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

Project Title: **ENRTF ID: 052-B**

Characterizing Fractured Bedrock to Assess Pollution Risk to Groundwater

Category: B. Water Resources

Total Project Budget: $ 330,000

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

Summary:

The project involves developing tools to quantitatively assess the site-specific environmental impact of a given contaminant source as controlled by the regional permeability of fractured bedrock.

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Sponsoring Organization: U of MN

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Location

Region: Metro, Southeast

County Name: Anoka, Dakota, Fillmore, Goodhue, Hennepin, Houston, Olmsted, Ramsey, Wabasha, Washington, Winona

City / Township:

Alternate Text for Visual:

Contaminants flowing through a fractured bedrock leading to pollution risk of groundwater

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%

PROJECT TITLE: CHARACTERIZING FRACTURED BEDROCK TO ASSESS POLLUTION RISK TO GROUNDWATER

I. PROJECT STATEMENT

Fractures in bedrock provide conduits for fluid flow and greatly amplify the pollution risk to groundwater, *e.g.* due to surface contamination. Accordingly, *in situ* knowledge of fracture permeability is essential to protect drinking water supplies from landfills, industrial wastes, and other pollution sources. Traditional means of determining fracture permeability through field tests require drilling and possibly coring, which are highly expensive and inefficient procedures. The proposed geophysical approach provides an untapped opportunity to predict the regional flow through fractured bedrock and thus to assess the pollution risk to groundwater.

The overall goal is to geophysically enable the regional prediction of contaminant flow through fractured bedrock. This will be accomplished by:

- quantifying by geophysical methods (seismic surveys) mechanical indices of the fracture network (density, connectivity, contact properties) in a given bedrock formation,
- correlating the geophysical fracture indices to the flow through fractured rock by laboratory hydraulic experiments, and
- validating *in situ* the use of geophysical indices toward predicting the contaminant flow and assessing the risk to groundwater.

It is well known that a strong correlation exists between the permeability of a fractured rock and mean fracture opening, whereby prevailing features of the fracture network dictate the success or failure to protect and remediate groundwater. Consider for instance the Magnolia member of the Platteville limestone, where the increased emphasis on subsurface hydrogeology is driven by pressing environmental concerns across southeastern Minnesota. The density and flow characteristics of subterranean fractures, described by their permeability, must be known beforehand in order to predict and manage seepage quantities.

The results of this laboratory study will reveal how seismic surveys can be used to identify *in situ* fracture permeability profiles and related flow quantities that are essential for managing groundwater. If our approach is successful, this would suggest that a non-invasive field technique can be developed for efficiently assessing seepage characteristics. If the data do not reveal the correlation, the study will provide critical information about fracture flow and permeability properties of actual fractured bedrock. These results will be valuable to State regulators and engineering consultants.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Perform small-scale geophysical testing of fractured rock **Budget: $83,000**

Seismic experiments will be performed in UMN's *Waves & Imaging Laboratory* on fractured limestone specimens (10 specimens from the Platteville formation) selected in cooperation with *Minnesota Geological Survey* (MGS). Limestone specimens will be machined into dimensions 100 × 87 × 44 mm and pre-stressed in the direction perpendicular to the predominant fracture orientation. The fractured rock specimens will then be excited by a piezoelectric transducer, providing laboratory-scale seismic excitation, while measuring the wave speed in the specimen from the time-of-flight measurements. In this setting, lab-scale seismic testing will be used to individually characterize each fractured specimen by measuring the variation of its seismic wave speed with increasing pressure, which mimics the field conditions. In essence, the fracture introduces a *time delay* to the propagation of seismic waves, which diminishes with increasing pressure on a fracture. Each specimen will be tested under five field values of overburden pressure, resulting in 10 x 5 = 50 seismic experiments.

Outcome	Completion Date
1. Seismic testing (ST) of fractured limestone specimens (50 experiments)	10/31/18
2. Estimating fracture geophysical indices from laboratory ST measurements	4/30/19

Activity 2: Measure flow characteristics through fractured rock **Budget: $96,000**

Flow experiments through fractured rock specimens will be conducted with the plane-strain apparatus in UMN's *Rock Mechanics Laboratory*. This unique apparatus was specifically developed for testing fluid-saturated rock under various stress states. Fractured limestone specimens, tested seismically in Activity 1, will be sealed with a polyurethane membrane and placed inside a pressure vessel to simulate subsurface conditions. A flow test will be performed by maintaining a constant pressure head difference across the specimen; this condition will be applied and preserved by connecting the pore water lines to microprocessor-based hydraulic pumps that maintain water pressure to appropriate values. An application of Darcy's law provides the basis for determining the permeability of a fractured rock specimen. The stress conditions will be changed and the permeability again measured. As in Activity 1, this effort will entail 50 permeability tests.

