Environment and Natural Resources Trust Fund
2017 Request for Proposals (RFP)

Project Title: **ENRTF ID:** **051-B**

New Self-Sustaining Nitrate and Pesticides Removal Biotechnology

Category: B. Water Resources

Total Project Budget: $ 318,162

Proposed Project Time Period for the Funding Requested: 2 years, July 2017 – June 2019

Summary:

In this project we will develop, demonstrate, and apply an efficient, cost-effective, and self-sustaining biofilter technology to remove nitrate and pesticides from contaminated groundwater in Minnesota.

Name: Sebastian Behrens

Sponsoring Organization: U of MN

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Location

Region: Southwest, Southeast

County Name: Blue Earth, Brown, Cottonwood, Faribault, Freeborn, Jackson, Le Sueur, Lyon, Martin, Nicollet, Redwood, Rice, Steele, Waseca, Watonman, Yellow Medicine

City / Township:

Alternate Text for Visual:

Minnesota's groundwater quality is impaired by contamination with nitrate and organic contaminants originating from overuse of fertilizers, manure, and pesticides. Polluted groundwater has a significant impact on environmental and human health and is often unsuitable for drinking water purposes. The State of Minnesota has a need for treatment technologies that are easily adaptable and scalable to local requirements with respect to volume of water to be treated and concentrations of contaminants to be removed. In this project we will demonstrate, apply, and disseminate an efficient, cost-effective, and self-sustaining biofilter technology to remove nitrate and pesticides from groundwater. Nitrate and pesticide removal are based on a new self-feeding (autotrophic) "biological nitrate-reducing iron oxide formation" process that significantly reduces water treatment costs.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

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

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: New self-sustaining nitrate and pesticides removal biotechnology

I. PROJECT STATEMENT

In this project we will demonstrate, apply, and disseminate an efficient, cost-effective, and self-sustaining biofilter technology to remove nitrate and organic contaminants (pesticides) from groundwater. Minnesota's groundwater is threatened by contamination with nitrate and organic pollutants originating from overuse of fertilizers, manure, herbicides, and insecticides. Polluted groundwater has a significant impact on environmental and human health and is often unsuitable for drinking water purposes. The quality of groundwater varies around the state. Even within an aquifer, the quality can change at different depths. Near-surface groundwater in areas of intensive agriculture is more likely to be contaminated with nitrate and pesticides. In southern Minnesota many sand and gravel aquifers have nitrate concentrations that exceed EPA guidelines for human health. The State of Minnesota has a need for treatment technologies that are easily adaptable and scalable to local requirements with respect to volume of water to be treated and concentrations of contaminants to be removed. Physical and chemical technologies to remove contaminants from water (e.g. ion exchange, reverse osmosis, electrodialysis) are very expensive. Thus, new effective and cost-efficient strategies for the removal of nitrate and pesticides are needed to meet Minnesota's water treatment demands. Stepwise biological nitrate reduction to ambient nitrogen gas (denitrification) in bioreactors is a widely used biological water treatment method to remove nitrate from contaminated waters. However, standard (heterotrophic) nitrate reduction requires an external nutrient supply (biodegradable forms of organic carbon) which serves as food for the microorganisms that reduce the nitrate. This limits the efficiency and longevity of the bioreactors as nutrients are consumed and washed out over time.

Recently, we have developed a very efficient, self-feeding (autotrophic) nitrate removal technology that operates independent of external carbon supply and has the potential to also remove organic pollutants. The nitrate reduction process gains its energy from dissolved iron which is an ubiquitous constituent of groundwater. Iron oxidation leads to the formation of iron oxide mineral phases that serve as excellent sorbents for organic contaminants, such as pesticides, promoting their transformation and removal from solution.

The self-feeding "nitrate-reducing iron oxide formation" process (1) eliminates potential risks of secondary organic pollution through washout, (2) significantly reduces operation costs (self-sustaining process, no feeding required), (3) broadens contaminant removal effectiveness beyond nitrate including a wide range of organic pollutants (herbicides, insecticides, and a variety of unregulated chemicals of emerging concern, such as pharmaceuticals, fragrances, fire retardants, and hormonally active agents), and (4) theoretically extends biofilter life-time indefinitely. We have been studying this unique self-sustaining biological process extensively in the last years. **In this project, we will conduct the necessary research to implement the technology into continuous biofilters for the removal of nitrate and pesticides from water, optimize filter performance under varying environmental conditions relevant for field implementation, and test the long-term performance and market maturity of the filters with contaminated waters from around the State of Minnesota.**

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Biofilter construction and testing **Budget: $ 157,384**

We will construct laboratory scale nitrate-reducing biofilters and test different filter media (e.g. sponge iron, silica gel, pyrogenic carbon) to support the biological activity. Tracer breakthrough tests will be performed and criticial strategies of biofilter operation such as 'empty bed contact time' and filter backwash procedures will be determined. Control and biologically active biofilters will be installed and compared to each other and batch reactor performance. Filter inoculation (seeding) and start-up conditions will be optimized.

