net Discharge [10 ⁶ m ³ /yr] =			11.74	Net Load [kg/yr] =		2,643

NOTES

¹ Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2006 Lake Response Modeling for Halsteds Bay			
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)	
		C _P =	1.04 [-]
		C _{CB} =	0.162 [-]
		b =	0.458 [-]
		W (total P load = inflow + atm.) =	2,643 [kg/yr]
		Q (lake outflow) =	11.7 [10 ⁶ m ³ /yr]
		V (modeled lake volume) =	9.1 [10 ⁶ m ³]
		T = V/Q =	0.78 [yr]
		P _i = W/Q =	225 [ug/l]
Model Predicted In-Lake [TP]			81.8 [ug/l]
Observed In-Lake [TP]			70.0 [ug/l]

2007 Loading Summary for Halsted Bay						
Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Drainage Area		Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load
Name	[km ²]	[m/yr]	[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]
1 Direct (Halsted's)	3.2	0.07	0.227	145	1.0	32.9
2 6-Mile Creek (DS of	6.9	0.07	0.491	144.6	1.0	70.9
3 North Trib	4.1	0.07	0.293	144.6	1.0	42.3
4					1.0	
5					1.0	
Summation		14	0	1		146.1
Point Source Dischargers						
		Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load	
Name		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
1				1.0		
2				1.0		
3				1.0		
4				1.0		
5				1.0		
Summation			0.000		0.0	
Failing Septic Systems						
Name	Total Systems	Failing Systems	Discharge	Failure [%]	Load	
			[10 ⁶ m ³ /yr]		[kg/yr]	
1						
2						
3						
4						
5						
Summation		0	0	0.0	0.0	
Inflow from Upstream Lakes						
		Discharge	Estimated P Concentration	Calibration Factor	Load	
Name		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
1 Mud Lake		9.47	144.6	1.0	1,369.91	
2			-	1.0		
3			-	1.0		
Summation			9.47	144.6	1,370	
Atmosphere						
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
[km ²]	[m/yr]	[m/yr]	[10 ⁶ m ³ /yr]	[kg/km ² -yr]	[-]	[kg/yr]
2.27	0.72	0.72	0.00	26.80	1.0	60.9
Dry-year total P deposition =				24.9		
Average-year total P deposition =				26.8		
Wet-year total P deposition =				29.0		
(Barr Engineering 2004)						
Groundwater						
Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
[km ²]	[m/yr]		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]
2.27	0.3		0.76	84	1.0	64
Internal						
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
[km ²]	[days]			[mg/m ² -day]	[-]	[kg/yr]
2.27	93.9		Oxic	2.7	1.0	572
2.27	28.1		Anoxic	10.1	1.0	647
Summation						1,220
Net Discharge [10 ⁶ m ³ /yr] =			11.24	Net Load [kg/yr] =		2,861

NOTES

¹ Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2007 Lake Response Modeling for Halsteds Bay			
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)	
		C _P =	1.04 [-]
		C _{CB} =	0.162 [-]
		b =	0.458 [-]
		W (total P load = inflow + atm.) =	2,861 [kg/yr]
		Q (lake outflow) =	11.2 [10 ⁶ m ³ /yr]
		V (modeled lake volume) =	9.1 [10 ⁶ m ³]
		T = W/Q =	0.81 [yr]
		P _i = W/Q =	254 [ug/l]
Model Predicted In-Lake [TP]			87.8 [ug/l]
Observed In-Lake [TP]			92.7 [ug/l]

2008 Loading Summary for Halsted Bay						
Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Drainage Area		Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load
Name	[km ²]	[m/yr]	[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]
1 Direct (Halsted's)	3.2	0.07	0.2	158	1.0	35
2 6-Mile Creek (DS of	6.9	0.07	0.5	157.6	1.0	75
3 North Trib	4.1	0.07	0.3	157.6	1.0	45
4					1.0	
5					1.0	
Summation		14	0.07	1	157.6	155
Point Source Dischargers						
		Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load	
Name		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
1					1.0	
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation			0.000		0.0	
Failing Septic Systems						
Name	Total Systems	Failing Systems	Discharge	Failure [%]	Load	
			[10 ⁶ m ³ /yr]		[kg/yr]	
1						
2						
3						
4						
5						
Summation		0	0	0.0	0.0	
Inflow from Upstream Lakes						
		Discharge	Estimated P Concentration	Calibration Factor	Load	
Name		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
1 Mud Lake		9.21	157.7	1.0	1,453	
2			-	1.0		
3			-	1.0		
Summation			9.21	157.7	1,453	
Atmosphere						
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
[km ²]	[m/yr]	[m/yr]	[10 ⁶ m ³ /yr]	[kg/km ² -yr]	[-]	[kg/yr]
2.27	0.67	0.67	0.00	26.80	1.0	60.9
Dry-year total P deposition =				24.9		
Average-year total P deposition =				26.8		
Wet-year total P deposition =				29.0		
(Barr Engineering 2004)						
Groundwater						
Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
[km ²]	[m/yr]		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]
2.27	0.3		0.76	84	1.0	64
Internal						
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
[km ²]	[days]			[mg/m ² -day]	[-]	[kg/yr]
2.27	97.0		Oxic	2.7	1.0	594
2.27	25.0		Anoxic	10.1	1.0	574
Summation						1,169
Net Discharge [10 ⁶ m ³ /yr] =			10.96	Net Load [kg/yr] =		

NOTES

¹ Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2008 Lake Response Modeling for Halsteds Bay			
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)	
		C _P =	1.04 [-]
		C _{CB} =	0.162 [-]
		b =	0.458 [-]
		W (total P load = inflow + atm.) =	2,902 [kg/yr]
		Q (lake outflow) =	11.0 [10 ⁶ m ³ /yr]
		V (modeled lake volume) =	9.1 [10 ⁶ m ³]
		T = V/Q =	0.83 [yr]
		P _i = W/Q =	265 [ug/l]
Model Predicted In-Lake [TP]			89.5 [ug/l]
Observed In-Lake [TP]			103.4 [ug/l]

2009 Loading Summary for Halsted Bay							
Water Budgets				Phosphorus Loading			
Inflow from Drainage Areas							
Drainage Area			Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load
Name	[km ²]	[m/yr]	[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1 Direct (Halsted's)	3.2	0.08	0.250	136	1.0	34.0	
2 6-Mile Creek (DS of M)	6.9	0.08	0.540	136.0	1.0	73.4	
3 North Trib	4.1	0.08	0.322	136.0	1.0	43.8	
4					1.0		
5					1.0		
Summation	14	0	1	136.0		151.2	
Point Source Dischargers							
			Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load	
Name			[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1					1.0		
2					1.0		
3					1.0		
4					1.0		
5					1.0		
Summation			0.000			0.0	
Failing Septic Systems							
Name	Total Systems	Failing Systems	Discharge			Load	
			[10 ⁶ m ³ /yr]	Failure [%]		[kg/yr]	
1							
2							
3							
4							
5							
Summation	0	0	0.0			0.0	
Inflow from Upstream Lakes							
			Discharge	Estimated P Concentration	Calibration Factor	Load	
Name			[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1 Mud Lake			10.37	136.1	1.0	1,411.28	
2					1.0		
3					1.0		
Summation			10.37	136.1		1,411	
Atmosphere							
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load	
[km ²]	[m/yr]	[m/yr]	[10 ⁶ m ³ /yr]	[kg/km ² -yr]	[--]	[kg/yr]	
2.27	0.76	0.76	0.00	26.80	1.0	60.9	
Dry-year total P deposition =				24.9			
Average-year total P deposition =				26.8			
Wet-year total P deposition =				29.0			
(Barr Engineering 2004)							
Groundwater							
Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load	
[km ²]	[m/yr]		[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
2.27	0.3		0.76	84	1.0	64	
Internal							
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load	
[km ²]	[days]			[mg/m ² -day]	[--]	[kg/yr]	
2.27	91.1		Oxic	2.6	1.0	547	
2.27	30.9		Anoxic	10.3	1.0	721	
Summation						1,267	
Net Discharge [10 ⁶ m ³ /yr] =			12.24	Net Load [kg/yr] = 2,955			

NOTES

¹ Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2009 Lake Response Modeling for Halsteds Bay			
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \frac{P_i}{1 + C_p \times C_{CB} \times \left(\frac{W_p}{V}\right)^b \times T}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C _p =	1.04 [-]
		C _{CB} =	0.162 [-]
		b =	0.458 [-]
		W (total P load = inflow + atm.) =	2,955 [kg/yr]
		Q (lake outflow) =	12.2 [10 ⁶ m ³ /yr]
		V (modeled lake volume) =	9.1 [10 ⁶ m ³]
		T = V/Q =	0.75 [yr]
		P _i = W/Q =	241 [ug/l]
Model Predicted In-Lake [TP]			87.2 [ug/l]
Observed In-Lake [TP]			104.1 [ug/l]

2010 Loading Summary for Halsted Bay							
Water Budgets				Phosphorus Loading			
Inflow from Drainage Areas							
Drainage Area			Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load
Name	[km ²]		[m/yr]	[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]
1 Direct (Halsted's)	3.2		0.09	0.271	156	1.0	42.4
2 6-Mile Creek (DS of	6.9		0.09	0.585	156.1	1.0	91.4
3 North Trib	4.1		0.09	0.350	156.1	1.0	54.6
4						1.0	
5						1.0	
Summation		14	0	1			188.3
Point Source Dischargers							
			Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load	
Name			[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
1					1.0		
2					1.0		
3					1.0		
4					1.0		
5					1.0		
Summation			0.000			0.0	
Failing Septic Systems							
Name	Total Systems	Failing Systems	Discharge			Load	
			[10 ⁶ m ³ /yr]	Failure [%]		[kg/yr]	
1							
2							
3							
4							
5							
Summation			0	0	0.0	0.0	
Inflow from Upstream Lakes							
			Discharge	Estimated P Concentration	Calibration Factor	Load	
Name			[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
1 Mud Lake			12.27	156.2	1.0	1,916.59	
2				-	1.0		
3				-	1.0		
Summation			12.27	156.2		1,917	
Atmosphere							
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load	
[km ²]	[m/yr]	[m/yr]	[10 ⁶ m ³ /yr]	[kg/km ² -yr]	[-]	[kg/yr]	
2.27	0.92	0.92	0.00	26.80	1.0	60.9	
Dry-year total P deposition =				24.9			
Average-year total P deposition =				26.8			
Wet-year total P deposition =				29.0			
(Barr Engineering 2004)							
Groundwater							
Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load	
[km ²]	[m/yr]		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
2.27	0.3		0.76	84	1.0	64	
Internal							
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load	
[km ²]	[days]			[mg/m ² -day]	[-]	[kg/yr]	
2.27	88.3		Oxic	2.7	1.0	535	
2.27	33.7		Anoxic	10.1	1.0	775	
Summation						1,310	
Net Discharge [10 ⁶ m ³ /yr] =			14.24	Net Load [kg/yr] = 3,539			

NOTES

¹ Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2010 Lake Response Modeling for Halsteds Bay			
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)	
		C _P =	1.04 [-]
		C _{CB} =	0.162 [-]
		b =	0.458 [-]
		W (total P load = inflow + atm.) =	3,539 [kg/yr]
		Q (lake outflow) =	14.2 [10 ⁶ m ³ /yr]
		V (modeled lake volume) =	9.1 [10 ⁶ m ³]
		T = V/Q =	0.64 [yr]
		P _i = W/Q =	249 [ug/l]
Model Predicted In-Lake [TP]			93.8 [ug/l]
Observed In-Lake [TP]			81.5 [ug/l]

2011 Loading Summary for Halsted Bay						
Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Drainage Area		Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load
Name	[km ²]	[m/yr]	[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]
1 Direct (Halsted's)	3.2	0.07	0.213	122	1.0	26.0
2 6-Mile Creek (DS of	6.9	0.07	0.459	122.0	1.0	56.1
3 North Trib	4.1	0.07	0.274	122.0	1.0	33.5
4					1.0	
5					1.0	
Summation		14	0	1		115.5
Point Source Dischargers						
		Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load	
Name		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
1				1.0		
2				1.0		
3				1.0		
4				1.0		
5				1.0		
Summation			0.000		0.0	
Failing Septic Systems						
Name	Total Systems	Failing Systems	Discharge	Failure [%]	Load	
			[10 ⁶ m ³ /yr]		[kg/yr]	
1						
2						
3						
4						
5						
Summation		0	0	0.0	0.0	
Inflow from Upstream Lakes						
		Discharge	Estimated P Concentration	Calibration Factor	Load	
Name		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]	
1 Mud Lake		9.37	122.1	1.0	1,144.26	
2			-	1.0		
3			-	1.0		
Summation			9.37	122.1	1,144	
Atmosphere						
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
[km ²]	[m/yr]	[m/yr]	[10 ⁶ m ³ /yr]	[kg/km ² -yr]	[-]	[kg/yr]
2.27	0.71	0.71	0.00	26.80	1.0	60.9
Dry-year total P deposition =				24.9		
Average-year total P deposition =				26.8		
Wet-year total P deposition =				29.0		
(Barr Engineering 2004)						
Groundwater						
Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
[km ²]	[m/yr]		[10 ⁶ m ³ /yr]	[ug/L]	[-]	[kg/yr]
2.27	0.3		0.76	84	1.0	64
Internal						
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
[km ²]	[days]			[mg/m ² -day]	[-]	[kg/yr]
2.27	90.0		Oxic	2.7	1.0	549
2.27	32.0		Anoxic	10.0	1.0	726
Summation						1,275
Net Discharge [10 ⁶ m ³ /yr] =			11.08	Net Load [kg/yr] =		2,660

NOTES

¹ Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2011 Lake Response Modeling for Halsteds Bay			
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)	
		C _P =	1.04 [-]
		C _{CB} =	0.162 [-]
		b =	0.458 [-]
		W (total P load = inflow + atm.) =	2,660 [kg/yr]
		Q (lake outflow) =	11.1 [10 ⁶ m ³ /yr]
		V (modeled lake volume) =	9.1 [10 ⁶ m ³]
		T = V/Q =	0.82 [yr]
		P _i = W/Q =	240 [ug/l]
Model Predicted In-Lake [TP]			83.9 [ug/l]
Observed In-Lake [TP]			74.9 [ug/l]

Average Loading Summary for Halsted Bay							
Water Budgets				Phosphorus Loading			
Inflow from Drainage Areas							
Drainage Area			Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load
Name	[km ²]	[m/yr]	[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1 Direct (Halsted's)	3.2	0.08	0.250	144.3	1.0	36.0	
2 6-Mile Creek (DS of	6.9	0.08	0.538	144.3	1.0	77.7	
3 North Trib	6.9	0.05	0.321	144.3	1.0	46.4	
4							
5							
Summation		17	0	1		160.0	
Point Source Dischargers							
			Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load	
Name			[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1							
2							
3							
4							
5							
Summation			0.000			0.0	
Failing Septic Systems							
Name	Total Systems	Failing Systems	Discharge	Failure [%]		Load	
			[10 ⁶ m ³ /yr]			[kg/yr]	
1							
2							
3							
4							
5							
Summation			0	0	0.0	0.0	
Inflow from Upstream Lakes							
			Discharge	Estimated P Concentration	Calibration Factor	Load	
Name			[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1 Mud Lake			10.74	144.5	1.0	1,551	
2				-	1.0		
3				-	1.0		
Summation			10.74	144.5		1,551	
Atmosphere							
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load	
[km ²]	[m/yr]	[m/yr]	[10 ⁶ m ³ /yr]	[kg/km ² -yr]	[--]	[kg/yr]	
2.27	0.79	0.79	0.00	26.80	1.0	60.9	
Dry-year total P deposition =				24.9			
Average-year total P deposition =				26.8			
Wet-year total P deposition =				29.0			
(Barr Engineering 2004)							
Groundwater							
Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load	
[km ²]	[m/yr]		[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
2.27	0.3		0.76	84	1.0	64	
Internal							
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load	
[km ²]	[days]			[mg/m ² -day]	[--]	[kg/yr]	
2.27	93.4		Oxic	2.7	1.0	568	
2.27	28.6		Anoxic	10.1	1.0	659	
Summation						1,227	
Net Discharge [10 ⁶ m ³ /yr] =			12.61	Net Load [kg/yr] = 3,063			

NOTES

¹ Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

Average Lake Response Modeling for Halsteds Bay			
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)	
		C _P =	1.04 [-]
		C _{CB} =	0.162 [-]
		b =	0.458 [-]
		W (total P load = inflow + atm.) =	3,063 [kg/yr]
		Q (lake outflow) =	12.6 [10 ⁶ m ³ /yr]
		V (modeled lake volume) =	9.1 [10 ⁶ m ³]
		T = V/Q =	0.72 [yr]
		P _i = W/Q =	243 [ug/l]
Model Predicted In-Lake [TP]			88.5 [ug/l]
Observed In-Lake [TP]			88.5 [ug/l]

Loading Summary at the Standard for Halsted Bay							
Water Budgets				Phosphorus Loading			
Inflow from Drainage Areas							
Drainage Area			Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load
Name	[km ²]	[m/yr]	[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1 Direct (Halsted's)	3.2	0.08	0.250	70.0	0.49	17.5	
2 6-Mile Creek (DS of	6.9	0.08	0.538	70.0	0.49	37.7	
3 North Trib	6.9	0.05	0.321	70.0	0.49	22.5	
4							
5							
Summation		17	0	1		77.6	
Point Source Dischargers							
			Discharge	Phosphorus Concentration	Loading Calibration Factor (CF) ¹	Load	
Name			[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1							
2							
3							
4							
5							
Summation			0.000			0.0	
Failing Septic Systems							
Name	Total Systems	Failing Systems	Discharge			Load	
			[10 ⁶ m ³ /yr]	Failure [%]		[kg/yr]	
1							
2							
3							
4							
5							
Summation			0	0	0.0	0.0	
Inflow from Upstream Lakes							
			Discharge	Estimated P Concentration	Calibration Factor	Load	
Name			[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
1 Mud Lake			10.74	60.0	0.42	644	
2				-			
3				-			
Summation			10.74	60.0		644	
Atmosphere							
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load	
[km ²]	[m/yr]	[m/yr]	[10 ⁶ m ³ /yr]	[kg/km ² -yr]	[--]	[kg/yr]	
2.27	0.79	0.79	0.00	26.80	1.0	60.9	
Dry-year total P deposition =				24.9			
Average-year total P deposition =				26.8			
Wet-year total P deposition =				29.0			
(Barr Engineering 2004)							
Groundwater							
Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load	
[km ²]	[m/yr]		[10 ⁶ m ³ /yr]	[ug/L]	[--]	[kg/yr]	
2.27	0.3		0.76	84	1.0	64	
Internal							
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load	
[km ²]	[days]			[mg/m ² -day]	[--]	[kg/yr]	
2.27	93.4		Oxic	0.6	0.23	128	
2.27	28.6		Anoxic	1.0	0.10	66	
Summation				0.7		194	
Net Discharge [10 ⁶ m ³ /yr] =			12.61	Net Load [kg/yr] =		1,041	

