Environment and Natural Resources Trust Fund

2025 Request for Proposal

General Information

Proposal ID: 2025-170

Proposal Title: Breaking Waves and Ice Forces on Coastal Infrastructure

Project Manager Information

Name: Craig Hill

Organization: U of MN - Duluth

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Project Basic Information

Project Summary: Great Lakes waves and ice conditions are changing. This project measures wave and ice forces on coastal infrastructure, informing designs to make Minnesota's coastal ecosystems resilient to extreme weather conditions.

ENRTF Funds Requested: $437,000

Proposed Project Completion: June 30, 2028

LCCMR Funding Category: Air Quality, Climate Change, and Renewable Energy (E)

Project Location

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

Region(s): NE

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

Region(s): NE

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.

Across the Great Lakes, winter ice cover is decreasing. Since 1973, annual maximum ice coverage has decreased nearly 5% per decade. Without ice to dampen large wave energy near Minnesota's coast, storms are capable of producing large waves that directly impact Minnesota's coastal ecosystems and communities. To design resilient coastal infrastructure, coastal engineering companies need improved guidelines. Design guidance for coastal structures often uses US Army Corps of Engineers guidelines published in 1995 or earlier (EM 1110-2-1614, etc.) with some guidance from recent academic publications resulting from scaled laboratory experiments. Scaled experiments lack measurements representing true environmental dynamics, particularly for air entrainment in large, breaking waves or waves that contain debris (e.g. floating ice) that can result in large impact forces on coastal structures. Uncertainty in horizontal and vertical uplift forces from these phenomena lead to design uncertainty in forces experienced by full-scale infrastructure. We hypothesize that by monitoring forces in the field from breaking waves and waves with broken and floating ice, data will guide improved design confidence and understanding on economic designs of coastal infrastructure, methods for protecting coastal ecosystems and communities, and better predict shoreline evolution as climate changes, particularly if decreasing ice cover trends continue.

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 propose implementing a multi-sensor approach for measuring horizontal and vertical forces from breaking waves and waves with floating ice under realistic field conditions along coastal Lake Superior. Using pressure transducer arrays and a multi-axis force sensor plate, coupled with co-located wave and meteorological observations systems, our approach pieces together high-resolution measurements to compare observed conditions against existing design guidelines for coastal structures. Leveraging experience in marine observation system design and deployment and coastal engineering expertise, this work will monitor conditions for 10 months each at two different sites. Year one of the project emphasizes data acquisition system design and testing in the laboratory prior to moving to field observations during years two and three. First, average and impact force conditions on existing coastal infrastructure on Lake Superior are monitored to gain exposure to large wave events and likely entrained broken ice. A second location within the Duluth harbor is monitored during the final year of the project to understand drifting and fixed ice forces on vertical harbor seawalls. For both locations, observed wave pressure and force data will be compared against calculation methodologies from USACE EM 1110-2-1614 guidelines among other commonly used coastal engineering design resources.

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?

Specific project outcomes seek to inform future coastal instructure designs to enhance resilience to extreme weather conditions on Minnesota's Lake Superior coastline and harbors. Through direct field observations of breaking wave and ice forces on existing infrastructure, data provide full-scale evidence to inform methodologies to protect and conserve coastal ecosystems and communities as climate changes and extreme weather events become more prevalent. Understanding these forces could increase public safety, decrease future financial burden, and protect coastal natural resources. Designing the system and methodologies enabling these observations can provide additional future opportunities to continue building knowledge that benefits the State's initiatives.

