Environment and Natural Resources Trust Fund
2018 Request for Proposals (RFP)

Project Title: **ENRTF ID:** **038-B**

Biological Sulfate Removal for Wastewater Treatment in Minnesota

Category: B. Water Resources

Total Project Budget: $ 494,000

Proposed Project Time Period for the Funding Requested: 3 years, July 2018 to June 2021

Summary:

Goal of the project is to improve Minnesota's water quality by removing sulfate from wastewater. The project will provide best management practices to integrate sulfate removal into wastewater treatment operations.

Name: Sebastian Behrens

Sponsoring Organization: U of MN

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Web Address

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

Shown are an image of the wastewater treatment plant in St. Cloud, MN, examples of bioreactors that can be used for sulfate removal:

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: Biological Sulfate Removal for Wastewater Treatment in Minnesota

I. PROJECT STATEMENT

The goal of the project is to improve Minnesota's water quality by removing sulfate during wastewater treatment. Currently, biological sulfate removal has not been implemented by Minnesota wastewater treatment facilities. In the near future, new regulations are expected on Minnesota's water-quality-based effluent limits for sulfate for the protection of wild rice waters. Although sulfate is not directly toxic to wild rice, it can be converted to sulfide which is toxic. Results from this project will inform municipalities, wastewater treatment plant operators, state agencies, and engineering consultants on how cost-effective biological removal of sulfate can be achieved at Minnesota's wastewater treatment plants to meet future sulfate discharge regulations.

In addition to naturally occurring sulfate in groundwater sources, various sulfate-containing wastewaters are produced from residential (fertilizers, household chemicals) and industrial processes, such as pulp and paper, fermentation, pharmaceutical production, food production, petrochemical, and mining processes. Also human feces naturally contain sulfur compounds. Sulfur compounds are chemically and biologically oxidized to sulfate in the presence of oxygen. The amounts of sulfate added to wastewater from each of these different sources does vary locally. Typical sulfate concentrations in untreated municipal wastewater range from 20 to 50 mg/L but can be as high as several hundred mg/L in certain areas of the state. Because these values are higher than current and proposed water-quality-based effluent limits for sulfate, municipalities operating wastewater treatment plants that discharge to wild rice waters will have to change their operations and add new treatment so that their discharge will meet enforced sulfate standards in the future.

Biological sulfate removal processes are advantages compared to chemical (precipitation, ion exchange) or physical (membrane-based filtration) processes because of their low cost and high removal efficiency even at low concentrations of sulfate. For decades, wastewater treatment facilities rely on microorganisms to remove nutrients (BOD, phosphorus, nitrogen) from the wastewater. From an engineering and operational perspective, it is challenging but possible to achieve BOD, total nitrogen, and phosphorus removal during wastewater treatment, but it is much more difficult to achieve simultaneous removal of sulfate because all four processes occur at very specific and distinct operating conditions. **In order to achieve sulfate removal in future wastewater treatment operations, a better process understanding and control is required; the research proposed herein will generate the knowledge and tools needed to provide this critical knowledge in close collaboration of University researcher and engineering consultants.**

We propose to:

- **Systematically probe WWTPs for the presence and activity of sulfate reducing bacteria at various water treatment stages;**
- **Evaluate different bioreactor designs and operating conditions for sulfate removal from wastewaters of different chemical composition;**
- **Outline conditions for technology scale-up and implementation in an engineering cost analysis**

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Occurrence and activity of sulfate reducing bacteria (SRBs) in Minnesota's wastewater treatment plants	Budget: $157,000

Samples will be collected from all treatment stages (e.g. inflow, activated sludge systems, anaerobic tanks in biological phosphorus removal systems, and anaerobic sludge digesters) at six WWTPs that are likely to exceed proposed water-quality-based effluent limits for sulfate (effluent concentration range 20-600 mg/L). We will determine the occurrence and quantity of SRBs and their activity in the different water and sludge samples and correlate the data to the plant performance data with respect to sulfate removal. *GOAL: Identifying the types,* *quantity, and activity of SRBs in existing wastewater treatment processes is an important prerequisite for better process control and the design of new bioreactors.*

Outcome	Completion Date
1. Sample collection from all treatment stages and parallel reactors at six WWTP	June 30, 2019
2. Identification, quantification, and activity of sulfate transforming microorganisms	June 30, 2020
3. Determine under which conditions SRBs occur and are most active in sulfate removal	June 30, 2020

