Environment and Natural Resources Trust Fund
2020 Request for Proposals (RFP)

Project Title: **ENRTF ID: 226-F**

New Solution for Streambank Erosion and Energy Conversion

Category: F. Methods to Protect, Restore, and Enhance Land, Water, and Habitat

Sub-Category:

Total Project Budget: $ 278,344

Proposed Project Time Period for the Funding Requested: June 30, 2023 (3 yrs)

Summary:

The project aims at scaling up a new technology, designed to protect river banks from erosion while producing energy, and deploy it in a river.

Name: Michele Guala

Sponsoring Organization: U of MN

Job Title: Dr.

Department: Department of Civil, Environmental, and Geo- Engineering

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Location:

Region: Statewide

County Name: Statewide

City / Township: Minneapolis

Alternate Text for Visual:

Design, reduced scale model, and potential deployment strategies of a new bank protection system for Minnesota rivers

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

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

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: NEW SOLUTION FOR STREAMBANK EROSION AND ENERGY CONVERSION IN RIVERS

I. PROJECT STATEMENT

Erosion protection systems can reach up to 1200$ per linear foot of streambank in urbanized areas, down to 125$ in rural areas with a total estimated annual cost of 0.6M per river mile in large scale restorations. This is expected to increase significantly in the next decade with the increasing frequency of flood and erosion damages. The main problem with standard and affordable concrete bank protection systems is that erosion is not eliminated but just transferred downstream of the protected areas. Nature-inspired protection systems with rocks, logs and vegetation are designed to dissipate some of the flow energy while sheltering the banks, but are more costly and require continuous maintenance. What we propose is a new solution to absorb 20-30% of the energy at the river streambank and convert a portion of it into electricity, reducing the flow velocity. Thus, not just shifting the problem downstream, but reducing the overall ability of the river to erode.

The proposed technology is based on an array of horizontal baffled wheels partially embedded in the bank, placed where the stream flow is more energetic, i.e. at the outer bank of meandering channels. While the flow sustains the wheel rotation and continuously produces electric energy, the stream velocity near the bank is reduced, along with the sidewall erosional rate. We have a preliminary design and a working scaled model (**see visual**). Further support is however needed for advanced experimentation and prototype construction, in order to have a market-ready product. The main tasks are: **1) Quantifying the efficiency of erosion-protection** by testing reduced-scale models in controlled meandering streams at the St. Anthony Falls Laboratory; **2) Prototype construction, deployment and performance assessment**, using a full-scale channel and a river chosen in collaboration with the MN Department of Natural Resources and the Minnesota Watershed Districts.

II. PROJECT ACTIVITIES AND OUTCOMES

Brief technical overview and a rationale for safe operation: *to reduce erosion the stream velocity has to diminish, implying that flow resistance elements have to be introduced in the river. We can choose between fixed rough elements (standard bank protection design), or smart rough elements that can vary the resistance based on the desired flow conditions. Our horizontal "Minnerota" wheel can achieve that by operating at different velocities and offering variable (smart) resistance, including a free-spinning mode in which it would be essentially invisible to the flow. For instance, under high flood we may decide to offer minimal resistance and avoid any water level increase. Each wheel is envisioned to operate at river mid-depth, ensuring the capability to work without interfering with ice and debris (e.g. wood branches, logs) floaters or canoes, as well as high sediment transport and migrating bedforms. Thanks to the low operating velocity (never larger than the current) the horizontal wheel will not be harmful to fish, beavers or swimmers. The partial exposure of the device to the flow guarantees decent energy conversion performance while keeping the gearbox, generator and all major electrical components away from the water, reducing deployment and maintenance costs, failure risks, and providing easy access to utility connection. The torque is generated by momentum transfer (as e.g. a Pelton hydropower turbine), which reduces biofouling effects due to leaves and algae build-up, ensuring all-season performance. Based on the available power coefficient estimates for laboratory models, the expected net power output of each device scaled up to a 5ft diameter is in the 0.1-0.2KW range (enough for one LED-based street light). More power extraction and stream bank protection can be achieved by vertically staggering devices along the river meander, so that 5-6 devices should power a river cabin or illuminate a bike trail.*

Activity 1: <u>*Measuring reduced erosion rates in a controlled meandering stream*</u> **Budget: $86,481**

Because of the specific purpose of preventing bank erosion, experiments will be conducted in the Outdoor Stream meandering flume at the St Anthony Falls Laboratory. Experiments will be performed during the summer months by a dedicated PhD student and two research undergraduates, under a range of discharge conditions.