Activities and Milestones

Activity 1: Design, Build, and Lab Testing the Wave and Ice Load Monitoring System

Activity Budget: $169,867

Activity Description:
Objectives for Activity 1 begin with designing a field deployable data acquisition (DAQ) system to accurately measure pressures and forces from breaking waves on existing coastal infrastructure. An array of submersible pressure transducers will provide data necessary to quantify hydrostatic and dynamic forces over a known area. Detailed horizontal and vertical forces from breaking waves will also be measured by a multi-axis force sensor plate. Environmental data (wave and meteorological conditions) add to the Team's capability to characterize forces from breaking waves and floating or shore-attached ice. During this activity, the Project Team (PI Hill, Graduate Student, and undergraduate researcher) will develop detailed engineering designs prior to purchasing, materials, sensors, and equipment. After design review by an external coastal engineering company (AMI Consulting Engineers), items will be purchased and fabricated at UMD into a complete system. This activity concludes with complete DAQ system testing in the laboratory at UMD prior to deploying in the field. Specific outcomes include a fully operational DAQ system, demonstrated data collection and analysis procedures in a laboratory environment, and detailed engineering designs reviewed by external coastal engineering experts. Successful completion of Activity 1 prepares the Team to pursue field deployments on existing coastal infrastructure.

Activity Milestones:

Description	Approximate Completion Date
Engineering designs and sensor selection of field data acquisition system	December 31, 2025
Equipment, Sensors, and Fabrication Supply Purchasing	February 28, 2026
Fabricate and fully assemble data acquisition system	May 31, 2026
Laboratory testing of force and pressure measurement system	July 31, 2026

Activity 2: Wave, ice, and load monitoring on coastal and harbor infrastructure

Activity Budget: $139,494

Activity Description:
Objectives for Activity 2 begin with coastal and harbor site selection and permitting for DAQ system installation. AMI Consulting Engineers will lead permit applications given their extensive experience doing so. Current priority sites include the end of Canal Park pier in Duluth, MN, the concrete breakwater structure at Two Harbors, MN, or the MN breakwater structure at the Twin Ports harbor Superior entrance. A harbor steel sheet piling site will be selected within the harbor. Following permitting, the DAQ system will be installed on the permitted coastal infrastructure and remain in place for nearly 11 months. This provides a full season of wave and ice monitoring with high likelihood of exposure to extreme weather events. AMI Consulting Engineers will assist with identification and review of appropriate installation methodologies and installation team. Following completion of DAQ operations on coastal infrastructure, the DAQ system will be relocated to a harbor steel sheet-piling location and resume DAQ operations for an additional 10 months. Using both coastal and harbor locations for monitoring provides data that informs a variety of seasonal conditions to inform future designs that make Minnesota's coastal ecosystems and communities resilient to changing and extreme Great Lakes weather events.

Activity Milestones:

Description	Approximate Completion Date

Site selection and permitting for installation	May 31, 2026
Install data acquisition, buoy, and site monitoring system on coastal infrastructure site 1	August 31, 2026
Field observations at coastal infrastructure site 1	July 31, 2027
Install data acquisition, buoy, and site monitoring system on harbor infrastructure site 2	August 31, 2027
Field observations at harbor infrastructure site 2	May 31, 2028

Activity 3: Data Analysis, Reporting, and Future Recommendations

Activity Budget: $127,639

Activity Description:
Objectives for Activity 3 focus on data analysis from both coastal and harbor infrastructure sites. Using pressure, force, wave, and meteorological observations throughout the project duration, the Project Team will compare actual observations against existing standard design guidelines. Both quasi-static (averaged) and maximum impact forces will be analyzed and compared to existing methodologies. Analysis will be led by the UMD Graduate Student researcher with oversight by PI Hill and assistance from an undergraduate researcher. Data analysis methods and results will be reviewed by external coastal engineering experts at AMI Consulting Engineers (St. Paul, MN). Upon completion of data analysis and review, the Team will summarize project activities and results into a Project Report. Additionally, two peer-reviewed manuscripts will be developed and target high impact coastal engineering journals. Impacts from this activity will provide field-based observations that can inform future coastal engineering designs to enhance resilience to Minnesota's coastal ecosystems and communities. Specifically, results could add to limited understanding on field scale forces on coastal infrastructure from floating ice entrained by large storm waves.

Activity Milestones:

Description	Approximate Completion Date
Analyze wave and load measurements from coastal infrastructure site	October 31, 2027
Analyze wave and load measurements from harbor infrastructure site	June 30, 2028
Write final report and provide design recommendations for future implementation	June 30, 2028

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?