NOTES

¹ Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

Average Lake Response Modeling for Halsteds Bay			
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
$P = \frac{P_i}{1 + C_p \times C_{CB} \times \left(\frac{W_p}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)	
		C _p =	1.04 [-]
		C _{CB} =	0.162 [-]
		b =	0.458 [-]
		W (total P load = inflow + atm.) =	1,041 [kg/yr]
		Q (lake outflow) =	12.6 [10 ⁶ m ³ /yr]
		V (modeled lake volume) =	9.1 [10 ⁶ m ³]
		T = V/Q =	0.72 [yr]
		P _i = W/Q =	83 [ug/l]
Model Predicted In-Lake [TP]			40.0 [ug/l]
Observed In-Lake [TP]			40.0 [ug/l]

Appendix D

Cost Estimates

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Alum Treatment of Halsted Bay - Scenario 1
Summary of Pre-Design Estimated Costs

Cost Component Description	Quantity	Units	Estimated Unit Price	Extension
Final Design (1.5%)	2%		Constr Cost	\$20,020
Permitting	1	lump sum	\$10,000	\$10,000
Bidding Documents	1	lump sum	\$5,000	\$5,000
Bidding Assistance	1%		Constr Cost	\$10,010
Construction Estimate:				
Mobilization	1	lump sum	\$70,000	\$70,000
Chemicals [AlSO_4 and $\text{NaAl}(\text{OH})_4$]	1	lump sum	\$931,000	\$931,000
Total Construction				\$1,001,000

Capital Costs	\$1,046,030
Construction Contingency (10%)	\$104,603
Annualized O&M	\$0
Annualized Monitoring	\$8,000
20-Year O&M/Monitoring:	\$8,000
Capital + 20-year Total Costs:	\$1,054,030
20-year TP Removal (lbs)	26160
\$/lb TP Removal Over 20-year Life	\$40.29

Alum Treatment of Halsted Bay - Scenario 2
Summary of Pre-Design Estimated Costs

Cost Component Description	Quantity	Units	Estimated Unit Price	Extension
Final Design (1.5%)	2%		Constr Cost	\$21,720
Permitting	1	lump sum	\$10,000	\$10,000
Bidding Documents	1	lump sum	\$5,000	\$5,000
Bidding Assistance	1%		Constr Cost	\$10,860
Construction Estimate:				
Mobilization	1	lump sum	\$75,000	\$75,000
Chemicals [AlSO_4 and $\text{NaAl}(\text{OH})_4$]	1	lump sum	\$1,011,000	\$1,011,000
Total Construction				\$1,086,000

Capital Costs	\$1,133,580
Construction Contingency (10%)	\$113,358
Annualized O&M	\$0
Annualized Monitoring	\$8,000
20-Year O&M/Monitoring:	\$8,000
Capital + 20-year Total Costs:	\$1,141,580
20-year TP Removal (lbs)	38140
\$/lb TP Removal Over 20-year Life	\$29.93

Hypolimnetic Aeration with Chemical Injection

Summary of Pre-Design Estimated Costs

Cost Component Description	Quantity	Units	Estimated Unit Price	Extension
Property Surveys	1	lump sum	\$7,000	\$7,000
Land Rights/Easements for Operation	5	acre	\$10,000	\$50,000
Land Rights/Easements for Access	1	acre	\$35,000	\$17,500
Preliminary Design (7%)	10%		Constr Cost	\$78,000
EAW	1	lump sum	\$50,000	\$50,000
Preliminary Permitting	1	lump sum	\$20,000	\$20,000
Final Design (1.5%)	2%		Constr Cost	\$15,600
Permitting	1	lump sum	\$10,000	\$10,000
Sediment Dosage Testing	1	lump sum	\$25,000	\$25,000
Bidding Documents	3%		Constr Cost	\$23,400
Bidding Assistance	1%		Constr Cost	\$7,800
Construction Estimate:				
Mobilization/Demobilization	1	lump sum	\$30,000	\$30,000
Site Access Road, Grading and Drainage	1	lump sum	\$50,000	\$50,000
Compressor/Chemical Storage/Controls and Building	1	lump sum	\$300,000	\$300,000
Power Source, Utilities	1	lump sum	\$50,000	\$50,000
Aerator Units	2	Each	\$125,000.00	\$250,000
Miscellaneous Piping/Electrical/chemical Feeds	1	lump sum	\$100,000.00	\$100,000
Total Construction				\$780,000
Construction Management Estimate	4	weeks	\$7,000	\$28,000

Capital Costs

\$1,112,300

Construction Contingency (10%)

\$111,230

Annualized O&M

\$75,000

Annualized Monitoring

\$3,000

20-Year O&M/Monitoring:

\$1,560,000

Capital + 20-year Total Costs:

\$2,672,300

20-year TP Removal (lbs)

26160

\$/lb TP Removal Over 20-year Life

\$102.15

Hypolimnetic Withdrawal, Alum Treatment, and Replacement

Summary of Pre-Design Estimated Costs

Cost Component Description	Quantity	Units	Estimated Unit Price	Extension
<u>Piping, Intake, Discharge, Pumps</u>				
Land Rights/Easements for Access	1	lump sum	\$50,000	\$50,000
Preliminary Design (10%)	10%		Constr Cost	\$95,300
Preliminary Permitting	1	lump sum	\$5,000	\$5,000
Final Design	3%		Constr Cost	\$28,590
Permitting	1	Lump sum	\$5,000	\$5,000
Construction Estimate:				
HDPE Manifolds, 36" HDPE and PVC Pipe	6,000	LF	\$80	\$480,000
Power Source	1	lump sum	\$8,000	\$8,000
2 Pumps, 25 HP, Housing	1	lump sum	\$55,000	\$55,000
PVC Piping from Alum Plant	5,500	LF	\$70	\$385,000
Discharge Structure	1	lump sum	\$25,000	\$25,000
Total Construction				\$953,000

Alum Treatment

Non-Construction Costs

\$2,380,000

Total Construction of 15 cfs Plant

\$4,760,000

Capital Costs

\$8,276,890

Construction Contingency (10%)

\$827,689

Power

\$5,000

Annualized O&M

\$150,000

Annualized Monitoring

\$10,000

20-Year O&M/Monitoring:

\$3,300,000

Capital + 20-year Total Costs:

\$11,576,890

20-year TP Removal (lbs)

26160

\$/lb TP Removal Over 20-year Life

\$443

Hypolimnetic Alum Circulation

Summary of Pre-Design Estimated Costs

Cost Component Description	Quantity	Units	Estimated Unit Price	Extension
Property Surveys	1	lump sum	\$7,000	\$7,000
Land Rights/Easements for Operation	5	acre	\$10,000	\$50,000
Land Rights/Easements for Access	1	acre	\$35,000	\$17,500
Preliminary Design (7%)	10%		Constr Cost	\$125,500
EAW	1	lump sum	\$50,000	\$50,000
Preliminary Permitting	1	lump sum	\$20,000	\$20,000
Final Design (1.5%)	2%		Constr Cost	\$25,100
Permitting	1	lump sum	\$10,000	\$10,000
Sediment Dosage Testing	1	lump sum	\$25,000	\$25,000
Bidding Documents	3%		Constr Cost	\$37,650
Bidding Assistance	1%		Constr Cost	\$12,550
Construction Estimate:				
Mobilization/Demobilization	1	lump sum	\$30,000	\$30,000
Site Access Road, Grading and Drainage	1	lump sum	\$50,000	\$50,000
Hypolimnetic Circulator	10	Each	\$70,000	\$700,000
Chemical & Storage/Controls and Building	1	lump sum	\$250,000	\$250,000
Power Source, Utilities	1	lump sum	\$50,000	\$50,000
Alum Storage Tank	1	lump sum	\$25,000	\$25,000
Pump Units	1	Each	\$50,000	\$50,000
Miscellaneous Piping/Electrical/chemical Feeds	1	lump sum	\$100,000	\$100,000
Total Construction				\$1,255,000
Construction Management Estimate	4	weeks	\$7,000	\$28,000

Capital Costs **\$1,663,300**
 Construction Contingency (10%) \$166,330

Annualized O&M \$125,000
 Annualized Monitoring \$10,000
20-Year O&M/Monitoring: **\$2,700,000**

Capital + 20-year Total Costs: **\$4,363,300**
 20-year TP Removal (lbs) 26160
 \$/lb TP Removal Over 20-year Life **\$166.79**

Off-line Alum Injection Summary of Pre-Design Estimated Costs

6. OPINION OF PROBABLE COST

Based on the layout for each alternative, an engineer's opinion of probable cost, estimated MCES SAC charges, and estimated operation and maintenance cost (20 year present value) are shown in Table 6.1 below. These opinions of cost incorporate anticipated 2013 construction costs and include a 25% contingency and 25% for indirect costs. The indirect costs include legal, engineering, administrative, and financing items. Table 6.2, following 6.1, provides greater detail of annual operation and maintenance costs.

**Table 6.1 – Engineer's Opinion of Probable Cost and
Estimated Operation and Maintenance Costs Present Value**

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Total Project Cost	\$7,203,695	\$10,079,406	\$5,013,695	\$7,469,406
MCES SAC Charges	\$94,945	\$258,942	\$94,945	\$258,942
Total Capital Cost	\$7,298,640	\$10,338,348	\$5,108,640	\$7,728,348
MCES Flow Charges (20 yr PV)	\$58,915	\$160,677	\$58,915	\$160,677
Labor, Power, Chemicals, and Depreciation Cost (20 yr PV)	\$2,716,893	\$6,043,543	\$2,716,893	\$6,043,543
Total Operation and Maintenance Costs (20 yr PV)	\$2,775,808	\$6,204,220	\$2,775,808	\$6,204,220
Total Project Cost (20 yr Present Value)	\$10,074,448	\$16,542,568	\$7,884,448	\$13,932,568

*It has been assumed an MCES Industrial Discharge Permit will be granted. Should sludge lagoons be required project costs would increase.

*Land purchase costs not included

In-line Alum Injection

Summary of Pre-Design Estimated Costs

Cost Component Description	Quantity	Units	Estimated Unit Price	Extension
Property Surveys	1	lump sum	\$7,000	\$7,000
Land Rights/Easements for Operation	5	acre	\$10,000	\$50,000
Land Rights/Easements for Access	1	acre	\$35,000	\$17,500
Preliminary Design (7%)	10%		Constr Cost	\$55,500
EAW	1	lump sum	\$50,000	\$50,000
Preliminary Permitting	1	lump sum	\$20,000	\$20,000
Final Design (1.5%)	2%		Constr Cost	\$11,100
Permitting	1	lump sum	\$10,000	\$10,000
Sediment Dosage Testing	1	lump sum	\$25,000	\$25,000
Bidding Documents	3%		Constr Cost	\$16,650
Bidding Assistance	1%		Constr Cost	\$5,550
Construction Estimate:				
Mobilization/Demobilization	1	lump sum	\$30,000	\$30,000
Site Access Road, Grading and Drainage	1	lump sum	\$50,000	\$50,000
Chemical & Storage/Controls and Building	1	lump sum	\$250,000	\$250,000
Power Source, Utilities	1	lump sum	\$50,000	\$50,000
Alum Storage Tank	1	lump sum	\$25,000	\$25,000
Pump Units	1	Each	\$50,000	\$50,000
Miscellaneous Piping/Electrical/chemical Feeds	1	lump sum	\$100,000	\$100,000
Total Construction				\$555,000
Construction Management Estimate	4	weeks	\$7,000	\$28,000

Capital Costs **\$851,300**
Construction Contingency (10%) \$85,130

Annualized O&M \$50,000
Annualized Monitoring \$3,000
20-Year O&M/Monitoring: **\$1,060,000**

Capital + 20-year Total Costs: **\$1,911,300**
20-year TP Removal (lbs) 27918
\$/lb TP Removal Over 20-year Life **\$68.46**

Iron Filtration

Summary of Pre-Design Estimated Costs

Cost Component Description	Quantity	Units	Estimated Unit Price	Extension
Property Surveys	1	lump sum	\$10,000	\$10,000
Land Rights/Easements for Operation	16	acre	\$35,000	\$560,000
Land Rights/Easements for Access	1	acre	\$35,000	\$35,000
Preliminary Design (10%)	10%		Constr Cost	\$336,650
Preliminary Permitting	1	lump sum	\$25,000	\$25,000
Final Design	3%		Constr Cost	\$100,995
Permitting	1	lump sum	\$10,000	\$10,000
No Association Determination	1	Each	\$1,000	\$1,000
Phase 1 EA	1	Each	\$2,500	\$2,500
Certificate of Closure (COC) Plan Contingency	1	Each	4,500	\$4,500
COC Implementation Contingency	1	lump sum	\$25,000	\$25,000
Bidding Documents	5%		Constr Cost	\$168,325
Bidding Assistance	1%		Constr Cost	\$33,665
Construction Estimate:				
Site Access	1	lump sum	\$100,000	\$100,000
Power, Utilities	1	lump sum	\$50,000	\$50,000
Site Grading and Development	1	lump sum	\$100,000	\$100,000
7000 gpm Lift Station and Screen House	1	lump sum	\$375,000	\$375,000
Liner	650,000	SF	\$0.55	\$357,500
Under-drain	70,000	LF	\$10.00	\$700,000
Intake and Discharge Lines	2,000	LF	\$50.00	\$100,000
Intake and Discharge Structures	2	Each	\$20,000.00	\$40,000
Coarse Sand	25,000	CY	\$15.00	\$375,000
Geotextile	660,000	SF	\$0.30	\$198,000
Coarse Filter Agregate	25,000	CY	\$35.00	\$875,000
Top Dressing	12,000	CY	\$8.00	\$96,000
Total Construction				\$3,366,500
Construction Management Estimate	12	weeks	\$5,000	\$60,000
Environmental Remediation Contingency	1	lump sum	\$50,000	\$50,000

Capital Costs

\$4,789,135

Construction Contingency (10%)

\$478,914

Annual Power

5040

Annualized O&M

\$25,000

Annualized Monitoring

\$5,000

20-Year O&M/Monitoring:

\$700,800

Capital + 20-year Total Costs:

\$5,489,935

20-year TP Removal (lbs)

17991.6

\$/lb TP Removal Over 20-year Life

\$305.14

Fish Migration Barrier

Summary of Pre-Design Estimated Costs

Cost Component Description	Quantity	Units	Estimated Unit Price	Extension
Land Rights/Easements for Access	1	lump sum	\$50,000	\$50,000
Preliminary Design (10%)	10%		Constr Cost	\$5,000
Preliminary Permitting	1	lump sum	\$500	\$500
Final Design	3%		Constr Cost	\$1,500
Permitting	1	Lump sum	\$1,500	\$1,500
Construction Estimate:				
Fish Barrier Device (using electric current)	1	lump sum	\$50,000	\$50,000
Total Construction				\$50,000

Capital Costs **\$108,500**

Construction Contingency (10%) \$10,850

Annualized O&M \$4,000

Annualized Monitoring \$750

20-Year O&M/Monitoring: **\$95,000**

Capital + 20-year Total Costs: **\$203,500**

20-year TP Removal (lbs) na

\$/lb TP Removal Over 20-year Life na

\$/lb TP Removal Over 20-year Life w/o Alum Plant na

Vegetation Management Summary of Estimated Management Costs

Annual Cost Component Description	Quantity	Units	Estimated Unit Price	Extension
Contract Harvester Treatment (1) (2)	0	AC	\$300	\$0
Contract Herbicide Treatment (2)	40	AC	\$350	\$14,000
Permitting	1	LS	\$1,000	\$1,000
Monitoring (3)	1	LS	\$2,500	\$2,500
Contract Management	1	LS	\$500	\$500
Annual Treatment Costs				\$18,000
Contingency (10%)				\$1,800
Annual Treatment Costs w/Contingency				\$19,800

20-Year Total Costs:

\$396,000

20-year TP Removal (lbs)

na

\$/lb TP Removal Over 20-year Life

na

\$/lb TP Removal Over 20-year Life w/o Alum Plant

na

(1) Assumed no harvesting since the majority of aquatic vegetation less than 5ft

(2) Based on average of vendor quotes assumes treatment two times per year - 20ac/treatment

(3) Monitoring assumed 2 staff at \$35/hr would be required to complete 60 hrs total of monitoring including vegetation sampling, water quality, and sediment sampling.

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Appendix B: 2013 Site Alternatives Analysis

FEASIBILITY STUDY

NUTRIENT REMOVAL SYSTEM

FOR THE MINNEHAHA CREEK WATERSHED DISTRICT

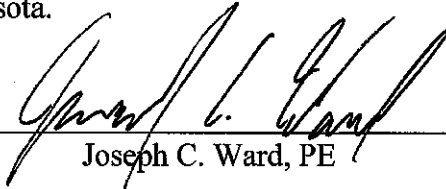
July 19, 2013

Prepared By:

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(763) 541-4800
(763) 541-1700 (Fax)**

CERTIFICATION

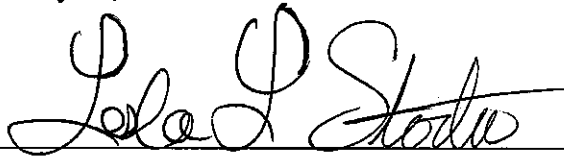
I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.



