2014

Soil-Bentonite Slurry Trench Cutoff Wall Proposal

Jeffrey C. Evans
Bucknell University, evans@bucknell.edu

Michael A. Malusis
Bucknell University, mam028@bucknell.edu

Robert W. Jacob
Bucknell University, rwj003@bucknell.edu

02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

Submit only ONE copy of this form **for each PI/PD and co-PI/PD** identified on the proposal. The form(s) should be attached to the original proposal as specified in GPG Section II.C.a. Submission of this information is voluntary and is not a precondition of award. This information will not be disclosed to external peer reviewers. ***DO NOT INCLUDE THIS FORM WITH ANY OF THE OTHER COPIES OF YOUR PROPOSAL AS THIS MAY COMPROMISE THE CONFIDENTIALITY OF THE INFORMATION.***

PI/PD Name: Jeffrey C Evans

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☒ White

Disability Status:
(Select one or more)
☐ Hearing Impairment
☐ Visual Impairment
☐ Mobility/Orthopedic Impairment
☐ Other
☐ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
Race Definitions:
American Indian or Alaska Native. A person having origins in any of the original peoples of North and South America (including Central America), and who maintains tribal affiliation or community attachment.
Asian. A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam.
Black or African American. A person having origins in any of the black racial groups of Africa.
Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.
White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.

WHY THIS INFORMATION IS BEING REQUESTED:

The Federal Government has a continuing commitment to monitor the operation of its review and award processes to identify and address any inequities based on gender, race, ethnicity, or disability of its proposed PIs/PDs. To gather information needed for this important task, the proposer should submit a single copy of this form for each identified PI/PD with each proposal. Submission of the requested information is voluntary and will not affect the organization's eligibility for an award. However, information not submitted will seriously undermine the statistical validity, and therefore the usefulness, of information recieved from others. Any individual not wishing to submit some or all the information should check the box provided for this purpose. (The exceptions are the PI/PD name and the information about prior Federal support, the last question above.)

Collection of this information is authorized by the NSF Act of 1950, as amended, 42 U.S.C. 1861, et seq. Demographic data allows NSF to gauge whether our programs and other opportunities in science and technology are fairly reaching and benefiting everyone regardless of demographic category; to ensure that those in under-represented groups have the same knowledge of and access to programs and other research and educational oppurtunities; and to assess involvement of international investigators in work supported by NSF. The information may be disclosed to government contractors, experts, volunteers and researchers to complete assigned work; and to other government agencies in order to coordinate and assess programs. The information may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records", 63 Federal Register 267 (January 5, 1998), and NSF-51, "Reviewer/Proposal File and Associated Records", 63 Federal Register 268 (January 5, 1998).

02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

Submit only ONE copy of this form **for each PI/PD and co-PI/PD** identified on the proposal. The form(s) should be attached to the original proposal as specified in GPG Section II.C.a. Submission of this information is voluntary and is not a precondition of award. This information will not be disclosed to external peer reviewers. ***DO NOT INCLUDE THIS FORM WITH ANY OF THE OTHER COPIES OF YOUR PROPOSAL AS THIS MAY COMPROMISE THE CONFIDENTIALITY OF THE INFORMATION.***

PI/PD Name: Robert W Jacob

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☐ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status: (Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☐

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
Race Definitions:
American Indian or Alaska Native. A person having origins in any of the original peoples of North and South America (including Central America), and who maintains tribal affiliation or community attachment.
Asian. A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam.
Black or African American. A person having origins in any of the black racial groups of Africa.
Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.
White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.

WHY THIS INFORMATION IS BEING REQUESTED:

The Federal Government has a continuing commitment to monitor the operation of its review and award processes to identify and address any inequities based on gender, race, ethnicity, or disability of its proposed PIs/PDs. To gather information needed for this important task, the proposer should submit a single copy of this form for each identified PI/PD with each proposal. Submission of the requested information is voluntary and will not affect the organization's eligibility for an award. However, information not submitted will seriously undermine the statistical validity, and therefore the usefulness, of information recieved from others. Any individual not wishing to submit some or all the information should check the box provided for this purpose. (The exceptions are the PI/PD name and the information about prior Federal support, the last question above.)

Collection of this information is authorized by the NSF Act of 1950, as amended, 42 U.S.C. 1861, et seq. Demographic data allows NSF to gauge whether our programs and other opportunities in science and technology are fairly reaching and benefiting everyone regardless of demographic category; to ensure that those in under-represented groups have the same knowledge of and access to programs and other research and educational oppurtunities; and to assess involvement of international investigators in work supported by NSF. The information may be disclosed to government contractors, experts, volunteers and researchers to complete assigned work; and to other government agencies in order to coordinate and assess programs. The information may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records", 63 Federal Register 267 (January 5, 1998), and NSF-51, "Reviewer/Proposal File and Associated Records", 63 Federal Register 268 (January 5, 1998).

02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

Submit only ONE copy of this form **for each PI/PD and co-PI/PD** identified on the proposal. The form(s) should be attached to the original proposal as specified in GPG Section II.C.a. Submission of this information is voluntary and is not a precondition of award. This information will not be disclosed to external peer reviewers. ***DO NOT INCLUDE THIS FORM WITH ANY OF THE OTHER COPIES OF YOUR PROPOSAL AS THIS MAY COMPROMISE THE CONFIDENTIALITY OF THE INFORMATION.***

PI/PD Name: Michael A Malusis

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☐

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
Race Definitions:
American Indian or Alaska Native. A person having origins in any of the original peoples of North and South America (including Central America), and who maintains tribal affiliation or community attachment.
Asian. A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam.
Black or African American. A person having origins in any of the black racial groups of Africa.
Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.
White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.

WHY THIS INFORMATION IS BEING REQUESTED:

The Federal Government has a continuing commitment to monitor the operation of its review and award processes to identify and address any inequities based on gender, race, ethnicity, or disability of its proposed PIs/PDs. To gather information needed for this important task, the proposer should submit a single copy of this form for each identified PI/PD with each proposal. Submission of the requested information is voluntary and will not affect the organization's eligibility for an award. However, information not submitted will seriously undermine the statistical validity, and therefore the usefulness, of information recieved from others. Any individual not wishing to submit some or all the information should check the box provided for this purpose. (The exceptions are the PI/PD name and the information about prior Federal support, the last question above.)

Collection of this information is authorized by the NSF Act of 1950, as amended, 42 U.S.C. 1861, et seq. Demographic data allows NSF to gauge whether our programs and other opportunities in science and technology are fairly reaching and benefiting everyone regardless of demographic category; to ensure that those in under-represented groups have the same knowledge of and access to programs and other research and educational oppurtunities; and to assess involvement of international investigators in work supported by NSF. The information may be disclosed to government contractors, experts, volunteers and researchers to complete assigned work; and to other government agencies in order to coordinate and assess programs. The information may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records", 63 Federal Register 267 (January 5, 1998), and NSF-51, "Reviewer/Proposal File and Associated Records", 63 Federal Register 268 (January 5, 1998).

List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:

Not Listed

REVIEWERS NOT TO INCLUDE:

Not Listed

Not for distribution

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 14-1 **NSF 14-1** **09/15/14**				FOR NSF USE ONLY NSF PROPOSAL NUMBER	
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) **CMMI - GEOTECHNICAL ENGINEERING**					
DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				003030335	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN) **240772407**	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE **Bucknell University**	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE **Bucknell University** **One Dent Drive** **LEWISBURG, PA. 178372111**
AWARDEE ORGANIZATION CODE (IF KNOWN) **0032383000**	
NAME OF PRIMARY PLACE OF PERF **Bucknell University**	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE **Bucknell University** **One Dent Drive** **Lewisburg ,PA ,178372111 ,US.**

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS
☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS
☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Field Testing and Monitoring of an Experimental Soil-Bentonite Cutoff Wall**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **383,177**	**36** months	**03/01/15**	

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG I.G.2)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ________ PHS Animal Welfare Assurance Number ________
- ☒ FUNDING MECHANISM **Research - other than RAPID or EAGER**
- ☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number ________ Exemption Subsection ________ or IRB App. Date ________
- ☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
- ☒ COLLABORATIVE STATUS **Not a collaborative proposal**

PI/PD DEPARTMENT **Civil and Environmental Engineering**	PI/PD POSTAL ADDRESS **Breakiron Engineering Building, Room 271** **Lewisburg, PA 17837** **United States**
PI/PD FAX NUMBER **570-577-3415**	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME **Jeffrey C Evans**	**PhD**	**1984**	**570-577-1112**	**evans@bucknell.edu**
CO-PI/PD **Robert W Jacob**	**DPhil**	**2006**	**570-577-1791**	**rob.jacob@bucknell.edu**
CO-PI/PD **Michael A Malusis**	**PhD**	**2001**	**570-577-1683**	**mam028@bucknell.edu**
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent) or Individual Applicant

By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding conflict of interest (when applicable), drug-free workplace, debarment and suspension, lobbying activities (see below), nondiscrimination, flood hazard insurance (when applicable), responsible conduct of research, organizational support, Federal tax obligations, unpaid Federal tax liability, and criminal convictions as set forth in the NSF Proposal & Award Policies & Procedures Guide,Part I: the Grant Proposal Guide (GPG). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

Certification Regarding Conflict of Interest

The AOR is required to complete certifications stating that the organization has implemented and is enforcing a written policy on conflicts of interest (COI), consistent with the provisions of AAG Chapter IV.A.; that, to the best of his/her knowledge, all financial disclosures required by the conflict of interest policy were made; and that conflicts of interest, if any, were, or prior to the organization's expenditure of any funds under the award, will be, satisfactorily managed, reduced or eliminated in accordance with the organization's conflict of interest policy. Conflicts that cannot be satisfactorily managed, reduced or eliminated and research that proceeds without the imposition of conditions or restrictions when a conflict of interest exists, must be disclosed to NSF via use of the Notifications and Requests Module in FastLane.

Drug Free Work Place Certification

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent), is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certification Regarding Nondiscrimination

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:

(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

Certification Regarding Responsible Conduct of Research (RCR)
(This certification is not applicable to proposals for conferences, symposia, and workshops.)

By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research.
The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

CERTIFICATION PAGE - CONTINUED

Certification Regarding Organizational Support

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Federal Tax Obligations

When the proposal exceeds $5,000,000, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal tax obligations. By electronically signing the Certification pages, the Authorized Organizational Representative is certifying that, to the best of their knowledge and belief, the proposing organization:
(1) has filed all Federal tax returns required during the three years preceding this certification;
(2) has not been convicted of a criminal offense under the Internal Revenue Code of 1986; and
(3) has not, more than 90 days prior to this certification, been notified of any unpaid Federal tax assessment for which the liability remains unsatisfied, unless the assessment is the subject of an installment agreement or offer in compromise that has been approved by the Internal Revenue Service and is not in default, or the assessment is the subject of a non-frivolous administrative or judicial proceeding.

Certification Regarding Unpaid Federal Tax Liability

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal Tax Liability:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has no unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

Certification Regarding Criminal Convictions

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Criminal Convictions:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has not been convicted of a felony criminal violation under any Federal law within the 24 months preceding the date on which the certification is signed.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER

PROJECT SUMMARY

Overview:

Soil-bentonite (SB) slurry trench cutoff walls are widely used for seepage control, levee repair, and pollutant containment. Their deployment in these critical applications mandates better understanding of the as-built conditions and long-term behavior, and field data from in-service walls are scarce. Regarding as-built conditions, the hydraulic conductivity (k) of an SB cutoff wall is influenced heavily by defects and by the in-situ stress distribution in the backfill. Typical construction quality (QC/QA) programs for backfill k rely on lab tests conducted on grab samples of backfill at assumed stresses that may not be representative of the in-situ stresses. Moreover, conventional QC/QA programs are insufficient to verify backfill homogeneity throughout the installation, and commercial technologies are not yet available for detecting or verifying the absence of defects. Regarding long-term behavior, several factors may cause changes in hydraulic performance of an SB barrier over time, including changes in stress and wet-dry cycling. This project seeks to address these short- and long-term issues through the design, construction, in-situ testing, and monitoring of a fully instrumented SB cutoff wall to be installed at a commercial sand/gravel quarry near the Bucknell University (BU) campus. The proposed wall(~200 m long,~7 m deep) will be installed in a well-characterized alluvial formation on a portion of the quarry property that has been set aside, in perpetuity, as a buffer zone between the mine permit boundary and an adjacent, natural wetland (the Montandon Marsh).

Intellectual Merit :

The SB cutoff wall will be fully instrumented to monitor in-situ conditions in the backfill (e.g., stresses, deformations, and pore water pressures) as a function of time and location. Electrical resistance (ER) imaging will be investigated for locating defects placed within the wall at known locations and of known size, with the goal of developing a viable ER methodology for defect detection. The monitoring will be complemented with lab tests and in-situ tests, also performed over time to reveal time-dependent behavior. Finally, numerical model simulations to predict the stress distribution within the backfill will be performed compared with the measured field stresses. All field and lab data will be managed within a GIS framework that will be made accessible to the public via the web. The project will be carried out by PIs from BU, a primarily undergraduate institution, in collaboration with our wall construction contractor, Geo-Solutions, Inc., an industry leader that has been involved in construction of >1,000 slurry walls around the world. The results of this study are likely to transform our understanding of the as-built conditions and long-term behavior of SB cutoff walls. This new knowledge can be applied to cutoff walls for dams, levees, pollution containment and other critical infrastructure.

Broader Impacts :

This project offers the potential for transformative advancements in the state of the art and practice for design, construction, QC/QA testing, and performance verification of SB cutoff walls used for long-term seepage control and pollutant containment. Also, as the project area has been utilized routinely by BU staff and students for research and pedagogical activities over the past 15 years, the PIs expect to utilize the wall site for research and teaching well beyond the proposed three-year project duration. The project will promote substantial teaching, training, and mentoring through:(a) the involvement of BU undergraduate and graduate students in the research, (b) interactions between BU students and the principals and staff of Geo-Solutions, which facilitates mentoring and exposes Geo-Solutions to a high quality pool of potential future employees; (c) outreach to secondary students as part of the annual BU engineering summer camp; and (d) exposure of students and practitioners to the state of the art/practice for cutoff walls through formal seminar presentations. The research results will be disseminated to the scientific and professional communities through oral presentations, refereed published papers, and a web-enabled GIS data repository.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

1. INTRODUCTION

Vertical barriers (i.e., cutoff walls) have been employed for more than 40 years to control groundwater flow and subsurface contaminant transport. In the US, the most common type of vertical barrier is the soil-bentonite (SB) slurry trench cutoff wall that takes its name from the nature of the final barrier materials (SB) and the method of construction (slurry trench). While numerous other methods are used to construct vertical barriers, such as the deep mixing method (e.g., see Larsson 2005), the trench remixing and deep wall (TRD) method (see Evans 2007), and self-hardening slurry methods like cement-bentonite and slag-cement-bentonite (e.g., Opdyke and Evans 2005), these other types of vertical barriers have been used far less frequently than SB slurry trench barriers.

Construction of SB slurry trench cutoff walls occurs in two phases, viz., (1) a vertical trench is excavated and simultaneously filled with bentonite-water slurry to maintain trench stability, and (2) the excavated trench spoils are mixed with slurry and dry bentonite (as needed) to create the SB backfill, which is pushed into the trench to complete the barrier (see Figure 1). The backfill should be homogeneous and sufficiently fluid to fill the entire trench without entrapping pockets of slurry, yet sufficiently dense that the backfill is not too compressible (Evans 1993). The backfill also must exhibit a sufficiently low hydraulic conductivity (k) to meet project requirements (typically $\leq 10^{-8}$ m/s or $\leq 10^{-9}$ m/s).