Outcome	Completion Date
1. Determining geophysical properties of fractured rock at various pressures	12/31/18
2. Measuring flow through fractured rock at various pressures	10/31/19

Activity 3: Correlate geophysical fracture indices to fluid flow characteristics **Budget: $70,000**

On completing Activity 1 and Activity 2, the fracture surface of each rock specimen will be exposed and probed by a white light scanner in order to quantify its surface roughness. From the data, *nomograms* will be developed that establish a correlation between the geophysical fracture indices and fluid flow characteristics, measured directly, as a function of (i) pressure on a fracture, and (ii) roughness of the fracture surface. This information will then be synthesized to enrich the data base for the ongoing *County Geologic Atlas* program, with the long-term goal of enabling seismic surveys to assess the pollution risk to groundwater.

Outcome	Completion Date
1. Measuring fracture surface roughness	12/31/19
2. Correlating seismic data on fractures to permeability	5/31/20

Activity 4: Conduct a pilot field study at a selected test site **Budget: $81,000**

The proposed developments will be field tested at an appropriate site managed by MGS, *e.g.* featuring two instrumented wells that penetrate the fractured Platteville formation. Cross-hole seismic tests will be performed by a consultant at several elevations, allowing the assessment of (depth-dependent) permeability of the geophysically tested fractured rock from the results of Activities 1-3. These estimates will then be used to inform a groundwater flow model in order to predict and confirm the hydraulic measurements made at the site.

Outcome	Completion Date
1. Estimating flow through fractured bedrock by geophysical testing	12/31/20
2. Validating the fluid flow estimates through *in situ* field tests	5/31/21

III. PROJECT STRATEGY

A. Project Team/Partners : The UMN team will be led by Professors Bojan Guzina and Joseph Labuz, Department of Civil, Environmental, and Geo- Engineering. It will include one graduate and one undergraduate student. Guzina has extensive experience in seismic imaging of fractured systems and Labuz is an expert on fracture testing and behavior of fluid-saturated rock. The MGS team, lead by Dr. Anthony Runkel, will assist in hydraulic field testing at an available site.

B. Project Impact and Long-Term Strategy: Stakeholders will have a tool to quantitatively assess the site-specific environmental impact of a given contaminant source as controlled by the regional permeability of fractured bedrock. Additionally, this will be the first study in the State of Minnesota to investigate how seismic imaging can provide relevant information on *in situ* susceptibility to contaminant transport and groundwater pollution. This will have major impact on the issuance of permits for industrial site development and operation.

C. Timeline Requirements: The project will be completed in a three-year period. The imaging and permeability measurements are time consuming and require detailed quality assurance/quality control protocols.

2018 Detailed Project Budget

Project Title: Characterizing fractured bedrock to assess pollution risk to groundwater