Joseph C. Ward, PE

Date: July 19, 2013

Lic. No. 45855



Leslee L. Storlie, EIT

Date: July 19, 2013

Quality Control Review By:



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TABLE OF CONTENTS

TITLE SHEET
CERTIFICATION SHEET
TABLE OF CONTENTS

1. EXECUTIVE SUMMARY	1
2. PURPOSE AND SCOPE.....	2
3. PROCESS BACKGROUND AND PERMITTING.....	3
4. PHOSPHORUS REMOVAL DESIGN ALTERNATIVES	5
5. ENVIRONMENTAL CONSIDERATIONS.....	8
6. OPINION OF PROBABLE COST.....	10
7. COST BENEFIT	12
8. FEASIBILITY AND RECOMMENDATION	13
9. OTHER CONSIDERATIONS.....	15

FIGURES

APPENDIX A

Opinion of Probable Costs

1.EXECUTIVE SUMMARY

This feasibility study is prepared as part of the Minnehaha Creek Watershed District (MCWD) and the City of Minnetrista's Halsted's Bay Phosphorus Reduction Project. Included is an evaluation of alternatives for the design of a nutrient removal system to improve water quality at Halsted's Bay of Lake Minnetonka. Halsted's Bay lies within Minnetrista, MN.

As part of this feasibility study, two site locations (Figure 1) were selected with two alternatives for process water flow rates at each location, resulting in four alternative designs. These alternatives are listed below.

- Alternative #1-West Location at 5 cfs (2,250 GPM)
- Alternative #2-West Location at 15 cfs (6,750 GPM)
- Alternative #3-East Location at 5 cfs (2,250 GPM)
- Alternative #4-East Location at 15 cfs (6,750 GPM)

Based on the project capital costs, staff operation and maintenance requirements, constructability, and removal efficiency Alternative #4 is recommended. The evaluation of operation and maintenance costs is included in Section 6. The engineer's opinion of probable capital costs is approximately \$7,500,000.

Additional project design recommendations are listed below.

- Engineering and design of the nutrient removal system was based on water quality and treatment process from similar lakes in the metro area. It is recommended that pilot plant (jar) testing be completed to verify treatment process assumptions included in this study and resulting structure sizes and necessary equipment. Removal efficiencies and a more detailed evaluation can be completed following jar testing.
- Begin permitting process with Minnesota Pollution Control Agency (MPCA) and Metropolitan Council on Environmental Services (MCES). Sludge disposal is a critical issue with MCES and if it will not be permitted, then additional land should be purchased for lagoons for sludge storage.
- An evaluation should be completed at the recommended nutrient removal system site and near intake/effluent piping locations to confirm existing soils are adequate for facility construction or if additional geotechnical improvements are necessary.

2. PURPOSE AND SCOPE

The purpose of the Halsted's Bay Off-Line Phosphorus Removal Facility Feasibility Study is to evaluate potential treatment facility locations, and determine sizing and construction costs necessary for a nutrient removal system.

The feasibility study involves the evaluation, design, and cost estimation of a clarification system to remove phosphorus from 6 Mile Creek upstream of Halsted's Bay. Within the study, consideration to pumping capacity, operations flexibility, sludge handling, and removal efficiency were evaluated.

The scope of this report includes a description of existing conditions, a presentation of the four alternatives for removing phosphorus from the surface water, a discussion of probable cost, and recommendations.

3. PROCESS BACKGROUND AND PERMITTING

A. PHOSPHORUS REMOVAL SYSTEM

Sedimentation systems have been used to effectively remove phosphorus from some metro area lakes. The sedimentation process consists of a clarification system that is designed to remove phosphorus from the creek water leading to Halsted's Bay. Addition of a flocculant (alum, ferric chloride, and/or in combination with a polymer) to the influent water forms large particles (floc) containing phosphorus. Water flows through a clarifier where the floc settles to the bottom, leaving cleaner water (effluent) near the top of the clarifier. The effluent is returned to the lake and the remaining floc (sludge), containing phosphorus, is disposed in the sanitary sewer or sludge holding lagoons.

B. FLOCCULANT ADDITION AND ALTERNATIVES

Several alternatives are available for flocculant addition including, aluminum sulfate (alum), ferric chloride, and alum or ferric chloride polymer combinations. The optimal flocculant type and dosage should be determined through jar testing. Some advantages and disadvantages of each flocculant type are listed below.

- Alum is typically 50% less in cost than ferric chloride, however prices do fluctuate and are dependent on delivery quantities.
- Alum is less corrosive than ferric chloride. Ferric chloride delivery systems can be more expensive, replaced more often, and require more care for operators to work with.
- Alum does not stain as much as ferric chloride. Ferric chloride's color stains tanks (making it difficult to read levels), walls, floors, and requires more cleaning and care for operators to work with.
- Phosphorus removal through alum dosing results in pH decrease, therefore caustic soda must be added to the water to return the water to a neutral pH.
- Ferric chloride reacts better in colder temperatures than alum.
- Ferric chloride can be stored outside in cold temperatures, alum cannot.
- Addition of ferric chloride introduces chlorides into the water which MPCA may have objections to during the agency permitting process.

It is emphasized that jar testing will determine the optimal flocculant and dosage for Halsted's Bay water quality. For example, although ferric chloride costs approximately 50% more than alum, ferric chloride may have greater phosphorus removal capacity and require less to be added to the influent water. Therefore, there would be no net difference in cost between the two flocculants. Also, the flocculant can be changed once the facility is in operation depending on operator preferences.

Based on past removal data from similarly designed systems, the system may have the ability to remove approximately 1,617 lb (15 cfs) or 1,095 lb (5 cfs) of phosphorus per year of operation, however, jar testing and laboratory testing is necessary to determine actual phosphorus removal expectations.

C. SLUDGE DISPOSAL AND PERMITTING

The sludge containing phosphorus floc remaining would likely consist of approximately 0.5 to 1% solids which are light and do not settle or dewater easily. Therefore, the most efficient method of disposal is by conveyance to the sanitary sewer system.

The City of Minnetrista owns and operates the local wastewater collection system, but ultimately conveys its wastewater to MCES interceptor sewers that transport wastewater to regional treatment plants for final disposal. MCES requires an industrial discharge permit for all facilities using water in its treatment process and one would be required for this system. Historically, MCES has granted industrial discharge permits for similar facilities, but as phosphorus limits are reduced at their regional treatment facilities, there is a strong possibility permits will not be granted in the future. Additionally, industrial discharge permits are reviewed on a regular basis and MCES can revoke the permit in the future.

In the event MCES does not authorize an industrial discharge permit, a sludge holding pond system would need to be utilized. A sludge lagoon would be designed to hold the sludge and allow drying. The ponds would need to be dredged as sludge builds up over time. Further sludge holding pond details are included in Section 8.

D. TREATMENT PROCESS PERMITTING

The treatment facility would withdraw water from and return it to a public water, therefore a National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) permit will be required from the MPCA. Similar facilities have been permitted in the past, and water quality monitoring may be required by the permit.

4. PHOSPHORUS REMOVAL DESIGN ALTERNATIVES

A. Alternative #1 (Figures 1 and 2) – West Location at 5 cfs (2,250 GPM)

This alternative is designed to treat water from 6 Mile Creek at a rate of 5 cfs at the West Location option as shown in Figure 1. Figure 2 shows the West Location options along with the necessary structures and piping layout for this design alternative.

Raw water would be drawn from an intake structure in 6 Mile Creek and pumped to a splitter box which would control the flow rate to each of the two clarifiers. At this stage flocculant would be added to improve the mixing of the water with the chemicals which can save on the volume of chemical needed during treatment.

Alternative #1 is designed using two 48' diameter clarifiers to allow the phosphorus floc to settle from the water. The use of two clarifiers instead of one allows for more flexibility in the operation of the facility. With two clarifiers available, operators would have the option of running the clarifiers in parallel or in series. During times of high water flow in the creek, the clarifiers could be run in parallel to treat the maximum volume of water. However, during times of low flow in the creek the clarifiers could be run in series allowing for better polishing of the water and better removal of phosphorus. In the future when phosphorus loading is reduced, the treatment system could be utilized in series to maximize removal, similar to creek low flow conditions.

Each clarifier would be equipped with a perimeter rake on the bottom of the structure and perimeter skimmer on the top of the water. The rake assists with the sludge disposal while the surface skimmer removes surface floc and prevents them from being discharged into Halsted's Bay.

Due to floc settling, a waste sludge is produced. It is estimated that approximately 11,000 gallons per day (gpd) sludge would be generated consisting of approximately 0.5 to 1% solids which are light and do not settle or dewater easily, so the sludge is mostly water and would flow from the bottom of the clarifier. The sludge discharge rate from the clarifier is greater than the capacity of the two lift stations that the sludge would ultimately flow to. Therefore, this design option would include two flow equalization tanks to temporarily store sludge flow which could then be pumped at a lower rate to the Minnetrista's sanitary sewer system and not exceed its capacity. Additionally, the flow equalization tanks would allow sludge to be pumped to the sanitary system during off-peak flow periods.

Depending upon jar testing results, it may be possible to use the equalization tanks for sludge thickening which would reduce the total volume of sludge discharged to Minnetrista's sanitary sewer system. The reduction in volume of sludge discharged would result in lower MCES disposal charges (SAC and flow charges). Through the use of a thickening tank and a polymer to reduce settling time, the sludge would be given time to settle and better separate from the water. The cleaner water on the top of the tank would be decanted and recycled to the head of the facility while the remaining sludge at the bottom of the tank would be pumped to the sanitary sewer system. It is estimated that

the sludge volume disposed of to the sanitary sewer could be as low as 3,000 gpd if thickening is possible.

Specifically, the sludge could be discharged to Minnetrista's Lift Station No. 12, which ultimately flows into Lift Station No. 13 and to the MCES interceptor system. Lift Station No. 12 has reserve peak flow capacity of approximately 110 GPM, so sludge flow to the lift station should be at a rate less than 110 GPM. However, if sludge is discharged to the lift station during off-peak hours the lift station may be able to accommodate the additional sludge flow.

Also included in this design is a chemical building to store and pump the necessary chemicals along with housing the controls for the treatment system. Chemical storage would allow for about 2-4 weeks of storage and would be delivered by tanker truck for optimal pricing. Based on experience at similar facilities in the region, chemical dosing rates were estimated at approximately 340 gallons (gal) of alum and 85 gal of caustic soda per day at an estimated cost of \$550/day.

Based on previous permitting experiences it is assumed that MCES will grant an industrial discharge permit allowing sludge to be disposed of to their wastewater treatment system. If the permit is denied, a sludge lagoon would be designed to hold the sludge and allow drying. The sludge lagoons would be approximately 1 acre if sludge thickening is possible and 4 acres if it is not possible.

Advantages and disadvantages of this alternative are summarized in the Feasibility and Recommendation section.

B. Alternative #2 (Figures 1 and 2) – West Location at 15 cfs (6,750 GPM)

Alternative #2 would be the same as Alternative #1 except that it would have the ability to treat up to 15 cfs of surface water. The increased treatment capacity does not require any additional structures or facilities but would require larger structures. The clarifiers would have a designed diameter of 80' and would be equipped with the same flexibility as with Alternative #1. In addition, a larger influent pump station would be needed for the increased influent volume and a larger chemical building is needed to hold the greater volume of flocculant needed to treat the larger volume of water.

Based on experience at similar facilities in the region, chemical dosing rates were estimated at approximately 1,000 gal alum and 250 gal caustic soda per day, at an estimated cost of \$1,630/day.

A similar sized splitter box would be utilized to split the flow evenly to the two clarifiers from the initial raw water pumping station. After the clarification process, the sludge would be handled in a similar manner as described in Alternative #1, however a greater volume of sludge would be produced (30,000 gpd). Sludge would be conveyed to Minnetrista's Lift Station No.12 which would have capacity to pump the increased sludge volume through the use of the equalization tanks.

Based on previous permitting experiences, it is assumed that MCES will grant an industrial discharge permit allowing sludge to be disposed of through their wastewater treatment system. If the permit is denied, a sludge lagoon would be designed to hold the sludge and allow drying. The sludge lagoons would be approximately 1 acre if sludge thickening is possible and 10 acres if it is not possible.

Advantages and disadvantages of this alternative are summarized in the Feasibility and Recommendation section.

C. Alternative #3 (Figures 1 and 3) – East Location at 5 cfs (2,250 GPM)

This alternative is the same as Alternative #1 but is located at the East location option (Figure 1). It is equipped to effectively remove phosphorus from the surface water at a treatment rate of 5 cfs. Figure 3 shows the East location options along with the necessary structures and piping layout for this design alternative.

The only difference between Alternative #1 and Alternative #3 is the site location. Alternative #3 is located closer to 6 Mile Creek as well as Halsted's Bay allowing for shorter pipe lengths and less overall headloss throughout the system as displayed in Figure 1.

Advantages and disadvantages of this alternative are summarized in the Feasibility and Recommendation section.

D. Alternative #4 (Figures 1 and 3) – East Location at 15 cfs (6,750 GPM)

This alternative is the same as Alternative #2 but is located at the East location option. Similar to Alternative #2, it could handle 15 cfs of surface water flow during treatment.

As with Alternative #3, due to the location, the pipe lengths and overall headloss are less for this option as compared to Alternatives #1 and #2.

Advantages and disadvantages of this alternative are summarized in the Feasibility and Recommendation section.

5. ENVIRONMENTAL CONSIDERATIONS

In an effort to reduce environmental impacts, the nutrient removal system would be designed with considerations for environmental impact. Included in each alternative design are the following environmental considerations: VFDs, water recycling, low impact site development, and solar power.

A. Variable Frequency Drives (VFDs)

Through the use of VFDs, a reduction in speed, flow, energy, and headloss is achieved. These savings are possible because the VFD alters the speed of the pump motor. Changing the speed of the motor places less stress on the piping and pumping components and electrical savings are achieved.

B. Water Recycling

Depending upon jar testing results, it may be possible to use the equalization tanks for sludge thickening which would reduce the total volume of sludge discharged to Minnetrista's sanitary sewer system. The reduction in volume of sludge discharged would result in lower MCES disposal charges (SAC and flow charges). Through the use of a thickening tank and a polymer to reduce settling time, the sludge is given time to settle and better separate from the water. The cleaner water on the top of the tank would be decanted and recycled to the head of the facility while the remaining sludge at the bottom of the tank would be pumped to the sanitary sewer system. It is estimated that the sludge volume disposed of to the sanitary sewer may be as low as 3,000 gpd if thickening is possible compared to approximately 30,000 gpd for the 15 cfs alternatives and 11,000 gpd for the 5 cfs alternatives.

C. Low Impact Site Development-Visual and Physical

Each alternative design would be located in either a current residential location or a location that may become residential in the future. To assist in providing a site with low visual impact, the clarifier structures could be constructed as close to level with grade as possible. A minimal amount of the structure could be visible to residents as the majority of the structure would be underground. The clarifier could be equipped with a flat cover, rather than a domed cover to improve aesthetics and decrease the visual impact the site has on the surrounding residents if a cover is necessary. To improve aesthetics, architectural finishes can be used for the building and the site landscaped.

The physical impact of the site development could be minimized through minimal grading and the consideration of the natural ground slope in the design of the system's hydraulics. Wetland impacts could be minimized through the use of best management practices for storm water pollution prevention.

D. Solar Panels

Along with the use of VFDs for electricity conservation, solar panels could also be installed and utilized to save energy. The solar energy could be used to provide a portion of power requirements and would be evaluated in greater detail during final design.

6. OPINION OF PROBABLE COST

Based on the layout for each alternative, an engineer's opinion of probable cost, estimated MCES SAC charges, and estimated operation and maintenance cost (20 year present value) are shown in Table 6.1 below. These opinions of cost incorporate anticipated 2013 construction costs and include a 25% contingency and 25% for indirect costs. The indirect costs include legal, engineering, administrative, and financing items. Table 6.2, following 6.1, provides greater detail of annual operation and maintenance costs.

**Table 6.1 – Engineer's Opinion of Probable Cost and
Estimated Operation and Maintenance Costs Present Value**

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Total Project Cost	\$7,203,695	\$10,079,406	\$5,013,695	\$7,469,406
MCES SAC Charges	\$94,945	\$258,942	\$94,945	\$258,942
Total Capital Cost	\$7,298,640	\$10,338,348	\$5,108,640	\$7,728,348
MCES Flow Charges (20 yr PV)	\$58,915	\$160,677	\$58,915	\$160,677
Labor, Power, Chemicals, and Depreciation Cost (20 yr PV)	\$2,716,893	\$6,043,543	\$2,716,893	\$6,043,543
Total Operation and Maintenance Costs (20 yr PV)	\$2,775,808	\$6,204,220	\$2,775,808	\$6,204,220
Total Project Cost (20 yr Present Value)	\$10,074,448	\$16,542,568	\$7,884,448	\$13,932,568

*It has been assumed an MCES Industrial Discharge Permit will be granted. Should sludge lagoons be required project costs would increase.

*Land purchase costs not included

**Table 6.2 – Estimated
Operation and Maintenance Costs**

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
MCES Flow Charges	\$3,960	\$10,800	\$3,960	\$10,800
Labor	\$36,000	\$36,000	\$36,000	\$36,000
Power	\$30,281	\$54,441	\$30,281	\$54,441
Chemicals	\$97,524	\$292,572	\$97,524	\$292,572
Depreciation	\$18,813	\$23,208	\$18,813	\$23,208
Total Estimated Annual Operations and Maintenance Cost	\$186,578	\$417,021	\$186,578	\$417,021

*Depreciation includes equipment items only and does not include structures.

7. COST BENEFIT

It has been assumed that the loading rate from the 6 Mile Creek, leading to Halsted's Bay, is approximately 2,724 lb/yr as an average annual load with an average concentration of 146 µg/L.

Under an assumption that the Halsted's Bay Off-Line Phosphorus Removal Facility is operational for 180 days a year, about 90 % of the previously stated load would be available for treatment, providing 2,452 lb/yr.