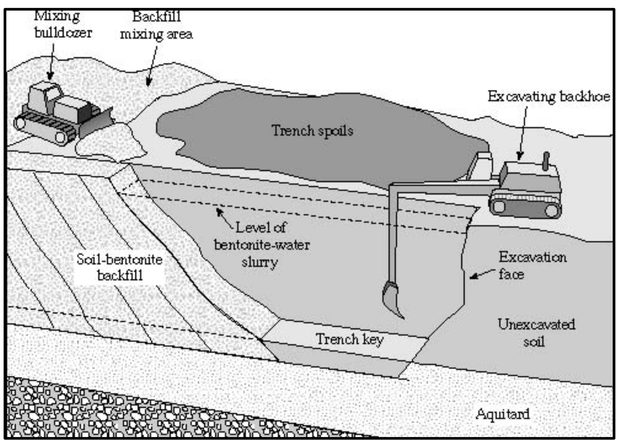


Figure 1. Schematic illustration of SB slurry wall construction (from LaGrega et al. 2000).

Soil-bentonite cutoff walls continue to be widely used for long-term applications, such as levee repair and *in-situ* geoenvironmental containment, in which the barrier is expected to maintain effective containment for years, if not decades, after installation. In these applications, both the short-term (as built) integrity of the barrier and the potential for degradation in the integrity of the barrier over time are of critical importance.

Short-term integrity of SB cutoff walls typically is assessed based on quality control/ quality assurance (QC/QA) testing of field-mixed SB backfill, primarily using laboratory methods (e.g., Millet and Perez 1981, Millet et al. 1992). However, the *in-situ* k of an SB cutoff wall depends upon the *in-situ* stress distribution in the wall, which typically is not measured and generally is not well understood. The vertical stress distribution likely is influenced by arching as a result of friction forces between the backfill and the trench sidewalls (Evans et al. 1985), and the horizontal stress distribution is believed to deviate from the at-rest earth pressure due to lateral squeezing of the backfill by the adjacent, native formation (Filz 1996). Laboratory k values obtained from field-mixed backfill specimens may not be representative of the *in-situ* k if the applied stress state in the test is not representative of the *in-situ* stress state (National Research Council 2007). Moreover, laboratory k tests are insufficient for verifying the absence of high-k construction defects, and only a few such defects can significantly increase the overall k of the barrier (Benson and Dwyer 2006). This point is underscored by the results of a recent study by Britton et al. (2004) in which laboratory and field methods for evaluating k of a pilot-scale SB cutoff wall were compared. In this study, laboratory k values obtained from undisturbed and remolded specimens of the field backfill were consistently lower than larger-scale k values obtained from *in-situ* measurements (piezocone and piezometer) and pumping tests. Regarding long-term integrity, several factors may cause changes in k of an SB barrier over time, including deformations, desiccation, freeze-thaw, and chemical incompatibility (National Research Council 2007). However, the significance of these factors on the effectiveness of field-scale SB barriers is largely unknown, as post-construction monitoring of SB walls is rarely performed and typically involves only monitoring of the aquifer downgradient of the wall rather than testing or monitoring of the wall itself.

Uncertainties in the state of stress (and thus hydraulic conductivity), time-dependent changes in backfill properties, variability of hydraulic conductivity under field conditions are all compelling reasons for this proposed research. Indeed, the PIs are aware of (and have worked as consultants on) several cases in which constructed cutoff walls have failed to provide the required containment due to construction defects or post-construction changes in the wall (as opposed to design deficiencies). In some of these cases, poor wall performance was revealed by groundwater monitoring data and attributed to localized defects such as sand lenses embedded in the wall during construction (in one publicized case, continuous cores were taken to identify and characterize these defects; see Evans et al. 2004). In other cases, post construction property changes and/or inadequate in-situ testing procedures have led to failure of a cutoff wall to meet the required hydraulic conductivity (e.g., Cermak et al. 2012).

Notwithstanding these examples, published case histories of cutoff wall failures and field investigations are scarce, in large part because there is great reluctance on the part of regulators, owners, designers and contractors to discover and report failures or deficiencies in completed cutoff walls. Should an installed cutoff wall be found to be deficient, disagreement over the assignment of responsibility between the designer and contractor is inevitable. Furthermore, site owners and regulators alike have concerns about losing public trust by having to announce that a system in which they have placed confidence is inadequate. For example, PI Evans was a consultant on a Superfund site in southern California where an SB cutoff wall was being used to isolate acidic tar sludge, and much of the wall was above the water table (in the arid southern California climate). Evans suggested long-term monitoring to assure the cutoff wall did not desiccate and crack but the contractor, designer, owner, state regulator and federal regulator all objected. Another layer of complexity is that post-construction testing or monitoring often is not adequate to detect wall deficiencies. Complex geology and ground water chemistry regimes may render detection of localized defects in a cutoff wall difficult unless the testing/monitoring is focused specifically on the wall. Although overall site compliance monitoring is generally undertaken, these data are often insufficient to conclude that there are defects in the wall.

In addition, site owners find long-term monitoring, other than perimeter ground water monitoring, disruptive and invasive. While there have been a few field studies in which sampling and in-situ testing of an SB wall have been performed (e.g., Evans and Ryan 2005, Ruffing et al. 2011), these studies have been limited in scope and duration due to site access limitations and concerns over potential impacts to the wall. For example, a cooperative municipality (Birdsboro, PA) allowed the PIs access to a newly constructed cutoff wall for approximately one year (see Ruffing et al. 2010, 2011, 2012 and Ruffing and Evans 2010) but once fences were built and grass planted, continued drilling, sampling and *in-situ* testing were not permitted.

For all of these reasons, a field cutoff wall built for the express purpose of investigation/ experimentation, one that is located at a site where unfettered, long-term access is available, is the only way to get answers to the fundamental performance questions posed for this research.

2. RESEARCH ISSUES

Based on the above, major uncertainties exist regarding both the as-built and long-term properties of SB cutoff walls, despite the widespread use of these walls for long-term hydraulic and geoenvironmental containment applications. In particular, three critical issues are (1) limited knowledge of the *in-situ* stress distribution within the barrier, both at the end of construction and over time as the backfill consolidates (without knowledge of *in-situ* stresses, estimates of *in-situ* hydraulic conductivity from laboratory tests may not be representative), (2) the potential for time-dependent changes in backfill properties (e.g., dry density, water content, saturation, shear strength, and hydraulic conductivity), with special consideration given to differences in these properties above and below the water table, and (3) the potential for undetected variations in homogeneity, including high-*k* defects, within the barrier at the time of construction. A separate description of each issue is provided below.

2.1 Uncertainty in the State of Stress

Both the magnitude of hydraulic conductivity (*k*) and the variability in *k* of SB backfill are heavily dependent upon effective stress. As shown in Figure 2a, lower effective stress tends to result in higher *k* and greater variability in *k* among replicate specimens. Without knowledge of the *in-situ* state of stress, reliable estimates of backfill *k* may not be obtained. Since effective stress varies with depth, *k* also will vary with depth. However, there is considerable uncertainty regarding the distribution of effective stress as a function of depth. Stress conditions during emplacement of soft, compressible SB backfill at high water contents within a narrow trench are influenced by uplift forces (arching) along the sidewalls of the trench as the backfill attempts to consolidate (e.g., see Evans et al. 1985). Limited investigations to quantify the impact of sidewall friction have suggested that, for shallow depths, there tends to be a non-linear increase in stress at very shallow depths (less than 2 m) followed by a stress distribution that is essentially constant with depth up to ~9 m (Evans et al. 1995). Subsequent investigations (Filz et al. 1999, Ruffing et al. 2010) have revealed that the horizontal stress likely increases with increasing depth due to lateral squeezing of the backfill by the adjacent formation, but the increase is lower than expected based on an assumed geostatic stress distribution (see Fig 2b).

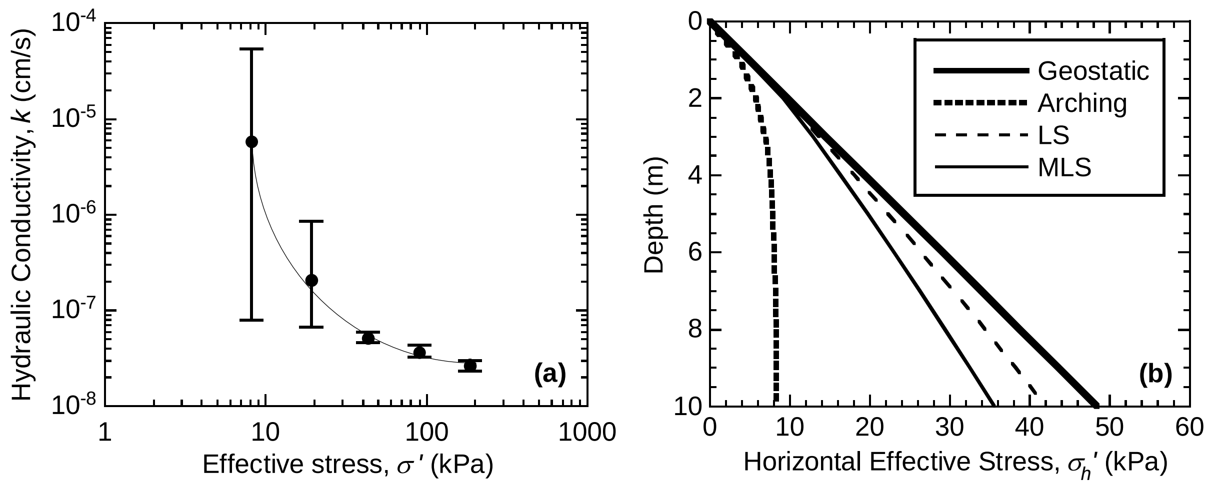


Figure 2. (a) Hydraulic conductivity of SB backfill as a function of effective consolidation stress (after Ruffing 2009); (b) predicted horizontal stresses in an SB cutoff wall based on geostatic, arching, lateral squeezing (LS), and modified LS (MLS) models (after Ruffing et al. 2010).

Research to investigate the *in-situ* stress distribution within an SB cutoff wall has been limited primarily to theoretical studies. However, in one study (Evans and Ryan 2005), earth pressure cells were mounted on sheet pile sections, as shown in Figure 3a, and installed in an SB cutoff wall during construction in an effort to evaluate the state of stress. The lateral pressure was monitored for a period of 10 days and had not yet stabilized (i.e., was decreasing with time) when the test was terminated, as shown in Figure 3b. The results in Figure 3b are plotted as a function of the log of time, modeling the traditional log-time format for plots illustrating time-rate of consolidation. A polynomial fit is shown with R^2 = 0.973 indicating that the initial portion of the curve is a parabola similar to the idealized log-time plot in a laboratory consolidation test. Using c_v = 3.7 m^2/yr (the highest value from the Casagrande method for the soils from this site) yields a time for 95 % consolidation of 16 days assuming a 30-inch wide trench (Filz et al. 2003). This information, coupled with the observation based on Figure 3b that the pressure had not yet stabilized, indicates that the final lateral pressures had not yet developed. ***No field investigations have been conducted to evaluate longer term stress conditions in a constructed SB cutoff wall and the resulting impact of these stress conditions on hydraulic conductivity.*** These data underscore the difficulty in researching long-term properties at sites where the owner limits the time available for monitoring.

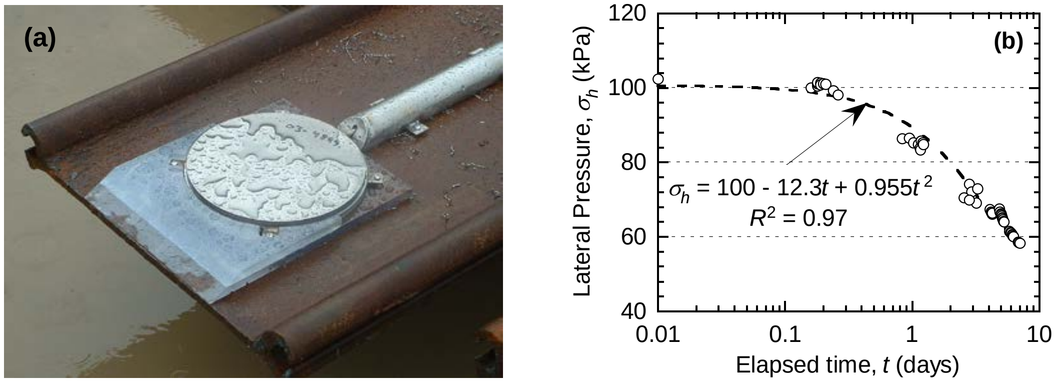


Figure 3. (a) Earth pressure cell mounted on sheet pile section; (b) Lateral earth pressure measured over time within an SB cutoff wall (after Evans and Ryan 2005).

2.2 Time-Dependent Changes in SB Backfill Properties

Given the increasing reliance upon vertical barriers for long-term applications, such as in levees and for *in-situ* geoenvironmental containment, the ability of SB cutoff walls to provide sustainable containment performance warrants serious consideration. While field-scale *k* measurements at the time of construction may provide a reasonable indication of short-term hydraulic performance, the test results may not be indicative of long-term hydraulic performance. Changes in backfill *k* may occur long after construction due to factors such as cyclic wetting/drying and freezing/thawing, changes in effective stress, deformations, and interaction between the bentonite and chemical constituents in groundwater (Evans 1993, Shackelford 1994, Evans 1995). The influence of some of these factors on the long-term performance of compacted clay and geosynthetic clay liners (GCLs) has been the subject of numerous laboratory and field studies (e.g., Boardman and Daniel 1996, Hewitt and Daniel 1997, Kraus et al. 1997, Petrov et al. 1997, Stern and Shackelford 1998, Lin and Benson 2000, Albrecht and Benson 2001, Abichou et al. 2002, Kolstad et al. 2004, Jo et al. 2005, Southen and Rowe 2005, Podgorney and Bennett 2006). However, far less attention has been given to SB backfill, and no comprehensive attempts have been made to investigate these factors in field-scale walls.

The influence of wet/dry cycling on backfill *k* is one important consideration that has received little attention. For levees in particular, some portion of a cutoff wall deployed within a levee will be above the water table except during periods of flooding. This portion of the wall must be an effective hydraulic barrier during these flooding periods. However, limited evidence suggests that SB backfill in field installations may be affected by wet/dry cycling. For example, Evans (1994) collected SB backfill samples from a constructed SB wall at depths of approximately 1 m above and below the adjacent water table. Results of flexible-wall tests performed on these specimens revealed a substantially greater *k* for the backfill obtained above the water table relative to the backfill collected from below the water table. These results were supported by measured water content profiles in the backfill, which showed that the water content had diminished in the backfill above the water table (see Evans 1994).