Engaging coastal engineering experts AMI Consulting Engineers in the system design and data analysis review ensures that results are seen by practitioners during the project period, increasing the ability to implement key results into actual designs. Results will be published in peer-reviewed journals and presented at the Minnesota Water Resources Conference, enhancing dissemination of key findings to broader communities and practitioners. If additional work is needed, future funding will be pursued through the Minnesota Department of Natural Resources Lake Superior Coastal Program among other funding opportunities. These future efforts can leverage system design and methodologies developed during this proposed project.

Project Manager and Organization Qualifications

Project Manager Name: Craig Hill

Job Title: Assistant Professor

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

Dr. Craig Hill brings extensive experience in developing observation systems for challenging marine environments and knowledge on fundamental wave processes. For nearly two decades, he has worked on collaborative research projects spanning marine renewable energy and multi-sensor observation systems. Prior to his faculty position at UMN Duluth, Dr. Hill worked as a marine research engineer where he designed and deployed large multi-sensor moorings for deep-water Lake Superior environments, designed and built small and large multi-sensor surface observation buoys for the Great Lakes, and worked in marine energy development with the University of Washington to explore methods for developing wave and current energy converters for harsh ocean marine environments. His current research is funded by the Minnesota Department of Natural Resources Lake Superior Coastal Program and from the US Department of Energy working closely with marine energy technology developers. Dr. Hill manages multiple graduate and undergraduate student researchers, mentors a Postdoctoral researcher, and leads multi-institutional research projects between UMN Duluth, Oak Ridge National Labs, and private industry. Recent projects from Dr. Hill's research team have focused on characterizing wave energy resource availability across the Great Lakes, exploring ways to harness coastal wave energy to protect coastal infrastructure and minimize shoreline erosion, deploying wave observation buoys to monitor nearshore risks for rip currents, and modeling wave energy converter dynamics. Additionally, he leads a research team developing new, low-cost wave and water quality monitoring buoys for coastal and inland lake monitoring applications. Dr. Hill teaches courses in fluid mechanics, sustainable energy, and data acquisition systems, and is guiding the development of new marine engineering curriculum at UMN Duluth. He is also affiliated with the UMN Duluth Large Lakes Observatory, UMN Institute on the Environment, and the UMN Water Resources Science Program.

Organization: U of MN - Duluth

Organization Description:

The University of Minnesota Duluth (UMD) is a comprehensive regional university. Undergraduate students can choose from 17 bachelor degrees in 89 majors and 76 minors as well as five certificates. UMD also offers graduate programs in 24 fields, 12 minors, and six certificates. The Mechanical and Industrial Engineering (MIE) Department at UMD is the largest engineering department within the Swenson College of Science and Engineering at UMD. With over 20 faculty members and an active student body of more than 500 students, the department excels in integrating research into undergraduate MIE curriculum and collaborating with regional companies on multidisciplinary senior design projects. Faculty in the department share affiliations with the Advanced Materials Center, Large Lakes Observatory, among other campus-affiliated and community-based organizations. The MIE Department also houses two graduate degree

programs, including the MS in Mechanical Engineering and MS in Environmental Health and Safety. Within the MIE Department and across the UMD campus, faculty are dedicated to providing applied teaching and research experiences sharing a common thread of sustainability while developing life-long learners from our graduates.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Craig Hill		PI			27.1%	0.15		$83,873
Grad student		Co-Lead with PI field sensor data acquisition system design, fieldwork, data collection, analysis			46%	1.44		$159,280
Undergrad researcher		Assist with field sensor calibrations, fieldwork, data collection, data processing, literature reviews			0%	0.57		$18,720
							Sub Total	**$261,873**
Contracts and Services								
AMI Consulting Engineers	Professional or Technical Service Contract	Arrange permitting for field installations, coordinate installation technical services, review design drawings, review of data collection proceduce, data quality, and analysis with respect to current design guidelines for coastal structures				0		$80,000
							Sub Total	**$80,000**
Equipment, Tools, and Supplies								
	Tools and Supplies	Field supplies	Supplies for mounting sensors and data acquisition system in field, anchors, mooring line supplies, system batteries					$2,365
	Equipment	Modem and Network camera	Webcam to remotely monitor field data acquisition (DAQ) system and visually document approaching wave conditions.					$2,276
	Tools and Supplies	KonectDGS	Coordinates remote data logging from field DAQ system and enables real-time archiving and viewing of on-site conditions					$1,170
							Sub Total	**$5,811**
Capital Expenditures								