Based on Diagram 7.1, flow and load "capture" can be determined for both the 5 cfs and 15 cfs design alternatives. Under the 5 cfs alternative, approximately 56% of the flow is captured at a load of 1378 lb/yr. For the 15 cfs alternative, approximately 83% of the flow is captured at a load of 2035 lb/yr.

Assuming a discharge concentration of 30 µg/L (more defined limit can be assumed after jar testing), the 5 cfs design option would be capable of removing approximately 1,095 lb/yr while the 15 cfs design option could be capable of removing approximately 1,617 lb/yr. As an approximation, the removal rate of the Halsted's Bay Off-Line Phosphorus Removal Facility would be about 80% of the captured load. It is important to note however, that jar testing should be completed to verify this assumption.

In an effort to determine the cost benefit of the Halsted's Bay Off-Line Phosphorus Removal Facility, the present worth calculations shown in Table 6.1 were divided by the removal capabilities described above. The cost benefits in \$/lb phosphorus removed can be found in Table 7.1.

Diagram 7.1 – 6 Mile Creek Flow Duration

<INSERT 6 MILE CREEK FLOW DURATION GRAPH>

Table 7.1 – Cost Benefit

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Total Project Cost (20 yr PV)	\$10,074,448	\$16,542,568	\$7,884,448	\$13,932,568
Phosphorus Removed, lb (20 yr)	21,900	32,340	21,900	32,340
Cost Benefit, \$/lb	\$460.02	\$511.52	\$360.02	\$430.82

8. FEASIBILITY AND RECOMMENDATION

Each design alternative includes advantages and disadvantages, which are summarized in Table 8.1 below based on site location and treatment capacity.

Table 8.1 –Advantages and Disadvantages of Alternative Designs

	<i>Location</i>		<i>Treatment Capacity</i>	
	Alternative #1 or #2	Alternative #3 or #4	Alternative #1 or #3	Alternative #2 or #4
	West Location	East Location	5 cfs	15 cfs
<i>Advantages</i>	high elevation		smaller pumps	greater phosphorus removal
	separated from City	close to Halsted's Bay and existing lift station	smaller diameter pipes	flow flexibility
	flat site area near clarifier placement			large enough for drinking water consideration
<i>Disadvantages</i>	far from Halsted's Bay-long pipe lengths			larger pumps
	great changes in elevation of road leading to bay	near a new development	more likely to short circuit settling process	larger diameter pipes

Based on the decision matrix presented above, Alternative #4 is recommended. This alternative is located at the East location and has capacity for the highest flow rate of 15 cfs. The recommendation of Alternative #4 over the other three alternatives is due to the following key reasons:

- Located close to 6 Mile Creek, Halsted's Bay, and the existing lift station allowing for shorter pipe lengths.
- The treated water effluent line follows a more regular terrain providing for more cost effective discharge piping and easier construction than the west location alternatives.
- At 15 cfs, the nutrient removal system includes greater capital costs due to the greater capacity but is marginally less than the 5 cfs alternative (Alternative #3) per unit of capacity due to economies of scale. For a tripling of capacity (from 5 to 15 cfs) the price increase is estimated to be approximately 50% higher making the 15 cfs option an economical treatment option.

Project design recommendations include:

- Engineering and design of the nutrient removal system was based on water quality and treatment process from similar lakes in the metro area. It is recommended that pilot plant (jar) testing be completed to verify treatment process assumptions included in this study

to determine the resulting structure sizes and necessary equipment. Removal efficiencies and a more detailed evaluation can be completed following jar testing.

- Begin permitting process with MPCA and MCES. Sludge disposal is a critical issue with MCES and if it will not be permitted, then additional land should be purchased for lagoons for sludge storage.
- An evaluation be completed at the recommended nutrient removal system site and near intake/effluent piping locations to confirm existing soils are adequate for facility construction or if additional geotechnical improvements would be necessary.

9. OTHER CONSIDERATIONS

A. Sludge Lagoons

In the event MCES does not authorize an industrial discharge permit, a sludge ponding system may be necessary. A sludge lagoon would be designed to hold the sludge and water mixture, allowing for the sludge to settle to the bottom and the water to separate. Within the lagoon structure, an adjustable decanting device could be used to pump the water back to the treatment facility for reuse, providing for a thicker sludge and greater volume of pond volume available for further sludge additions.

The lagoon system would be designed for flexibility in operation. It would contain extra volume for emergency use and to prevent overflow during normal operating conditions. To allow for sufficient drying, four ponds would be available to allow rotation every three months. After being used for three months, a pond would be allowed to dry for three months. In addition, to reduce the overall surface area needed for the lagoon system, a five year dredging schedule is initially contemplated. It is expected with this design that each pond would be cleaned every five years to maintain ample volume for sludge storage.

In total, the lagoon system would be different for the 15 cfs alternatives (10 acres) and 5 cfs alternatives (4 acres) as noted in the alternative descriptions. Also, if sludge thickening is possible (based on jar testing) it should be possible to greatly reduce the lagoon size to approximately 1 acre under both the 15 or 5 cfs alternative.

B. Drinking Water Treatment Plant

In the event that the City of Minnetrista would like to expand the nutrient removal system for phosphorus into a drinking water treatment facility, there are processes and additional chemicals that would need to be added. In general, the processes of coagulation and clarification, disinfection, filtration, and distribution disinfection would be required. Through these additional process chemicals such as lime, soda ash, flocculants (alum or ferric chloride), polymer, polyphosphates, carbon dioxide, chlorine (or other disinfectant), ammonia, and fluoride may be necessary. These additional treatment processes could require an expansion in the chemical storage capabilities of the nutrient removal system to contain equipment such as lime slakers, lime silos, chemical batch tanks, sludge containment, chemical diffusers, pumps, and chlorine storage and containment. Table 9.1 provides a list of the potential processes and likely equipment that would be needed for a surface water drinking water treatment plant. Highlighted items indicate items included in the planned nutrient removal system at Halsted's Bay. It should be noted that existing water quality is unknown, but preliminary processes have been identified based on water quality from typical surface waters in the metro area.

Table 9.1 – Drinking Water Treatment Plant Considerations

<i>Surface Water Treatment Facilities</i>		
<i>Processes</i>	<i>Chemicals</i>	<i>Equipment</i>
Coagulation	Lime	Lime Slakers
Softening	Soda Ash	Lime Silos
Sludge Handling	Ferric or Alum	Soda Ash Batch Tanks
Disinfection	Polymer	Polymer Mix Tanks
Recarbonation	Polyphosphate	Center Mixer
Filtration	Carbon Dioxide	Perimeter Rake
Polishing	Ozone	Sludge Discharge
Booster Station	Chlorine	Contact Chambers
	Ammonia	Fine Bubble Diffusers
	Fluoride	Injection Pumps
	Liquid Oxygen	Ozone Generators
	Calcium Thiosulfate	PSA or LOX
		Ozone Compressors
		Ozone Destruct Units
		Backwash Pumps
		Air Scour Pumps
		Filter Waste Return Tank
Included in Off-Line Phosphorus Removal System		Chemical Building
		Pumps for Chemicals
		Mix Tanks
		Day Tanks
		Dry Chemical Hoppers
		Chlorine Containment

Softening

Ozone Disinfection

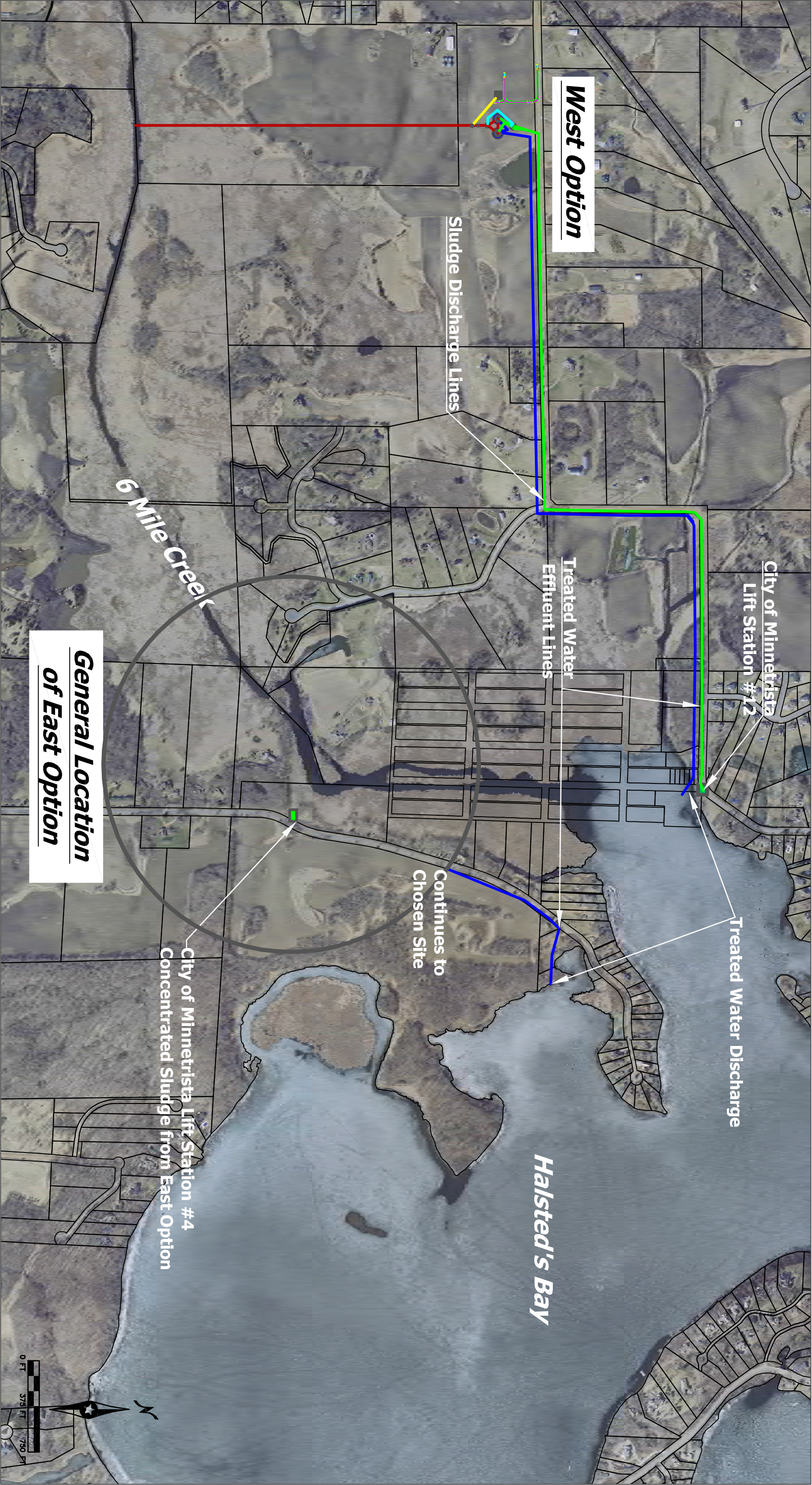
Filtration

Chemicals

An ozone disinfection system is illustrated in Table 9.1, however, a chlorine disinfection system would also be a possible form of disinfection.

With the addition of the treatment processes described above, increases in cost to an approximate cost of about \$5 million per million gallons per day (MGD) of treatment capacity. For example, to construct a facility to treat approximately 10 MGD (15.4 cfs) of water, a project cost of approximately \$50 million could be expected.

FIGURES



***General Location
of East Option***

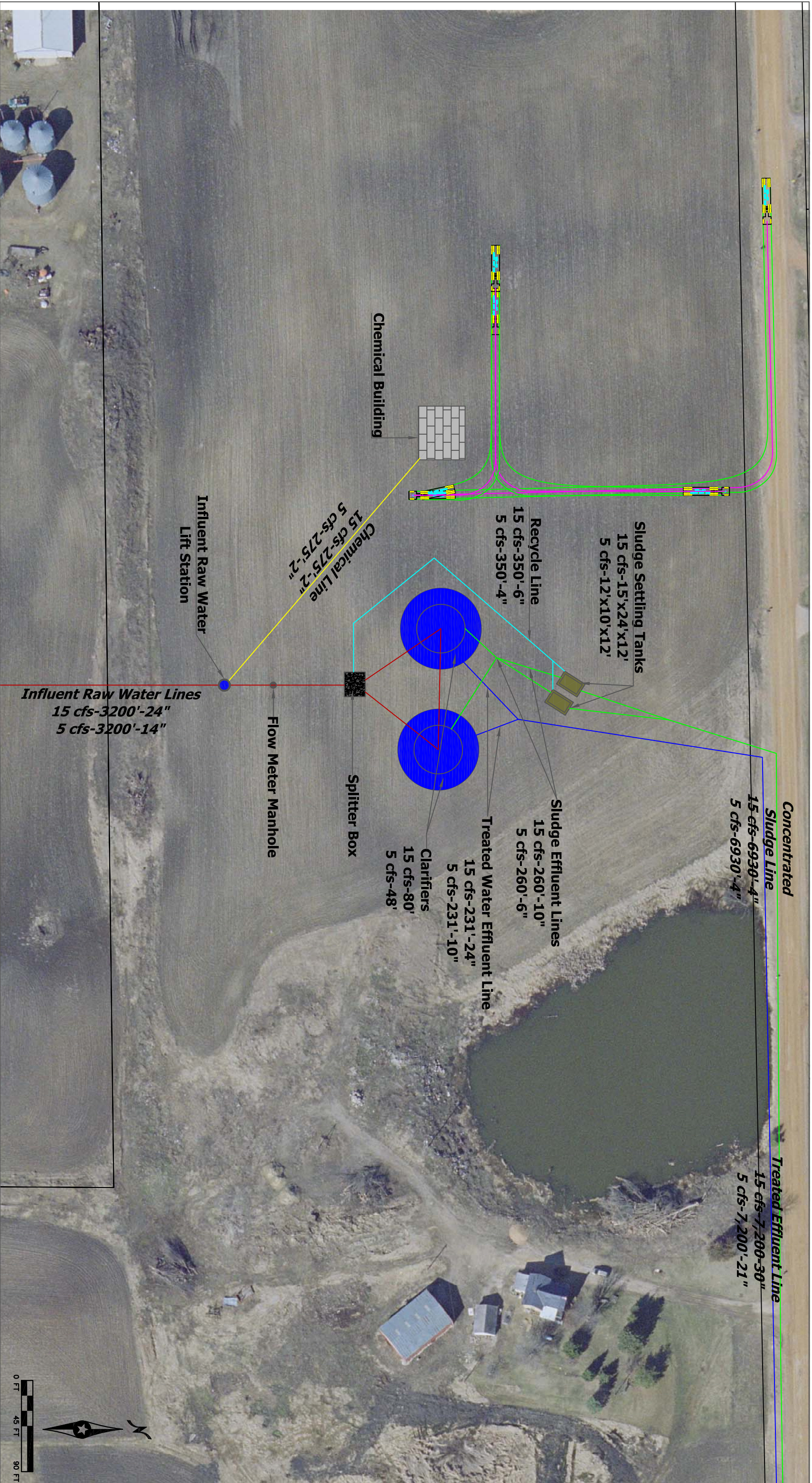


Figure 2: West Option

Halsted's Bay
Off-line Phosphorus Removal Facility
WSB Project No. 02213-000

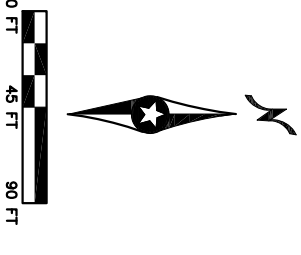
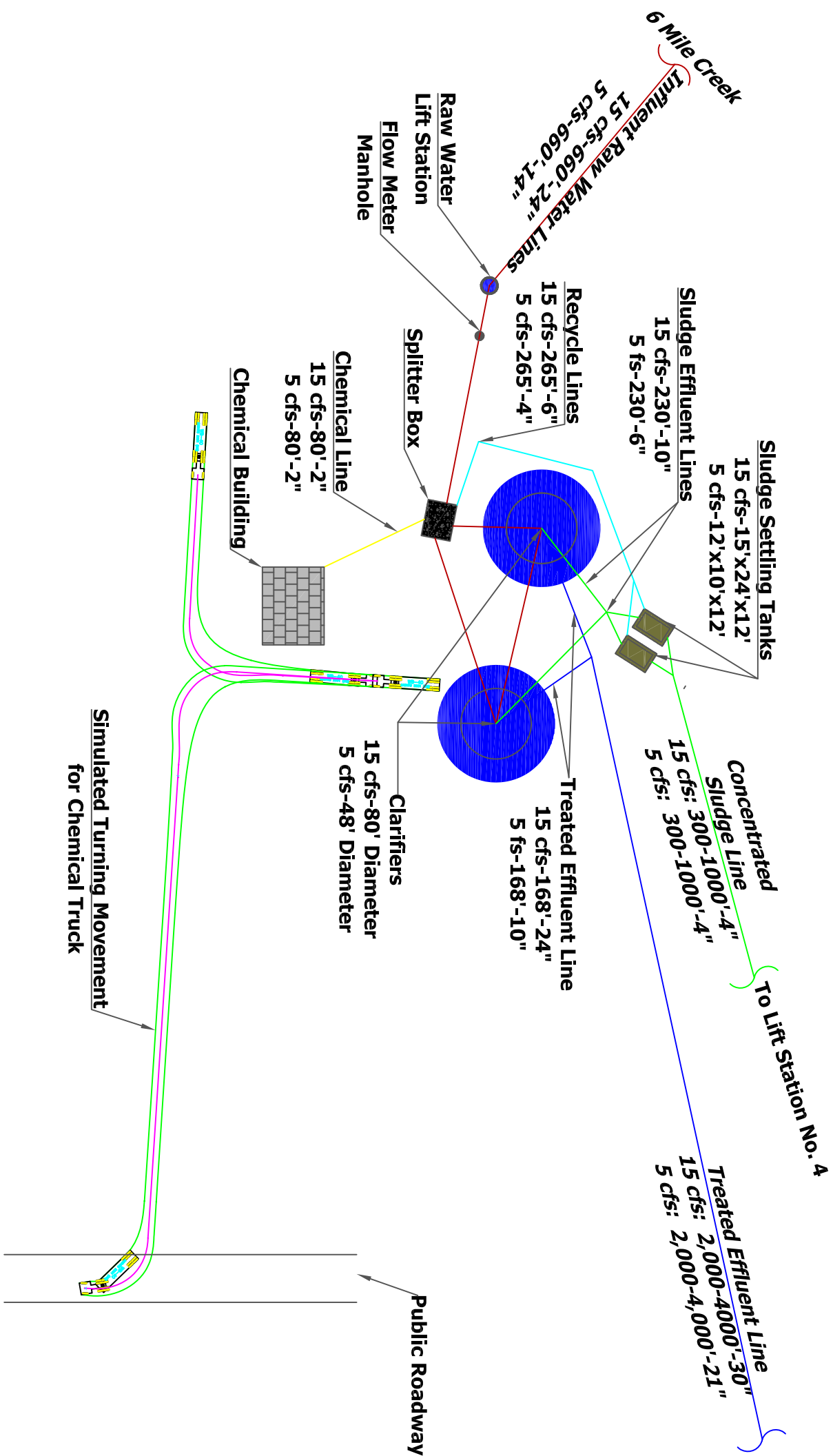