More recently, the potential for changes in *k* of two model SB backfills subjected to wet-dry cycling was investigated by Malusis et al. (2011). The backfills were prepared with the same base soil (clean, fine sand) but different bentonite contents (2.7 and 5.6 %). Saturation (*S*), volume change, and *k* of consolidated backfill specimens (effective stress = 24 kPa) were evaluated over three to seven cycles in which the matric suction, Ψ_m, in the drying stage ranged from 50 to 700 kPa. Both backfills exhibited susceptibility to degradation in *k* caused by wet-dry cycling (e.g., see Figure 4). Mean *k* for specimens dried at Ψ_m = 50 kPa (*S* = 30-60 % after drying) remained low after two cycles, but increased by 5- to 300-fold after three or more cycles. Specimens subjected to higher suctions and, therefore, greater drying (*S* < 30 %) were less resilient and exhibited 500- to 10,000-fold increases in *k* after three or more cycles. The findings are consistent with those of Evans (1994) and suggest that increases in *k* due to wet-dry cycling may be a concern for SB barriers located within the zone of a fluctuating groundwater table.

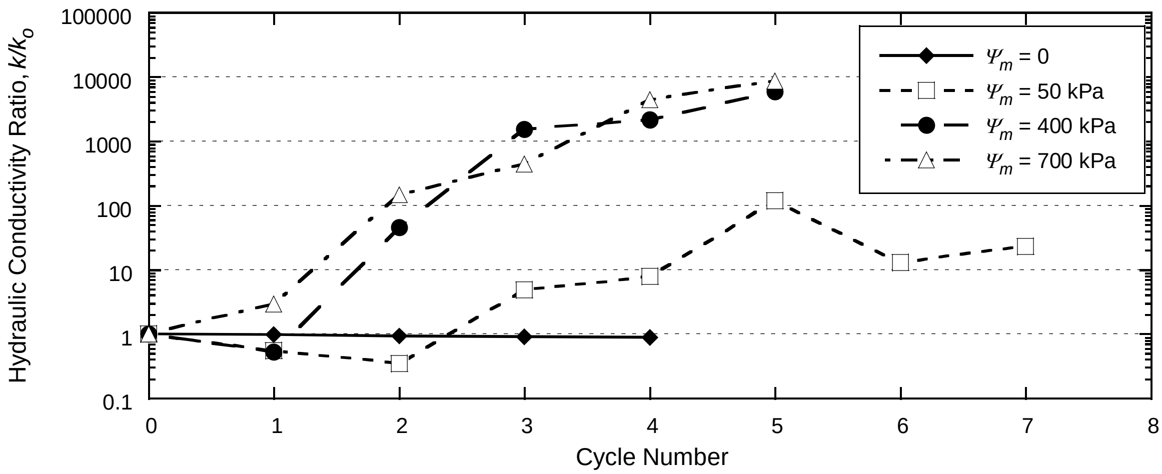


Figure 4. Hydraulic conductivity ratio, k/k_o (where k_o = hydraulic conductivity prior to drying) as a function of the number of wet-dry cycles for backfill specimens (5.6 % bentonite) subjected to different drying suctions (Ψ_m = 0, 50, 400, and 700 kPa) (replotted after Malusis et al. 2011).

2.3 Field Scale Variability in Hydraulic Conductivity

One of the most common questions asked by site owners about the viability of a vertical barrier is, "how can you demonstrate the as-constructed wall is homogeneous and free of defects?" Unfortunately, this question cannot be answered definitively based on the current state of practice. Heterogeneities within the backfill inevitably will exist at the time of construction due to factors such as incomplete mixing of the backfill prior to placement, development of coarse-grained "windows" due to spalling from the trench walls or settlement of coarse-grained particles through the slurry, and zones of entrapped slurry created during backfill placement (Barvenik and Ayres 1987, Ryan 1987, Evans 1993). Typically, this variability is not easily investigated, and the *in-situ* *k* of the backfill generally is assumed to be equal to the laboratory *k* of backfill specimens created from bulk samples obtained in the field prior to placement in the wall. However, in one published case study (Evans et al. 2004), testing was performed on backfill samples recovered from areas within an SB cutoff wall that were considered suspect due to a high sand content near the base of the wall. The study found that, although the *k* of the as-mixed backfill met the project requirements ($<10^{-6}$ cm/s), the *in-situ* backfill near the base of the wall was substantially coarser and was found to have a *k* of $3\text{x}10^{-4}$ cm/s. ***These data, along with data from other field sites where cutoff walls have performed inadequately, point to the need for more comprehensive in-situ investigations of SB cutoff walls and the development of cost-effective techniques to examine the wall at the end of construction.***

Several testing methods may be utilized to estimate the *in-situ* *k* of an SB barrier. These methods include (1) laboratory testing of undisturbed backfill samples collected from the constructed barrier, (2) slug tests performed in the barrier, (3) piezocone soundings with pore pressure dissipation measurements, and (4) large-scale pump tests using wells installed adjacent to the barrier (Britton et al. 2004, Choi and Daniel 2006). Undisturbed backfill samples typically are collected by drilling through the backfill to the desired depth and pushing a piston sample tube into the lower material. Although collection of high-quality undisturbed samples can be difficult in soft backfill, laboratory *k* values for undisturbed backfill specimens tend to be conservative (higher) relative to laboratory *k* values for remolded specimens (Britton et al. 2004). Regardless, laboratory specimens typically are small (60 to 100 mm in diameter) and are less likely to capture defects and macrofeatures that often govern *k* at the field scale (Daniel 1984, Shackelford and Javed 1991, Benson et al. 1999). Therefore, laboratory tests may yield *k* values lower than those from piezometer, piezocone, and pump tests that capture a larger representative volume of the barrier and are more likely to be influenced by macrofeatures. For example, Britton et al. (2004) compared the *k* of SB backfill in three pilot-scale cutoff walls (W1, W2, and W3) based on small-scale laboratory tests, piezometer tests, piezocone soundings, and large-scale pump tests. Laboratory tests on remolded specimens were performed using a filter press, whereas laboratory tests on undisturbed specimens were performed in a rigid-wall configuration (within cut sections of the sample tube). The results, summarized in Table 1 below, indicate that both remolding and test scale have a significant impact on measured k of the backfill in each of the three pilot-scale walls. In each case, small-scale laboratory tests on remolded samples yielded the lowest k, whereas the *in-situ* tests consistently yielded higher k. ***These results underscore the importance of field testing to assess the true hydraulic performance of a constructed soil-bentonite cutoff wall.***

Table 1. Hydraulic conductivity measurements on SB backfill (k_b) in three pilot-scale slurry trench cutoff walls (data from Britton et al. 2004).

Wall ID	Test Method	No. of Samples	Average k_b (m/s)	Sample Size (m^3)
W1	Lab - remolded	6	1.3×10^{-8}	2.2×10^{-4}
	Lab - undisturbed	2	2.2×10^{-8}	1.1×10^{-4}
	Piezocone	5	3.1×10^{-8}	$1.0 \times 10^{-3} – 2.0 \times 10^{-3}$
	Piezometer	8	3.5×10^{-8}	$2.0 \times 10^{-2} – 4.5 \times 10^{-2}$
W2	Lab - remolded	6	2.0×10^{-8}	2.2×10^{-4}
	Lab - undisturbed	2	4.3×10^{-8}	1.1×10^{-4}
	Piezometer	2	4.8×10^{-8}	$2.0 \times 10^{-2} – 4.5 \times 10^{-2}$
W3	Lab - remolded	6	1.1×10^{-9}	2.2×10^{-4}
	Lab - undisturbed	4	2.4×10^{-9}	1.1×10^{-4}
	Piezometer	4	3.3×10^{-9}	$2.0 \times 10^{-2} – 4.5 \times 10^{-2}$
	Large-scale pump test	1	6.6×10^{-9}	13

In addition to the above, while large-scale *in-situ* tests may indicate the existence of high-k zones within a constructed SB barrier, these tests are expensive and are rarely performed. In addition, these tests cannot be relied upon to determine the precise locations and sizes of defects. ***The development and demonstration of an effective geophysical technique for defect detection and in-situ verification of wall integrity would greatly enhance the confidence in SB cutoff walls for owners, designers and contractors.*** Based on the review of Pearlman (1999), electrical resistance (ER) imaging, which involves passing current between electrodes installed in a soil and measuring the voltage across two other electrodes, may be a promising technology for detecting defects in vertical barriers. Electrodes may be placed within the wall or in the soil adjacent to the wall to identify detects, such as sand lenses, that exhibit contrasting resistivity relative to the backfill. Pearlman (1999) noted that ER was used successfully to identify a breach in a concrete diaphragm wall that was later confirmed by excavation. Also, Daily and Ramirez (2000) used ER to construct images of grout and polymer barriers and indicate that ER works equally well below and above the water table. Moreover, ER was used effectively for detecting defects in a geomembrane installed within a cement-bentonite cutoff wall (Emsley 2000). These limited studies suggest that ER is a potentially viable technology for detecting defects in SB cutoff walls, but research has not yet been performed to investigate ER in a field-scale SB installation.

3. RESEARCH PLAN

3.1 Project Goals

Based on the issues identified and described above, additional field research is needed to bridge the gap between our understanding of the behavior of SB cutoff walls based primarily on laboratory studies to the behavior of real-world cutoff walls in service. ***Thus, the PIs propose this project to design and construct an experimental SB cutoff wall that will serve as a dedicated field site for research on the short- and long-term integrity of field-scale SB barriers.*** The goals of the project are as follows:

(1) to investigate the *in-situ* state of stress in the wall, both at the end of construction and over time;

(2) to investigate changes in the *in-situ* properties of the wall with time, including water content, *k*, and shear strength, with special consideration given to differences above and below the water table; and

(3) to investigate the optimal and efficient parameters of ER imaging to detect variations in homogeneity, including defects, within the wall.

The project will be carried out as an industry-university collaboration between Bucknell University (BU), a primarily undergraduate institution, and Geo-Solutions, Inc., an industry leader in construction of vertical barriers. A detailed description of the proposed scope, tasks, and project team is provided below.

3.2 Experimental SB Cutoff Wall Site

The proposed site for the experimental SB cutoff wall is on the property of a commercial sand/gravel quarry operated by Central Builders Supply (CBS) in Montandon, PA, approximately 3 km east of the BU campus (see Fig. 5). The wall will be 200 m long and 0.6 m wide, and will be installed on a portion of the property that has been set aside in perpetuity as a buffer zone between the permitted mining area and an adjacent, natural wetland known as the Montandon Marsh (see Fig. 5c). For many years, the owners of CBS (BU alumni) have allowed BU faculty and students to access the marsh area for research and education activities, and they enthusiastically support our proposed project. Also, the conservancy organization responsible for protecting the wetland (the Linn Conservancy) is fully supportive of the project. Letters of support are provided in Supplemental Documents.

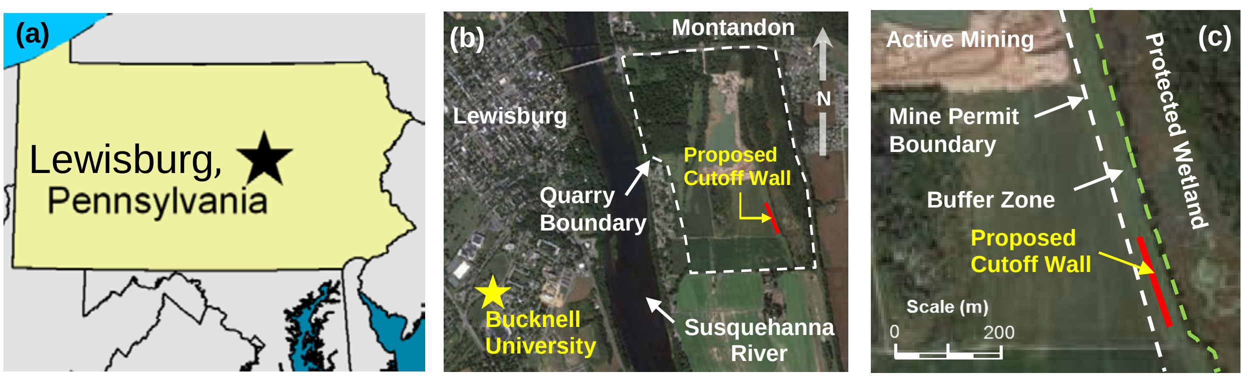


Figure 5. (a) Index map showing the proposed site location in PA; (b) aerial photo showing the relative proximity of the proposed cutoff wall to the Bucknell University campus; (c) aerial photo of the portion of the quarry where the proposed cutoff wall will be located.

The proposed cutoff wall will be installed in an alluvial deposit within the footprint of the Susquehanna River paleochannel. The wetland area in Figure 5c has been the site of numerous geologic and hydrogeologic studies by BU students and faculty over the past 15+ years. As a result, the local geotechnical and hydrogeologic conditions near the proposed cutoff wall location have been well characterized. In addition, an exploratory soil boring was completed at the midpoint of the proposed cutoff wall alignment in November 2012 to confirm the subsurface conditions and verify the feasibility of the site for cutoff wall construction. The results of this boring, illustrated in Figure 6, show that the alluvial aquifer is composed primarily of silty and clayey sand containing minor

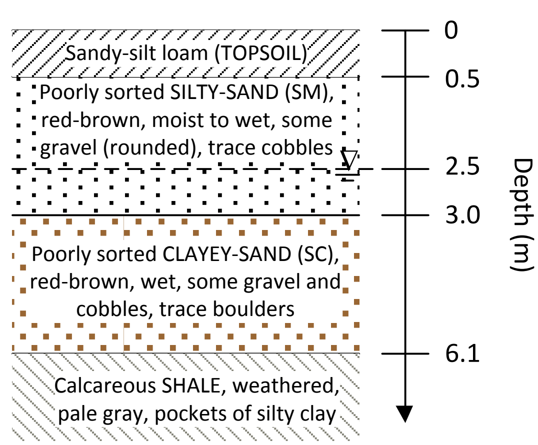


Figure 6. Subsurface profile at midpoint of proposed cutoff wall alignment (November 2012).

amounts of rounded gravel and cobbles. The aquifer is underlain by weathered calcareous shale at a depth of ~6.1 m. These findings are consistent with historic borings performed along the western edge of the wetland and indicate that the subsurface conditions are amenable to construction of a 7-m deep SB cutoff wall (keyed into the weathered shale aquitard) using conventional backhoe excavation. The depth to groundwater was 2.5 m in November 2012, but historic water levels measured in existing monitoring wells along the perimeter of the wetland indicate that the depth to groundwater approaches 0.5 m during wet seasons. Thus, at least 2 m of seasonal groundwater fluctuation is expected at the site, which is ideal for investigating the influence of wet-dry cycling on the portion of the wall within this zone of groundwater fluctuation. Dimensions of the test wall (shown later in Figure 8) were carefully selected to be representative of commercial construction projects while at the same time providing adequate spacing for instrumentation and monitoring to minimize interference effects and ensure high-quality data.

3.4 Project Tasks

3.4.1 Task 1: Detailed site characterization

At the start of the project, a detailed site characterization program needs to be carried out along the proposed cutoff wall alignment to create a detailed subsurface profile along the alignment and to obtain samples for laboratory testing (grain size distribution, Atterberg limits, and moisture content) needed to design the SB backfill. Borings will be completed at 50-m intervals along the wall alignment to supplement the boring data collected in November 2012 (see Figure 6). The borings will be completed by hollow stem drilling with an Acker Soil Scout track-mounted drilling rig (Figure 7), which was acquired by BU in 2008 through an NSF Major Research Instrumentation (MRI) award for field research on SB cutoff walls (Award CMMI-0722584). The surface topography along the alignment will be surveyed and used to establish the bottom elevations for the trench key. In addition, baseline geophysical surveys will be conducted along the entire planned SB wall location prior to construction to further characterize the subsurface geology, image the depth to bedrock along the alignment, and check for anomalies that may impact wall construction. These surveys will include ER imaging, seismic reflection/refraction, and ground penetrating radar (GPR).