Activity 2: Determine the performance of different bioreactors types for sulfate removal from Minnesota's wastewater.	**Budget: $155,000**

We will set-up six different types of laboratory-scale bioreactors (up-flow or down-flow anaerobic fluidized-bed; sludge blanket; gas lift; fix and packed bed reactors) to test which reactor will most effectively remove sulfate from Minnesota's wastewater. Bioreactors will be operated at different temperature, pH, chemical oxygen demand (COD), sulfate, salt, and oxygen concentrations and seeded with wastewater/sludge that contains sulfate reducing bacteria (Activity 1). Experiments will be performed with synthetic wastewater amended with sulfate and organic matter and with real wastewater collect from Minnesota's WWTPs. *GOAL: Identify suitable bioreactor designs and relevant process parameters for effective sulfate removal from wastewaters of different composition.*

Outcome	Completion Date
1. Sulfate removal efficiency of different bioreactor types	Dec 31, 2020
2. Bioreactor operating conditions for wastewater with different COD/sulfate ratios	Dec 31, 2020

Activity 3: Conditions for pilot-scale test, up-scaling, implementation, and cost/benefit analysis	**Budget: $182,000**

We will work with an engineering consultant company to outline conditions for pilot-scale tests off the most effective bioreactor systems identified in Activity 2. We will analyze the benefits and limitations of up-scaling, placement, and operation of different bioreactor systems at different WWTPs in Minnesota. *GOAL: Results will be published in a report summarizing the costs, benefits, and best management practices to implement biological sulfate removal at WWTPs in Minnesota.*

Outcome	Completion Date
1. Determine conditions for scale-up, placement, implementation and pilot-scale tests	June 30, 2021
2. Cost-benefit analysis and final report	June 30, 2021

III. PROJECT STRATEGY

A. Project Team/Partners

The project team consists of: PI Prof. Dr. Sebastian Behrens, Dept. of CEGE, UMN; receiving funds
Prof. Dr. Timothy LaPara, Dept. of CEGE, UMN; not receiving funds

The proposed research will be conducted in collaboration with a local engineering consultant company with expertise in engineering cost analyses and wastewater treatment in Minnesota. Results of the proposed research will be shared with the MPCA to support the regulatory analysis on the affected entities and cost of compliance of proposed future sulfate standards.

B. Project Impact and Long-Term Strategy

The project will help to protect the water quality of Minnesota's precious water resources and pristine aquatic ecosystems. This project will provide critical knowledge on the microorganism that the State of Minnesota depends on to remove sulfate during wastewater treatment. Future regulations on discharge limits for sulfate will pose a challenge to wastewater treatment in the State and will require detailed knowledge of the microorganisms and process control parameters for wastewater treatment. This proposed project will help meet that critical need.

C. Timeline Requirements

The proposed project will be completed in the allotted three-year period.

2018 Detailed Project Budget

Project Title: Biological Sulfate Removal for Wastewater Treatment in Minnesota

IV. TOTAL ENRTF REQUEST BUDGET *3* years

BUDGET ITEM		AMOUNT
Personnel:		
Prof. Dr. Sebastian Behrens, Project Manager (75% salary, 25% fringe)12% FTE for each of the 3 years	$	69,000
Postdoctoral Research (TBD) (82% salary, 18% fringe) 100% FTE for each of the 3 years	$	174,000
Graduate student (TBD) (57% salary, 43% tuition and fringe) 50% FTE for each of the 3 years	$	134,000
Professional/Technical/Service Contracts: Engineering consultant on T&M basis to perform feasibility and cost screening of reactor options, including discussion of scale-up and operation. Consultant will be selected by compatative bidding process.	$	20,000
Equipment/Tools/Supplies: Materials to construct and operate bioreactors (six reactors and pumps $5K each plus $5K for tubing, fittings, and valves, total $35K); Water quallity analysis: Ion Chromatography and Flow Injection Analysis: Ammonia, nitrate, nitrite, phosphorus, sulfate and chloride; Total carbon/total nitrogen/total organic carbon/total inorganic carbon; ICP-OES: metals (200 samples per reactor, 6 reactors, $15 per sample, total $18K); Consumables and chemicals, gases, plastic ware for bioreactor operation and reagents and fees for molecular biology experiments (DNA extraction/DNA sequencing; quantitative PCR at University of Minnesota Genomics Center) ($7K per year for the postdoc and the graduate student, total $42k)	$	95,000
Acquisition (Fee Title or Permanent Easements):		N/A
Travel: In-state travel to local conferences (e.g. Annual Conference of Minnesota's Wastewater Operators Association) and travel costs to collect samples from wastewater treatment plants for PI, postdoc, and graduate student	$	2,000
Additional Budget Items:		N/A
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$	494,000