Figure 3: East Option-Generalized Site Plan

Halsted's Bay
Off-line Phosphorus Removal Facility
WSB Project No. 02213-000

APPENDIX A

OPINION OF PROBABLE COSTS

MCWD Halsted's Bay Nutrient Removal System					
Alternative #1 - West Location Option at 5 cfs					
Cost Summary, Engineer's Opinion of Probable Cost					
Item No.	Description	Estimated Construction Cost	Contingency Cost (25%)	Indirect Cost (25%)	Total Estimated Cost
1	16" INFLUENT SUCTION (INTAKE TO SPLITTER BOX)	\$271,500.00	\$67,875.00	\$67,875.00	\$407,250.00
2	INFLUENT LIFT STATION AND METER MANHOLE	\$301,000.00	\$75,250.00	\$75,250.00	\$451,500.00
3	28' X 52' X 13' MASONRY CHEMICAL BUILDING	\$716,875.00	\$179,218.75	\$179,218.75	\$1,075,312.50
4	SITE PIPING (BETWEEN CLARIFIERS, TANKS, BUILDING,	\$90,500.00	\$22,625.00	\$22,625.00	\$135,750.00
5	SITE SURFACE IMPROVEMENTS (ROADWAY, FENCING)	\$178,500.00	\$44,625.00	\$44,625.00	\$267,750.00
6	SPLITTER BOX	\$97,300.00	\$24,325.00	\$24,325.00	\$145,950.00
7	2 - 48' DIA. CLARIFIERS	\$1,247,288.00	\$311,822.00	\$311,822.00	\$1,870,932.00
8	SETTLING TANKS (INCLUDING PUMPS, PIPING)	\$140,000.00	\$35,000.00	\$35,000.00	\$210,000.00
9	4" SLUDGE PIPING FROM SETTLING TANK TO LIFT STATION	\$292,000.00	\$73,000.00	\$73,000.00	\$438,000.00
10	21" EFFLUENT FROM CLARIFIER TO BANK (PVC)	\$760,000.00	\$190,000.00	\$190,000.00	\$1,140,000.00
11	21" EFFLUENT FROM BANK TO OUTLET (PVC)	\$67,500.00	\$16,875.00	\$16,875.00	\$101,250.00
12	2 - EFFLUENT INTERMEDIATE PUMP STATIONS	\$640,000.00	\$160,000.00	\$160,000.00	\$960,000.00
TOTAL		\$4,802,463.00	\$1,200,615.75	\$1,200,615.75	\$7,203,694.50

MCWD Halsted's Bay Nutrient Removal System					
Alternative #2 - West Location Option at 15 cfs					
Cost Summary, Engineer's Opinion of Probable Cost					
Item No.	Description	Estimated Construction Cost	Contingency Cost (25%)	Indirect Cost (25%)	Total Estimated Cost
1	24" INFLUENT SUCTION (INTAKE TO SPLITTER BOX)	\$348,000.00	\$87,000.00	\$87,000.00	\$522,000.00
2	INFLUENT LIFT STATION AND METER MANHOLE	\$370,000.00	\$92,500.00	\$92,500.00	\$555,000.00
3	40' X 52' X 13' MASONRY CHEMICAL BUILDING	\$882,500.00	\$220,625.00	\$220,625.00	\$1,323,750.00
4	SITE PIPING (BETWEEN CLARIFIERS, TANKS, BUILDING)	\$131,000.00	\$32,750.00	\$32,750.00	\$196,500.00
5	SITE SURFACE IMPROVEMENTS (ROADWAY, FENCING)	\$178,500.00	\$44,625.00	\$44,625.00	\$267,750.00
6	SPLITTER BOX	\$104,610.00	\$26,152.50	\$26,152.50	\$156,915.00
7	2 - 80' DIA. CLARIFIERS	\$2,354,494.00	\$588,623.50	\$588,623.50	\$3,531,741.00
8	SETTLING TANKS (INCLUDING PUMPS, PIPING)	\$240,000.00	\$60,000.00	\$60,000.00	\$360,000.00
9	4" SLUDGE PIPING FROM SETTLING TANK TO LIFT STATION	\$292,000.00	\$73,000.00	\$73,000.00	\$438,000.00
10	30" EFFLUENT FROM CLARIFIER TO BANK (PVC)	\$976,000.00	\$244,000.00	\$244,000.00	\$1,464,000.00
11	30" EFFLUENT FROM BANK TO OUTLET (PVC)	\$82,500.00	\$20,625.00	\$20,625.00	\$123,750.00
12	2 - EFFLUENT INTERMEDIATE PUMP STATIONS	\$760,000.00	\$190,000.00	\$190,000.00	\$1,140,000.00
TOTAL		\$6,719,604.00	\$1,679,901.00	\$1,679,901.00	\$10,079,406.00

MCWD Halsted's Bay Nutrient Removal System					
Alternative #3 - East Location Option at 5 cfs					
Cost Summary - Engineer's Opinion of Probable Cost					
Item No.	Description	Estimated Construction Cost	Contingency Cost (25%)	Indirect Cost (25%)	Total Estimated Cost
1	16" INFLUENT SUCTION (INTAKE TO SPLITTER BOX)	\$89,500.00	\$22,375.00	\$22,375.00	\$134,250.00
2	INFLUENT LIFT STATION AND METER MANHOLE	\$301,000.00	\$75,250.00	\$75,250.00	\$451,500.00
3	28' X 52' X 13' MASONRY CHEMICAL BUILDING	\$716,875.00	\$179,218.75	\$179,218.75	\$1,075,312.50
4	SITE PIPING (BETWEEN CLARIFIERS, TANKS, BUILDING,	\$90,500.00	\$22,625.00	\$22,625.00	\$135,750.00
5	SITE SURFACE IMPROVEMENTS (ROADWAY, FENCING)	\$178,500.00	\$44,625.00	\$44,625.00	\$267,750.00
6	SPLITTER BOX	\$97,300.00	\$24,325.00	\$24,325.00	\$145,950.00
7	2 - 48' DIA. CLARIFIERS	\$1,247,288.00	\$311,822.00	\$311,822.00	\$1,870,932.00
8	SETTLING TANKS (INCLUDING PUMPS, PIPING)	\$140,000.00	\$35,000.00	\$35,000.00	\$210,000.00
9	4" SLUDGE PIPING FROM SETTLING TANK TO LIFT STATION	\$34,000.00	\$8,500.00	\$8,500.00	\$51,000.00
10	21" EFFLUENT FROM CLARIFIER TO BANK (PVC)	\$380,000.00	\$95,000.00	\$95,000.00	\$570,000.00
11	21" EFFLUENT FROM BANK TO OUTLET (PVC)	\$67,500.00	\$16,875.00	\$16,875.00	\$101,250.00
TOTAL		\$3,342,463.00	\$835,615.75	\$835,615.75	\$5,013,694.50

MCWD Halsted's Bay Nutrient Removal System					
Alternative #4 - East Location Option at 15 cfs					
Cost Summary, Engineer's Opinion of Probable Cost					
Item No.	Description	Estimated Construction Cost	Contingency Cost (25%)	Indirect Cost (25%)	Total Estimated Cost
1	24" INFLUENT SUCTION (INTAKE TO SPLITTER BOX)	\$114,000.00	\$28,500.00	\$28,500.00	\$171,000.00
2	INFLUENT LIFT STATION AND METER MANHOLE	\$370,000.00	\$92,500.00	\$92,500.00	\$555,000.00
3	40' X 52' X 13' MASONRY CHEMICAL BUILDING	\$882,500.00	\$220,625.00	\$220,625.00	\$1,323,750.00
4	SITE PIPING (BETWEEN CLARIFIERS, TANKS, BUILDING)	\$131,000.00	\$32,750.00	\$32,750.00	\$196,500.00
5	SITE SURFACE IMPROVEMENTS (ROADWAY, FENCING)	\$178,500.00	\$44,625.00	\$44,625.00	\$267,750.00
6	SPLITTER BOX	\$104,610.00	\$26,152.50	\$26,152.50	\$156,915.00
7	2 - 80' DIA. CLARIFIERS	\$2,354,494.00	\$588,623.50	\$588,623.50	\$3,531,741.00
8	SETTLING TANKS (INCLUDING PUMPS, PIPING)	\$240,000.00	\$60,000.00	\$60,000.00	\$360,000.00
9	4" SLUDGE PIPING FROM SETTLING TANK TO LIFT STATION	\$34,000.00	\$8,500.00	\$8,500.00	\$51,000.00
10	30" EFFLUENT FROM CLARIFIER TO BANK (PVC)	\$488,000.00	\$122,000.00	\$122,000.00	\$732,000.00
11	30" EFFLUENT FROM BANK TO OUTLET (PVC)	\$82,500.00	\$20,625.00	\$20,625.00	\$123,750.00
TOTAL		\$4,979,604.00	\$1,244,901.00	\$1,244,901.00	\$7,469,406.00

Appendix C: 2017 Phosphorus Loading Analysis

Technical Memo



Responsive partner.
Exceptional outcomes.

To: Anna Brown, Minnehaha Creek Watershed District
Kelly Dooley, Minnehaha Creek Watershed District

From: Sarah Nalven, Wenck Associates, Inc.
Brian Beck, Wenck Associates, Inc.
Joe Bischoff, Wenck Associates, Inc.

Date: March 17, 2017

Subject: Six Mile Marsh Phosphorus Loading Analysis

Problem

Recently, anecdotal evidence emerged that the wetland between Mud Lake and Halsted Bay (Six Mile Marsh) is exporting phosphorus.¹ Therefore, we set out to determine if Six Mile Marsh is a source of phosphorus to Six Mile Creek, and if so, to what extent.

Wetland Phosphorus Cycling

Wetland processes typically associated with phosphorus removal from surface waters include settling of particulate phosphorus (PP) and uptake of orthophosphorus (orthoP) by aquatic vegetation (Figure 1). Conversely, processes that contribute phosphorus to surface waters include release of adsorbed orthoP from minerals in the sediment and release of orthoP during organic matter decomposition (Figure 1). Hydrologic, geochemical, and morphological characteristics influence the magnitude of these processes and determine a wetland's ability to be a net source, sink, or transformer of phosphorus.

Similar to stormwater ponds, one of the primary mechanisms of phosphorus removal in wetlands is the settling of PP. The rate of PP settling depends on hydraulic detention times, inlet phosphorus fraction (PP vs. orthoP), and grain size distribution (larger particles tend to settle faster). However, phosphorus associated with settled PP may be available for release if wetland sediments become anoxic.

A primary mechanism of phosphorus release in wetlands is the desorption of mineral-bound orthoP. OrthoP adsorbs to minerals such as Fe, Al, Ca, or Mg, which are found in wetland sediment and in suspended particles that enter wetlands and eventually settle in wetland sediment. OrthoP bound to these oxidized metals can be mobilized if geochemical parameters such as dissolved oxygen or pH are significantly altered within the wetland. For example, mineral-bound orthoP is released from wetland sediments if sediment porewater is anoxic (devoid of oxygen).

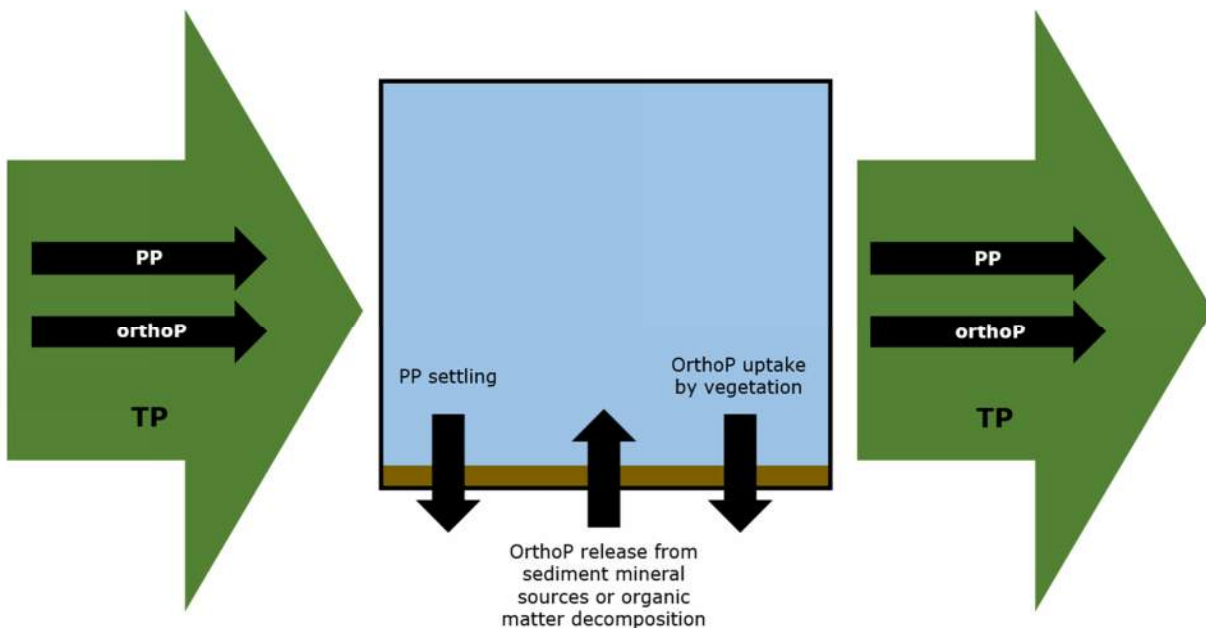


Figure 1. Conceptual model of phosphorus inputs and outputs to wetland systems.

Total Phosphorus Loading in Six Mile Marsh

We calculated total phosphorus (TP) inputs and outputs to Six Mile Marsh. We assumed TP inputs to Six Mile Marsh come from either the Six Mile Creek inlet (via Mud Lake) or the wetland's direct watershed. Therefore, we calculated TP input loads by combining P8 modeled direct watershed load with Six Mile Creek inlet load. The Six Mile Creek inlet load was calculated from flow and phosphorus concentration data collected at water monitoring station CSI-02 (Figure 2). Output loads were calculated from Six Mile Creek outlet data (flow and phosphorus concentration) collected at water monitoring station CSI-17 (Figure 2). To calculate net TP load from Six Mile Marsh, we subtracted input load from output load. We assumed that the difference between input and output loads could be attributed to one of the mechanisms in Figure 1. We also assumed, based on a desktop review of aerial photos and topography of Six Mile Marsh, that there are no major preferential flow paths within the wetland.

Six Mile Marsh appears to be a small sink of phosphorus (Figure 3), removing 115 lbs. of TP per year on average (Table 1). This removal is likely due to the settling of particulate phosphorus or plant uptake of orthoP (Figure 1). Whatever the cause, this removal represents 2% of the annual TP load to Halsted Bay, assuming the annual average TP load to Halsted Bay is 6,753 pounds per year.²

Net TP load appears to be related to annual flow conditions (Figure 3 and Figure 4). In 2013 and 2015, when flow was low to average (Figure 4), the average TP removal was 197 lbs. (Table 1). In contrast, Six Mile Marsh experienced extremely high flow in 2014 (Figure 4), and it became a slight phosphorus source, releasing 49 lbs. of TP (Table 1).