Figure 7. Photograph of BU track-mounted drilling rig at SB cutoff wall field site in Birdsboro, PA (2009).

3.4.2 Task 2: Wall design and construction

Composite samples of material recovered from the borings will be used to develop candidate SB backfill mixtures for laboratory testing of slump and *k*. The mixtures will be created by blending the composite samples with dry sodium bentonite (as needed) and bentonite-water slurry (~5 % sodium bentonite by weight) to achieve a target slump (ASTM C-143) of 125 mm ± 12.5 mm, a range consistent with typical field specifications for SB backfill (Evans 1993, Ryan and Day 2003). The candidate backfill mixtures will be tested for *k* in flexible-wall cells (ASTM D-5084), and the design backfill will be selected from among the candidate mixtures that exhibit $k \leq 10^{-9}$ m/s or less. Backfill preparation and *k* testing procedures will be similar to those described by Malusis et al. (2009, 2011).

The results of the site characterization and backfill design programs will be used as the basis for development of design plans and specifications for construction of the wall. The specifications will be prepared in accordance with appropriate standards of practice and will address the following components (see sample specification at http://www.geo-solutions.com/sample-specs/index.php):

- construction coordination, equipment set-up, and site layout;
- equipment specifications (e.g., for excavation, backfill mixing, and slurry mixing);
- procedures for slurry mixing, trench excavation, backfill mixing, and backfilling;
- specifications for the sodium bentonite clay;
- required properties of the bentonite-water slurry (i.e., viscosity, mud density, filtrate loss, and pH);
- required backfill proportions and properties (e.g., slump, hydraulic conductivity);
- specifications for the mixing water;
- requirements for construction quality control testing; and
- lines, grades, width, and tolerances for trench excavation.

Construction of the wall will be performed by Geo-Solutions, Inc. on a fixed price basis (see Budget Justification). Geo-Solutions will supply a mixing plant and operators to execute the various steps of the construction sequence, including slurry preparation, trench excavation, and backfill mixing and placement. Also, Geo-Solutions will oversee and assist with all construction quality control testing performed by the project team. At a minimum, the following quality control measures will be employed (testing frequencies and required properties will be formally defined in the specifications):

1. Soundings: Using a weighted tape, the depth to the bottom of the trench will be measured at 3-m intervals to verify the excavation depth as excavation progresses. Soundings will also be taken at intervals of 3 m at the end and start of each working day and compared to verify the nature of any overnight sedimentation or sloughing on the backfill slope or excavation bottom.
2. Slurry Viscosity: Slurry viscosity will be measured by Marsh funnel on samples obtained during slurry placement in the trench and on grab samples of slurry in the trench. Typical requirements for Marsh viscosity are 32-40 s for freshly prepared slurry and >40 s for in-trench slurry.
3. Slurry density: Slurry density will be measured on samples obtained from the mixing plant and the trench using an API mud balance. Typical requirements for density on commercial projects are >10 kN/m^3 (>64 pcf) for freshly prepared slurry and 10-13.4 kN/m^3 (64-85 pcf) for in-trench slurry.
4. Slurry Filtrate loss: Filtrate loss will be measured on samples obtained from both the mixing plant and the trench using an API filter press. Typical requirements for filtrate loss on commercial projects is <25 mL over 30 min at 15.7 kPa (100 psi) of pressure.
5. Backfill slump: Samples of the as-mixed backfill will be tested for slump using an ASTM C-143 slump cone. The typical slump range for commercial projects is 100-150 mm (4-6 in).
6. Backfill gradation: Grab samples of the field mixed backfill will be tested for fines content (ASTM D-1140) to ensure that the backfill is homogenous and contains the desired amount of fines.
7. Backfill hydraulic conductivity: Flexible-wall hydraulic conductivity (*k*) tests (ASTM D-5084) will be performed on specimens prepared from grab samples of the field mixed backfill, to ensure that the backfill exhibits $k \leq 10^{-9}$ m/s.
8. Bench-scale ER testing: ER will be measured using a standard resistance box and BU's Sting R1 on field mixed backfill samples obtained during construction. The results will be compared to ER imaging data obtained after wall construction (see Section 3.4.5).

The PIs will install permanent monitoring instrumentation within and around the wall prior to, during, and/or shortly after construction. Tentative locations for monitoring instrumentation are shown in Figure 8. The instrumentation will include: (1) inclinometers installed at two locations immediately outside the trench to measure lateral deformations as a function of depth; (2) earth pressure cell cages to measure the three-dimensional state of stress within the backfill; (3) paired sensors to measure moisture content and suction within the backfill; (4) settlement plates to measure vertical deformation; (5) piezometers within the wall to measure water levels and *in-situ* hydraulic conductivity of the backfill (by slug testing); (6) monitoring wells outside the wall (adjacent to the piezometers); and (7) stainless steel electrodes for ER imaging. The instrumentation is described in more detail in Sections 3.4.3-3.4.5.

3.4.3 *Task 3: Investigate the in-situ state of stress (Project Goal #1)*

The stress distribution in the experimental cutoff wall will be measured directly using earth pressure cells employed in two different ways. First, earth pressure cell cages will be placed at four locations within the wall (see Fig. 8) to measure the three-dimensional stress state (i.e., the vertical stress and the horizontal stresses in the transverse and longitudinal directions) within the backfill continuously over time. Second, continuous profiles of longitudinal and transverse horizontal earth pressure will be measured using a push-in pressure cell (or "spade cell") capable of measuring total earth pressure and pore water pressure within the backfill. The push-in cell will be attached to a section of drill rod, slowly pushed into the backfill (with the spade oriented in the desired direction) to obtain the lateral stress profile, then extracted for later use at other desired locations and times.

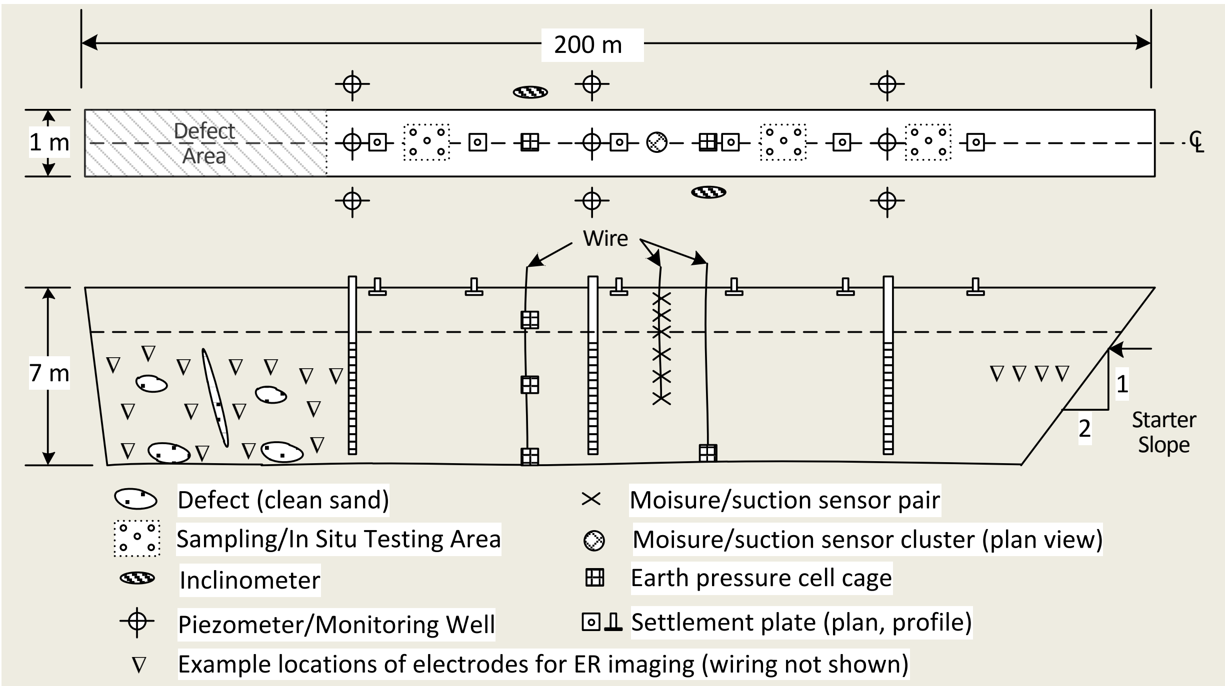


Figure 8. Plan and profile views of experimental SB cutoff wall showing tentative locations for monitoring instrumentation, sampling/*in-situ* testing areas, and the defect investigation area (not to scale).

Figure 9. Photograph of earth pressure cell cage (RST Instruments, Maple Ridge, BC, Canada).

The earth pressure cell cage proposed for use in this study, illustrated in Figure 9, includes three vibrating wire stress sensors mounted in three cardinal directions to measure vertical and horizontal (longitudinal and transverse) stresses. Each cage also has one vibrating wire piezometer (to measure pore pressure), a biaxial tiltmeter and magnetic compass (to measure the as-placed orientation), and matric suction and volumetric water content sensors. All sensors are connected to a Kevlar-reinforced cable that will extend vertically out the wall for data acquisition. The cages were originally designed for use in mine paste backfill and, therefore, have an open structure that is ideal for allowing the fluid SB backfill to fill the cage and cover the sensors. The cages will be placed at different depths within the slurry-filled trench (prior to backfill placement) and will be fixed in place using hydraulic trench jacks mounted to the sides of each cage. The trench jacks will prevent the cages from being displaced from their desired location and orientation during backfill placement.

The stress measurements will be complemented with measurements of vertical and horizontal deformations obtained from settlement plates and inclinometers, respectively (see Fig. 8). The stresses will be compared against simulated stresses using the theoretical models shown in Figure 2b, and the combined stress-deformation data will be used as a basis for numerical modeling that simulates the development of stress and strain over time. With better knowledge of the stress state, coupled with existing knowledge of the dependence of hydraulic conductivity on stress, these findings could transform the way designers select stresses to be used in laboratory tests for SB cutoff walls.

3.4.4 Task 4: Investigate time-dependent changes in in-situ properties of SB backfill (Project Goal #2)

Time-dependent changes in *in-situ* properties of the wall (i.e., *k*, shear strength, and moisture content) will be evaluated using a combination of sensors, *in-situ* tests, and lab tests on backfill collected from the wall. For example, *k* will be measured at discrete locations using slug tests, cone penetration tests (CPTs) with pore pressure dissipation, and lab tests on undisturbed specimens. Also, strength and compressibility will be measured via CPTs, vane shear tests, and dilatometer tests. Sampling and *in-situ* testing will be performed in dedicated areas of the wall (see Fig. 8). All equipment needed for sampling and lab/*in-situ* testing is already available at BU. Finally, a vertical string (6 pairs) of moisture content and suction sensors (time domain reflectometers [TDRs] and vibrating wire piezometers) will be placed within the upper half of the wall (see Fig. 8) to evaluate the extent to which wet-dry cycling occurs in the backfill within the zone of expected groundwater fluctuation. Installation procedures for the TDRs are described in Ruffing et al. (2012).

3.4.5 Task 5: Investigate optimal parameters of ER imaging for defect detection (Project Goal #3)

The ability of ER imaging for successfully detecting defects in a constructed SB barrier depends on both site specific conditions and electrode placement. Site conditions include the defect size, number of defects, location relative to other defects, location relative to the wall base, and the contrast in resistivity between the defect and the surrounding material (i.e., the backfill). These conditions are not controlled in a pre-existing slurry wall, thus a controlled environment is necessary to optimize the placement procedure and locations for electrodes in order to efficiently detect wall defects. In this study, different size defects comprised of clean sand will be placed within a dedicated 50-m section of the wall (i.e., the "defect area" in Fig. 8) during construction. This section will be free of other monitoring instrumentation that could affect the ER measurements. The PIs will perform preliminary tests during the wall design phase of Task 2 to determine the expected contrast in resistivity between the sand defects and the backfill mixture chosen for design. Preliminary analyses conducted on a model SB backfill containing sodium bentonite and poorly-graded sand as the soil component yielded a resistivity of 10 ohm-m for the model backfill. Sand defects in a SB slurry wall are expected to be 10 to 100 times more resistive, provided that the conductivity of the water within the defect and the backfill is the same. This analysis will be refined during Year 1 using the site-specific backfill and the sand that will be used to create the defects.

Defects will be created at different locations within the defect area of the cutoff wall by placing burlap sacks of clean sand in the wall during backfill placement. We anticipate that two of the defects will be large (1.0 x 0.25 x 0.15 m) and will be placed at two different locations and elevations (i.e., one at the bottom of wall and one at a depth of approximately 3 m). Also, at least two smaller defects (0.5 x 0.25 x 0.15 m) will be placed 10 m away from a large defect and approximately 4 m deep. Finally, long, thin defects may be placed within the wall after construction by, for example, pushing a sand-filled PVC tube into the soft backfill and extracting the tube to create sand stringers (e.g., see Fig. 8). The precise locations, sizes, and placement methods for all defects will be finalized during the design stage of Task 2.

Approximately 50 cone-tipped electrodes will be manufactured at BU, as described by Pidlisecky et al. (2006), and will be placed within the backfill to allow for pole-dipole ER imaging, although alternative imaging geometries may be considered. Multiple electrodes will be placed around the defects (at 1 m and larger distances) soon after construction by pushing the electrodes to desired depths in the wall. Several electrodes also will be installed at mid-depth in the area of the wall near the starter slope, which is not affected by defects or instrumentation (see Fig. 8), as quality control on the ER data. We will collect reciprocal measurements, where each electrode will be used to transmit current as well as to measure potential, to quantify the uncertainty of the resistivity measurements. Co-PI Jacob and an undergraduate student will process and analyze these data to estimate an optimal electrode spacing and position within the wall to detect a defect of a specified size and resistivity. The results will be analyzed for defect detection at the time of data collection as well as using an inversion scheme that would generate an image displaying the resistivity of the slurry wall for defect detection post-field work. Based on the experience gained from this work, the PIs will design a standard methodology and test this methodology within the defect area. Additional electrodes will be installed as necessary to facilitate this testing.

Because it is necessary to know the nature and location of defects to properly evaluate the efficacy of ER, it is not possible to conduct this research on a commercially constructed site. Regulators, owners, designers and contractors are reluctant to provide access for ER testing and, should anomalies be discovered, it would be necessary to investigate though drilling, sampling, testing and excavation, the nature and extent of the anomaly in order to validate the ER finding. By testing a wall with known defects, guidance can be published as to the precisions and resolution of the method. If successful, this could transform *in-situ* quality control of cutoff walls.