Experiments will be focused on the assessment of the energy performance and erosion protection during summer and winter months, to make sure that the device can operate as planned throughout the year. A critical factor to quantify is the velocity reduction near the streambank suggesting the optimal separation between devices.

Outcome: ***Meandering flume advanced*** **testing**	**Completion Date**
1. Design a structural system for model deployment in the outdoor stream laboratory	*March. 2021*
2. Assess the device performance with and without moving sediments	*Sept. 2021*
3. Quantify downstream erosion potential under varying operating regimes	*March 2022*

Activity 2: *Simulating, fabricating and field-testing a full scale prototype* **Budget: $191,863**

The blade and rotor geometry will be scaled-up and integrated with available mechanical components for prototype fabrication. The device will be built in-house and tested in the SAFL Main Channel under both clear water and active sediment transport conditions. The channel is 278ft long, 9ft wide, and able to operate with a mean flow velocity 3ft/s, at depth up to 4ft, thus representative of a small-medium scale river in Minnesota. Flow rate, sediment discharge, and stream depth will be controlled during experimental tests designed to quantify both side-bank sheltering and power extraction capabilities. The channel bathymetry and flow field will be monitored to ensure that no localized erosion will be developing. In a second phase, i) the anchoring system for river deployment will be designed, ii) a stream near Minneapolis will be selected and monitored; iii) the prototype will be deployed and

Outcome: Prototype construction and field testing	**Completion Date**
1. Build and test a prototype able to operate in a 0.5-1.5m depth channel	*July 2022*
2. Select a field site, obtain necessary permits, and collect velocity measurements near the stream bank: pre-deployment feasibility study, baseline measurements for comparison	*September2022*
3. Deploy the prototype in a Minnesota river, assess performance and wake velocity	*June 2023*

III. PROJECT PARTNERS AND COLLABORATORS:

The principal investigator (PI), prof. Michele Guala (Civil Environmental and Geo- Eng., UMN), is the patent holder, and the responsible for the product development, laboratory experimentation and field testing; co-PI Jeff Marr (Associate Director for Engineering) and Lian Shen (SAFL Director) will contribute to the prototype design, fabrication and field testing. The team has expertise in stream restoration, river engineering, and sediment transport (Guala, Marr), mechanical engineering and structural design (Marr, Shen), energy conversion (Guala, Shen).

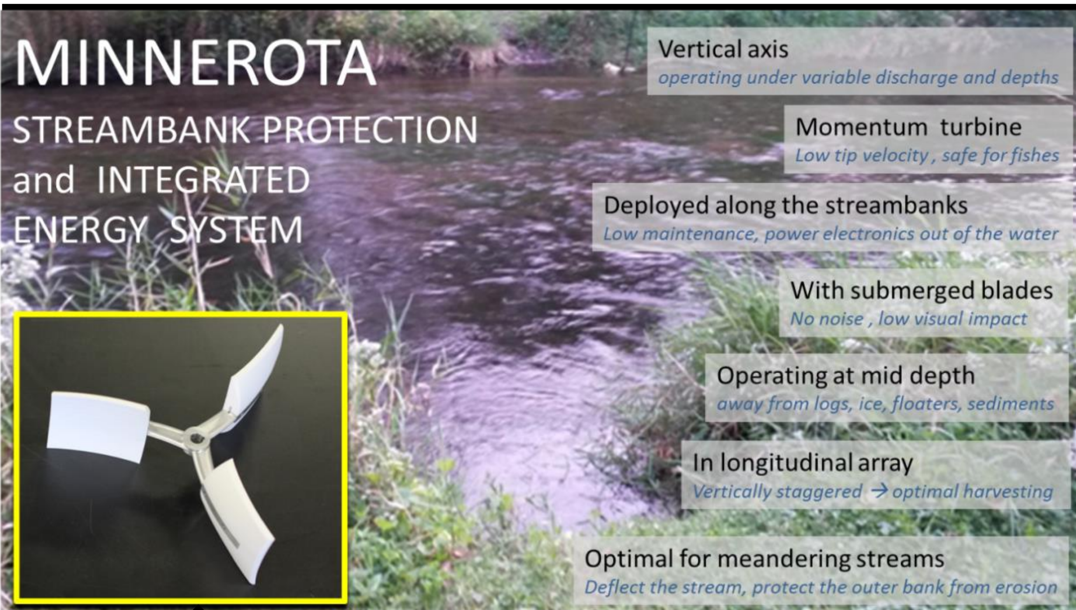
IV. LONG-TERM IMPLEMENTATION AND FUNDING: The overarching goal is to provide a novel stream-restoration technology to river managers, home owners and/or tourist infrastructure near water bodies in pristine ecosystems, integrating river bank protection with local renewable energy production at the lowest environmental costs (invisible, inaudible). **The intellectual property is currently protected under US Patent App. 15/914,183 (pending) filed through the UMN Office of Technology and Commercialization (OTC).** In 2017 we received seed funding for the development of a reduced scale model and for preliminary experimental testing that we are currently conducting (see visual). **Recently we joined a pilot project of the OTC to assess our technology readiness level and define the value proposition of our product:** with the multitude of streams and water front properties in Minnesota, this technology could resonate with a large segment of riverfront private residents or with environmental monitoring programs. In addition of **reducing stream erosion** the benefit of local electricity production will be directed to **illumination, security and motions sensors, wildlife monitoring and water quality stations**, and so on. Because of the design dual-purpose, we anticipate deployments in natural parks, independent riverfront properties, or at the riverside of state, county or cycling roads. Future steps will include creating a startup company and seek support from the Department of Energy through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR).