Outcome	**Completion Date**
1. Construction of continuous-flow biofilters	*December 31, 2017*

2. Tracer breakthrough test and steady-state operation	*December 31, 2017*
3. Determine biofilter operation parameters	*June 30, 2018*
4. Filter seeding and start up	*June 30, 2018*

Activity 2: Nitrate and pesticide removal optimization **Budget: $ 160,778**

We will optimize filter performance by quantifying filter efficiency at various environmental conditions (such as flow rates, nitrate, iron and pesticide concentrations). We will derive critical parameters for long-term biofilter operation (biomass growth and activity), system scale-up and successful field implementation of the technology. Results will be sumarized in a brochure that will be disseminated among state agencies and professionals in the water treatment area.

Outcome	**Completion Date**
1. Quantification and optimization of biofilter performance	*June, 30 2019*
2. Derive critical parameters for biofilter scale-up and field installation	*June, 30 2019*
3. Publish and communicate results to state professionals in the water treatment area	*June, 30 2019*

III. PROJECT STRATEGY

A. Project Team/Partners

The project team consists of Dr. Sebastian Behrens (Assoc. Prof. Dept. of CEGE, University of Minnesota), a postdoctoral research associate and a graduate student. The project manager Behrens will supervise the postdoctoral researcher and the graduate student in the execution of the proposed work. Behrens is an expert in microbial denitrification and pollutant degradation and has expertise in the development, characterization and testing of bioreactors and biofilters for water purification.

B. Project Impact and Long-Term Strategy

Ground and surface water are very valuable natural resources in Minnesota. Over 70% of Minnesota's 5.5 million population (2014) rely on groundwater as drinking water source. From the state's 1,000 community water supply systems, 98% draw from groundwater resources. Only Minneapolis, St. Paul, St. Cloud, Mankato, Moorhead, Duluth, and a few smaller communities rely on rivers or lakes for drinking water. Clean and safe groundwater is also vital for irrigation and industrial needs, and is essential for recharging lakes, streams, and many wetlands. The local geology makes many aquifers in the south of the State very susceptible to nitrate and pesticide pollution from land use activities such as agriculture and wastewater pointsources. Reducing nitrate and pesticide leavels in rivers, streams and aquifers in southern Minnesota will require cost effective, widely applicable, and adaptable water purification technology (from individual household wells to controlled drainage structures and large scale in-field bioreactors). Biological nitrate and organic pollutant removal technologies need further development in Minnesota to make these practices more available and adoptable to local needs. The long-term strategy of the project is to lower the environmental impact of agricultural and industrial water pollution and to protect Minnesota's precious surface and groundwater resources.

The target audience for results from this research will be professionals in the area of groundwater treatment, specifically environmental engineers and scientists in academia, industry, state agencies such as the MDA, DNR, and MPCA, and environmental consultants. Results will be disseminated through scholarly publications in peer-reviewed scientific journals and via a publically available final report. Results from the research project will also be presented at local/regional conferences.

C. Timeline Requirements

The proposed project will be completed in the allocated two-year period.

2017 Detailed Project Budget

Project Title: New self-sustaining nitrate and pesticides removal biotechnology

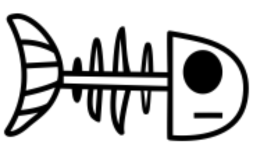
IV. TOTAL ENRTF REQUEST BUDGET for three (2) years

