MINNEHAHA CREEK
WATERSHED DISTRICT
QUALITY OF WATER, QUALITY OF LIFE

Meeting: Board of Managers
Meeting date: 6/23/2020
Agenda Item #: 11.1
Request for Board Action

Title:	Wassermann Lake Internal Load Management Project
Resolution number:	20-050: Ordering of the Wassermann Internal Load Management Project 20-051: Approval of Wassermann Internal Load Project Agreement 20-052: Authorization to Contract with UW-Stout to Analyze Wassermann Lake Sediment for Alum Treatment Engineering Design
Prepared by:	Name: Anna Brown and Brian Beck Phone: (952) 641-4522 Abrown@minnehahacreek.org or Bbeck@minnehahacreek.org
Reviewed by:	Name/Title: Michael Hayman, Project Planning Manager
Recommended action:	Project ordering of the Wassermann Lake Internal Load Management Project; Approval of a project assurance agreement with the Board of Water and Soil Resources; Approval of a contract for sediment core analysis to assist project design.
Schedule:	Summer 2020: Pre-project monitoring and engineering design Fall 2020: Public engagement Winter 2020/21: Project bidding Spring 2021: First alum treatment Fall 2022: Second alum treatment
Budget considerations:	Sediment Core Analysis Fund name and code: 500-5001-4520 Fund budget: $120,400 Expenditures to date: $0 Requested amount of funding: $15,000 *Sediment core analysis is the only budget item at this time. Future expenditures for the project will approved at the time of contract.*
Past Board action:	Res # 19-072 Title: Authorization to Apply for BWSR Clean Water Funds Res # 20-020 Title: Authorization to Execute Grant Agreement for Wassermann Internal Load Management Project

Summary:
In May 2014, the Minnehaha Creek Watershed District (MCWD) Board of Managers formally adopted the Six Mile Creek-Halsted Bay (SMCHB) subwatershed as a geography of strategic planning and implementation focus. In March 2015, the City of Victoria and MCWD executed a memorandum of understanding (MOU) which identifies the mutual value both agencies find in cooperative planning, coordination across agencies on priority water resource issues, and increasing regulatory coordination to support and foster integrated water and natural resources management. One of the priority water resource management areas identified for increased collaboration is Lake Wassermann, an impaired waterbody within the City of Victoria.

Since adoption of the 2017 Water Management Plan, MCWD has been working to implement high impact capital projects within the SMCHB subwatershed, with particular focus in the City of Victoria and Laketown Township, where current land use pressure presents a unique opportunity to implement high impact capital projects concurrent with

development. Under this plan, MCWD has invested substantially in the restoration of Wassermann Lake through both watershed and in-lake management activities.

In 2016, MCWD partnered with Lennar Corporation to restore vegetative diversity and predevelopment hydrology in a 22 acre wetland along the upstream segment of Six Mile Creek, improving habitat and nutrient cycling. Since 2018, MCWD has been working on a subwatershed wide carp management program that has effectively reduced the carp population in Wassermann, improving aquatic plant communities and slowing sediment and nutrient resuspension in the water column. In spring 2019, MCWD applied aluminum sulfate (alum) in the six acre pond on the Wassermann West property, resulting in a 75 pound per year decrease in phosphorus loading to Wassermann Lake. Finally, MCWD and the City are constructing a 33.5 acre park preserve and habitat restoration project on the west shore of Lake Wassermann which offers an opportunity to showcase the improvements to Wassermann Lake and the SMCHB Subwatershed while creating a unique recreational asset for Victoria residents.

Internal loading is the last remaining significant source of nutrient pollution in Lake Wassermann. The 2013 SMCHB Diagnostic Study estimates an annual internal release rate of 375 pounds per year, the largest nutrient source identified**.** Alum treatment is projected to reduce internal loading by an estimated 90%, for a reduction of 336 pounds per year.

In January 2020, MCWD was awarded a Clean Water Fund grant from the Board of Water and Soil Resources (BWSR), positioning us for an initial alum treatment in spring 2021 and a subsequent treatment in fall 2022. The total budget for this project is $355,900, including $284,720 in grant funds and $71,180 in match. MCWD's match funds will be allocated to feasibility, pre- and post-project sediment analysis, and some of the cost of treatment. The grant dollars will be allocated exclusively to alum treatment.