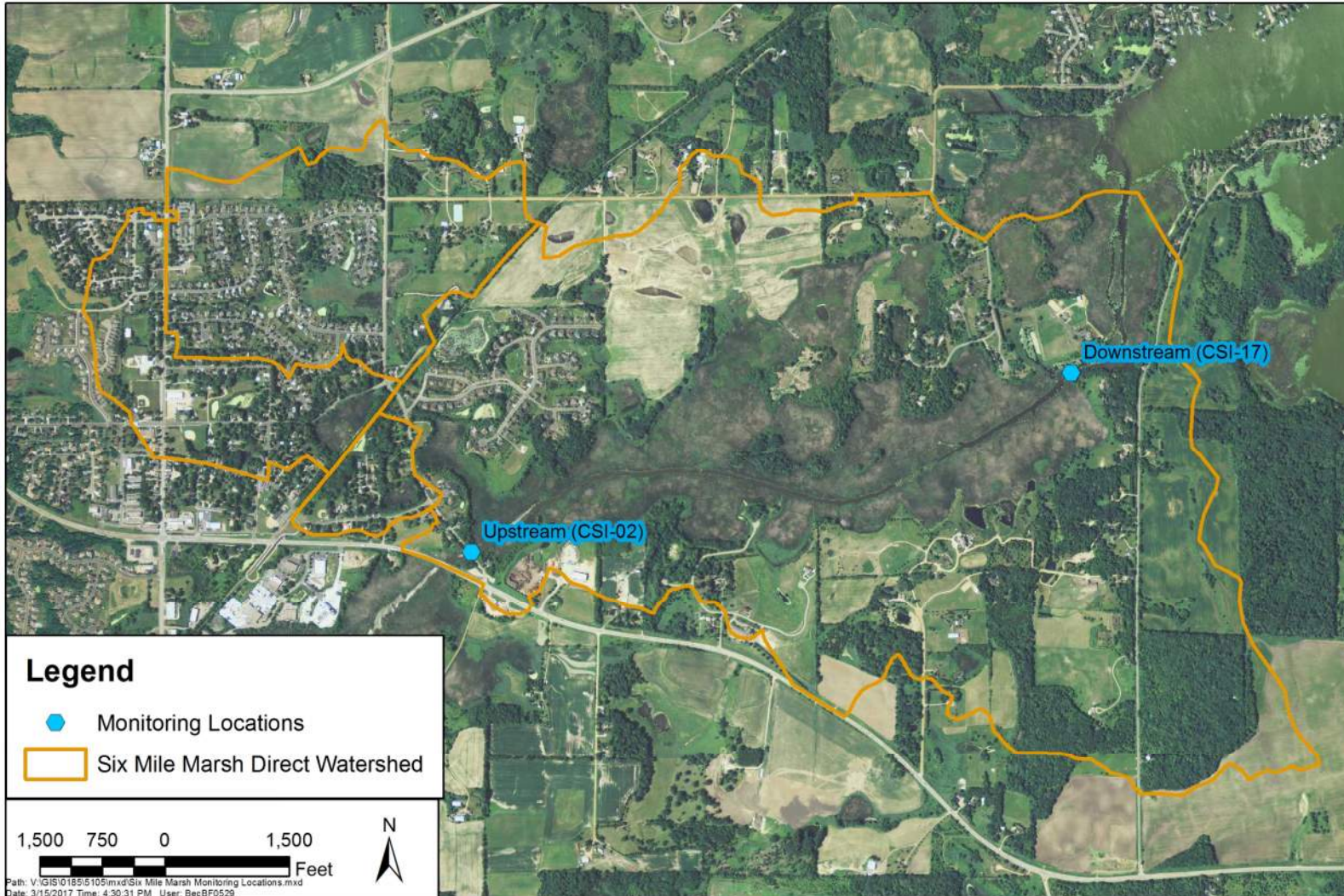


Figure 2. Six Mile Marsh with Six Mile Creek's inlet (CSI-02) and outlet (CSI-17) water monitoring locations (blue), and direct watershed boundaries (yellow).

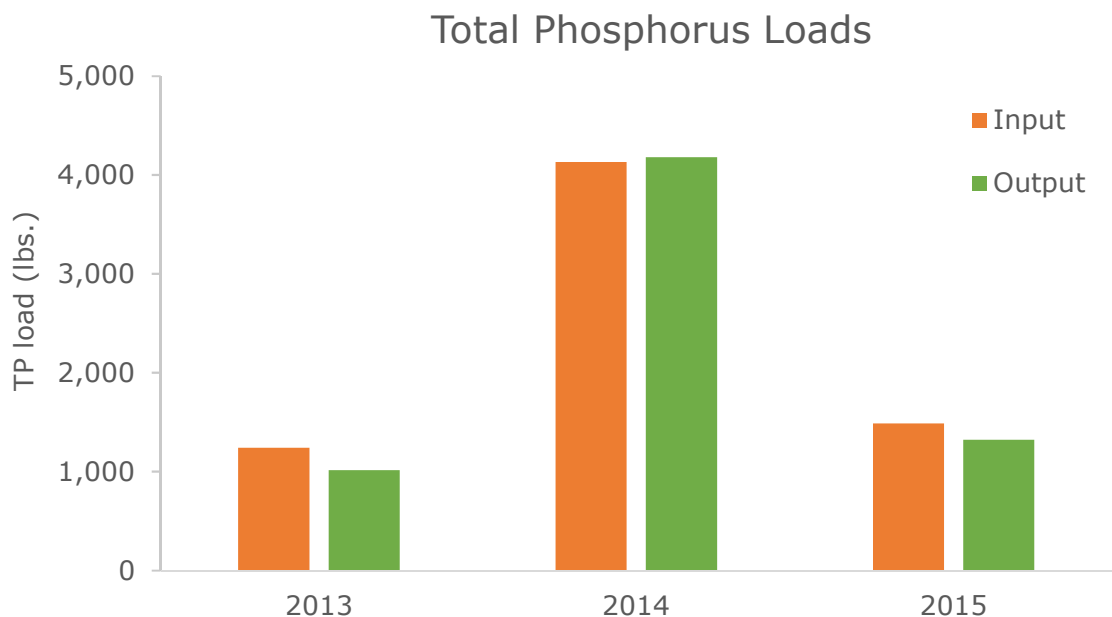


Figure 3. Annual input and output total phosphorus (TP) loads in Six Mile Marsh.

Table 1. Annual input, output, and net total phosphorus (TP) loads in Six Mile Marsh.

	TP Inputs (lbs.)	TP Outputs (lbs.)	Net TP Load (lbs.)
2013	1,242	1,013	-229
2014	4,131	4,180	49
2015	1,487	1,322	-165
Average	2,287	2,172	-115

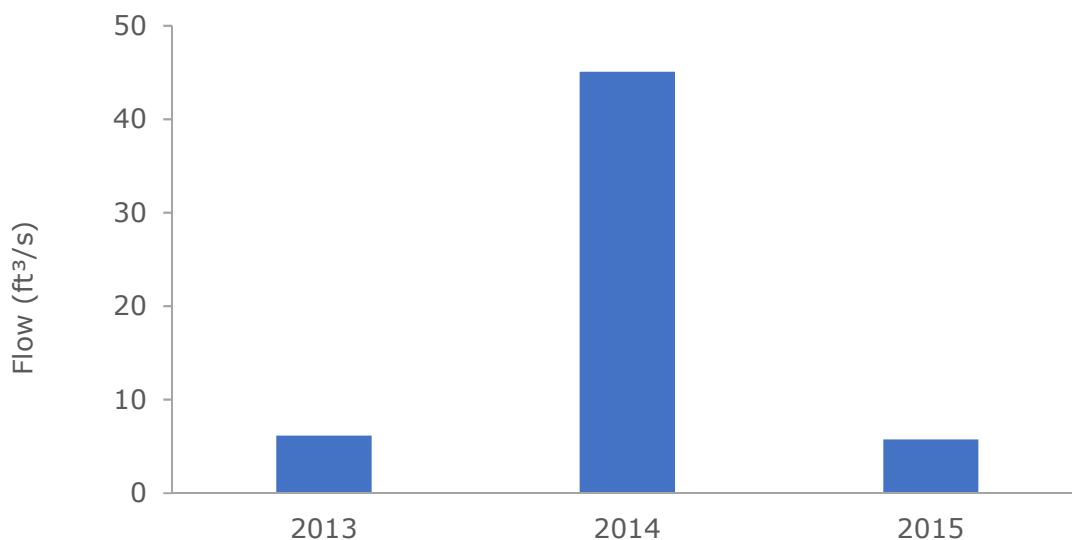


Figure 4. Average annual flow of Six Mile Creek at the inlet monitoring location (CSI-02).

The results in Table 1 suggest that during most years Six Mile Marsh removes phosphorus from upstream sources, positively impacting the phosphorus balance of Halsted Bay. However, net TP load from Six Mile Marsh fails to depict the gross ortho-phosphorus load released from Six Mile Marsh's sediment. The next sections examine the gross phosphorus loads upstream and downstream of Six Mile Marsh—specifically, gross PP and orthoP loads—to understand the phosphorus processing taking place within Six Mile Marsh.

Phosphorus Transformation in Six Mile Marsh

Six Mile Marsh appears to be a transformer of phosphorus, removing PP from the water and adding orthoP. For each year analyzed, PP load decreases in Six Mile Marsh, while orthoP load increases over the same period (Figure 5, Figure 6, and Table 2). These findings can be explained primarily by two processes. First, Six Mile Marsh removes PP by settling a large fraction of the incoming suspended solid load. The wetland decreases water velocity, increasing settling rates of PP. Second, Six Mile Marsh promotes production of orthoP. This occurs when bacteria consume oxidized iron or organic matter, releasing orthoP that had previously been immobilized.

Particulate and Ortho- Phosphorus Load

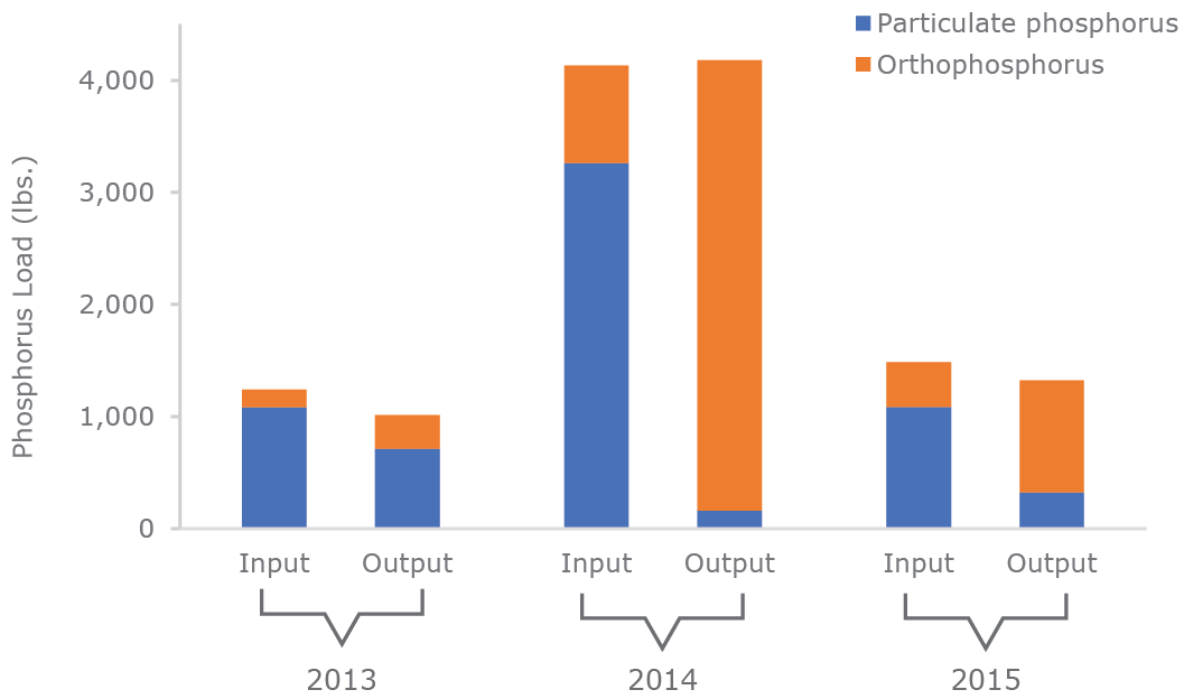


Figure 5. Input and output particulate and ortho- phosphorus loads in Six Mile Marsh.

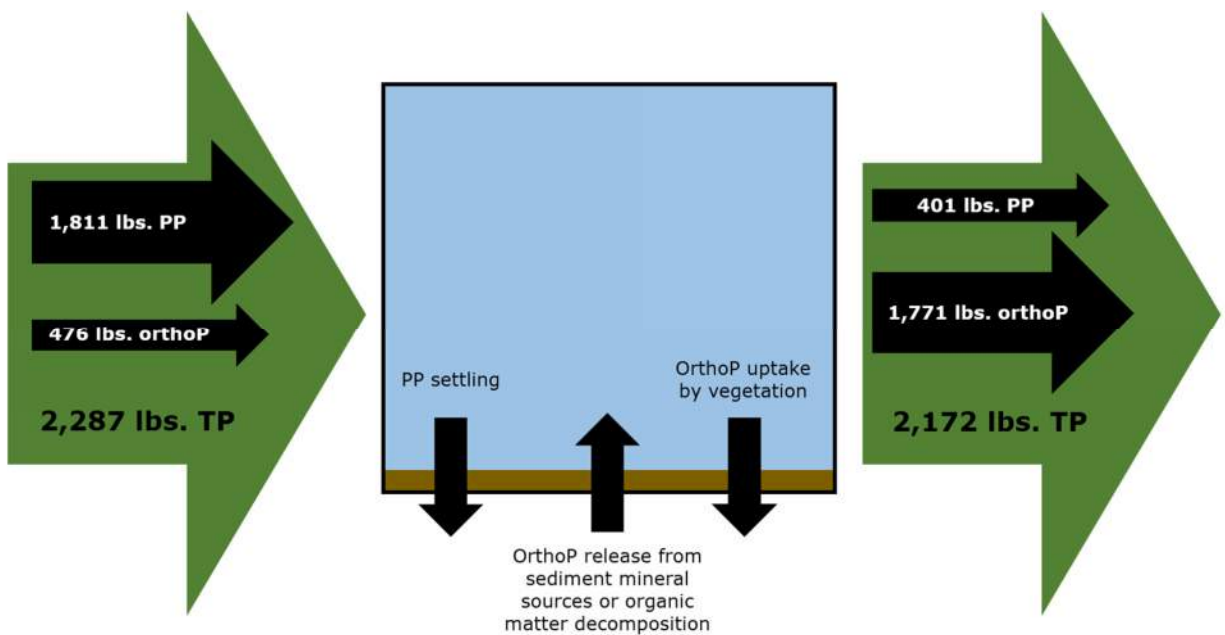


Figure 6. Box Model of phosphorus in Six Mile Marsh. Estimates of phosphorus loads reflect annual averages from 2013-2015.

Table 2. Annual input, output, and net orthophosphorus (orthoP) loads and particulate phosphorus (PP) loads in Six Mile Marsh, and net TP load from Six Mile Marsh.

	Input OrthoP (lbs.)	Output OrthoP (lbs.)	Net OrthoP (lbs.)	Input PP (lbs.)	Output PP (lbs.)	Net PP (lbs.)	Net TP (lbs.)
2013	160	299	139	1,083	715	-368	-229
2014	868	4,016	3,148	3,263	164	-3,099	49
2015	400	999	599	1,087	323	-764	-165
Average	476	1,771	1,295	1,811	401	-1,410	-115

Timing of Total Phosphorus Load

The timing of net TP load is consistent with the concept that Six Mile Marsh acts as a transformer of phosphorus, settling PP and releasing orthoP. Net TP loads from Six Mile Marsh (defined as output TP load minus input TP load) are mostly negative in spring and positive in summer (summer is defined as June 1 - September 30), indicating that Six Mile Marsh is generally a phosphorus sink in spring and a phosphorus source during portions of the summer (Figure 7). Consistently, greater settling of PP happens in spring when high flow conditions bring large suspended solid loads to wetlands, thus increasing the settling capacity of wetlands. Meanwhile greater orthoP release happens in summer, when warm temperatures increase microbial activity, and in turn, cause phosphorus release from wetland sediments. Therefore, Six Mile Marsh's flip from phosphorus sink to source at the end of spring further supports the idea that Six Mile Marsh not simply a conduit for phosphorus, but a transformer.

The importance of Six Mile Marsh's role as a phosphorus transformer should not be overlooked. It implies that the phosphorus that enters Six Mile Marsh is not the same phosphorus that leaves. For example, if upstream BMPs significantly reduced watershed loading in Six Mile Creek this would do little to affect output orthoP load, which could remain at 1,771 lbs. per year (Table 2). Furthermore, the timing of this transformation has dramatic implications for the health of Halsted Bay. This is because the highest orthoP releases occur during the summer growing season, when algae in Halsted Bay are most responsive to phosphorus, especially orthoP.

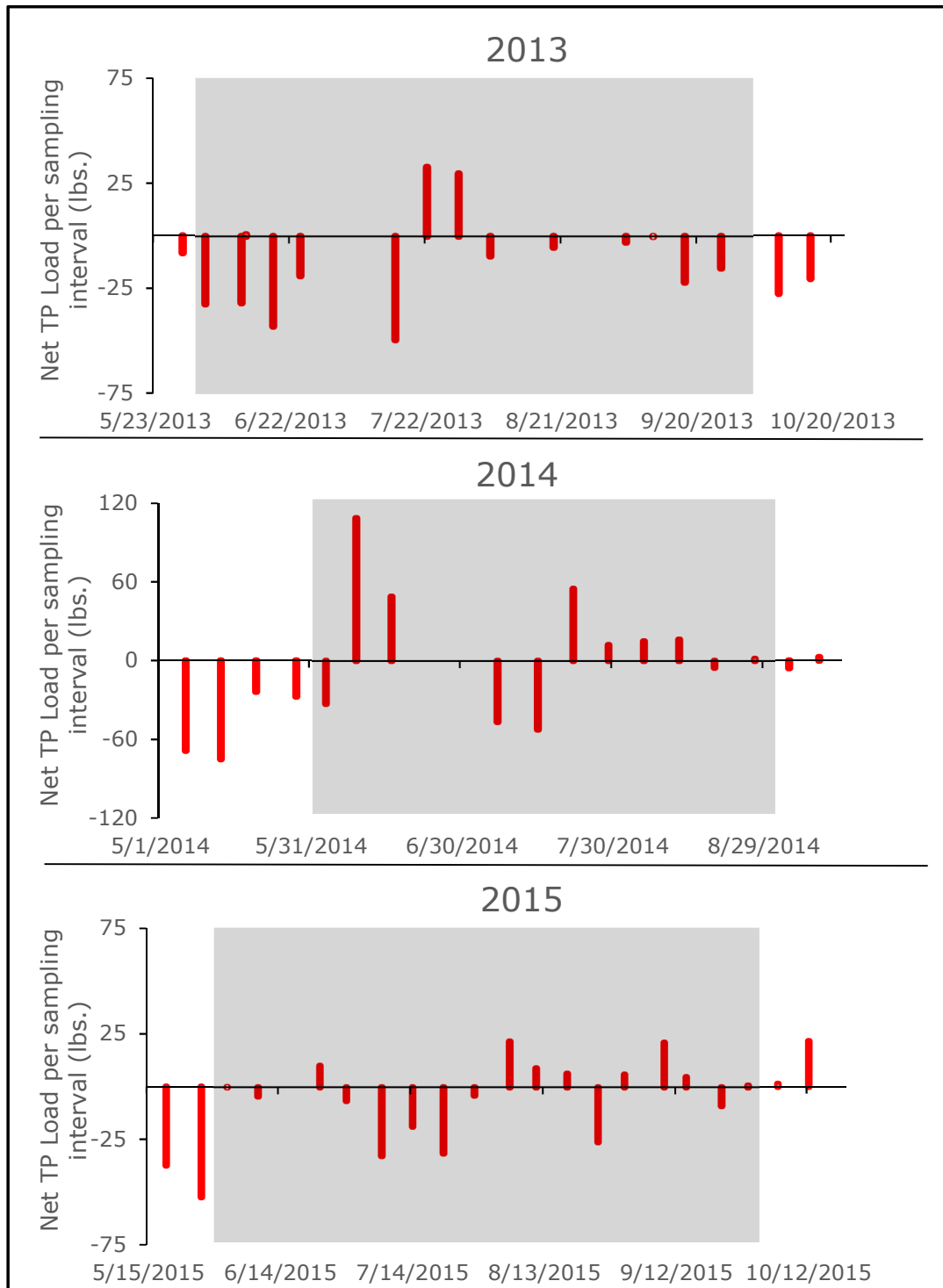


Figure 7. Net total phosphorus (TP) load from Six Mile Marsh per sampling interval for 2013, 2014, and 2015. Net TP load is defined as output TP load minus input TP load. Sampling intervals were determined by the length between TP concentration measurements. Summer, defined as June 1 through Sept. 30, is highlighted in gray.