4. INDUSTRY INVOLVEMENT

This project has been designed as an industry-university collaboration between BU and our construction contractor, Geo-Solutions. The project will be managed and conducted by the PIs, with contracting expertise provided by Geo-Solutions Project Manager Daniel Ruffing

PI Evans has over 35 years of research and consulting experience on a wide variety of geotechnical and environmental projects, including numerous projects involving design, construction, and performance of SB cutoff walls. Since his first SB wall project in 1978, he has worked to advance the state of the art and practice for vertical barriers used in pollution control and dams/levees. He has conducted numerous research projects on SB barriers and has consulted on cutoff wall projects in Arizona, California, Colorado, Delaware, Florida, Ohio, Wisconsin, Utah, and Quebec. His contributions include a widely cited textbook chapter on vertical barriers (Evans 1993) and dozens of publications pertaining to studies he has performed on vertical barriers over the past 30 years (e.g. Evans and Fang 1982, Evans and Garbin 2009, and numerous others cited throughout this proposal). Co-PI Malusis has more than 15 years of experience on geotechnical research and consulting projects, including SB cutoff wall projects in Colorado, Illinois, and Pennsylvania. His recent research projects include evaluation of novel bentonites for SB cutoff walls (Malusis et al. 2010a, Malusis and McKeehan 2013, Bohnhoff et al. 2013), investigation of amended SB backfills for enhanced sorption (Malusis et al. 2009, 2010b, Hong et al. 2012), and studies on wet-dry behavior of SB backfill (Malusis et al. 2011, Ruffing et al. 2012). Co-PI Jacob has more than 15 years of experience using geophysics to address environmental questions, including numerous applications of ER on hydrologic and geotechnical projects. His research is focused on assessing and improving geophysical methods for near surface applications.

Geo-Solutions (www.geo-solutions.com) is headquartered in New Kensington, PA (approximately 300 km west of the BU campus) and is an industry leader in specialty geotechnical and geoenvironmental contracting. The principals and staff of Geo-Solutions have been involved in construction of >1,000 slurry walls around the world and have published numerous papers on SB cutoff walls over the past 30+ years (e.g., D'Appolonia and Ryan 1979, Ryan 1987, Ryan and Day 2003, Day 1994, Evans and Ryan 2005, Ryan and Spaulding 2008, Ruffing and Evans 2010, Ruffing et al. 2010, 2011, 2012). Geo-Solutions Project Manager Ruffing (a BU alumnus) has several years of field experience in SB barrier construction and worked directly with PIs Evans and Malusis on his MS thesis project involving field evaluation of an SB cutoff wall constructed in Birdsboro, PA (Ruffing 2009). He is lead author of several publications with PIs Evans and Malusis (Ruffing and Evans 2010, Ruffing et al. 2010, 2011, 2012). Mr. Ruffing will be directly involved in supporting the design and overseeing the construction of the wall as well as dissemination of the research and student education/mentoring. He will have the full support and assistance of the senior management of Geo-Solutions, including Robert Schindler (President) and Ken Andromalos (Vice President of Engineering) (see attached letter in Supplementary Documents).

The PIs will lead all tasks (with support from Geo-Solutions) and will perform the laboratory testing required to design the SB backfill. Under the direction of PIs Malusis and Jacob, the project team and BU students will deploy the instrumentation in the wall with assistance from the BU Director of Civil Engineering Laboratories, James Gutelius. Geo-Solutions will review the design specifications and assist with field QC sampling and testing performed by the PIs and students. Geo-Solutions also will contribute to the education, mentoring, and dissemination components of the project as described in Section 5 below. Close communication between BU and Geo-Solutions will be maintained throughout the project through face-to-face project meetings (at least two meetings per year) and additional videoconferencing (as appropriate) to facilitate regular exchange of ideas as the research progresses.

5. BROADER IMPACTS

Soil-bentonite slurry trench cutoff walls have been used in critical infrastructure applications for decades, and yet no comprehensive field studies, such as proposed herein, have ever been conducted. Although numerous lab and theoretical studies (many of which are cited in this proposal) have been performed on various aspects of SB barrier performance, published field data are scarce and are largely based on studies limited in scope and duration. Moreover, ER imaging offers substantial promise as a commercial technology for locating defects in SB walls, but needs to be investigated in a thoughtful and systematic way. This type of study is long overdue and has the potential to greatly enhance the profession's understanding of the *in-situ* conditions in SB cutoff walls and to transform the standard of practice for wall design, construction, and quality testing to ensure short- and long-term integrity of these walls. Beyond the impact on SB cutoff walls, understanding of the fundamental performance will add understanding to a wider range of wall types, including cement-bentonite and *in-situ* mixed barriers. The academic and industrial team will work together to disseminate the findings to the academic, practicing, and regulatory communities through published papers, presentations at technical conferences, creation of a web-based GIS data repository accessible to the public (including other researchers who may have use for the data), and industry seminars offered in the third year of the project.

Furthermore, this project will create a field site that provides invaluable opportunities for students to gain experiential education in a real-world setting, outside of the typical classroom or laboratory. Such experiences can inspire university students to pursue employment or advanced study in geotechnical/geoenvironmental engineering or geology, and can awaken interest in younger students contemplating a career in science or engineering. As undergraduate education is central to the BU mission, the PIs will integrate undergraduate education and mentoring throughout the project. The project will involve at least nine undergraduate research assistants over the course of the three-year study period (three students per year). Our experience at BU indicates that undergraduates who participate in research are far more likely to pursue graduate study than students who take summer internships with industry. Also, the PIs routinely attract student researchers from underrepresented groups whose representation is badly needed in our profession. More than half of the students currently working with the PIs on research projects are women or ethnic minority students, and our goal for this project is to attract a similar cohort. We will work with the BU chapters of the Society of Women Engineers (SWE) and the National Society for Black Engineers (NSBE) to assist in recruiting diversity students for the project.

In addition to the above, the site will be used routinely as a field education site for undergraduate and graduate students in geotechnical engineering and geology courses. Field laboratories conducted in these courses will include fundamentals of subsurface investigation, *in-situ* testing, and geophysics. We envision that at least some of the site characterization and *in-situ* testing proposed in this project will be integrated into these field laboratories, as was the case in November 2012 when 34 undergraduates in the BU soil mechanics course participated in a field laboratory integrated with completion of the soil boring shown in Figure 6. Finally, the PIs will use the site for educational outreach in a week-long summer engineering camp held annually at BU for secondary school students. This highly successful camp, which originated in 2006 with funding from an NSF NEU award, hosts ~90 students each year. We anticipate that these education and outreach programs will continue well beyond the three-year project period, given that BU faculty and students have already been accessing this site for the past 15+ years.

Geo-Solutions will make major contributions to the education, mentoring, and outreach component of this project. In addition to working closely with the BU research students and providing a contractor's perspective to the research activities, Mr. Ruffing and/or other senior staff members at Geo-Solutions will present guest lectures on vertical barriers to BU students in geotechnical courses. Geo-Solutions also will sponsor up to two summer internships per year for BU students and will participate in industry seminars held during the second and third years of the project.

6. PROJECT SCHEDULE

A three-year schedule is proposed for the project, as shown in Table 2. Year 1 will include the site characterization, design, and construction planning components, and will culminate in wall construction in early Fall 2015. Design specifications and work plans for construction and instrumentation will be developed during Year 1. Upon completion of the construction, monitoring and testing will begin (as well as the subsequent management and analysis of data) and will continue for the duration of the project. Numerical modeling will be initiated at the end of Year 2 and will include evaluation and possible modification or refinement of our previously published model on earth pressures (Ruffing et al. 2010) based on the field data. Dissemination will likely begin at the end of Year 2. Outreach and student internships will be offered during the three summer periods of the project, and student education and mentoring will be integrated throughout the project through coursework and interaction with the research students. The two industry seminars will be held in Years 2 and 3.

Table 2. Proposed three-year project schedule (SP = Spring; SU = Summer; FW = Fall/Winter).

	Calendar								
	YEAR 1: 2015			**YEAR 2: 2016**			**YEAR 3: 2017**		
Task	**SP**	**SU**	**FW**	**SP**	**SU**	**FW**	**SP**	**SU**	**FW**
1a. Site investigation and laboratory testing	■	■							
2a. Materials procurement	■	■							
2b. Preliminary testing/analysis for ERT	■	■							
2c. Wall design	■	■							
2d. Construction planning/site preparation	■	■	■						
2e. Wall construction			■						
2f. Installation of monitoring equipment			■	■					
3a. Monitor in-situ stress distribution				■	■	■	■	■	■
3b. Numerical modeling						■	■	■	■
4. Sampling/lab testing and *in-situ* testing				■	■	■	■	■	■
5. Defect investigation (ERT)				■	■	■	■	■	■
Student education and mentoring	■	■	■	■	■	■	■	■	■
Dissemination						■	■	■	■
Outreach (BU engineering summer camp)		■			■			■	
Student internships at Geo-Solutions		■			■			■	
Industry Seminars						■			■

7. RESULTS FROM PRIOR NSF SUPPORT

Principal Investigators: M.A. Malusis (BU), J.C. Evans (BU), C.D. Shackelford (CSU)
Award No., Period, and Amount: CMS-0625159, 10/01/06 to 09/30/09, $94,598 (BU portion)
Title: COLLABORATIVE RESEARCH: Enhanced Clay Membrane Barriers for Sustainable Waste Containment

Intellectual Merit: This collaborative project was performed to evaluate the concept of improving the efficiency and duration of waste containment through use of clay barriers exhibiting semipermeable membrane behavior and enhanced adsorption capacities. Specimens of model SB backfills amended with up to 10 percent (by dry weight) of two types of activated carbon (for enhanced sorption of organic solutes) and three types of zeolite (for enhanced adsorption of inorganic solutes) were evaluated using flexible-wall *k* tests, consolidation tests, batch equilibrium sorption tests, and osmotic tests. Results showed that the amended specimens exhibited similar *k* and compressibility but markedly improved sorption capacity relative to unamended specimens. Membrane efficiencies for the backfill specimens were low (i.e., less than 10 percent), indicating that SB backfills containing predominantly sand as the base soil are less effective membranes relative to bentonite-amended soils containing native fines. Theoretical models for 1-D solute transport through enhanced clay barriers, accounting for both membrane efficiency and nonlinear adsorption capacity, were developed and used to predict the influence of the improved sorption capacity on solute breakthrough time in simulated cutoff wall applications.

Broader Impacts: Student researchers on the project included two undergraduate students (Emily Daniels and Greg Zarski, BU), one MS student (Edward Barben, BU), and one Ph.D. student (Catherine Hong, CSU). Eight refereed papers acknowledging the grant were published, including Barben et al. (2008), Malusis et al. (2009, 2010b, 2012), Hong et al. (2012), and Shackelford (2011, 2012, 2013). A website was created to make project data and other resources pertaining to research on membrane behavior in clay soils available to the public.

Principal Investigators: R.C. Kochel (BU), J.M. Trop (BU), R.W. Jacob (BU)
Award No., Period, and Amount: EAR-1224720, 01/01/13 to 12/31/15, $275,552
Title: COLLABORATIVE RESEARCH: Geomorphic Response of Glacial Decoupling in Alpine Regions in Response to Climate Warming: Icy Debris Fans and Early Paraglacial Landscape Evolution

Intellectual Merit: This project is investigating a suite of alpine processes and landforms linked to climate change. The research focuses on field investigations to decipher the depositional processes that form icy debris fans, the influence of catchment morphometry on fan morphology, and sedimentological characteristics of icy fans compared with similar landforms not dominated by ice. We are using a novel combination of ground-based LiDAR mapping surveys (TLS), time-lapse photography, and remote-control aircraft to quantify rates and volumes of depositional processes and morphology of fans formed in different settings through time. Sedimentological data and subsurface geophysical surveys are being used to document the sedimentary architecture of icy debris fans. We are in Year 2 of this project and have completed a three-week field effort on the South Island of New Zealand and a two-week field effort in McCarthy Alaska. We collected TLS and ground penetrating radar (GPR) data, and installed time-lapse cameras at four different glaciers. Preliminary analysis shows the subsurface three-dimensional depositional architecture, including lenticular and lobate features that vary in scale, but are consistent with the geometry of debris flow and avalanche deposits.

Broader Impacts: In Years 1 and 2, we trained eight BU undergraduates in working with image analysis, TLS data and GPR data/equipment (Darin Rockwell, Stewart Kabis, Tracey Smith, Erica Rubino, Mattie Reid, Chris Duda, Charles Scales, Alex Pellicciotti). These students were recruited with the goal of retaining students in the geosciences and providing a bridge to graduate school. Geology programs at liberal arts institutions such as BU play an important role in the research training of motivated students, and the majority of graduates pursue a MSc and/or PhD in the geosciences. We presented two conference abstracts at the 2013 fall meetings of the Geological Society of America (Kochel et al. 2013) and American Geophysical Union (Smith et al. 2013). We have submitted two conference abstracts for presentations at 2014 Geological Society of America fall meeting (Rubino et al. 2014 and Reid et al. 2014).

References

Abichou, T., Benson, C.H., and Edil, T.B. (2002). Foundry green sands as hydraulic barriers: field study. *Journal of Geotechnical and Geoenvironmental Engineering*, 128(3), 206-215.

Albrecht, B.A., and Benson, C.H. (2001). Effect of desiccation on compacted natural clays. *Journal of Geotechnical and Geoenvironmental Engineering*, 127(1), 67-75.

Barben, E.J., Malusis, M.A., and Evans, J.C. (2008). Slump evaluation of soil-bentonite backfill amended with activated carbon. *GeoCongress 2008: Geotechnics of Waste Management and Remediation*, ASCE Geotechnical Special Publication 177, 636-643.

Barvenik, M.J. and Ayres, J.E. (1987). Construction quality control and post-construction performance verification for the Gilson Road Hazardous Waste Site cutoff wall. *EPA/600/2-87/065*, U.S. Environmental Protection Agency, Cincinnati, OH.

Benson, C.H. and Dwyer, S.F. (2006). Material stability and applications. In *Barrier Systems for Environmental Contaminant Containment and Treatment*, C.C. Chien, H.I. Inyang, and L.G. Everett, eds., CRC Press, Boca Raton, FL, 143-207.

Benson, C.H., Daniel, D.E., and Boutwell, G.P. (1999). Field performance of compacted clay liners. *Journal of Geotechnical and Geoenvironmental Engineering*, 125(5), 390-403.

Boardman, B.T. and Daniel, D.E. (1996). Hydraulic conductivity of desiccated geosynthetic clay liners. *Journal of Geotechnical Engineering*, 122(3), 204-208.

Bohnhoff, G., Shackelford, C., Malusis, M., Scalia, J., Benson, C., Edil, T., Di Emidio, G., Katsumi, T., and Mazzieri, F. (2013). Novel bentonites for containment barrier applications. *Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering*, Paris, France, Sept. 2-6, in press.

Britton, J.P., Filz, G.M., and Herring, W.E. (2004). Measuring the hydraulic conductivity of soil-bentonite backfill. *Journal of Geotechnical and Geoenvironmental Engineering*, 130(12), 1250-1258.

Cermak, J., Evans, J.C., and Tamaro, G.J. (2012). Evaluation of soil-cement-bentonite wall performance – effects of backfill shrinkage. *Proceedings of the 4th International Conference on Grouting and Deep Mixing*, Geotechnical Special Publication 228, L.F. Johnsen, D.A. Bruce, and M.J. Byle, Eds., ASCE, Reston, VA, 502-511.

Choi, H. and Daniel, D.E. (2006). Slug test analysis in vertical cutoff walls II: Applications. *Journal of Geotechnical and Geoenvironmental Engineering*, 132(4), 439-447.

Daily, W. and Ramirez, A.L. (2000). Electrical imaging of engineered hydraulic barriers. *Geophysics*, 65, 83-94.