Project Ordering
The MCWD Watershed Management Plan identifies the Wassermann Lake Internal Load Management Project for the purpose of reducing phosphorus loading from internal sediment release and improving water clarity. In accordance with Minnesota Statues 103B.251, before entering into a commitment to incur project costs for capital project design or construction, the Board of Managers must hold a public hearing and order the project on the basis of a finding that the project will advance the District's water resource goals and should proceed. The public hearing has been duly noticed for June 23, 2020 and will be held prior to Board's consideration of this request for action.

Project Assurance Agreement
BWSR requires an operations and maintenance plan for its implementation practices as a component of the Grant Agreement. Because alum does not have inspection and maintenance protocols in a traditional sense, BWSR has requested all alum treatment projects execute a project assurance agreement in lieu of an O&M plan. This assurance document commits MCWD to monitoring the efficacy of the treatment and, if nutrient loading increases and can be attributed to a failure of the treatment, to take remedial action. This may result in a spot treatment or maintenance treatment on the lake if there is found to be an issue with the treatment within the 15 year project horizon.

Sediment Core Analysis
In 2019, MCWD conducted a preliminary feasibility study to estimate the total phosphorus load reduction and cost for an alum treatment on Wassermann Lake. However, the cost estimate was relatively course grain due to the limited data available at the time. Therefore, MCWD will collect sediment cores to refine the cost developed in 2019 and identify the most cost effective phosphorus load reduction possible. Two types of sediment analysis will be conducted, which include measuring the total amount of legacy phosphorus in Wassermann Lake sediment and the rate at which phosphorus is released from sediment into the water column. Both of these analysis will be conducted by the University of Wisconsin Stout.

Supporting Documents
- Project Assurance Agreement
- University of Wisconsin Stout Cost Estimate

MINNEHAHA CREEK
WATERSHED DISTRICT
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RESOLUTION

Resolution number: 20-050

Title: Ordering of the Wassermann Lake Internal Load Management Project

WHEREAS, pursuant to Resolution 14-047 the MCWD Board of Managers has identified the Six Mile Creek subwatershed as a priority area for focusing District planning activities and coordination efforts with subwatershed partners;

WHEREAS, on March 26, 2015 the Board authorized the District to enter a Memorandum of Understanding with the City of Victoria (the City), outlining opportunities to collaborate and integrate mutual efforts in the realms of coordinated planning of local water and land use plans, assessment of specific water management issues, and coordinated regulatory review of water and land development, and specifically identified a shared interest between the two parties in addressing the impairment of Wassermann Lake;

WHEREAS, the MCWD Watershed Management Plan identifies the Wassermann Lake Internal Load Management Project (the Project) as a planned capital investment to reduce internal nutrient loading, improve water clarity, and create a more abundant and diverse aquatic vegetation community;

WHEREAS, on August 22, 2019, the MCWD Board of Managers authorized staff to submit an application to the Board of Water and Soil Resources Clean Water Fund grant program requesting $284,720, and requiring a 25% match of $71,180, for the implementation of the Project, and received notice in January 2020 that the grant was awarded in the full amount;

WHEREAS, in accordance with Minnesota Statutes § 103B.251, subdivision 3, the MCWD held a duly noticed public hearing on ordering of the Project on June 23, 2020, at which time all interested parties had an opportunity to address the Board on the question of implementation of the Project; and

WHEREAS, the Board of Managers finds that the Project will be conducive to public health and promote the general welfare, and is in compliance with Minnesota Statutes §§103B.205 to 103B.255 and the MCWD's Watershed Management Plan adopted pursuant to §103B.231;

NOW, THEREFORE, BE IT RESOLVED that pursuant to Minnesota Statutes § 103B.251 and the Watershed Management Plan, the Minnehaha Creek Watershed District Board of Managers orders the Wassermann Lake Internal Load Management Project.