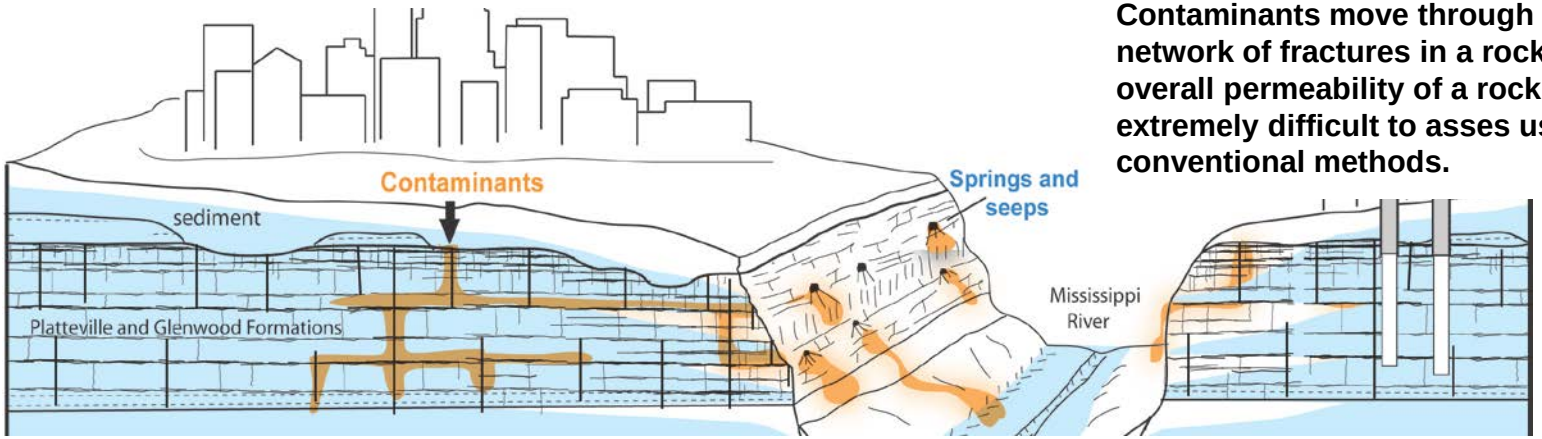
IV. TOTAL ENRTF REQUEST BUDGET 3 years

BUDGET ITEM	AMOUNT
Personnel: Guzina PI; 8% time per year for three years, salary 74.9% of cost, fringe benefits 25.1% of cost. Project supervision, provide guidance on seismic/ultrasonic imaging for the project, including transducer selection, transducer calibration, and data interpretation.	$ 50,145
Personnel: Labuz co-PI; 6% time per year for three years, salary 74.9% of cost, fringe benefits 25.1% of cost. Laboratory supervision, provide guidance on permeability measurements for the project, including specimen preparation, stress conditions, and fracture development.	$ 41,145
Personnel: Graduate student; 50% time per year for 2.75 years, 59.1% salary, 25.2% tuition, 8.9% fringe benefits. Conduct laboratory experiments and data analyses.	$ 129,210
Personnel: Undergraduate student; Approximately 180 hours per year, 100% salary. Assist with specimen preparation and experimental setup.	$ 7,000
Professional/Technical/Service Contracts: Minnesota Geological Survey and "Seismic" Consultant. Field testing at selected sites and review of testing procedures. Working with County Geologic Atlas program.	$ 81,000
Equipment/Tools/Supplies: Syringe pump for permeability measurements ($16,000). Laboratory supplies, including membranes, diamond saw blade, and grinding wheel ($2,000). Machining of platens to house ultrasonic transducers ($2,000). Replacement of transducers, including ultrasonic, pressure, or displacement ($1,000) .	$ 21,000
Travel: Mileage charges to field sites for sample collection. Mileage will be reimbursed at University of Minnesota rates.	$ 500
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 330,000

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ Being Applied to Project During Project Period: N/A	$ -	
Other State $ Being Applied to Project During Project Period: N/A	$ -	
In-kind Services During Project Period: Guzina and Labuz will provide unpaid time to the project, including 1% cost-share each. Because the project has no indirect costs, laboratory space, electricity, and other overhead expenses are provided at no charge to the project. The University of Minnesota indirect cost recovery rate is 54%.	$13,325 (1% Guzina & Labuz), $147,183 (54% F&A)	
Remaining $ from Current ENRTF Appropriation (if applicable): N/A	$ -	
Funding History: N/A	$ -	

Goal: characterize fractured bedrock toward assessing pollution risk to groundwater

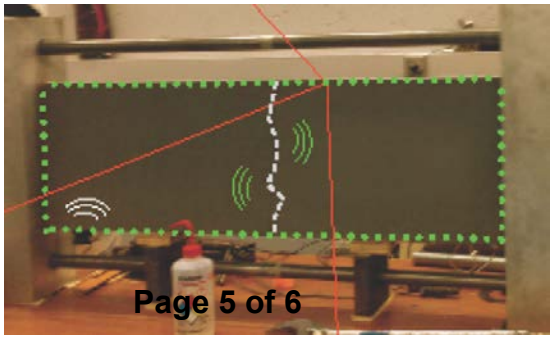


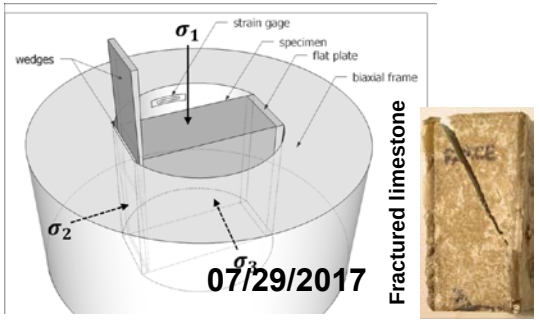
Contaminants move through a complex network of fractures in a rock formation. The overall permeability of a rock formation is extremely difficult to asses using conventional methods.