Daniel, D.E. (1984). Predicting hydraulic conductivity of clay liners. *Journal of Geotechnical Engineering*, 110(2), 285-300.

D'Appolonia, D.J. and Ryan, C.R. (1979). Soil-bentonite slurry trench cutoff walls. *Proceedings, Geotechnical Exhibition and Technical Conference*, Chicago, Illinois, March 26, www.geo-solutions.com/tech-papers/pdf/slurrywallpdf04.pdf.

Day, S.R. (1994). The compatibility of slurry cutoff wall materials with contaminated groundwater. *ASTM STP 1142, Hydraulic Conductivity and Waste Contaminant Transport in Soil*, D.E. Daniel and S.J. Trautwein, eds., 15 p.

Emsley, S. (2000). Detecting defects in slurry cut-off walls used for liquid containment. *Water Online Newsletter*, July 25, http://www.wateronline.com/doc.mvc/Detecting-defects-in-slurry-cut-off-walls-use-0001.

Evans, J.C. (1993). Vertical cutoff walls. *Geotechnical Practice for Waste Disposal*. D.E. Daniel, ed., Chapman and Hall, London.

Evans, J.C. (1994). Hydraulic conductivity of vertical cutoff walls. *Hydraulic Conductivity and Waste Contaminant Transport in Soils, ASTM STP 1142*, D. E. Daniel and S. J. Trautwein, eds., American Society for Testing and Materials, Philadelphia, 79-94.

Evans, J.C. (1995). Soil- and cement-based vertical barriers with focus on materials. *Assessment of Barrier Containment Technologies – A Comprehensive Treatment for Environmental Applications*.

R. Rumer and J. Mitchell, eds., U.S. Department of Energy, U.S. Environmental Protection Agency, Dupont Company, Baltimore, 5-43.

Evans, J.C. (2007). The TRD method: slag-cement materials for *in situ* mixed vertical barriers. *GeoDenver 2007, New Peaks in Geotechnics,* ASCE Geotechnical Special Publication 172, 1-11.

Evans, J.C. and Ryan, C.R. (2005). Time-dependent strength behavior of soil-bentonite slurry wall backfill. *Waste Containment and Remediation: Proceedings of the Geo-Frontiers 2005 Congress*, ASCE Geotechnical Special Publication No. 142.

Evans, J.C. and Garbin, E.J. (2009). The TRD Method for *in situ mixed* vertical barriers. *Proceedings of the U.S.-China Workshop on Ground Improvement Technologies,* ASCE Geotechnical Special Publication 188, 271-280.

Evans, J.C. Costa, M. and Cooley, B. (1995). The state of stress in soil-bentonite slurry trench cutoff walls. *ASCE Specialty Conference on Characterization, Containment, Remediation and Performance in Environmental Geotechnics, The Geoenvironment 2000,* ASCE Geotechnical Special Publication No. 46.

Evans, J.C., Fang, H.Y., and Kugelman, I.J. (1985). Containment of hazardous materials with soil-bentonite slurry walls," *Proceedings of the 6th National Conference on the Management of Uncontrolled Hazardous Waste Sites*, Washington, D.C., November, 1985, 249-252

Evans, J.C. and Fang, H.Y. (1982). Geotechnical aspects of the design and construction of waste containment systems. *Proceedings of the 3rd National Conference on the Management of Uncontrolled Hazardous Waste Sites*, Washington, D. C., November, 1982, 175-182.

Evans, J.C., Trast, J.M. and Frank, R.L. (2004). Lessons learned from the Macon County slurry wall. *Proceedings: Fifth International Conference on Case Histories in Geotechnical Engineering*, NY, NY, April 13-17.

Filz, G.M. (1996). Consolidation stresses in soil-bentonite back-filled trenches. *Proceedings of the 2nd International Congress on Environmental Geotechnics,* M. Kamon, ed., Osaka, Japan, 497-502.

Filz, G.M., Baxter, D.Y., Bentler, D.J., and Davidson, R.R. (1999). Ground deformations adjacent to a soil-bentonite cutoff wall. *Proceedings, Geo-Engineering for Underground Facilities,* ASCE Geotechnical Special Publication 90, 121-139.

Filz, G.M., Evans, J.C. and Britton, J.P. (2003). Soil-bentonite hydraulic conductivity: measurement and variability. *Proceedings of the 12th PanAmerican Conference on Soil Mechanics and Geotechnical Engineering, VGE, Essen, Germany*, 1323-1328.

Hewitt, R.D. and Daniel, D.E. (1997). Hydraulic conductivity of geosynthetic clay liners after freeze-thaw. *Journal of Geotechnical and Geoenvironmental Engineering*, 123(4), 305-313.

Hong, C., Shackelford, C.D., and Malusis, M.A. (2012). Compressibility and hydraulic conductivity of zeolite-amended soil-bentonite backfills. *Journal of Geotechnical and Geoenvironmental Engineering*, 138(1), 15-25.

Jo, H.Y., Benson, C.H., Shackelford, C.D., Lee, J-M, and Edil, T.B. (2005). Long-term hydraulic conductivity of a geosynthetic clay liner permeated with inorganic salt solutions. *Journal of Geotechnical and Geoenvironmental Engineering*, 131(4), 405-417.

Kochel R.C., Trop, J., Jacob, R. W., Smith, T., Rockwell, D., Kabis, S., & Williams, K. (2013). Integrating terrestrial laser scanning, ground-penetrating radar, and time-lapse photography to understand surficial processes/morphology and subsurface architecture of icy debris fans in deglaciating alpine environments. In *Geological Society of America Abstracts with Programs*, 45(7), in press.

Kolstad, D.C., Benson, C.H., and Edil, T.B. (2004). Hydraulic conductivity and swell of nonprehydrated geosynthetic clay liners permeated with multispecies inorganic solutions. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 130(12), 1236-1249.

Kraus, J.F., Benson, C.H., Erickson, A.E., and Chamberlain, E.J. (1997). Freeze-thaw cycling and hydraulic conductivity of bentonitic barriers. *Journal of Geotechnical and Geoenvironmental Engineering*, 123(3), 229-238.

LaGrega M.L., Buckingham, P.L., and Evans, J.C. (2000). *Hazardous Waste Management*, 2nd Ed., McGraw-Hill Book Company, New York, NY.

Larsson, S. (2005). State of practice report - execution, monitoring and quality control. *International Conference on Deep Mixing. Best Practice and Recent Advances. Deep Mixing ´05*, Stockholm, Sweden, May 23-25.

Lin, L.C. and Benson, C.H. (2000). Effect of wet-dry cyclic swelling on hydraulic conductivity of GCLs. *Journal of Geotechnical and Geoenvironmental Engineering*, 126(1), 40-49.

Malusis, M.A. and McKeehan, M.D (2013). Chemical compatibility of model soil-bentonite backfill containing multiswellable bentonite. *Journal of Geotechnical and Geoenvironmental Engineering*, 139(2), 189-198.

Malusis, M.A., Barben, E.J., and Evans, J.C. (2009). Hydraulic conductivity and compressibility of a model soil-bentonite backfill amended with activated carbon. *Journal of Geotechnical and Geoenvironmental Engineering,* 131(5), 664-672.

Malusis, M.A., McKeehan, M.D., and LaFredo, R.A. (2010a). Multiswellable bentonite for soil-bentonite vertical barriers. *Proceedings, 6th International Congress on Environmental Geotechnics*, New Delhi, India, Nov 8-12, McGraw-Hill, 764-769.

Malusis, M.A., Maneval, J.E., Barben, E.J., Shackelford, C.D., and Daniels, E.R. (2010b). Influence of adsorption on phenol transport through soil-bentonite vertical barriers amended with activated carbon. *Journal of Contaminant Hydrology,* 116, 58-72.

Malusis, M.A., Yeom, S., and Evans, J.C. (2011). Hydraulic conductivity of model soil-bentonite backfills subjected to wet-dry cycling. *Canadian Geotechnical Journal*, 48(8), 198-211.

Malusis, M.A., Shackelford, C.D., and Maneval, J.E. (2012). Critical review of coupled flux formulations for clay membranes based on nonequilibrium thermodynamics. *Journal of Contaminant Hydrology*, 152(1), 133-147.

Millet, R.A., Perez, J.Y., and Davidson, R.R. (1992). USA Practice Slurry Wall Specifications 10 Years Later. *Slurry Walls: Design, Construction, and Quality Control*, ASTM STP 1129, Paul, Davidson and Cavalli, Eds., American Society for Testing and Materials, Philadelphia, PA, 42-68.

Millet, R.A. and Perez, J.Y. (1981). Current USA Practice: Slurry Wall Specifications. *Journal of the Geotechnical Engineering Division*, ASCE, 107(GT8), 1041-1056.

National Research Council (2007). *Assessing the Performance of Surface and Subsurface Engineered Barriers.* National Academies Press, Washington, D.C.

Opdyke, S.M. and Evans, J.C. (2005). Slag-cement-bentonite slurry walls. *Journal of Geotechnical and Geoenvironmental Engineering,* 131(6), 673-681.

Pearlman, L. (1999). Subsurface containment and monitoring systems: Barriers and beyond. *March 1999 Report for U.S. Environmental Protection Technology Innovation Office*, Washington, DC, www.clu-in.info/download/studentpapers/pearlman.pdf.

Petrov, R.J., Rowe, R.K., and Quigley, R.M. (1997). Selected factors influencing GCL hydraulic conductivity. *Journal of Geotechnical and Geoenvironmental Engineering*, 123(8), 683-695.

Pidlisecky, A., Knight, R., and Haber, E. (2006). Cone-based electrical resistivity tomography. *Geophysics*, 71(4), G157-G167.

Podgorney, R.K. and Bennett, J.E. (2006). Evaluating the long-term performance of geosynthetic clay liners exposed to freeze-thaw. *Journal of Geotechnical and Geoenvironmental Engineering*, 132(2), 265-268.

Reid, M.M., Kochel, R.C., Trop, J.M., Jacob, R.W., Duda, M.C., Rubino, E.M., and Williams, K. (2014). Mass wasting processes, geomorphic responses, and temporal evolution of icy debris fans along the La Perouse and Douglas Glaciers, Southern Alps, New Zealand. *Geological Society of America 2014 Meeting*.

Rubino, E.M., Jacob, R.W., Kochel, R.C., Trop, J.M., Reid, M.M., Scales, C.A., Duda, M.C., and Williams, K. (2014). Geophysical investigation of icy debris fans with ground penetrating radar on the La Perouse and Douglas Glaciers, Southern Alps, New Zealand. *Geological Society of America 2014 Meeting*.

Ruffing, D.G. (2009). A reevaluation of the state of stress in soil-bentonite cutoff walls. *MS Thesis*, Bucknell University, Lewisburg, PA.

Ruffing, D. G., and Evans, J. C., (2010). In situ evaluation of a shallow soil-bentonite slurry trench cutoff wall. *Proceedings of the 6th International Congress on Environmental Geotechnics*, New Delhi, India, Tata McGraw-Hill, ISBN 13:9780070707108, 758-763.

Ruffing, D.G., Evans, J.C., and Malusis, M.A. (2010). Prediction of earth pressures in soil-bentonite cutoff walls. *GeoFlorida 2010: Advances in Analysis, Modeling, and Design*, ASCE Geotechnical Special Publication 199, 2416-2425.

Ruffing, D.G., Evans, J.C., and Malusis, M.A. (2011). Evaluations of lateral earth pressure in a soil-bentonite slurry trench cutoff wall. *Proceedings, 14th Pan-American Conference on Soil Mechanics and Geotechnical Engineering*, CD-ROM (ISBN 978-0-920505-47-2).

Ruffing, D.G., Evans, J.C., and Malusis, M.A. (2012). Long term in situ measurements of the volumetric water content in a soil-bentonite slurry trench cutoff wall. *State of the Art and Practice in Geotechnical Engineering, Proceedings of the 2012 GeoCongress*, ASCE Geotechnical Special Publication 225, 3429-3436.

Ryan, C.R. (1987). Vertical barriers in soil for pollution containment. *Geotechnical Practice for Waste Disposal '87, Geotechnical Special Publication No. 13*, R. Woods, ed., Reston, VA, ASCE, 182-204.

Ryan, C.R. and Day, S.R. (2003). Soil-bentonite slurry wall specifications. *Pan American Conference on Soils Mechanics & Geotechnical Engineering, ASCE Geo-Institute and MIT, Cambridge, MA*, 8 p.

Ryan, C.R. and Spaulding, C.A. (2008). Strength and permeability of a deep soil bentonite slurry wall. Proceedings of the Geo-Congress 2008, ASCE Geotechnical Special Publication 177, 644-651.

Shackelford, C.D. (1994). Waste-soil interactions that alter hydraulic conductivity. *ASTM STP 1142, Hydraulic Conductivity and Waste Contaminant Transport in Soil*, D.E. Daniel and S.J. Trautwein, eds., 111-168.

Shackelford, C.D. (2011). Membrane behavior in geosynthetic clay liners. *Geo-Frontiers 2011*: *Advances in Geotechnical Engineering*, J. Han and D.E. Alzamora, eds., ASCE Geotechnical Special Publication 211 (CD-ROM), 1961-1970.

Shackelford, C.D. (2012). Membrane behavior of engineered clay barriers for geoenvironmental containment: state of the art. *GeoCongress 2012, State of the Art and Practice in Geotechnical Engineering*, R.D. Hryciw, A. Athanasopoulos-Zekkos, and N. Yesiller, eds., ASCE Geotechnical Special Publication 225, 3419-3428.

Shackelford, C.D. (2013). Membrane behavior in engineered bentonite-based containment barriers: state of the art. *Coupled Phenomena in Environmental Geotechnics*, Proceedings of the International Symposium, ISSMGE TC-215, Torino, Italy, July 1-3, M. Manassero, A. Dominijanni, S. Foti, and G. Musso, Eds., Taylor and Francis Group, London, UK, 45-60.

Shackelford, C.D. and Javed, F. (1991). Large-scale permeability testing of a compacted clay soil. *ASTM Geotechnical Testing Journal*, 14(2), 171-179.

Southen, J.M. and Rowe, R.K. (2005). Laboratory investigation of geosynthetic clay liner desiccation in a composite liner subjected to thermal gradients. *Journal of Geotechnical and Geoenvironmental Engineering*, 131(7), 925-935.

Smith, T., Jacob, R.W., Trop, J., Williams, K., and Kochel, R.C. (2013). Geophysical Investigation of Subsurface Characteristics of Icy Debris Fans with Ground Penetrating Radar in the Wrangell Mountains, Alaska. *AGU Fall Meeting Abstracts*, American Geophysical Union, Washington, D.C., in review.

Stern, R.T. and Shackelford, C.D. (1998). Permeability of sand-processed clay mixtures with calcium chloride solutions. *Journal of Geotechnical and Geoenvironmental Engineering*, 124(3), 121-131.