Conclusions

The traditional paradigm in wetland ecology is that wetlands act simply as sinks of phosphorus. Total phosphorus loading analysis suggests that Six Mile Marsh fits this paradigm. Over the three years studied (2013-2015), Six Mile Marsh removed an average of 115 lbs. of phosphorus from the water annually. However, further analysis demonstrates that biogeochemical cycling of phosphorus within Six Mile Marsh is complex. Particulate phosphorus (PP) and orthophosphorus (orthoP) loads suggest that Six Mile Marsh removes PP from the watershed, but also releases orthoP. It is likely that PP removal is due to settling of suspended solids, while orthoP release is caused by microbial activity in the sediment. These processes do not always act in tandem, but are driven by different seasonal factors that cause PP removal in spring and orthoP release in summer.

Six Mile Marsh's role as a transformer rather than a sink of phosphorus has serious implications for Halsted Bay. First, orthoP release occurs during the summer growing season, just as water bodies downstream are most sensitive to orthoP loads. So even if Six Mile Marsh is a phosphorus sink on an annual basis, summer orthoP release could still cause large algal blooms. Second, these findings indicate that the processes controlling settling and release of phosphorus from Six Mile Marsh are largely independent. Therefore, reducing PP load to Six Mile Marsh would not necessarily affect orthoP release from Six Mile Marsh.

Recommendations

Any restoration efforts of Six Mile Marsh may be short-lived if deposition of PP continues due to excessive upstream loading. Wenck recommends enacting upstream watershed improvements to reduce PP loading to Six Mile Marsh to support restoration of Six Mile Marsh.

However, these analyses suggest that Six Mile Marsh has a measurable impact on the water quality of Halsted Bay and that internal phosphorus release from the wetland complex will need to be reduced to improve water quality in Halsted Bay. Restoring the biogeochemical cycle to a net phosphorus sink in a wetland is complex and many restoration techniques are still experimental. To identify appropriate approaches, several in-wetland processes need further quantification including porewater and sediment chemistry, flow paths and a general wetland water balance.

Prior to restoration design, Wenck recommends collecting wetland phosphorus porewater samples and deploying wetland piezometers and groundwater monitoring wells. Collecting porewater phosphorus samples and water depths will improve understanding of the loading and hydraulics of Six Mile Marsh. Wenck also recommends collecting additional sediment chemistry data to assess the total amount of phosphorus within the wetland to determine if chemical inactivation is a potential mitigation technique.

Anna Brown
MCWD
March 17, 2017



References

- ¹ Wenck Associates, Inc. 2013. Six Mile Creek Diagnostic Study. Report to the Minnehaha Creek Watershed District.
- ² Wenck Associates, Inc. 2013. Halsted Bay Load Management Feasibility Project. Report to the Minnehaha Creek Watershed District.

Appendix

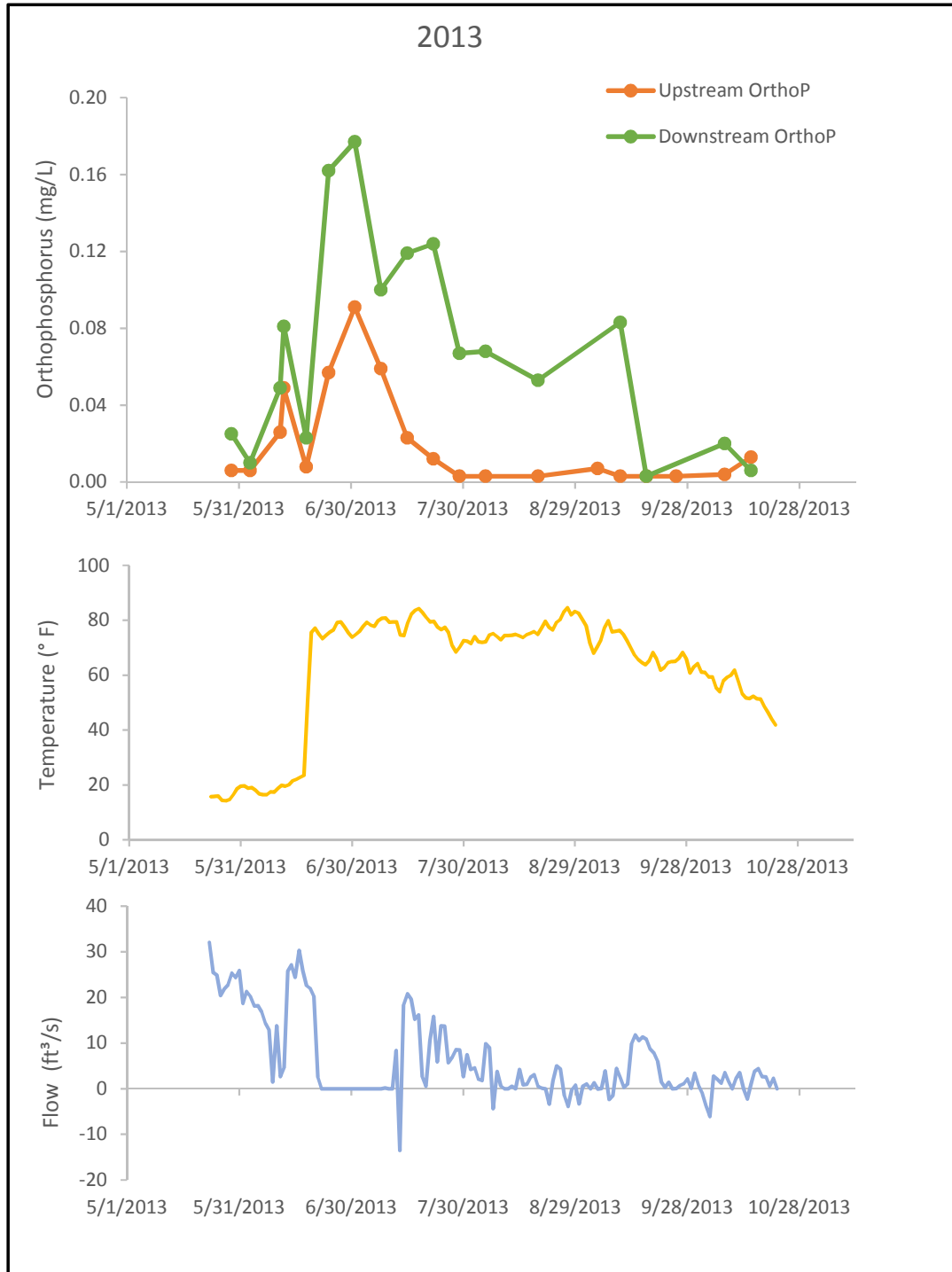


Figure A. Orthophosphorus concentration at CSI-02 (Upstream OrthoP) and CSI-17 (Downstream OrthoP), temperature of water at CSI-02, and flow rate at CSI-02. July and August are highlighted in gray.

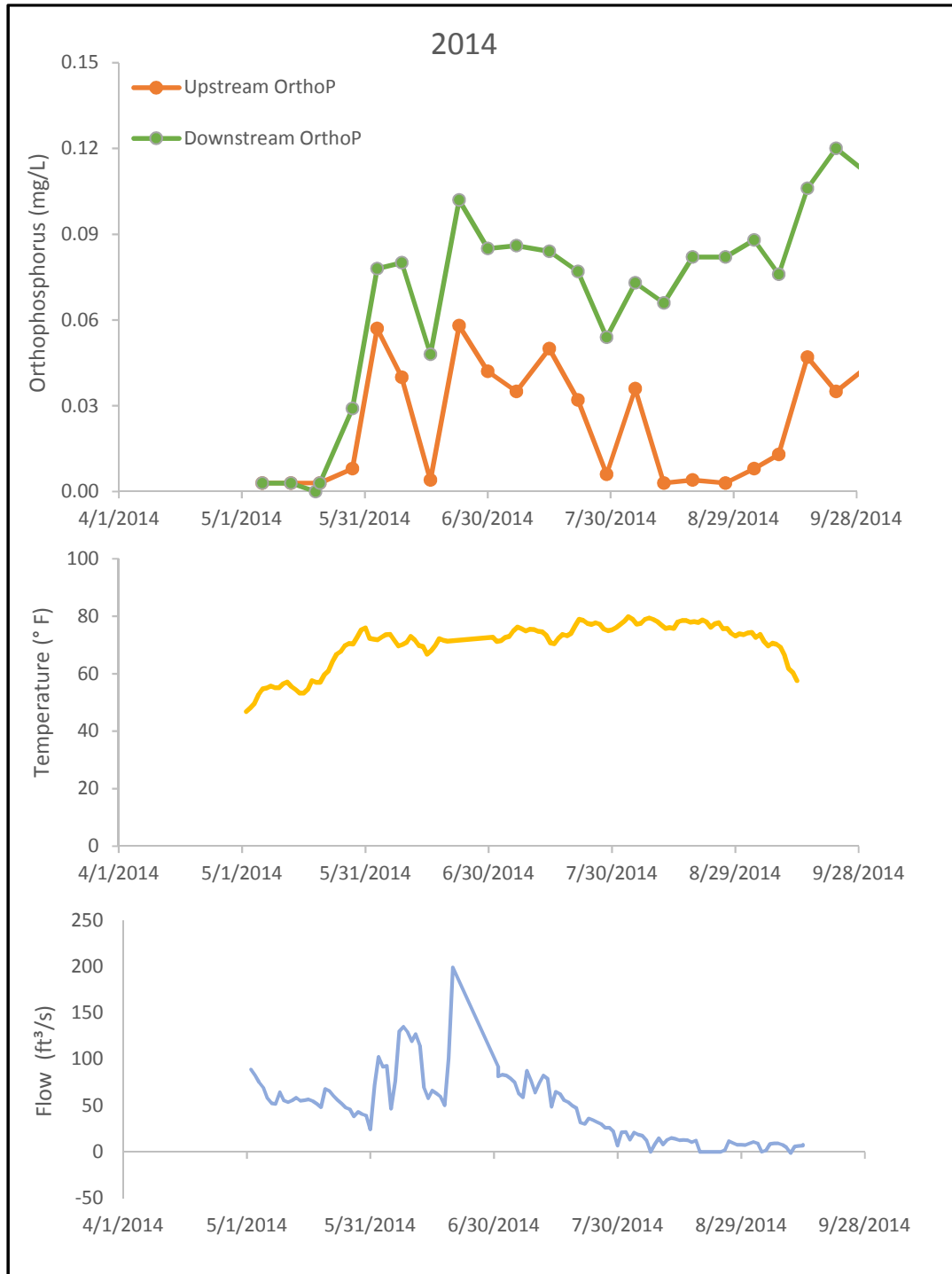


Figure B. Orthophosphorus concentration at CSI-02 (Upstream OrthoP) and CSI-17 (Downstream OrthoP), temperature of water at CSI-02, and flow rate at CSI-02. July and August are highlighted in gray.

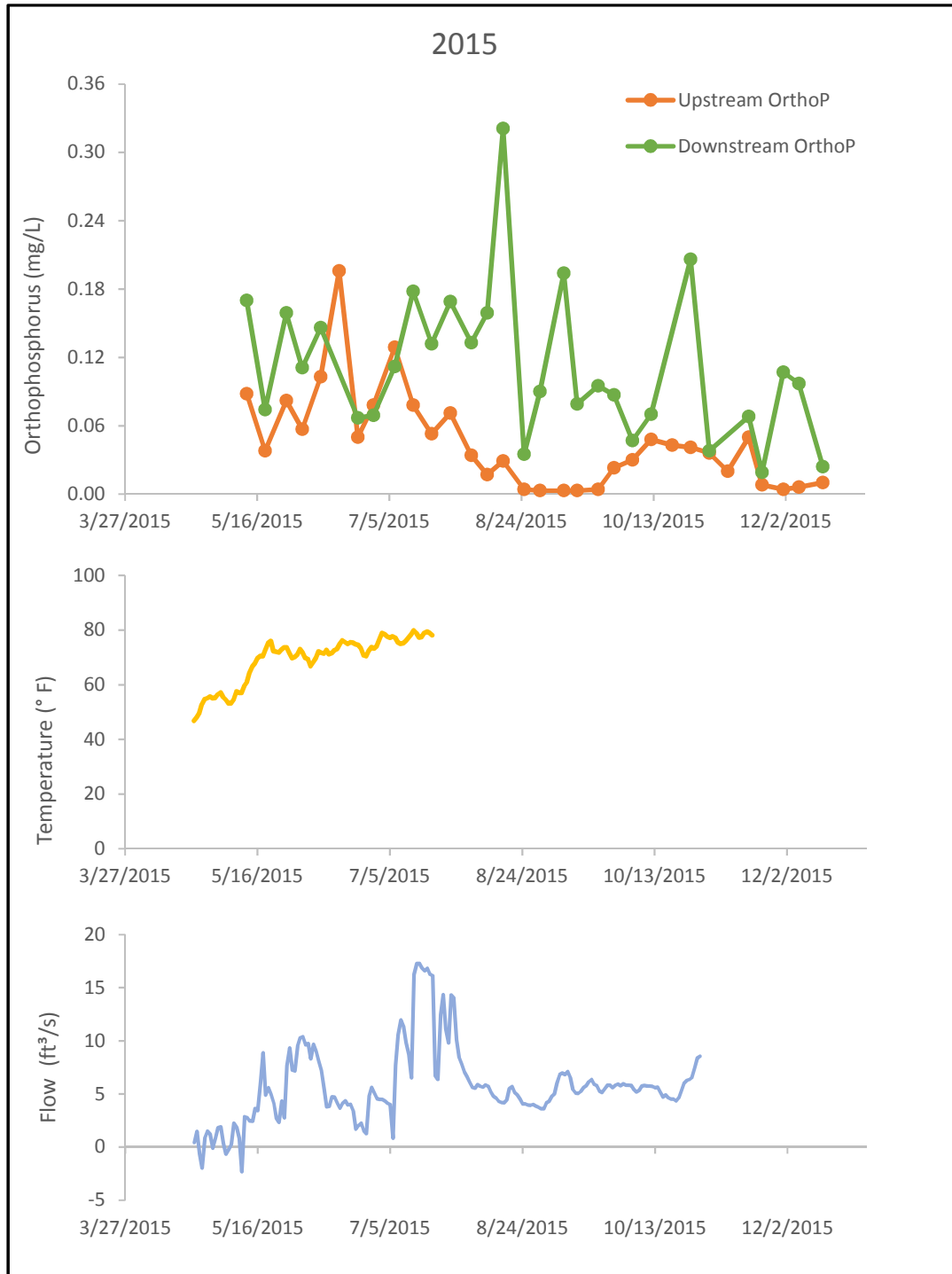
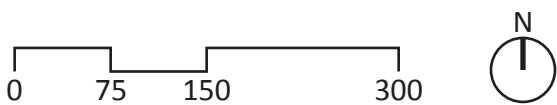
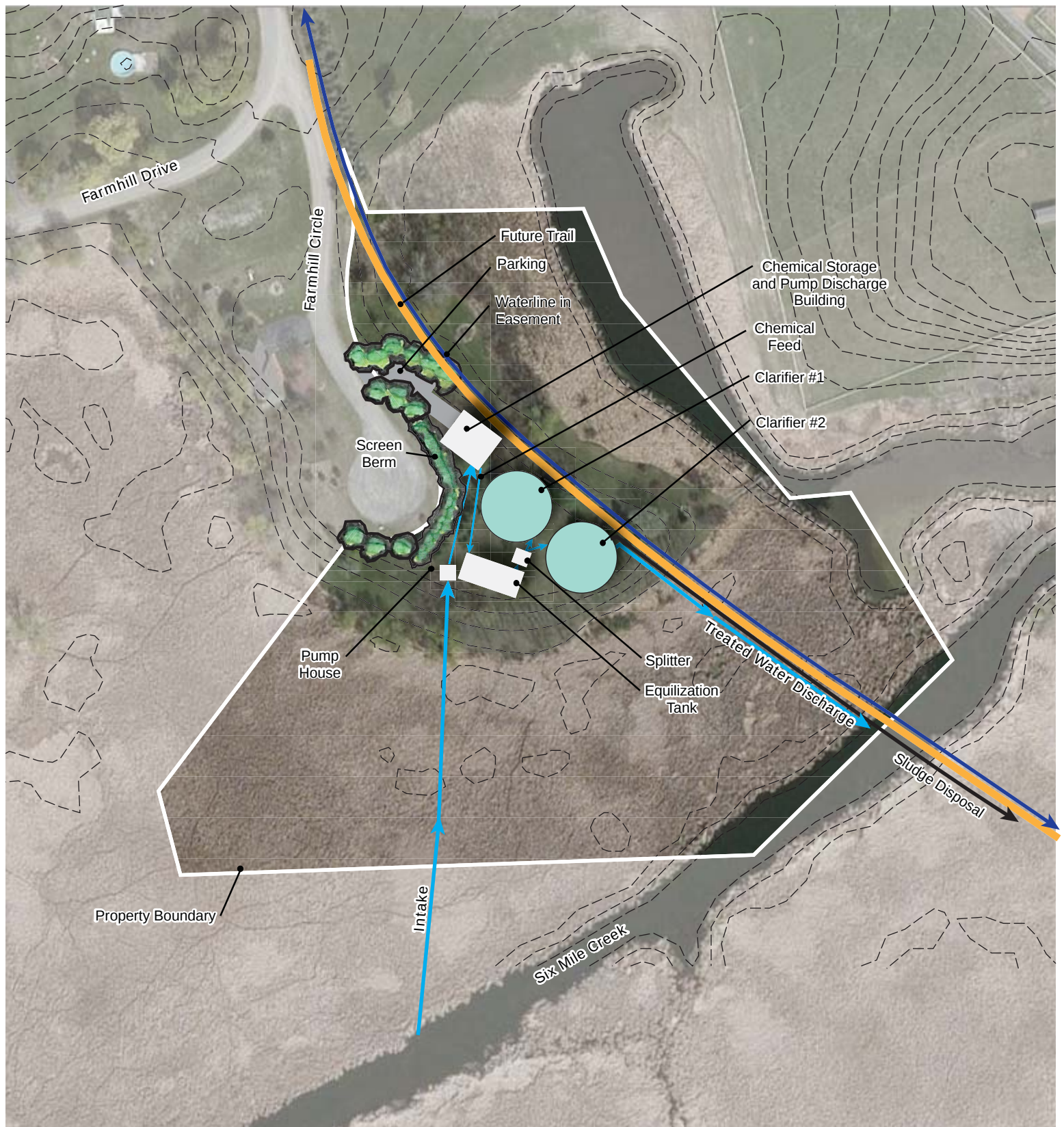


Figure C. Orthophosphorus concentration at CSI-02 (Upstream OrthoP) and CSI-17 (Downstream OrthoP), temperature of water at CSI-02, and flow rate at CSI-02. July and August are highlighted in gray. Note also that no upstream water temperature data is available after mid-July.