BUDGET ITEM	AMOUNT
Personnel: Sebastian Behrens, Assoc. Professor, 9 month appointment, Dept. CEGE, Principle investigator, project coordination, overall technical direction, supervision and training of postdoctoral researcher and gradute student, PI asks for 6 weeks salary for each of the 2 years (15%), fringe rate at 33.7%	$48,205
Postdoctoral researcher (to be named), full time (100%) for 2 years, fringe rate 22.4%	$115,167
Graduate student (to be named), 50% position for each of the 2 years, fringe rate at 92.89%	$91,745
Equipment/Tools/Supplies: Materials to construct bioreactors including pumps, tubing, fittings, valves and machining ($ 24,000); Chemicals, gases, glass ware for anaerobic cultivation and filter operation ($ 10,000); Chemical analyses of influent and effluent water samples and bioreactor matrix extracts - Ion chromatography, total C/N analysis, ICP-MS, ASE, solid phase extraction, HPLC-MS-MS ($ 15 per sample, 800 samples = $12,000); Reagents for microbial community analyses by DNA sequencing, quantitative PCR, and fluorescence in situ hybridization ($ 14,000)	$60,000
Travel: Collection of water samples, conference participation (year 1 $1500; year 2 $1545)	$3,045
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$318,162

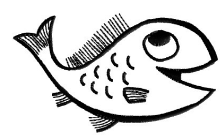
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	N/A	N/A
Other State $ To Be Applied To Project During Project Period:	N/A	N/A
In-kind Services To Be Applied To Project During Project Period: The University of Minnesota does not charge the State of Minnesota its typical overhead rate of 52% of the total modified direct costs (graduate tuition is excluded).	$146,918	secured
Funding History: German Science Foundation 2012-2015 "Iron cycling in freshwater sediments under oxic and anoxic conditions" ($185k*); German Science Foundation 2011-2014 "Microbial processes and iron-mineral formation in household sand filters used to remove arsenic from drinking water in Vietnam" ($308k*); German Science Foundation 2012-2015 "Abundance, activity, and interrelation of phototrophic and chemotrophic microbial iron oxidation in freshwater sediments " ($301k*); LGFG Fellowship, State of Baden-Württemberg Germany 2013-2014 "Biochar effects on microbial nitrous oxide formation in soils - composition and activity of the nitrous oxide-forming microbial community" ($114k*); German Science Foundation 2011-2014 Research Unit: "Natural halogenation processes in the environment - Direct and indirect formation of organohalogens by microorganisms" ($381k*); German Science Foundation (2015-2018) “Deciphering stable isotope fractionation (δ13C; δ37Cl) during reductive dehalogenation of chlorinated ethenes: Effects of bacterial growth physiology and expression of key enzymes” ($376k*) (*using 1:1 Euro to US Dollar conversion); University of Minnesota - Office of the Vice President for Research (2015-2016) Research Infrastructure Investment Program Award “High-Throughput Single Cell Isolation by Fluorescence-Activated Cell Sorting” ($500k); MnDrive Seed Grant (2015-2016) “Engineered biochars for sulfate removal from mine water” ($65k)	$2,230,000	secured
Remaining $ From Current ENRTF Appropriation: LCCMR (2016-2019) 054-B: “Engineered Biofilter for Sulfate Removal from Mine Waters”; project has not started yet	$440,000	pending

Groundwater Pollution



Water quality improvement



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.

RECENT PRODUCTS MOST CLOSELY RELATED TO THE PROJECT PROPOSAL

[1] Shaomei H, Tominski C, Kappler A, **Behrens S**, Roden EE (2016) Metagenomic analyses of the autotrophic Fe(II)-oxidizing, nitrate-reducing enrichment Culture KS. *Applied and Environmental Microbiology: in press*

[2] Laufer K, Nordhoff M, Roy H, Schmidt C, **Behrens S**, Jorgensen BB, Kappler A (2016) Co-existence of microaerophilic, nitrate-reducing, and phototrophic Fe(II)-oxidizers and Fe(III)-reducers in coastal marine sediment. *Applied and Environmental Microbiology: in press*

[3] Nitzsche KS, Lan VM, Trang PTK, Viet PH, Berg M, Voegelin A, Planer-Friedrich B, Zahoransky J, Mueller SK, Byrne JM, Schroeder C, **Behrens S**, Kappler A (2015) Arsenic removal from drinking water by a household sand filter – effect of filter usage practices on arsenic removal efficiency and microbiological water quality. *Science of the Total Environment* 502: 526-536.

[4] Melton ED, Swanner ED, **Behrens S**, Schmidt C, Kappler A (2014) The interplay of microbially mediated and abiotic reactions in the biogeochemical Fe cycle. *Nature Reviews Microbiology* 12: 797-808.

[5] Melton ED, Stief P, **Behrens S**, Kappler A, Schmidt C (2014) High spatial resolution distribution and interconnections between Fe- and N-redox processes in profundal lake sediments. *Environmental Microbiology* 16: 3287-3303.

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.