Environment and Natural Resources Trust Fund

2026 Request for Proposal

General Information

Proposal ID: 2026-179

Proposal Title: Enabling Widespread Real-Time River-Flow and Habitat Monitoring

Project Manager Information

Name: Andrew Wickert

Organization: U of MN - St. Anthony Falls Laboratory

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Project Basic Information

Project Summary: Advance and augment Minnesota's stream-gauging network by developing and deploying low-cost and open-source devices that combine cameras and laser rangefinders to monitor water depth, water velocity, and streambed changes.

ENRTF Funds Requested: $688,000

Proposed Project Completion: June 30, 2029

LCCMR Funding Category: Water (B)

Project Location

What is the best scale for describing where your work will take place?

Region(s): Metro, NE, SE,

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project and In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Real-time river monitoring supports environmental management, infrastructure planning, and flood safety. Currently, Minnesota has 317 stream gauges returning real-time streamflow data. With 92,000 miles of river in the state, many rivers are gauged at only one or a few locations, and small-to-mid-size catchments (drainage areas <100 square miles) are often unmonitored. These catchments are significant sources of sediment and agricultural runoff and may produce hazardous flash floods. Furthermore, without adequate measurements for calibration, hydrological models struggle to predict streamflow associated with Minnesota's iconic lakes, wetlands, snowpack, and diverse plant ecology. Ongoing climate and land-use change further reduce streamflow predictability and reshape the river channels themselves. More and better data are needed to make informed decisions and improve predictive models.

Minnesota's stream-gauging networks must be expanded to serve these broad human and environmental motivations. Current stream-gauging methods require large equipment that has remained unchanged for decades alongside frequent field surveys to build empirical calibrations. They cost $20,000–35,000 to install and $16,000/year to operate. This presents the opportunity to re-envision and redesign the technology and methods behind streamflow measurements in a way that reduces costs while providing more information on Minnesota's waters and aquatic habitat.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

We will expand working prototypes into a deployed stream-gauging system that measures water level, photographically maps water-surface velocity and conditions, and applies computational fluid dynamics to estimate streambed elevation and roughness. These capabilities go beyond those of national-standard USGS gauges, which measure only water-surface elevation ("stage") and require costly manual surveys of streambed geometries to empirically relate stage to streamflow. Our next-generation stream-gauge systems will require approximately $6000 to install and $4000/year to operate, reducing costs by 3–6x while improving accuracy and adding significant additional data.

By measuring water level with a centimeter-precision laser rangefinder, recently developed for self-driving cars, we will ensure interoperability with standard USGS stream gauges while supplanting their underwater sensors with an option that is cheaper, easier to maintain, and avoids damage from ice and debris. A pair of cameras will use "Stereoscopic Large-scale Particle Imaging Velocimetry" (LS-PIV), tracking water-surface features to measure flow velocity, while providing repeat qualitative checks on water condition, including turbidity. Stage and surface velocities will feed a "ray–isovel" hydrodynamic computer model to solve for streamflow and river-bed geometry, giving the critical new capacity to correctly attribute changes in stage to streamflow or to river-bed and aquatic habitat change.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

Minnesota's waterways host rich ecosystems and nurture human communities through recreation, commerce, and education. Climate and land-use change alter streamflow and, through these changing floods, reshape river-channel geometry and the habitat provided for aquatic organisms. To capture the real-time status of these ongoing hydrologic and geomorphic changes, we will develop and implement a next-generation stream gauge. The resultant continuous and enhanced data stream on Minnesota's rivers will help target management and restoration efforts and responses. Furthermore, these stream gauges will improve quantification and management of water resources across the state.