		Spotter Buoy and Smart Mooring System	Buoy and mooring system measures wave parameters, high resolution water surface elevation, and water temperatures. Provides necessary real-time observations for approaching wave fields, average surface elevation, and water temperatures needed to quantify wave forces.	X				$12,388
		3-axis submersible force sensor and DAQ system	Mounts between force plate material and coastal infrastructure. Provides high-resolution horizontal and vertical forces when breaking waves and/or ice impact structure.	X				$25,000
		Cabled RBRcoda3 T.D. sensor	Water temperature and depth sensor mounted on coastal infrastructure directly below pressure and force measurement systems. Provides co-located synchronized measurements of key wave parameters.	X				$6,610
		Fabricated DAQ system	This system incorporates several different sensors. Two data loggers will acquire data from an array of multiple pressure transducers and a multi-parameter meteorological sensor. These data will be logged onsite, processed, and transmitted in near real-time via cellular network from a remote monitoring station. This system includes all electronics enclosures and necessary power components. The pressure transducer array data provides spatial and temporal variations of wave pressures, while meteorological data provide baseline information for understanding external forcing along with wave measurements.	X				$22,267
							Sub Total	**$66,265**

Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Conference Registration Miles/ Meals/ Lodging	MN Water Resources Conf, 2 people, Years 2 and 3, 310 miles, 2 days full per diem, 2 travel days per diem, 2 nights lodging, conference registration	Project team to attend MN Water Resources Conference to present project progress and research findings					$3,990
							Sub Total	**$3,990**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Publication	Publications	Funds to enable two publications (one in Year 2 and one in Year 3) from the research. Project Team will target coastal engineering journals to disseminate research results					$6,000
							Sub Total	**$6,000**
Other Expenses								
		Telecommunications Fee	Three years of $350 per year data services fee from field data acquisition system.					$1,050
		Shipping	Total shipping estimates for buoy system, sensors, and supplies used to develop data acquisition systems					$1,200
		Kingfisher Boat use time	8 days of boat use spanning 3 years. One day for buoy system deployment and one for recovery each year. In years two and three, an additional day of boat use for system checks.					$8,795