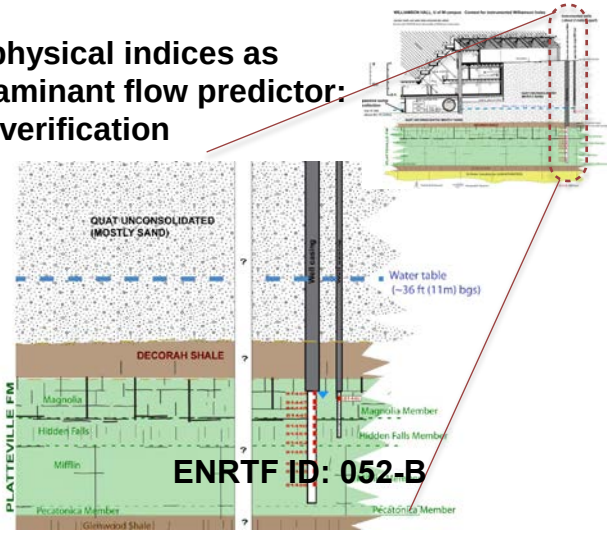
Approach

1. **Relate geophysical measurements in fractured rock to mechanical indices of the fracture network (density, connectivity, contact properties): laboratory geophysical tests**
2. **Correlate the fracture density & contact properties to fractured rock permeability: laboratory fluid flow tests**
3. **Validate *in situ* the use of geophysical indices as pollutant flow predictors; (i) measure geophysical indices of fractured Platteville rock; (ii) verify the groundwater flow estimates versus direct field measurements**

1. **Lab geophysics of fractured rock** → 2. **Fluid flow through fractured rock (lab)** → 3. **Geophysical indices as contaminant flow predictor: field verification**







Project Manager Qualifications and Organization Description

Project title: Characterizing fractured bedrock to assess pollution risk to groundwater

Project Manager Qualifications

Bojan G. Guzina
Shimizu Professor, Department of Civil, Environmental, and Geo- Engineering, University of Minnesota, Minneapolis, MN. Guzina has been at Minnesota since 1998, and he is leading expert in seismic imaging of fractured rock.
1996 Ph.D. Geotechnical Engineering, University of Colorado, Boulder, CO
1992 M.S. Geotechnical Engineering, University of Colorado, Boulder, CO
1989 Dipl. Inz., Civil Engineering, University of Belgrade, Yugoslavia

Joseph F. Labuz
MSES/Miles Kersten Professor, Department of Civil, Environmental, and Geo- Engineering, University of Minnesota (UMN), Minneapolis, MN. Labuz has been at Minnesota since 1987, and he is a world leader in experimental investigation of fracture and damage of fluid-saturated rock.
1985 Ph.D. Civil Engineering, Northwestern University, Evanston, IL
1981 M.S. Civil Engineering, Northwestern University, Evanston, IL
1979 B.S. Civil Engineering (with honors), Illinois Institute of Technology, Chicago, IL

Organization Description

The University of Minnesota (UMN) has a world-class program in environmental and geo- engineering, with over 50 years of initiating and promoting research and applications in fractured bedrock. Several significant contributions to the geoengineering field were devised or refined at UMN. These include the displacement discontinuity method for predicting the stability of underground excavations, the distinct element method for modeling the behavior of blocky rock masses, and the constitutive response of fluid-saturated rock for determining solid-fluid coupling and flow characteristics of fractured rock.

The geomechanics laboratories at UMN are well equipped for determining hydro-mechanical properties of rock, including permeability and triaxial testing. Basic instrumentation associated with an experimental mechanics laboratory is also available. A rock specimen preparation room is fully equipped with circular saws, surface grinder, drill press, and lathe. Maintenance of hydraulic systems is performed annually by a certified technician. Supporting equipment to monitor fracture include acoustic emission and a laser Doppler vibrometer.

The Minnesota Geological Survey (MGS) is the geological mapping agency for the State of Minnesota, as directed by its enabling legislation. Its primary goal is to produce comprehensive geologic mapping and related databases statewide. This mapping supports informed land use management and decision-making that protects and wisely allocates resources.