Resolution Number 20- 050 was moved by Manager _____, seconded by Manager _____. Motion to adopt the resolution ___ ayes, ___ nays, ___abstentions. Date: 6/23/2020

_____ Date: _____

Secretary

MINNEHAHA CREEK
WATERSHED DISTRICT
QUALITY OF WATER, QUALITY OF LIFE

RESOLUTION

Resolution number: 20-051

Title: Approval of Wassermann Internal Load Management Project Agreement

WHEREAS, pursuant to Resolution 14-047 the MCWD Board of Managers has identified the Six Mile Creek subwatershed as a priority area for focusing District planning activities and coordination efforts with subwatershed partners;

WHEREAS, on March 26, 2015 the Board authorized the District to enter a Memorandum of Understanding with the City of Victoria (the City), outlining opportunities to collaborate and integrate mutual efforts in the realms of coordinated planning of local water and land use plans, assessment of specific water management issues, and coordinated regulatory review of water and land development, and specifically identified a shared interest between the two parties in addressing the impairment of Wassermann Lake;

WHEREAS, the MCWD Watershed Management Plan identifies the Wassermann Lake Internal Load Management Project (the Project) as a planned capital investment to reduce internal nutrient loading, improve water clarity, and create a more abundant and diverse aquatic vegetation community;

WHEREAS, on August 22, 2019, the MCWD Board of Managers authorized staff to submit an application to the Board of Water and Soil Resources (BWSR) Clean Water Fund grant program requesting $284,720, and requiring a 25% match of $71,180, for the implementation of the Project, and received notice in January 2020 that the grant was awarded in the full amount;

WHEREAS, as a condition of fund disbursement, BWSR has requested a project assurance agreement that specifies an efficacy monitoring approach and remedial actions that will be pursued in the event that the treatment is not found to be effective within the project lifespan.

NOW, THEREFORE, BE IT RESOLVED that the Minnehaha Creek Watershed District Board of Managers authorizes the District Administrator, on advice of counsel, to execute a project assurance agreement with Board of Water and Soil Resources for the Wassermann Lake Internal Load Management project.

Resolution Number 20- 051 was moved by Manager _____, seconded by Manager _____. Motion to adopt the resolution ___ ayes, ___ nays, ___abstentions. Date: 6/23/2020

_____ Date: _____

Secretary

MINNEHAHA CREEK
WATERSHED DISTRICT
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RESOLUTION

Resolution number: 20-052

Title: Authorization to Contract with UW-Stout to Analyze Wassermann Lake

WHEREAS, pursuant to Resolution 14-047 the MCWD Board of Managers has identified the Six Mile Creek subwatershed as a priority area for focusing District planning activities and coordination efforts with subwatershed partners;

WHEREAS, on March 26, 2015 the Board authorized the District to enter a Memorandum of Understanding with the City of Victoria (the City), outlining opportunities to collaborate and integrate mutual efforts in the realms of coordinated planning of local water and land use plans, assessment of specific water management issues, and coordinated regulatory review of water and land development, and specifically identified a shared interest between the two parties in addressing the impairment of Wassermann Lake;

WHEREAS, the MCWD Watershed Management Plan identifies the Wassermann Lake Internal Load Management Project (the Project) as a planned capital investment to reduce internal nutrient loading, improve water clarity, and create a more abundant and diverse aquatic vegetation community;

WHEREAS, on August 22, 2019, the MCWD Board of Managers authorized staff to submit an application to the Board of Water and Soil Resources (BWSR) Clean Water Fund grant program requesting $284,720, and requiring a 25% match of $71,180, for the implementation of the Project, and received notice in January 2020 that the grant was awarded in the full amount;

WHEREAS, the MCWD will obtain sediment core samples from Wassermann Lake to inform the final alum dosing design and costs for the Project, which will serve as a portion of the match funds for the BWSR Clean Water Fund grant.

NOW, THEREFORE, BE IT RESOLVED that the Minnehaha Creek Watershed District Board of Managers authorizes the District Administrator to execute contract with University of Wisconsin - Stout to analyze sediments from Wassermann Lake for an amount not to exceed $15,000.

Resolution Number 20- 052 was moved by Manager _____, seconded by Manager _____. Motion to adopt the resolution ___ ayes, ___ nays, ___abstentions. Date: 6/23/2020

_____ Date: _____

Secretary

FISCAL YEAR 2020 CLEAN WATER FUND COMPETITIVE GRANT PROGRAM PROJECT AGREEMENT
Wassermann Lake Internal Load Management

This Fiscal Year 2020 Clean Water Fund Competitive Grant Program Project Agreement ("**AGREEMENT**") is made as of this ____ day of _____, 2020 by and between the Minnehaha Creek Watershed District, a political subdivision of the State of Minnesota ("**DISTRICT**"), and the Minnesota Board of Water and Soil Resources ("**BWSR**") (together, the "parties").