Appendix D: 2018 Massing Study Concept Plan



May 8, 2017



6 Mile Creek Alum Treatment Plant

CONCEPT PLAN

Appendix E: Six Mile Creek Data Availability

Six Mile Creek - Halsted Bay Data Inventory				
Summary of available continuous and discrete monitoring data				
Parameter	Years Available	Months Sampled	Data Points	Median Monthly Sampling Frequency
Mud Lake				
Total Phosphorus, mg/L	2006–2021	Jan, Feb, May, Jun, Jul, Aug, Sep, Oct	91	2
Orthophosphate, mg/L	2014–2021	Jan, Feb, May, Jun, Jul, Aug, Sep, Oct	55	2
Total Suspended Sediment, mg/L	2012–2021	Jan, Feb, May, Jun, Jul, Aug, Sep, Oct	78	2
Dissolved Oxygen, mg/L	2012–2021	Jan, Feb, Mar, May, Jun, Jul, Aug, Sep, Oct, Dec	76	2
pH	2012–2021	May, Jun, Jul, Aug, Sep, Oct	68	2
Total Nitrogen, mg/L	2012–2021	May, Jun, Jul, Aug, Sep, Oct	73	2
Chloride, mg/L	2013–2021	May, Jun, Jul, Aug, Sep	20	1
Six Mile Creek Inlet				
Continuous Flow, cfs	2017–2026	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov	197,340	5,843
Discrete Flow, cfs	2009–2026	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	374	3
Water Depth, ft	2017–2017	Apr, May, Jun, Jul, Aug, Sep, Oct	12,188	1,887
Water Temperature, C	2017–2026	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov	197,505	5,840
Total Phosphorus, mg/L	2009–2026	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	365	2
Orthophosphate, mg/L	2009–2026	Jan, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	329	3
Total Suspended Sediment, mg/L	2009–2026	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	251	2
Dissolved Oxygen, mg/L	2009–2026	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	366	2
pH	2009–2026	Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	362	2
Total Nitrogen, mg/L	2009–2026	Jan, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	151	1
Chloride, mg/L	2009–2026	Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	164	1
Six Mile Creek Outlet				
Discrete Flow, cfs	2013–2017	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	102	3
Water Depth, ft	2016–2018	Apr, May, Jun, Jul, Aug, Sep, Oct	53,931	2,881
Water Temperature, C	2016–2018	Apr, May, Jun, Jul, Aug, Sep, Oct	53,927	2,881
Total Phosphorus, mg/L	2013–2016	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	108	4
Orthophosphate, mg/L	2013–2016	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	107	4
Total Suspended Sediment, mg/L	2013–2016	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov	57	2
Dissolved Oxygen, mg/L	2013–2016	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	106	4
pH	2013–2016	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec	102	3
Total Nitrogen, mg/L	2013–2016	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov	28	1
Chloride, mg/L	2013–2016	Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov	27	1
Halsted Bay				
Total Phosphorus, mg/L	2006–2026	Apr, May, Jun, Jul, Aug, Sep, Oct	195	2
Orthophosphate, mg/L	2006–2026	Apr, May, Jun, Jul, Aug, Sep, Oct	181	2
Total Suspended Sediment, mg/L	2017–2026	May, Jun, Jul, Aug, Sep, Oct	55	1
Dissolved Oxygen, mg/L	2006–2026	Apr, May, Jun, Jul, Aug, Sep, Oct	189	2
pH	2006–2026	Apr, May, Jun, Jul, Aug, Sep, Oct	185	2
Total Nitrogen, mg/L	2008–2026	Apr, May, Jun, Jul, Aug, Sep, Oct	140	2
Chloride, mg/L	2010–2026	Apr, May, Jun, Jul, Aug, Sep, Oct	79	1



Halsted Bay

Six Mile Creek Outlet

3940 Farmhill Cir.

Six Mile Creek Inlet

Mud Lake

Appendix F: MCWD Contract Template

**AGREEMENT BETWEEN
MINNEHAHA CREEK WATERSHED DISTRICT and
[CONSULTANT]**

[Project Title]

This agreement is entered into by the Minnehaha Creek Watershed District, a public body with powers set forth at Minnesota Statutes chapters 103B and 103D (MCWD), and [CONSULTANT], a Minnesota corporation (CONSULTANT). In consideration of the terms and conditions set forth herein and the mutual exchange of consideration, the sufficiency of which hereby is acknowledged, MCWD and CONSULTANT agree as follows:

1. Scope of Work

CONSULTANT will perform the work described in the [DATE] Scope of Services attached as Exhibit A (the Services). Exhibit A is incorporated into this agreement and its terms and schedules are binding on CONSULTANT as a term hereof. MCWD, at its discretion, in writing may at any time suspend work or amend the Services to delete any task or portion thereof. Authorized work by CONSULTANT on a task deleted or modified by MCWD will be compensated in accordance with paragraphs 5 and 6. Time is of the essence in the performance of the Services.

2. Independent Contractor

CONSULTANT is an independent contractor under this agreement. CONSULTANT will select the means, method and manner of performing the Services. Nothing herein contained is intended or is to be construed to constitute CONSULTANT as the agent, representative or employee of MCWD in any manner. Personnel performing the Services on behalf of CONSULTANT will not be considered employees of MCWD and will not be entitled to any compensation, rights or benefits of any kind from MCWD.

3. Subcontract and Assignment

CONSULTANT will not assign, subcontract or transfer any obligation or interest in this agreement or any of the Services without the written consent of MCWD and pursuant to any conditions included in that consent. MCWD consent to any subcontracting does not relieve CONSULTANT of its responsibility to perform the Services or any part thereof, nor in any respect its duty of care, insurance obligations, or duty to hold harmless, defend and indemnify under this agreement.

4. Duty of Care; Indemnification

CONSULTANT will perform the Services with due care and in accordance with national standards of professional care. CONSULTANT will hold harmless and indemnify MCWD, its board members, employees and agents, from any and all actions, costs (including reasonable attorney fees), damages and liabilities of any nature arising from CONSULTANT's or a subconsultant's lack of professional due care, and will defend, hold harmless, and indemnify MCWD, its board members, employees and agents from any and all actions, costs, damages and liabilities of any nature arising from CONSULTANT's or a subconsultant's negligent or otherwise wrongful act or omission, or breach of a specific contractual duty owed by CONSULTANT to MCWD, other than the duty of professional due care. For any claim subject to this paragraph by an employee of CONSULTANT or

MCWD Prof Svcs Template (Jan 2023)

a subconsultant, the indemnification obligation is not limited by a limitation on the amount or type of damages, compensation or benefits payable by or for CONSULTANT or the subconsultant under workers' compensation acts, disability acts or other employee benefit acts.

5. Compensation

MCWD will compensate CONSULTANT for the Services on [an hourly OR a lump-sum] basis and reimburse for direct costs in accordance with Exhibit A. Invoices will be submitted monthly for work performed during the preceding month. Payment for undisputed work will be due within 30 days of receipt of invoice. Direct costs not specified in Exhibit A will not be reimbursed except with prior written approval of the MCWD administrator. Subconsultant fees and direct costs, as incurred by CONSULTANT, will be reimbursed by MCWD at the rate specified in MCWD's written approval of the subcontract

[The total payment for each task will not exceed the amount specified for that task in Exhibit A.] The total payment for the Services will not exceed [\$_____]. Total payment in each respect means all sums to be paid whatsoever, including but not limited to fees and reimbursement of direct costs and subcontract costs, whether specified in this agreement or subsequently authorized by the administrator.

CONSULTANT will maintain all records pertaining to fees or costs incurred in connection with the Services for six years from the date of completion of the Services. CONSULTANT agrees that any authorized MCWD representative or the state auditor may have access to and the right to examine, audit and copy any such records during normal business hours.

6. Termination; Continuation of Obligations

This agreement is effective when fully executed by the parties and will remain in force until [DATE] unless earlier terminated as set forth herein.

MCWD may terminate this agreement at its convenience, by a written termination notice stating specifically what prior authorized or additional tasks or services it requires CONSULTANT to complete. CONSULTANT will receive full compensation for all authorized work performed, except that CONSULTANT will not be compensated for any part performance of a specified task or service if termination is due to CONSULTANT's breach of this agreement.

Insurance obligations; duty of care; obligations to defend, indemnify and hold harmless; duty to cooperate in assignment of intellectual property; and document-retention requirements will survive the completion of the Services and the term of this agreement.

7. No Waiver

The failure of either party to insist on the strict performance by the other party of any provision or obligation under this agreement, or to exercise any option, remedy or right herein, will not waive or relinquish such party's rights in the future to insist on strict performance of any provision, condition or obligation, all of which will remain in full force and affect. The waiver of either party on one or more occasion of any provision or obligation of this agreement will not be construed as a waiver of any subsequent breach of the same provision or obligation, and the consent or

MCWD Prof Svcs Template (Jan 2023)

approval by either party to or of any act by the other requiring consent or approval will not render unnecessary such party's consent or approval to any subsequent similar act by the other.

Notwithstanding any other term of this agreement, MCWD waives no immunity in tort. This agreement creates no right in and waives no immunity, defense or liability limit with respect to any third party.

8. Insurance

At all times during the term of this Agreement, CONSULTANT will have and keep in force the following insurance coverages:

- A. General: \$1.5 million, each occurrence and aggregate, covering CONSULTANT's ongoing operations on an occurrence basis.
- B. Professional liability: \$1.5 million each claim and aggregate. Any deductible will be CONSULTANT's sole responsibility and may not exceed \$50,000. Coverage may be on a claims-made basis, in which case CONSULTANT must maintain the policy for, or obtain extended reporting period coverage extending, at least three (3) years from completion of the Services.
- C. Automobile liability: \$1.5 million combined single limit each occurrence coverage for bodily injury and property damage covering all vehicles on an occurrence basis.
- D. Workers' compensation: in accordance with legal requirements applicable to CONSULTANT.

General and automobile liability limits above \$1 million may be met by means of a follow form excess or umbrella policy. CONSULTANT will not commence work until it has filed with MCWD a certificate of insurance clearly evidencing the required coverages and naming MCWD as an additional insured for general liability, and any associated excess or umbrella policy, along with a copy of the additional insured endorsement establishing coverage for CONSULTANT's ongoing operations as primary coverage on a noncontributory basis. The certificate will name MCWD as a holder and will state that MCWD will receive written notice before cancellation, nonrenewal or a change in the limit of any described policy under the same terms as CONSULTANT.

9. Compliance With Laws

CONSULTANT will comply with the laws and requirements of all federal, state, local and other governmental units in connection with performing the Services and will procure all licenses, permits and other rights necessary to perform the Services.

In performing the Services, CONSULTANT will ensure that no person is excluded from full employment rights or participation in or the benefits of any program, service or activity on the ground of race, color, creed, religion, age, sex, disability, marital status, sexual orientation, public assistance status or national origin; and no person who is protected by applicable federal or state laws, rules or regulations against discrimination otherwise will be subjected to discrimination.

MCWD Prof Svcs Template (Jan 2023)

10. Data and Information

All data and information obtained or generated by CONSULTANT in performing the Services, including documents in hard and electronic copy, software, and all other forms in which the data and information are contained, documented or memorialized (together, here and in sections 11 and 12, the "Materials"), are the property of MCWD. CONSULTANT hereby assigns and transfers to MCWD all right, title and interest in: (a) its copyright, if any, in the Materials; any registrations and copyright applications relating to the Materials; and any copyright renewals and extensions; (b) all works based on, derived from or incorporating the Materials; and (c) all income, royalties, damages, claims and payments now or hereafter due or payable with respect thereto, and all causes of action in law or equity for past, present or future infringement based on the copyrights. CONSULTANT agrees to execute all papers and to perform such other proper acts as MCWD may deem necessary to secure for MCWD or its assignee the rights herein assigned.

MCWD may immediately inspect, copy or take possession of any Materials on written request to CONSULTANT. On termination of the agreement, CONSULTANT may maintain a copy of some or all of the Materials except for any Materials designated by MCWD as confidential or non-public under applicable law, a copy of which may be maintained by CONSULTANT only pursuant to written agreement with MCWD specifying terms.

11. Data Practices; Confidentiality

If CONSULTANT receives a request for data pursuant to the Data Practices Act, Minnesota Statutes chapter 13 (DPA), that may encompass data (as that term is defined in the DPA) CONSULTANT possesses or has created as a result of this agreement, it will inform MCWD immediately and transmit a copy of the request. If the request is addressed to MCWD, CONSULTANT will not provide any information or documents, but will direct the inquiry to MCWD. If the request is addressed to CONSULTANT, CONSULTANT will be responsible to determine whether it is legally required to respond to the request and otherwise what its legal obligations are, but will notify and consult with MCWD and its legal counsel before replying. Nothing in the preceding sentence supersedes CONSULTANT's obligations under this agreement with respect to protection of MCWD data, property rights in data or confidentiality. Nothing in this section constitutes a determination that CONSULTANT is performing a governmental function within the meaning of Minnesota Statutes section 13.05, subdivision 11, or otherwise expands the applicability of the DPA beyond its scope under governing law.

CONSULTANT agrees that it will not disclose and will hold in confidence any and all proprietary Materials owned or possessed by MCWD and so denominated by MCWD. CONSULTANT will not use any such Materials for any purpose other than performance of the Services without MCWD written consent. This restriction does not apply to Materials already possessed by CONSULTANT or that CONSULTANT received on a non-confidential basis from MCWD or another party. Consistent with the terms of this section 11 regarding use and protection of confidential and proprietary information, CONSULTANT retains a nonexclusive license to use the Materials and may publish or use the Materials in its professional activities. Any CONSULTANT duty of care under this agreement does not extend to any party other than MCWD or to any use of the Materials by MCWD other than for the purpose(s) for which CONSULTANT is compensated under this agreement.

MCWD Prof Svcs Template (Jan 2023)

12. MCWD Property

All property furnished to or for the use of CONSULTANT or a subcontractor by MCWD and not fully used in the performance of the Services, including but not limited to equipment, supplies, and Materials, will remain the property of MCWD and returned to MCWD at the conclusion of the performance of the Services, or sooner if requested by MCWD. CONSULTANT further agrees that any proprietary Materials are the exclusive property of MCWD and will assert no right, title or interest in the Materials. CONSULTANT will not disseminate, transfer or dispose of any proprietary Materials to any other person or entity unless specifically authorized in writing by MCWD.

Any property including but not limited to Materials supplied to CONSULTANT by MCWD or deriving from MCWD is supplied to and accepted by CONSULTANT as without representation or warranty including but not limited to a warranty of fitness, merchantability, accuracy or completeness. However, CONSULTANT's duty of professional care under paragraph 4, above, does not extend to Materials provided to CONSULTANT by MCWD or any portion of the Services that is inaccurate or incomplete as the result of CONSULTANT's reasonable reliance on those Materials.

13. Notices

Any written communication required under this agreement to be provided in writing will be directed to the other party as follows:

To MCWD:

Administrator
Minnehaha Creek Watershed District
15320 Minnetonka Boulevard
Minnetonka, MN 55345

To CONSULTANT:

[Authorized Representative
Organization
Address]

Either of the above individuals may in writing designate another individual to receive communications under this agreement.

14. Choice of Law; Venue

This agreement will be construed under and governed by the laws of the State of Minnesota. Venue for any action will lie in Hennepin County.

15. Whole Agreement

The entire agreement between the two parties is contained herein and this agreement supersedes all oral agreements and negotiations relating to the subject matter hereof. Any

MCWD Prof Svcs Template (Jan 2023)

modification of this agreement is valid only when reduced to writing as an amendment to the agreement and signed by the parties hereto. MCWD may amend this agreement only by action of the Board of Managers acting as a body.

IN WITNESS WHEREOF, intending to be legally bound, the parties hereto execute and deliver this agreement.

CONSULTANT

By _____
Its _____

Date: _____

Approved as to Form and Execution

MCWD Attorney

MINNEHAHA CREEK WATERSHED DISTRICT

By _____
Its _____

Date: _____

Exhibit A
Scope of Services

TEMPLATE