Attachment A: Project Budget Spreadsheet
Environment and Natural Resources Trust Fund
M.L. 2020 Budget Spreadsheet
Legal Citation:
Project Manager: Michele Guala
Project Title: Developing Bank-Protection Energy-Converter Systems for Minnesota Rivers
Organization: Regents of the University of Minnesota
Project Budget: $278,344
Project Length and Completion Date: 3 years, June 30, 2023
Today's Date: April 10, 2019

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 244,344	$ -	$ 244,344
Michele Guala, PI (74% salary, 26% benefits); 3% FTE , 0.25 month per year for 3 years. Guala brings critically important expertise in experimental fluid dynamics and renewable energy a. He is the inventor of the device being patented and he will supervise all the tasks listed in the project activities with specific focus on laboratory and field sclae testing at SAFL ($12,673)			
Jeff Marr, CO-PI (74% salary, 26% benefits); 3% FTE, 2 weeks per year for year 2 and 3. Marr is the associate director for applied research at SAFL. He has expertise in river dynamics, sediment transport and project management. Marr will supervise the prototype building and deployment and all field-scale operations, inlcuding permitting ($13,385)			
Lian Shen, CO-PI (74% salary, 26% benefits); 3% FTE , 0.25 month per year for year 1-2. Prof. Shen is an expert in computational fluid dynamics and renewable energy. He will facilitate the scaling up from laboratory model to the prototype deployable in a river. ($11,724)			
Staff Engineer (92% salary, 8% fringe): 3% FTE (4 weeks in year 2,3) . He will help the PhD student to build the prototype, deploy it and obtain the performance curves. He will also be the main operator during field deployments (year 3). ($11,422)			
Graduate student (58% salary, 42% fringe): One student will be hired. He will be responsible for building the experimental model, collect data, and collaborate with the numerical researcher to achieve the best perfornig design under reasonable flow hydrographs ($153,921)			
Machinist (77% salary, 23% fringe): 8% FTE (years 1 & 3), 16% FTE (year 2) . He will build the prototype (year 1,2) , and the anchoring system (year 2) , deploy it, secure in the river streambank and provide the necessary maintenance (year 3). ($25,693)			
Jesse Kozarek (74% salary, 26% benefits): 8% FTE research scientist will be devoted to the erosion tests performed in the meandering OSL flume planned in year 1. ($8,526)			
Undergraduate students (100% salary, 0% benefits); 2 stundets for 3 months (summer of year 1), contributing to the OSL outer meander flume experiments, ($7,000)			
Equipment/Tools/Supplies			
Supplies: General supplies for laboratory and field setups are quantified based on previous experience. Year 1 & 3 ($5,000), Year 2 ($2,000). The amounts will include : sand supply for the OSL and main channel experiment (year 1,2), Acquisition board and computer for the student to record and process laboratory and field experiment data (year 1-3), SAFL main channel and OSL operating and maintenance costs (include updates on the laser scanner for bed topography measurements)(year 1-2), anchorisng system and ADV sensor deployment structure for velocity measurements at the field site (year 2,3)	$ 12,000	$ -	$ 12,000
Capital Expenditures Over $5,000			
Equipment: turbine components. Blade and torque producing elements will be rapid prototyped or 3D printed ($7,000, for various shapes). Controller and induction motor drive are expecte to bring the component cost up to approximately $20,000	$ 20,000	$ -	$ 20,000
Travel expenses in Minnesota			
Travel: $2,000 are budgeted for several site visits (site to be determined in accord with DNR), prototype transportation and deployment cost in year 2 and 3. We expect 8 trips at approximately $250 each	$ 2,000	$ -	$ 2,000
COLUMN TOTAL	$ 278,344	$ -	$ 278,344