RECITALS

A. The Wassermann Internal Load Management Project is the next phase in restoring Wassermann Lake, a waterbody impaired for nutrients. The Wassermann Lake TMDL attributes 505 lb/yr of phosphorus to internal loading and requires an 88% reduction. An estimated 374 lb/yr of this internal load is attributed to internal sediment release. Wassermann Lake water quality improvement will also benefit downstream waterbodies East Auburn Lake and Halsted Bay of Lake Minnetonka, both of which are impaired for phosphorus as well.

B. The restoration of Wassermann Lake has been a multi-year, multi-element strategy culminating in alum treatment to address the high rate of internal loading. The DISTRICT already has effectively managed known sources of watershed loading, and reduced carp to a level that allows for alum treatment efficacy. Further sediment analysis before application will ensure cost-effective treatment by targeting lake depths with highest release rates.

C. The DISTRICT sought Fiscal Year (FY) 2020 Clean Water Fund (CWF) Competitive Projects and Practices grant funds from BWSR to complete two aluminum sulfate treatments on Wassermann Lake as described in the DISTRICT's "Lake Wassermann Internal Load Management" FY2020 CWF Competitive Project and Practices grant application attached hereto as Exhibit A (collectively, the "**PROJECT**");

D. BWSR awarded the DISTRICT FY 2020 CWF Competitive Projects and Practices grant funds in the amount of $284,720 ("**GRANT**") with a local match by the DISTRICT in the amount of $71,180, for completion of the PROJECT;

E. The DISTRICT will submit a GRANT work plan for the PROJECT and BWSR, and the DISTRICT will mutually enter into a GRANT agreement for the release, use and reimbursement of GRANT funds by the DISTRICT on eligible PROJECT expenditures for completion of the PROJECT in accordance with the BWSR approved GRANT work plan and GRANT agreement, attached hereto as Exhibit B.

F. As a condition of release of the GRANT funds and reimbursement of eligible PROJECT expenditures, BWSR requires a statement of technical and project assurance that the PROJECT is designed to reduce internal nutrient loading of phosphorous in Wassermann Lake by 336 pounds each year, for at least 15 years, in accordance with the FY 2020 CWF Competitive Projects and Practices grant application and GRANT work plan; and

G. The DISTRICT agrees to carry out the PROJECT in accordance with the terms and conditions of the FY2020 CWF GRANT Agreement and this Agreement.

AGREEMENT

In consideration of the mutual promises and covenants contained herein, the parties agree as follows:

1. PROJECT. The DISTRICT agrees to complete the PROJECT, consisting of alum treatments in 2021 and 2022, in accordance with the grant application, Exhibit A; the GRANT work plan; the GRANT Agreement, Exhibit B; and the following:

   (a) The DISTRICT will comply with all applicable contracting laws in hiring contractors to complete the PROJECT.

   (b) The DISTRICT will ensure all required permits and permissions required to complete the PROJECT are obtained.

   (c) The DISTRICT has engaged the services of Wenck, a Minnesota engineering firm that employs engineers, lake ecologists and limnologists, and soil geochemistry scientists experienced in developing lake aluminum sulfate dosing recommendations, and designing, inspecting, monitoring, and overseeing implementation of lake aluminum sulfate treatment projects. [ ] or another qualified individual with BWSR approval will provide technical project oversight and project certification.

   (d) The DISTRICT will obtain sediment core samples to assist in final PROJECT dosing and design. On the basis of sample analysis, the qualified individual will confirm or adjust the expected phosphorus loading reduction stated in Recital F, above. The DISTRICT will provide a copy of this assessment to BWSR.

   (e) Using grant and local funds as stated above, the DISTRICT will complete the PROJECT and apply the aluminum sulfate treatment to specific treatment areas of Wassermann Lake in 2021 and 2022 in accordance with PROJECT design and established application protocol.

   (f) The DISTRICT will conduct and collect, at a minimum, annual lake water quality monitoring data for Wassermann Lake, to track the effectiveness of the aluminum sulfate treatment in reducing the lake bottom sediment release of phosphorous and achieving the PROJECT goal of reducing internal nutrient loading of phosphorous in Wassermann Lake by 336 pounds each year, or as may have been adjusted under paragraph 1.d. The DISTRICT will make the data and progress updates available to BWSR on request.