Activities and Milestones

Activity 1: Design and build sensor system to measure water level and water-surface velocity

Activity Budget: $247,138

Activity Description:

To develop the next-generation stream-gauging system, we will combine existing and in-development technology by PI Wickert's lab with a stereographic pair of commercially available cameras to photographically map flow velocities and river-bed geometry. We will expand upon our working prototype of the in-house-developed low-power and open-source "Okapi" data logger to control the stream gauge and return data via mobile-phone-network and satellite telemetry. This will connect with the open-source "Apis" laser rangefinder, also developed in Wickert's lab, to measure water-surface elevation (river "stage"). A pair of cameras will obtain stereographic (i.e., three-dimensional) images of the water surface over time and save these images to a Raspberry Pi 4 Model B single-board computer. This single-board computer will map flow velocity across the water surface by tracking motion between the photos using LS-PIV. Velocities and river stage will be telemetered to a compute cluster, which will post them online and simultaneously calculate and post streambed geometry, streambed roughness, and streamflow (i.e., river discharge), alongside uncertainty estimates. These improve hydrological data cover and quality, and the measured geomorphic change will permit immediate understanding of how floods, dam failures (e.g., Rapidan), and changing sediment supply affect aquatic habitat and the near-stream environment.

Activity Milestones:

Description	Approximate Completion Date
Update the functional "Project Okapi" prototype telemetry-enabled data logger into a mass-producible single-board device	December 31, 2026
Build and test the stereo-camera subsystem that will capture streamflow images to track water-surface velocity	December 31, 2026
Program the Raspberry Pi single-board computer to compute flow velocities from images using Stereoscopic LS-PIV	April 30, 2027
Construct the battery and solar-panel power-supply unit to power to the full stream-gauging system	April 30, 2027
Assemble and integrate the full stream gauge: Data logger, laser rangefinder, cameras, power, telemetry	August 31, 2027

Activity 2: Build the computational fluid mechanical computer model to solve for streamflow (i.e., discharge) and channel-bed characteristics

Activity Budget: $79,002

Activity Description:

Our team will expand Wickert's existing fluid-mechanical "Ray–Isovel" model code into a complete software module that uses stream-gauge outputs to solve for streamflow and river-bed changes. This model, employing the established "ray–isovel" approach for distributing turbulence and flow velocities, will ingest a time series of water-surface velocity and stage measurements. It will output plausible river-bed geometries, surface roughnesses, and cross-sectional (over width and depth) flow-velocity distributions, providing best estimates and error quantification for river-bed shape, bed texture, and streamflow. By incorporating sensor data and fluid-mechanical modeling, our stream-gauging solution provides multiple upgrades over current empirical approaches, improving accuracy and adding real-time streambed conditions. We will evaluate the success of our data–model integration against benchmarks with known hydraulic geometries.

Computed stream geometries and roughnesses inform aquatic habitat suitability. Dynamic channel changes alter streamflow estimations and disturb habitat, but are only coarsely quantified using standard rating-curve techniques. Likewise, streambed roughness corresponds to grain size and bedforms. These may change over the course of natural flows and are critical to fish habitat and reproduction, but are not incorporated into standard rating-curve-based streamflow calculations. We will evaluate and improve on these measurements and calculations in Activities 3 and 4.

Activity Milestones:

Description	Approximate Completion Date
Convert the current ray–isovel model into a robust, reusable module implementing the gauge datastream	February 28, 2027
Evaluate model sensitivity to channel geometry, streambed elevation, and streambed texture to guide further improvements	May 31, 2027
Finalize model for cross-sectional flow velocities, streamflow, and stream geometry using stream-gauge test outputs	August 31, 2027

Activity 3: Test and iterate hardware, firmware, and software designs in the laboratory

Activity Budget: $170,667

Activity Description:
We will validate and improve the linked next-generation stream gauge and hydrodynamic modeling system at the University of Minnesota's Saint Anthony Falls Laboratory (SAFL). Here, we will assess the performance of the sensor system against known and measured flow and streambed conditions. We will construct a stream-gauge prototype and mount it above the SAFL main channel, which carries water from the Mississippi River through the lab's indoor facility. We will vary flow and streambed conditions, measuring both independently as well as with the stream gauge. This provides the first critical test of the system against ground truth. We will use these data to adjust the physical position and photo timing of the cameras for the stereoscopic (LS-PIV) system and improve the velocity-solving software. Simultaneously, we will mount two stream-gauge prototypes in the SAFL Outdoor StreamLab. We will vary flows to test and improve their capacity to interpret in-channel and across-floodplain flows against independent measurements in a simulated natural stream. We anticipate that these tests will inform image-filtering approaches under real, variable-light conditions. Furthermore, we will identify and correct the housing and physical structure to improve protection against the elements.