F. Biographical Sketch for Jeffrey C. Evans, P.E.

(i) Professional Preparation

Clarkson University, Civil and Environmental Engineering, B.S., 1973
Purdue University, Civil Engineering, M.S., 1974
Lehigh University, Civil Engineering, Ph.D., 1984

(ii) Appointments

Bucknell University, Department of Civil and Environmental Engineering Professor, 1994-Present; Chair, 2003-13; Associate Professor, 1988-94; Assistant Professor, 1985-88
Cambridge University, Cambridge, England, Academic Visitor, 2012-2113 (sabbatical)
University of Nottingham, Nottingham, England, Visiting Academic, 1998-99 (sabbatical)
Warren Spring Laboratory, Stevenage, England, Sr. Scientific Officer, 1991-92 (sabbatical)
Lehigh University, Adjunct Associate Professor of Civil Engineering, 1984-85
Woodward-Clyde Consultants, Staff, Project and Senior Project Engineer, 1975-85
U.S. Army, Corps of Engineers Reserves, 2nd Lieutenant, 1st Lieutenant and Captain, 1973-81
Purdue University, Teaching Assistant, 1973-74
Mobile Drilling Company, Research Engineer, 1974
Karteganer Associates, Staff Engineer, 1973

(iii) Publications

Ruffing, D.G. and Evans, J.C. (2014) "Interpretation of Cone Penetration Data in Soil-Bentonite Slurry Trench Cutoff Walls" Accepted for publication *Proceedings of the International Foundations Congress and Equipment Exposition*, San Antonio TX March 17-21, 2015

Evans, J.C. and Jefferis, S.A (2014) "Volume Change Characteristics of Cutoff Wall Materials" *Proceedings of the 7th International Congress on Environmental Geotechnics*, Melbourne, AU, November 10-14, in press.

Soga, K., Joshi, K. and Evans, J. C. (2013) “Cement bentonite cutoff walls for Polluted sites.” *Coupled Phenomena in Environmental Geotechnics*, 149.

Ruffing, D. G., Evans, J.C., Malusis, M.A. (2012) “Long Term In Situ Measurements of the Volumetric Water Content in a Soil Bentonite Slurry Trench Cutoff Wall.” *ASCE State of the Art and Practice in Geotechnical Eng. GSP 225,* pp. 3429-3436.

Malusis, M.A., Yeom, S., and Evans, J.C. (2011). “Hydraulic conductivity of model soil-bentonite backfills subjected to wet-dry cycling.” *Canadian Geotechnical Journal*, 48(8), 198-211.

Ruffing, D. G., Evans, J. C., and Malusis, M. A. (2011) “Evaluations of Lateral Earth Pressure in a Soil-Bentonite Slurry Trench Cutoff Wall" *Proceedings of the 2011 Joint Pan American and Canadian Geotechnical Society Conference*, Toronto, Canada

Ruffing, D. G., Evans, J. C., and Malusis, M. A., (2010) “Prediction of Earth Pressures in Soil-Bentonite Cutoff Walls,” *ASCE GeoFlorida 2010 Advances in Analysis, Modeling and Design GSP 199,* pp. 2416-2425.

Malusis, M. A., Barben, E. J., and Evans, J. C. (2009) “Hydraulic Conductivity and Compressibility of Soil-Bentonite Backfill Amended with Activated Carbon” *ASCE J. of Geotechnical and Geoenvironmental Engineering,* Volume 135, No. 3, pp. 664-672.

Malusis, M. A., Evans, J. C., McLane, M. H. and Woodward, N. R., (2008) “A Miniature Cone for Measuring the Slump of Soil Bentonite Slurry Trench Cufoff Wall Backfill,” *ASTM Geotechnical Testing Journal*, Vol. 31, No. 5, (September 2008).

LaGrega M. L., Buckingham, P. L., and Evans, J.C., Hazardous Waste Management, 2nd Ed., Waveland Press, New York, NY, 2010 (reissue).

(iv) Synergistic Activities

- Developed and offered geotechnical engineering module to STEM students attending Engineering Camp at Bucknell University in 2011, 2112 and 2013.
- In service to the profession at the national level, Dr. Evans is a President of the Board of Directors of USUCGER and organized an early career workshop in Boston in 2012.
- Dr. Evans co-developed a study abroad course entitled "Engineering in a Global and Societal Context." He co-taught the course for the first time in the UK in 2004 and has since co-led the course in the UK (2006), Argentina (2007), Norway/Sweden (2009) and Argentina (2013).
- Dr. Evans developed a successful exchange program with the University of Nottingham in the UK enabling numerous Bucknell and Nottingham engineering students to study abroad in a programs that have proven compatible for over 15 years.
- Dr. Evans has provided consulting services on cutoff wall projects including the Herbert Hoover Dike, the Wolf Creek Dam and the Tuttle Creek Dam.

(v) Collaborators and other Affiliations

a) Collaborators and Co-Editors

Dawson. A.	Uni. of Nottingham (paper)
Daniel, D.	UT- Dallas (book chapter)
Elton, D.	Auburn U. (book)
Filz, G.	Virginia Tech (paper)
Lynch D.	Dartmouth (paper)
Malusis, M.	Bucknell (papers/book)
Maneval, J.	Bucknell (paper)
Prince. M.	Bucknell (papers)
Russell, J.	Wisconsin (papers)
Shackelford, C.	CSU (papers)
Soga, K.	Cambridge (paper)

b) Graduate Advisors

Fang, H. Y. Lehigh University
Kovacs, W. D. University of Rhode Island
Lovell, C. W. Purdue University

c) Thesis Advisor and Postgraduate Sponsors

1. Sandy (Zbicki) Tosca: PA DoT
2. Stephen Pancoski: Optima Technology Associates,
3. Stephen Zarlinski: CH2M Hill
4. Troy Adams: Delaware DoT
5. Bradford Cooley: Propex Geosyn.
6. Michael Costa: Investment advisor
7. Douglas Beveridge: Alexander Group
8. Holly Borcherdt: employment unknown
9. William Reichardt: Reichardt Drilling
10. William Rinker: Kleinfelder
11. Raymond Robbins: consultant
12. John Henning: Dawood Consulting
13. Stephan Lacz, Steve S&ME
14. Shana (Opdyke) Carroll: GeoStructures
15. Meghan Lithgow: Group Delta Consultants, Inc.
16. Sean McCarthy: ARM Group, Inc.
17. Jeff Orazi: Whiting-Turner
18. SeungCheol Yeom: Drexel PhD candidate
19. Chris Kulish, ARM Group, Inc.
20. Andi Sicwebu: Golder Associates

Robert W. Jacob
Assistant Professor
Department of Geology
Bucknell University
Lewisburg, PA 17837 USA
Phone: 570-577-1791, Fax: 570-577-3031, E-mail: rob.jacob@bucknell.edu

Education

Bucknell University	Geology	BS 1997
Brown University	Geological Sciences	MS 2003
Brown University	Geological Sciences	Ph.D. 2006
Brown University	Hydrogeophysics and Soil Physics	Post-Doc 2006 - 2008

Professional Experience

2008-present, Bucknell University, Assistant Professor of Geology
2010, Forschungszentrum Jülich, Agrosphere Division, Germany, Visiting Academic (untenured leave)
2006-2008, Rhode Island School of Design, Providence, RI, Adjunct Professor - Geology
2001-2008, Conrad Consulting, Geophysics Division, Providence, RI, Geophysicist
2001-2006, Brown University, Providence, RI, Research and Teaching Assistant
1997-2001, Roy F. Weston, Inc., West Chester, PA, Associate Geophysicist and Geologist

Products

(i) Closely related products

Jacob, R.W. and Urban, T. M. (accepted – August 2014) Ground-penetrating radar velocity determination and precision estimates using common-mid-point (CMP) collection with hand-picking, semblance analysis, and cross-correlation analysis: a case study and tutorial for archaeologists. Archaeometry

Jacob, R.W., Byler, J.B. and Gray, M.B. (2013) Integrated Geophysical Investigation of the St. James Fault Complex: a Case Study. Geophysics, Vol. 78 No. 5, B275-B285

Hermance, J.F., Jacob, R.W., and Bohidar, R. (2010) Composite Moveout Correction to a Shallow Mixed Reflection/Refraction GPR Phase. In Advances in Near-surface Seismology and Ground-penetrating Radar (editors: Miller, R., Bradford J., and Holliger, K.) publisher SEG.

van der Kruk, J., Jacob, R.W., and Vereeken, H. (2010) Properties of precipitation induced multi-layer surface waveguides derived from inversion of dispersive TE and TM GPR data. Geophysics 75 (4):

Jacob, R.W. (2006) Precision Ground Penetrating Radar Measurements to Monitor Hydrologic Processes Occurring in Unsaturated Subsurface Material. PhD Dissertation, Brown Univ., Providence, RI. p. 135.

(ii) Other significant products

Jacob, R.W. and Hermance, J.F. (2005) Random and non-random uncertainties in precision GPR measurements: Identifying and compensating for instrument drift. Subsurface Sensing Technologies and Applications Journal 6 (1): 59-71.

Jacob, R.W. and Hermance, J.F. (2004) Assessing the precision of GPR velocity and vertical two-way travel time estimates. Journal of Environmental and Engineering Geophysics 9 (3): 143-153.

Vesconi, M. A., Wright, S. P., Spagnuolo, M., Jacob, R., Cerrutti, C., Garcia, L., Fernandez, E. and Cassidy, W. A. (2011), Comparison of four meteorite penetration funnels in the Campo del Cielo crater field, Argentina. Meteoritics & Planetary Science, 46: 935–949.

Bradley, B.A., Jacob R.W., Hermance, J.F., and Mustard, J.F. (2007) A curve-fitting technique to derive inter-annual phenologies from time series of noisy satellite data. Remote Sensing of Environment 106: 137-145.

Deb, Arun K, Hasit, Y., Williams Jr., J.A., and Jacob, R.W. (2001) New Techniques for Precisely Locating Buried Infrastructure. AWWA Research Foundation and the Amer. Water Works Assoc., Denver, CO. p. 158.

Synergistic Activities (Past 5 years listed)

- Teaching and research are dedicated to undergraduate education, from collaborative research that encourages students to carry out field work all over the world (New Zealand, Alaska, Pennsylvania and Greece are most recent) and analyze and publish their data, to developing grant proposals.
- Watershed restoration project combining topographic surveying (RTK-GPS, laser theodolite, and limited TLS data – ground-based LiDAR data) and geophysics (resistivity, electromagnetic, seismic refraction, gravity, magnetic, and GPR) with Civil Engineers, Soil Scientists and Biologists.
- For the near surface geophysics community: Organizing comm. for 2012 Hydrogeophysics Workshop in Boise, Idaho. President – Near Surface Geophysics Section (NSGS) of Society of Exploration Geophysicists (SEG) – 2009.
- For the general public: I have been interviewed by local media in response to earthquake felt in community. Bucknell Geology Open House. Provided elementary teachers in the Hopkington, MA school district with examples and hands-on demonstration for soil science lessons.
- For the geoscience community: Reviewed journal articles and proposals (NSF and Univ. of Wisconsin Water Resources Institue). Instructor for NSF sponsored Near Surface Geophysics and Hydrogeophysics workshops at Penn State Univ. for undergraduate students.

.**Collaborators & Other Affiliations**

Collaborators:

Anandakrishnan, S.	Penn State University (associated scientist on funded project)
Cassidy, W.	University of Pittsburgh (papers)
Daly, K.	Bucknell University (project and accepted manuscript)
Evans, J.	Bucknell University (this proposal)
Gray, M.B.	Bucknell University (paper)
Hermance, J.	Brown University (papers, proposals, projects)
Kochel, R.C.	Bucknell University (funded proposal, project)
Kruk, J.v.d.	Research Centre Jülich (papers)
Larson, S.	Bucknell University (project and accepted manuscript)
Malusis, M.	Bucknell University (this proposal)
Singha, K.	Colorado School of Mines (project and pending manuscript)
Sak, P.	Dickenson College (unfunded proposal)
Trop, J.	Bucknell University (funded proposal, project)
Urban, T.	Oxford University and Brown University (papers, proposals, projects)

Graduate and Postdoctoral Advisors:

Graduate and Postdoctoral Advisor: Prof. John Hermance, Brown University (MS and Ph.D.)

Thesis Advisor and Postgraduate-Scholar Sponsor:

Matt Sirianni, Florida Atlantic University (former B.S. student, current Ph.D. student)
Tracey Smith, Key Environmental Inc. (former B.S. student)
Jon Algeo, Rutgers University, Newark (former B.S. student, current Ph.D. student)
Emily Bitely, University of Arkansas (former B.A. student, M.Sc. Univ. of Arkansas)
Jeremy Byler, ARM, Inc. (former B.A. student)
Akmal Daniyarov, Andisiwe Sicwebu ,Daniel Ruffing, (M.S. thesis committee)
Anne Strader, University of California, Los Angeles (former B.S. student, current Ph.D. student)
Total number of graduate students advised: 0

Michael A. Malusis
Associate Professor
Department of Civil and Environmental Engineering
Bucknell University
Lewisburg, PA USA
Phone: 570-577-1683, Fax: 570-577-3415, E-mail: michael.malusis@bucknell.edu

Professional Preparation

Bucknell University	Civil Engineering	BS	1989
Colorado State University	Civil (Geotechnical) Engineering	MS	1995
Colorado State University	Civil (Geotechnical) Engineering	Ph.D.	2001

Appointments
2012-present, Bucknell University, Associate Professor of Civil & Environmental Engineering
2005-2012, Bucknell University, Assistant Professor of Civil & Environmental Engineering
2003-2005, Sentinel Consulting Services, LLC, Englewood, Colorado, Principal, Senior Engineer
2000-2003, GeoTrans, Inc., Westminster, Colorado, Project/Senior Engineer
1993-2000, Colorado State University, Research and Teaching Assistant

Products
(i) Closely related products

Ruffing, D.G., Evans, J.C., and Malusis, M.A. (2012). Long term in situ measurements of the volumetric water content in a soil-bentonite slurry trench cutoff wall. *State of the Art and Practice in Geotechnical Engineering, Proceedings of the 2012 GeoCongress*, Geotechnical Special Publication 225, ASCE, Reston, Va., 3429-3436.

Malusis, M.A., Yeom, S., and Evans, J.C. (2011). Hydraulic conductivity of model soil-bentonite backfills subjected to wet-dry cycling. *Canadian Geotechnical Journal*, 48(8), 198-211.

Ruffing, D.G., Evans, J.C., and Malusis, M.A. (2011). Evaluations of lateral earth pressure in a soil-bentonite slurry trench cutoff wall. *Proceedings, 14th Pan-American Conference on Soil Mechanics and Geotechnical Engineering*, CD-ROM (ISBN 978-0-920505-47-2).

Ruffing, D.G., Evans, J.C., and Malusis, M.A. (2010). Prediction of earth pressures in soil-bentonite cutoff walls. *GeoFlorida 2010: Advances in Analysis, Modeling, and Design*, Geotechnical Special Publication 199, ASCE, Reston, Va., 2416-2425.

Malusis, M.A., Barben, E.J., and Evans, J.C. (2009). Hydraulic conductivity and compressibility of a model soil-bentonite backfill amended with activated carbon. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 131(5), 664-672.

(ii) Other significant products

Malusis, M.A. and McKeehan, M.D (2013). Chemical compatibility of model soil-bentonite backfill containing multiswellable bentonite. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 139(2), 189-198.

Hong, C., Shackelford, C.D., and Malusis, M.A. (2012). Compressibility and hydraulic conductivity of zeolite-amended soil-bentonite backfills. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 138(1), 15-25.

Malusis, M.A., Maneval, J.E., Barben, E.J., Shackelford, C.D., and Daniels, E.R. (2010). Influence of adsorption on phenol transport through soil-bentonite vertical barriers amended with activated carbon. *Journal of Contaminant Hydrology*, 116, 58-72.