   (g) The DISTRICT will perform sediment core analysis after the second treatment to assess treatment success. Ten years after the second treatment is completed, the DISTRICT will perform additional sediment core analysis and, by a qualified individual, will assess whether the PROJECT will achieve the PROJECT phosphorus loading reduction goal for a period of 15 years from completion of the second treatment. If the data indicate this is not the case, the DISTRICT will take other feasible steps to provide for that load reduction. In addition, if at any time annual monitoring data indicate that the PROJECT goal for internal sediment release control may not be occurring, the DISTRICT will consult with BWSR and take feasible actions designed to achieve that result. BWSR may relieve the DISTRICT from further action otherwise required by this paragraph if, in its judgment, observed inadequate phosphorus load control is due to factors other than PROJECT ineffectiveness.

2. Audit. All DISTRICT books, records, documents, and accounting procedures related to the PROJECT are subject to examination by BWSR for a period of six years.

3. Data Practices. The DISTRICT will retain and make available data related to the letting of contracts and the conducting of the PROJECT in accordance with the Minnesota Government Data Practices Act.

4. Term. This Agreement is in effect as of the date first written above and terminates at the end of the 15-year effective life of the PROJECT and the follow-up testing and other actions as provided for herein. The beginning date for the PROJECT effective life is the date the second alum treatment is completed.

5. Entire Agreement. The Agreement, including the recitals and Exhibits A and B, is the entire understanding between the parties. No modification to the Agreement is valid unless reduced to writing and signed by both parties.

IN WITNESS WHEREOF, the parties have caused this Agreement to be executed by their duly authorized officers on behalf of the parties as of the day and date first above written.

MINNEHAHA CREEK WATERSHED DISTRICT

By:_____
Its President

Date:_____

MINNESOTA BOARD of WATER and SOIL RESOURCES

By:_____

Its:_____

Date:_____

Determination of Rates of Phosphorus Release and Sediment chemistry Wassermann Lake, Minnesota

PROPOSAL OF RESEARCH

15 June, 2020

University of Wisconsin - Stout
Sustainability Sciences Institute
Center for Limnological Research and Rehabilitation
Menomonie, Wisconsin 54751
715-338-4395
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1.0 BACKGROUND.

Bottom sediments represent an important internal source of phosphorus (P) that can potentially subsidize high algal productivity, even when external P loading from the watershed has been reduced. For sediments containing iron (Fe) compounds, P is usually coupled with Fe dynamics and flux to the water column is regulated by oxidation-reduction (i.e., eH) and pH reactions (Mortimer 1971). A thin oxidized microzone exists in the sediment surface layer when the overlying water column is oxygenated. Under these conditions, Fe is in an oxidized state (i.e., Fe^{+3}) in the microzone as Fe~(OOH) and adsorbs P, thereby controlling its diffusion into the overlying water column. Elevated pH and production of hydroxyl ions (OH^-) during periods of intense photosynthesis can also indirectly enhance rates of P release from sediment under aerobic conditions via ligand exchange (i.e., competition for binding sites by OH^-). Under anoxic conditions at the sediment-water interface, anaerobic bacterial reduction of iron from Fe^{+3} to Fe^{+2} results in P desorption and diffusion into the water column for potential uptake by algae. Internal P loading via these recycling pathways can account for a substantial portion of the P economy of aquatic systems and hinder restoration efforts targeted at reducing algal biomass.

Fe~(OOH)~PO_4 or redox-sensitive P can be quantified via extraction with a strong reducing agent (dithionite-bicarbonate; BD; Nürnberg 1988). Additionally, biologically-labile P in the form of bacterial polyphosphates and labile organic P compounds and can be recycled to the overlying water column via mineralization and metabolic breakdown and is extracted with a basic solution (0.1 to 1.0 N NaOH; Psenner and Puckso 1988). Thus, the size of the biologically-labile P pool (i.e., redox-P and labile organic P; subject to recycling and internal P loading) in surface sediment can be quantified for evaluation and be compared to other systems to assess the potential importance as a source of P recycling in lakes.

2.0 PURPOSE.

The objectives of these investigations are to:

1. measure rates of P release from sediment under anaerobic conditions,
2. examine sediment mobile P fractions that are active in internal P loading for estimation of alum dosage,

3.0 SCOPE OF WORK.

Intact sediment cores will be collected for P flux and sediment characteristics in the deep basin of 5 lakes.