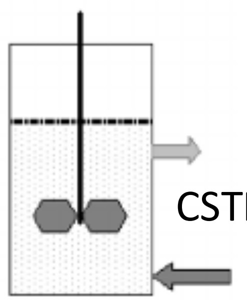
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status

Project Title: Biological Sulfate Removal for Wastewater Treatment in Minnesota

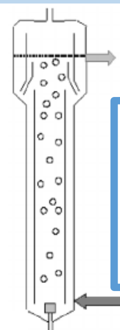
Sulfate containing wastewater from households and local industries

Removal of sulfate by biological water treatment

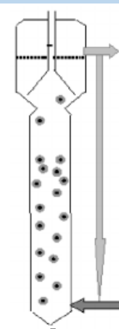


CSTR

GLB

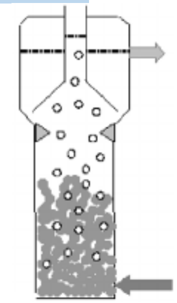


Differences in local water quality require adaptation of water treatment



FBR

UASB



Water discharged into wild rice areas will meet future sulfate standards

PROJECT MANAGER QUALIFICATIONS

Sebastian Felix Behrens

a. Professional Preparation.

Institution	Major	Degree	Year
University of Bremen, Germany	Biology	B.S.	1997
University of Bremen, Germany	Microbiology	Diploma	2000
MPI for Marine Microbiology, Germany	Microbial Ecology	Ph.D.	2003

b. Appointments.

Since 2015	Assoc. Professor, Civil, Environmental, and Geo-Engineering, University of Minnesota
2008-2014	Junior Group Leader, Center for Applied Geosciences, University of Tuebingen, Germany
2004-2008	Postdoctoral Researcher, Civil and Environmental Engineering, Stanford University

c. Products.

SELECTION OF RECENT PUBLICATIONS

[1] Hagemann N, Kammann CI, Schmidt H-P, Kappler A, Behrens S (2017) Nitrate capture and slow release in biochar amended compost and soil. *PLOS One* 12: e0171214.

[2] Harter J, Guzman-Bustamante I, Kuehfuss S, Ruser R, Well R, Spott O, Kappler A, Behrens S (2016) Gas entrapment and microbial N_2O reduction reduce N_2O emissions from a biochar-amended sandy clay loam soil. *Scientific Reports* 6:39574.

[3] Nitzsche KS, Weigold P, Lösekann-Behrens T, Kappler A, Behrens S (2015) Microbial community composition of a household sand filter used for arsenic, iron, and manganese removal from groundwater in Vietnam. *Chemosphere* 138: 47-59.

[4] Harter J, Krause HM, Schuettler S, Ruser R, Fromme M, Scholten T, Kappler A, Behrens S (2014). Linking N_2O emissions from biochar-amended soil to the structure and function of the N-cycling microbial community. *ISME Journal* 8: 660-674.

d. Synergistic activities.

My research focuses on linking environmental processes to the spatial-temporal distribution and metabolic activity of key functional groups of microorganisms. I follow an interdisciplinary approach that combines the disciplines biogeochemistry, microbiology, and molecular biology to understand the basic microbial ecology principles driving the biogeochemical cycling of metals and metalloids, the biodegradation of organic contaminants, and the emission of greenhouse gases from the molecular to the ecosystem scale. The gained knowledge on microbial transformation processes in natural and engineered ecosystems is then implemented in order to optimize microbial remediation approaches, resource recovery, and the biological treatment of water (drinking water, surface water, groundwater, or waste water), thereby spanning the gap between basic and applied research aspects of bioremediation.

ORGANIZATION DESCRIPTION

The University of Minnesota is the State’s main research and graduate teaching institution. The University partners with communities and governmental agencies across Minnesota to engage students, faculty, and staff in addressing society's most pressing issues. The Department of Civil, Environmental and Geo-Engineering focuses on collaborative and interdisciplinary research within critical areas such as managing and sustaining water and land-use infrastructure, mitigating disaster of the natural and built environments, engineering and developing earth resources, and designing renewable energy systems.