Activity Milestones:

Description	Approximate Completion Date
Install three complete stream-gauge systems for testing: one indoors and two outdoors	August 31, 2027
Outdoor laboratory tests complete; outdoor stream gauges will remain installed for long-term monitoring	October 31, 2027
Indoor laboratory tests complete	February 28, 2028
System upgrades based on indoor and outdoor laboratory tests	June 30, 2028
Housing improvements and weather hardening from overwintering in the Outdoor StreamLab	August 31, 2028

Activity 4: Field deployment, testing, and design improvements

Activity Budget: $111,587

Activity Description:
Following our laboratory tests and associated upgrades, we will deploy our stream-gauge systems in two experimental networks that bookend the range of conditions typically found throughout the state. The first network will be in the Whitewater River Valley of southeastern Minnesota, where flash floods are common and sediment loads are a major

habitat concern. Here, our team has established relationships with staff at Whitewater State Park and the Whitewater Wildlife Management Area. The second network will be at Project Partner Ng's study sites near Cloquet in northern Minnesota, with the goal of monitoring flows through lake-filled watersheds that are too slow and muck-bottomed to be easily measured using traditional stream-gauging equipment. Considering the variable flows in these field sites, we will first write algorithms to adaptively alter the lag time between individual image frames used to measure velocity fields: slower flows require more time to develop a velocity signal. Next, we will establish and document installation methods. Some of the new gauges will be installed alongside established stream gauges; at these locations, we will validate our measurements. Based on these deployments, we will make further improvements as needed to designs, data acquisition, and weatherproofing.

Activity Milestones:

Description	Approximate Completion Date
Automate photo lag-time selection to allow measurements statewide at wide-ranging flow velocities	August 31, 2027
Build and install the stream gauges at the two experimental watersheds and produce installation instructions	October 31, 2028
Evaluate performance and study stream-gauge sensitivity to changing streambed properties and associated habitat	June 30, 2029
Improve field-installation designs and stream-gauge weatherproofing, and finalize installation instructions	June 30, 2029

Activity 5: Disseminate stream-gauging designs, techniques, and advances

Activity Budget: $79,606

Activity Description:
We will ensure efficient expansion of next-generation stream-gauging networks across Minnesota via documentation and dissemination. First, all hardware designs and assembly documentation will be made open source and freely available via publicly accessible online platforms (GitHub, Zenodo, and open-access journal articles). This includes the Okapi data logger, the Apis laser-rangefinding system, our to-be-designed stereo-camera system, and associated housing and mounting infrastructure. Second, all firmware and software will likewise be open source and freely available. This includes sensor-driver firmware, customizable data-logger firmware, and software routines to process the stereophotos and to solve for streamflow, streambed geometry, and streambed roughness.

We will invite practitioners (including DNR, MnDOT, USGS, consultants) to a hybrid technical clinic at SAFL to demonstrate the designs, assembly process, theoretical approaches, and computational algorithms. Additionally, we will share our designs and progress at the Upper Midwest Stream Restoration Symposium. For broader engagement, we will collaborate with interpretive rangers at Whitewater State Park—itself the site of major flooding—to present how our design addresses the need for river-condition and flood monitoring and explain the measurements that our instrumentation collects. This outreach will position scientific research as work that meets community needs and builds relationships with the public.

Activity Milestones:

Description	Approximate Completion Date
Present the design at the Upper Midwest Stream Restoration Symposium	February 28, 2029
Host a working-group meeting and technical clinic on streamflow measurement at SAFL	April 30, 2029
Host an event at Whitewater State Park to share the stream-gauging technologies	June 30, 2029
Submit design-related open-access scientific journal publications	June 30, 2029

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Jessica Kozarek	University of Minnesota	Saint Anthony Falls Laboratory Outdoor StreamLab Manager	Yes
Jeffrey Marr	University of Minnesota	Saint Anthony Falls Laboratory Associate Director of Engineering and Facilities	Yes
Gene-Hua Crystal Ng	University of Minnesota	Associate Professor of Hydrology	Yes

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?