Task 1 - Laboratory-derived rates of P release from sediment under anaerobic conditions:

Triplicate intact sediment cores will be collected by MCWD personnel from a deep basin station in each lake for the determination of rates of P release from sediment under controlled laboratory conditions. All cores will be carefully drained of overlying water in the laboratory and the upper 10 cm of sediment will be 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 each lake will be 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. They will be placed in a darkened environmental chamber and incubated at a constant temperature of ~ 20 ^{o}C to reflect summer conditions. The oxidation-reduction environment in the overlying water will be controlled by gently bubbling nitrogen (anaerobic) through an air stone placed just above the sediment surface in each system. Bubbling action will insure complete mixing of the water column but not disrupt the sediment. For each station, duplicate cores will be subjected to anaerobic conditions.

Water samples for soluble reactive P will be collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter. The water volume removed from each system during sampling will be replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes are accurately measured for determination of dilution effects. Soluble reactive P is measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of P release from the sediment (mg/m^2 d) are 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 is used to estimate rates over the linear portion of the data.

Task 2 - Evaluation of sediment P characteristics:

The objectives of this task are to quantify sediment physical-textural characteristics and P fractions in the upper 5-cm sediment layer of each lake. Sediment sections will be analyzed for the variables listed in **Table 1**. Subsamples will be dried at 105 °C to a constant weight and burned at 500 °C for determination of moisture content, sediment density, and organic matter content (Håkanson and Jensson 2002). Phosphorus fractionation will be conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (1 M NH_4Cl; loosely-bound P), bicarbonate-dithionite-extractable P (0.11 M BD; iron-bound P), and sodium hydroxide-extractable P (0.1 N NaOH; aluminum-bound P). A subsample of the sodium hydroxide extract will be digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P is calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P.

Table 1. Textural-physical variables and biologically-labile sediment phosphorus pools.
Moisture content (%)
Sediment wet and dry bulk density (g/cm^3)
Organic matter content (%)
Loosely-bound P (mg/g)
Iron-bound P (mg/g)
Labile organic P (mg/g)
Aluminum-bound P (mg/g)

The loosely-bound (Loose-P) and iron-bound P (Fe-P) fractions are readily mobilized at the sediment-water interface under anaerobic conditions that result in desorption of P from bacterially-reduced iron compounds (i.e., Fe^{+3} to Fe^{+2}) in the sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988). The sum of the Loose-P and Fe-P fractions are referred to as redox-sensitive P (i.e., redox-P; the P fraction that is active in P release under anaerobic and reducing conditions). In addition, labile organic P (LOP) 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 LOP is collectively referred to a biologically-labile P. This fraction is generally active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column and potential assimilation by algae.

4.0 REFERENCES.

APHA (American Public Health Association). 2005. Standard Methods for the Examination of Water and Wastewater. 21th ed. American Public Health Association, American Water Works Association, Water Environment Federation.

Boström B. 1984. Potential mobility of phosphorus in different types of lake sediments. Int. Revue. Ges. Hydrobiol. 69:457-474.

Gächter R., Meyer JS, Mares A. 1988. Contribution of bacteria to release and fixation of phosphorus in lake sediments. Limnol. Oceanogr. 33:1542-1558.

Gächter R, Meyer JS. 1993. The role of microorganisms in mobilization and fixation of phosphorus in sediments. Hydrobiologia 253:103-121.

Håkanson L, Jansson M. 2002. Principles of lake sedimentology. The Blackburn Press, Caldwell, NJ USA

Hjieltjes AH, Lijklema L. 1980. Fractionation of inorganic phosphorus in calcareous sediments. J. Environ. Qual. 8: 130-132.

Hupfer M, Gächter R., Giovanoli R. 1995. Transformation of phosphorus species in settling seston and during early sediment diagenesis. Aquat. Sci. 57:305-324.

Mortimer CH. 1971. Chemical exchanges between sediments and water in the Great Lakes – Speculations on probable regulatory mechanisms. Limnol. Oceanogr. 16:387-404.

Nürnberg GK. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. Can. J. Fish. Aquat. Sci. 45:453-462.

5.0 COST ANALYSIS

Sediment Chemistry Price List					
Variable		Unit	Cost		
			Each	Quantity	Total
Textural and Physical Characteristics	Moisture Content-Bulk Density-organic matter	per sediment section	$30	30	$900
Sediment Phosphorus Extractions	Biologically-labile Phosphorus	per sediment section	$135	30	$4,050
Sediment Flux or Internal Loading	Incubation for rates of soluble reactive P release	per 10 cm core	$540	18	$9,720
Total					$14,670