SOURCE AND USE OF OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Budget	Spent	Balance
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind: Because the project is overhead free, laboratory space, electricty, and other facilities/adminstrative costs (54% of direct costs excluding permanent equipment and graduate student tuition benefits) are provided in-kind.	secured	$ 112,817	$ -	$ 112,817
Other ENRTF APPROPRIATIONS AWARDED IN THE LAST SIX YEARS	**Amount legally obligated but not yet spent**	**Budget**	**Spent**	**Balance**
		$ -	$ -	$ -

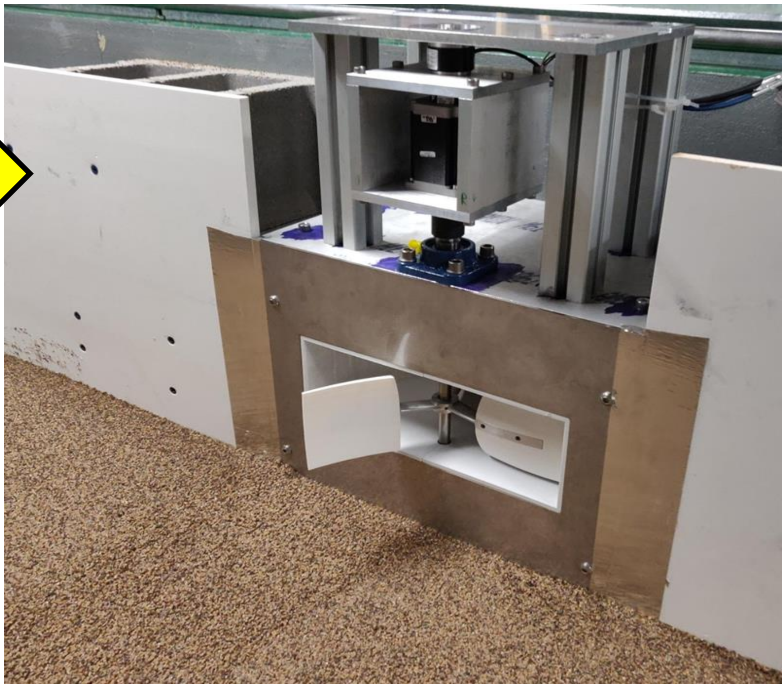
NEW SOLUTION FOR STREAMBANK EROSION AND ENERGY CONVERSION IN RIVERS



GOAL 1: mitigate side bank erosion

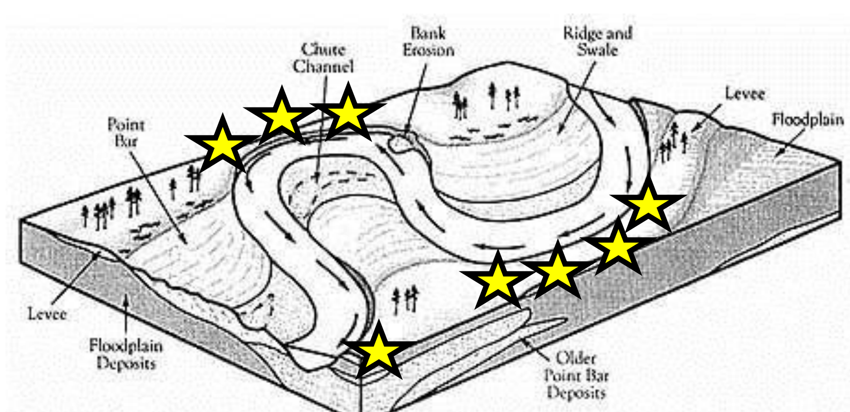
GOAL 2: Expand renewable energy in rivers

patented design and laboratory model are currently available :