We will (1) establish a pilot network of 10 next-generation stream gauges in southeastern and northern Minnesota and (2) publish accessible open-source resources to rapidly expand this network across Minnesota. These resources comprise (a) design and manufacturing files for a telemetered data logger, laser-rangefinder system, and stereo-camera system; (b) software image analysis (river velocity); (c) firmware for stream-gauge field operations; (d) inverse-model computer code to solve for streamflow and channel geometry; and (e) documentation on field installation and weatherproofing. We will host hybrid technique-sharing meetings at the St. Anthony Falls Laboratory and provide bridge-installable designs directly to MnDOT.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Land-Use and Climate Impacts on Minnesota's Whitewater River	M.L. 2022, , Chp. 94, Art. , Sec. 2, Subd. 03h	$199,000
Ditching Delinquent Ditches: Optimizing Wetland Restoration	M.L. 2023, , Chp. 60, Art. 2, Sec. 2, Subd. 04a	$199,000

Project Manager and Organization Qualifications

Project Manager Name: Andrew Wickert

Job Title: Associate Professor

Provide description of the project manager's qualifications to manage the proposed project.

Dr. Andrew Wickert, Associate Professor in Geomorphology at the University of Minnesota, has broad expertise in understanding Earth's surface environments and how they change. He obtained his S.B. in Earth, Atmospheric, and Planetary Science from MIT (2008), where his research on river systems and geophysics earned him the highest honors in his department, the Goetze Prize and Crosby Award. For his Ph.D. in Geology from the University of Colorado Boulder (2014), he demonstrated how global glaciation deformed the solid Earth and its gravity field and reshaped rivers across North America. Alongside this research, Wickert developed and built open-source electronic instrumentation for environmental monitoring and gained experience working in environmentally focused projects in rivers and watersheds. He added field and computational experience in river response to changing climate and flooding during his 2014–2015 postdoc at the Universität Potsdam before arriving at the University of Minnesota in Fall 2015, where he joined the Department of Earth & Environmental Sciences and the St. Anthony Falls Laboratory.

At the University of Minnesota, Wickert built a research program with three broad focus areas: (1) the mechanics of rivers and their watersheds and how they reshape themselves in response to environmental change, (2) regional to global patterns of climate-induced hydrologic and sea-level change, and (3) design of innovative open-source instrumentation to support environmental monitoring in the field. He and his group have developed the equations to describe how rivers reshape their slopes and valleys in response to changing water and sediment inputs; constructed field-based data sets on river dynamics and catchment-scale erosion; built computationally efficient tools to map and simulate lakes and wetlands; designed software to remotely map glacier and land-surface velocities; and invented and installed hundreds of inexpensive low-power sensors to monitor rivers, glaciers, snowpack, and watershed-scale hydrology.

Organization: U of MN - St. Anthony Falls Laboratory

Organization Description:
The Saint Anthony Falls Laboratory (SAFL) is a world-renowned research facility for environmental fluid mechanics and related fields. This 4,880-square-meter facility is built into the side of St. Anthony Falls in downtown Minneapolis, whose water it uses to run some of the largest hydraulics experiments in the world. In addition to direct experimentation with flowing water, SAFL hosts a diverse group of scientists and engineers who work on environmental fluid mechanics as it applies to the atmosphere, climate, land surface, sediments, and biological processes. The faculty, staff, and students at SAFL spread their efforts across both basic scientific advances and work with immediate applications to infrastructure, the environment, and societal needs. The current SAFL director is Prof. Lian Shen, with Jeff Marr as the associate director for engineering and facilities.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Project manager		Coordinate project. Guide technology development. Coordinate and reporting. Dissemination.			26.8%	0.24		$52,667
Hydrologist		Coordinate northern Minnesota field deployments; provide design input			26.8%	0.06		$13,457
Outdoor StreamLab Manager		Manage deployments in the Outdoor StreamLab. Aid in design process.			36.6%	0.3		$47,636
Research Engineers		Co-design and build the stream gauge and its housing, coordinate indoor laboratory tests, and assist in field deployments			26.8%	0.84		$103,585
Facilities manager		Coordinate experimental aparatus; supervise construction; manage safety			26.8%	0.15		$18,518
Laboratory staff		Set up and run experiments; construct apparatus			24.4%	0.18		$16,945
Electrical engineer		Circuit-board design, testing, and assembly; guiding the PhD students			6.9%	0.2		$29,193
PhD Student		Design, build, test, and implement stream gauge and streamflow model			42.9%	6		$341,762
Undergraduate students		Control flows and make measurements during experiments in the Outdoor StreamLab			0%	0.19		$6,800
							Sub Total	**$630,563**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	Mateirals and circuit boards to prototype and assemble 25 data-logger, laser-rangefinder, and camera systems	5 prototype units, 3 units for laboratory deployment, and 17 units for field deployment					$39,000
							Sub Total	**$39,000**

Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	Driving from Minneapolis to Elba. 3 trips; 4 people/trip; 200 miles/trip; camping to save costs	Field deployment and testing in the Whitewater River valley					$1,421
	Miles/ Meals/ Lodging	2 trips; 4 people; 6 days total; 700 miles per trip	Field deployment and testing in slow-moving streams in northern Minnesota					$3,134
	Conference Registration Miles/ Meals/ Lodging	2 trips to the Upper Midwest Stream Restoration Symposium when it is in Minnesota. 4 people per trip. Registration, mileage (variable), per diem, and hotel	Disseminating knowledge of the stream-gauging system					$5,780
							Sub Total	**$10,335**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Publication	Five open-access publications on the stream-gauging system: (1) telemetered data logger; (2) camera system; (3) stereoscopic LS-PIV approach; (4) full system; (5) field-tested results	Disseminate findings to state agencies and practitioners; connect design schematics, code, and metadata to these publications					$8,102
							Sub Total	**$8,102**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$688,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**-**

Total Project Cost: $688,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: 78d5d8cf-290.pdf

Alternate Text for Visual Component

Image of a river with a bridge over it. Our current in-house-designed water-level-only stream gauge is attached to the bridge. In cartoon style, it is augmented with a pair of cameras to track flow velocity. A laser rangefinder measures the water surface. With these, it computes streamflow and streambed geometry....

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
SPA endorsement letter	76540c9e-746.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Do you understand that travel expenses are only approved if they follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I understand the UMN Policy on travel applies.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

Yes

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

Yes

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF? If so, describe here (1) the source and estimated amounts of any revenue and (2) how you propose to use those revenues:

Yes, This project is fully open-source but should be possible to commercialize. By sharing our full development with the public, and hence also the state, we ensure that the public investment remains in the public sphere.

Does your project include original, hypothesis-driven research?

No

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Does your project include the pre-design, design, construction, or renovation of a building, trail, campground, or other fixed capital asset costing $10,000 or more or large-scale stream or wetland restoration?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services (as defined in Minnesota Statutes section 299C.61 Subd.7 as "the provision of care, treatment, education, training, instruction, or recreation to children")?

No

Provide the name(s) and organization(s) of additional individuals assisting in the completion of this proposal:

Prof. Gene-Hua Crystal Ng, St. Anthony Falls Laboratory, University of Minnesota
Dr. Jessica Kozarek, St. Anthony Falls Laboratory, University of Minnesota
Uma Ashrani, St. Anthony Falls Laboratory, University of Minnesota
Mr. Jeffrey Marr, St. Anthony Falls Laboratory, University of Minnesota
Ms. Angela Boutch, St. Anthony Falls Laboratory, University of Minnesota

Do you understand that a named service contract does not constitute a funder-designated subrecipient or approval of a sole-source contract? In other words, a service contract entity is only approved if it has been selected according to the contracting rules identified in state law and policy for organizations that receive ENRTF funds through direct appropriations, or in the DNR's reimbursement manual for non-state organizations. These rules may include competitive bidding and prevailing wage requirements

N/A