		Sofar Spotter Buoy Data Fee	Total from monthly data services fee for Spotter Wave Buoy over the span of the project.					$2,016
							Sub Total	**$13,061**
							Grand Total	**$437,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Expenditures		Spotter Buoy and Smart Mooring System	This project is about measuring wave and ice forces on coastal infrastructure and informing designs to make Minnesota's coastal ecosystems resilient to extreme weather conditions. The buoy system will perform the measurements and generate the data needed to inform the design of our coastal infrastructure to protect communities and ecosystems. The buoy and mooring system measures wave parameters, high resolution water surface elevation, and water temperatures. **Additional Explanation :** The useful life of the buoy system will extend beyond the 3-year project. The PI plans to continue deploying this system annually in nearshore environments along Minnesota's coastal Lake Superior environment to monitor real-time wave conditions. These data are of interest to numerous stakeholders, including the NWS Duluth Office (for forecasting), MN Sea Grant and its various extension offices, marine shipping industries, and recreational users (fishing, etc.). Real-time data will be accessible via the Great Lakes Observing System SeaGull web platform. Observations will aid in understanding annual changes in wave conditions as climate changes, and how those changes could be impacting coastal ecosystems and communities.
Capital Expenditures		3-axis submersible force sensor and DAQ system	The purpose of this project is to understand both horizontal and vertical forces on infrastructure from breaking waves and ice. This 3-axis force sensor provides that data (two horizontal directions and vertical). Using the data from this system will allow measurements of actual forces from conditions at the monitoring sites to compare against existing design theories, and allow future designs to appropriately adapt to coastal conditions. **Additional Explanation :** The useful life of the force sensor will go beyond the 3-year project. Upon completion, project recommendations will indicate what, if any, additional data are required to continue building knowledge of forces on coastal infrastructure and ecosystems. The system will be available for similar projects on other infrastructure (e.g. wave current and/or ice forces on bridge piers). If the force sensor is no longer needed to continue making wave or ice impact measurements, PI Hill performs research in marine renewable energy. This force system would be an asset to many of those projects to understand wave forces on various floating structure configurations.
Capital Expenditures		Cabled RBRcoda3 T.D. sensor	This sensor measures water temperature and depth directly under the force and pressure measurement systems on the coastal infrastructure being monitored. By positioning it directly below the pressure and force measurement systems, it provides co-located and synchronized measurements of key wave parameters. The wave characteristics are typically not measured, but relate directly to the experienced forces. The waves measured by this system will be different in size compared to the Spotter buoy system that is positioned away from the infrastructure in deeper waters. Having both allows for a deeper understanding of wave changes immediately where they impact the structures.

			Additional Explanation : This sensor will have a lifespan longer than the 3-year project. After this project, this temperature and depth cabled sensor will be integrated into other coastal wave monitoring systems. Specifically, PI Hill anticipates integrating this into a specially configured wave observation buoy located near Park Point Beach in Duluth, MN. That buoy system can integrate other sensors at its anchor, and this temperature and depth sensor would add key information to better understand wave conditions as water level changes (e.g. due to weather patterns, hydrologic patterns, etc.). Additionally, that wave buoy system is used by the NWS Duluth office to issue rip current risk levels, and adding in detailed depth and deeper temperature measures could aid in understanding rip current formations.
Capital Expenditures		Fabricated DAQ system	Breaking waves expose infrastructure to variable pressures depending on the depth and wave characteristics. Measuring these pressure is a key element to existing design guidelines, as they are used in calculating the total expected forces. Along with that, knowing baseline meteorological conditions assists in understanding external effects from temperatures, wind loads, and waves. This combined DAQ system serves as the main data collection system to acquire information from a number of different sensors required for the project while maintaining a synchronized clock between all measurements. **Additional Explanation :** This data acquisition (DAQ) system is highly adaptable and is anticipated to last longer than the 3-year project period. The Project Team plans to seek additional funding to continue supporting measurements at harbor sea walls. If wave pressure measurements are no longer needed, the DAQ system can easily be adapted to support ongoing work that requires integrating multiple sensors into a synchronized measurement system. It is likely that this system will be used to support continued efforts to understand changing wave conditions along coastal Lake Superior, which requires detailed meteorological measurements to assist with modeling wave parameters.

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
In-Kind	UMN unrecovered indirect costs are calculated at the UMN federally negotiated rate for research of 55% modified total direct costs	Indirect costs are those costs incurred for common or joint objectives that cannot be readily identified with a specific sponsored program or institutional activity. Examples include utilities, building maintenance, clerical salaries, and general supplies. (https://research.umn.edu/units/oca/fa-costs/direct-indirect-costs)	Secured	$175,064
			Non State Sub Total	**$175,064**
			Funds Total	**$175,064**

Total Project Cost: $612,064

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: e300968b-ab3.pdf

Alternate Text for Visual Component

Schematic of a coastal breakwater wall shows keys design variables and locations of five sensor stations used for this project, including a wave buoy, pressure and force plates, meteorological station, and co-located pressure sensor under force plates. Ideal monitoring locations along coastal Lake Superior and in Duluth harbor are identified....

Supplemental Attachments

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

Title	File
Transmittal Letter - Authorization to Submit	d02bf343-180.docx

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

No

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

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No

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