What we want to do:

1) Test the model in a meandering stream
2) Build a prototype
3) Increase technology level readiness
4) Deploy in a real river ★



Potential deployment locations of single- or multi- unit systems ★

Project Manager Qualifications and Organization Description

Michele Guala, Associate professor, Department of Civil Environmental and Geo- Engineering CEGE,
Associate Director of St. Anthony Falls Laboratory (SAFL), University of Minnesota, Minneapolis, 55414, MN

Education

Ph.D. Hydraulic Engineering, 2003, University of Padova, Italy
Laurea (BS+MS) Civil and Environmental Engineering, 1998, University of Genova, Italy

Professional experience

UMN , SAFL & Department of Civil, Environmental, and Geo- Engineering, associate professor 2017--
UMN , SAFL & Department of Civil, Environmental, and Geo- Engineering, assistant professor 2011-2017
Caltech Postdoctoral GALCIT, Caltech, Pasadena , 2008-2010, SLF, Davos Research scientist 2007,
ETH Zurich, CH Postdoctoral fellow at the Institute of Hydromechanics 2003-2006

Awards/Recognitions

Recipient of the **NSF CAREER award** "Geophysical Flow Control" (2014-2019)
Recipient of the **IREE Early Career Award** (UMN) "*Evaluating wind farm performance under realistic thermal and complex terrain conditions: the first path towards optimization*

Publications ***(Relevant to this LCCMR proposal)***

1) B Dou, M Guala, L Lei, P Zeng "Wake model for horizontal-axis wind and hydrokinetic turbines in yawed conditions" **Applied Energy** 242, 1383-1395, (**2019)**
2) Musa M, Hill C., Sotiropoulos F., Guala M. "Performance and resilience of hydrokinetic turbine arrays under large migrating fluvial bedforms" **Nature Energy** 3 (10), **(2018).**
3) Musa M. Heisel M. and Guala M. "Predictive model for local scour downstream of hydrokinetic turbines in erodible channels "**Physical Review Fluids** 3 (2), 02460, **(2018).**
4) Hill C., Musa M. and Guala M. "Interaction between axial flow hydrokinetic turbines and uni-directional flow bedforms. " **Renewable Energy** 86, 409-421 (**2016**)
5) Hill C, Kozarek J. Sotiropoulos F., Guala M. "Hydrodynamics and sediment transport in a meandering channel with a model axial flow hydrokinetic turbine" **Water Resources Research** (**2016**)
6) Hill C. , M Musa , LP Chamorro, C Ellis, M Guala , "Local Scour around a Model Hydrokinetic Turbine in an Erodible Channel**" Journal of Hydraulic Engineering**, 140(8) 04014036, (**2014**).

ORGANIZATION DESCRIPTION: University of Minnesota

The proposed research will be performed at the St. Anthony Falls Laboratory (SAFL), University of Minnesota. SAFL faculty, staff and researchers have an excellent scientific reputation and experience in conducting and analyzing laboratory and field measurements for energy converter installations in wind tunnel and river flows, as well as deploying utility-scale device (EOLOS 2.5MW wind turbine). The SAFL Outer stream laboratory and Main channel are unique facilities that are perfectly suitable for these tests.
The team recently participated to a Pilot Workshop on technology innovation sponsored by the Office of Technology and Commercialization of UMN (April 2019). The major value proposal emerging is in the bank protection capability enabling this technology to increase the readiness level and be price competitive before marketing.

TEAM DESCRIPTION

Michele Guala will supervise the turbine design, the performance quantification, and the sheltering effects on side bank erosion. He will be coordinating all the research activities, including documentation and reporting.
Jeff Marr is the SAFL director of applied research. He has expertise in laboratory experiments and testing, river mechanics, sediment transport and field scale models. He will supervise prototype fabrication, field testing and deployment.
Lian Shen (professor in Mechanical Eng. UMN, and SAFL associate director) is an expert in computation fluid mechanics and fluid structure interaction. He will contribute to design optimization and to scaling up to the prototype.