Malusis, M.A., Evans, J.C., McLane, M.H., and Woodward, N.R. (2008). A miniature cone for measuring the slump of soil-bentonite slurry trench cutoff wall backfill. *Geotechnical Testing Journal,* ASTM, 31(5), 373-380.

Barben, E.J., Malusis, M.A., and Evans, J.C. (2008). Slump evaluation of soil-bentonite backfill amended with activated carbon. *GeoCongress 2008: Geotechnics of Waste Management and Remediation*, Geotechnical Special Publication 177, ASCE, Reston, Va., 636-643.

Synergistic Activities

- Associate Editor for the ASCE *Journal of Geotechnical and Geoenvironmental Engineering*.
- Invited discussion leader for Session 1 (Landfill Bottom and Side Lining Systems), TC-215 Symposium on Coupled Flows in Environmental Geotechnics, Politecnico di Torino, Italy, July 1-3, 2013.
- Member of the ASCE GeoInstitute (GI) and the GI Geoenvironmental Committee.
- Session Co-Chair, Track B, Session 21 (Innovations in Engineered Barriers for Geoenvironmental Containment) of ASCE GeoCongress 2014 (Atlanta, GA).
- Director of the Bucknell University Writing Program.

Collaborators & Other Affiliations

Collaborators:

Benson, C.	University of Wisconsin (paper)
Bohnhoff, G.	University of Wisconsin-Platteville (paper)
Di Emidio, G.	Ghent University (paper, research project)
Edil, T.	University of Wisconsin (paper)
Elton, D.	Auburn University (book)
Evans, J.	Bucknell University (book, papers, proposals, research projects)
Jacob, R.	Bucknell University (proposal)
Kang, J.	Engineering Analytics (paper)
Katsumi, T.	Kyoto University (paper)
Maneval, J.	Bucknell University (paper)
Mazzieri, F.	Universita Politecnica delle Marche (paper)
Ruffing, D.	Geo-Solutions (papers, research projects)
Scalia, J.	Exponent (paper)
Shackelford, C.	Colorado State University (papers, proposals, research projects)
Wakabayashi, K.	Bucknell University (paper, research project)

Graduate and Postdoctoral Advisors:
Prof. Charles D. Shackelford, Colorado State University (MS and Ph.D.)

Thesis Advisor and Postgraduate-Scholar Sponsor:
Melissa Replogle, Bucknell University (current MS student)
Akmal Daniyarov, Bucknell University (MS)
Matthew McKeehan, U.S. Army (MS)
Seung-Choel Yeom, Drexel University (MS, co-advised with J. Evans)
Edward Barben, Gannett Fleming (MS)
Total number of graduate students advised: 5
Total number of undergraduate students advised: >10

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Jeffrey Evans

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Field Testing and Monitoring of an Experimental Soil-Bentonite Cutoff Wall

Source of Support: NSF

Total Award Amount: $ 383,177 Total Award Period Covered: 03/01/15 - 02/28/18

Location of Project: Bucknell University

Person-Months Per Year Committed to the Project. Cal: 0.00 Acad: 0.00 Sumr: 1.00

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: NEESR-CR: Phase Transition and Post-Liquefaction Strength of Cohesionless Soils

Source of Support: NSF

Total Award Amount: $ 147,148 Total Award Period Covered: 10/01/09 - 09/30/14

Location of Project: Bucknell University

Person-Months Per Year Committed to the Project. Cal: 0.00 Acad: 0.00 Sumr: 1.00

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Robert Jacob

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Geomorphic Response of Glacial Decoupling in Alpine Regions in Response to Climate Warming: Icy Debris Fans and Early Paraglacial Landscape Evolution.

Source of Support: NSF-EAR

Total Award Amount: $ 275,552 Total Award Period Covered: 01/01/13 - 12/31/15

Location of Project: Bucknell University

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 0.50

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Field Testing and Monitoring of an Experimental Soil-Bentonite Cutoff Wall

Source of Support: NSF

Total Award Amount: $ 383,177 Total Award Period Covered: 03/01/15 - 02/28/18

Location of Project: Bucknell University

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 1.00

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Michael Malusis

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Field Testing and Monitoring of an Experimental Soil-Bentonite Cutoff Wall

Source of Support: NSF

Total Award Amount: $ 383,177 Total Award Period Covered: 03/01/15 - 02/28/18

Location of Project: Bucknell University

Person-Months Per Year Committed to the Project. Cal: 0.00 Acad: 0.00 Sumr: 1.00

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

 USE ADDITIONAL SHEETS AS NECESSARY

Facilities, Equipment and Other Resources

The Jeffrey C. Evans Geotechnical Engineering Laboratory at Bucknell University is a new facility on the ground floor of the Breakiron Engineering Building and includes 1,250 square feet of space. This space is divided into three rooms: 1) main room with perimeter laboratory benches and services and four large work tables centered within the space, 2) sample preparation room with oven, chemical hood and outside access, and 3) lockable computation room with desks, networked computers, printer, bookshelves and filing cabinets.

The Geotechnical Engineering Laboratory is equipped with modern soil mechanics equipment positioned around the perimeter of the space where compressed air, vacuum, water, and drain connections are located to service soil testing equipment. Equipment available to determine engineering properties of soils includes triaxial control panels with 21 stations for shear strength and permeability measurements, four direct shear devices, fourteen consolidometers, five computer-controlled loading frames for triaxial strength or automated consolidation testing. The laboratory also has a Quanser Shake Table II including full instrumentation and computer control and data acquisition for use on this project. In addition, equipment available for physical property testing includes sieves, sieve shakers, hydrometers and hydrometer jars for grain size distribution; liquid limit devices and glass plates for Atterberg Limit determinations; compaction molds and hammers to determine density-moisture relationships; and an oven and balance for moisture content determinations. In addition, a flow pump and chemico- osmotic efficiency unit is operating in the geotechnical engineering laboratory and three more flow-pump systems are being assembled. The laboratory is equipped with a hood for working with volatile materials.

The Robert Brungraber Building houses Bucknell University's drilling rig and field geotechnical equipment. The Department has a remotely driven, track mounted, Acker drilling rig secured with NSF-MRI funds for slurry wall research. The drilling rig is transported to the site on its own trailer pulled with the 4wd Department truck purchased for this purpose. Once on site, the track-mounted rig readily navigates the messy work space associated with slurry wall construction. In addition to the drilling rig itself, the Brungraber Building houses 100 ft of 4" ID hollow stem augers and tools/equipment for in situ testing and sampling. Capabilities include cone penetration testing (CPT), Marchetti dilatometer testing, ground movement monitoring (inclinometers), vane shear testing, standard penetration testing and sampling, and thin-walled piston sampling. While the drilling rig is not heavy enough for CPT testing in dense soils, experience has demonstrated the rig works well when testing with the CPT in soil-bentonite backfill. PI's Evans, Malusis, and Jacob have experience operating the drilling rig and in situ devices as does our Director of Laboratories described below.

Another resource available for this project is Mr. Jim Gutelius, Director of Laboratories for the Department of Civil and Environmental Engineering. Mr. Gutelius has over 25 years experience in research support including 14 years with IBM and is co-holder of a patent entitled *Computer equipment having an earthquake damage protection mechanism* (United States Patent 6059251 issued on May 9, 2000). He will provide assistance in various aspects of the research, including equipment development and materials acquisition, and has at his disposal a fully equipped project development laboratory (machine shop) and supporting staff members available to assist in any fabrication needs for the project. He also has experience operating the drilling rig and conducting the proposed *in-situ* tests.

The Environmental and Engineering Geophysics facility at Bucknell University has dedicated space for equipment storage, repair, and maintenance. In addition, the facility has two work-stations capable of processing geophysical data and running MATLAB inversion codes to analyze the electrical resistivity data. Geophysical equipment include a Sting R1 with Swift automatic switching electrical resistivity system, a PulseEKKO Pro GPR system with 100, 200, 500, and 1000 MHz separable antennas, a L&R Graviton gravimeter, a Geonics EM-31, a Geometrics G-858 magnetometer, and a Seistronix RAS-24 seismic system. Necessary software for downloading, processing, analyzing, and interpreting are owned by Bucknell and routinely used by Jacob and Geophysics undergraduate students. A Trimble R8, RTK-GPS and 5600 robotic total station are also available for this project. Co-PI Jacob routinely checks the calibration for all geophysical and surveying equipment, in addition all equipment has been calibrated by manufacturer or representative within last 5 years. Jacob also has experience trouble-shooting and fixing all geophysical and surveying equipment.

The data and related electronic files will be stored and preserved in Bucknell University's Digital Library as part of the Digital Commons, as stated in data management plan. The data stored here is no cost to the project and is available to the public. When appropriate, geospatial data will be saved as an ArcGIS geodatabase and/or a KMZ file for Google Earth. Bucknell University owns multiple shared licenses for ArcGIS (release 10 currently) and has a GIS specialist (Janine Glather). The computers available to geology and engineering students have ArcGIS installed and are capable of processing data. For any intensive ArcGIS data processing required during the project (none is currently envisioned), the high-end workstations in the geophysics lab have single copy licenses for ArcGIS 10 and are available for use on this project.

Data Management Plan

In an effort to facilitate data-sharing, this data management plan includes types of data, standards for data form, policies for access and sharing, policies for data reuse, and plans for archiving the data. The plan is robust and offers current and future researchers access to a unique data set for analysis and reanalysis as the profession develops.

1. Types of data

The investigation of the in situ behavior of a soil-bentonite (SB) slurry trench cutoff wall through the construction, instrumentation, in situ testing, laboratory testing, analysis and modeling will result in the production of numerous data types, physical samples, and educational materials. The types of data expected are described in this section.

Site characterization will be accomplished using geophysical methods. The geophysical data will be maintained in the raw format with electronic copies of data collection notes. The notes must include time, date, GPS location of the measurements, equipment used, and specifics of data collection procedure.

Construction of the SB wall will generate construction information regarding the mix proportions at the slurry plant, slurry storage and use, slurry viscosity, density, and filtrate characteristics, excavation depth, width and length, backfill slump and water content, excavation starter slope, backfill slope beneath slurry, and slurry level in the trench. Also of this data must include date, time and location (GPS coordinates and depth) information.

Samples of the formation soils and samples of the SB backfill will be obtained using ASTM standardized sampling methods. Data associated with these samples include date, time, location (GPS coordinates and depth), and sampling method. These samples will tested in the geotechnical engineering laboratory. Laboratory tests for water content, grain size distribution, Atterberg Limits, consolidation, permeability, and shear strength will all produce data and results associated with the test methods.

In situ tests including cone penetration tests (CPT), Marchetti dilatometer tests (DMT), standard penetration tests (SPT), and push-in earth pressure cells are all planned for this project. These in situ tests will produce raw data files (such as A and B readings from the DMT) as well results files (such as dilatometer modulus versus depth for the DMT). All in situ testing will have associated date, time and location (GPS coordinates and depth) data.

In situ instrumentation planned for the project include earth pressure cells at three orientations and two locations (total of six), up to fifty electrodes for geophysical investigations, and Casagrande piezometers. The earth pressure cells and Casagrande piezometers will generate earth pressure and ground water levels, respectively, that are connected with date, time and location data. The electrodes will generate electropotentials in the format of the geophysical equipment used – text file for the AGI Sting resistivity meter planned containing time, date, applied current, and measured voltage. The notes collected at time of electrical resistance data collection must include time, date, GPS location of the measurements, and specifics of data collection procedure. The resistivity data will be maintained in the raw format with electronic copies of data collection notes. Interpretations and graphical representations of these results will also be generated.

The above data types will be integrated during the analysis phase, generating additional data sets that correspond to graphical representations of the results. These analyzed data sets will also generate input data for modeling efforts and the modeling, in and of itself, will generate input and output data files.

2. Standards for data and metadata

While the investigations and research questions for this project are unique, the types of data generated are common as can be seen in the data type descriptions presented in section 1 of this Data Management Plan. As a result the data will recorded and analyzed using standard formats appropriate for the test type. This will require the use of data forms for many of the field and laboratory measurements and project specific data forms will be developed in advance of the actual testing. Similarly, some data will be recorded in field data loggers and transferred to personal computers. All data will be imported into readily available software (MS Word and MS Excel) for archiving and for future analysis and modeling. Standard analyses methods will be employed as per ASTM or other appropriate procedures.

In order to facilitate their use and retrieval, a project file naming scheme will be developed that can be indexed. Electronic data will be stored on public space allocated on Bucknell University's server with automated backup also provided by the University. Industry standards for file format assure these files will be accessible to researchers.

3. Policies for re-use and redistribution

This project is expected to produce a definitive understanding of the state of stress in SB cutoff walls and an improved understanding of long-term behavior as well as insight into the use of geophysics to detect defects in a constructed wall. With these objectives in mind, the proposers are not placing limitations on the redistribution or reuse of the data. Web-based access to the data base will be provided. Uses must acknowledge the source of the data as with appropriate journalistic practices.

4. Plans for archiving data

The data and related electronic files will be stored and preserved in Bucknell University's Digital Library as part of their Digital Commons. This service is provided by our Library and Information Technology group. Initial space allocation is 200 GB (with possible increases in the future) in size, and will be stored, preserved, and made accessible at no cost to the project. The PI(s) will evaluate, distill, and select the data for preservation, and supply traditional and contextual metadata that will be reviewed and augmented as appropriate by librarians who are experts in digital repositories, including data and metadata organization and management. The data sets, associated publications, and metadata will be deposited and preserved in the digital repository for a period of 5 years after project completion.

R.S.T. INSTRUMENTS LTD.
11545 Kingston Street
Maple Ridge BC V2X 0Z5 Canada
Tel: 604 540-1100
Fax: 604 540-1005
www.rstinstruments.com
HST/GST No: 802836577
BC PST No. PST-1006-2953

ISO 9001

BUCKNELL UNIVERSITY
DEPARTMENT OF CIVIL & ENVIRONMENTAL ENG.
JEFFREY C. EVANS
LEWISBURG, PA 17837
USA

QUOTE

No.	**102020**
Date	09-Sep-2014
Customer ID	BUCKUNI/10666
Contact	RAHAN
Page	1 / 3

Fax (570) 577-3415

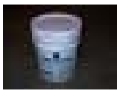
Your inquiry: Q102020

BUDGETARY QUOTE - MISSING BENTONITE

Pos	Item Description	Qty	Unit	Price USD	Value USD
	TASK 1 - IN SB CUTOFF WALL BACKFILL, MEASURE EARTH PRESSURE AT TWO LOCATIONS ON ALL THREE LOCATIONS				
1	**LPPBM-230** PASTE BACKFILL MONITOR INCLUDES: (3) VW TOTAL PRESSURE CELLS, CABLE ASSEMBLY BOX WITH WATERPROOF BLOCKOUTS, FRAME. PRESSURE RANGE TO BE DETERMINED. TBD - 25M PRESSURE RANGE - CABLE LENGTH	**4**	**PCS**	3,255.00	13,020.00
2	**EL380012** CABLE, 12C 24AWG, PP, KEVLAR, WB, BLK POLYURETHANE JACKET	**100**	**M**	9.35	935.00
	TASK 2 - MEASURE EARTH PRESSURE AT VARIOUS LOCATIONS, DEPTH AND TIMES				
3	**VWPC2100-0.35** 0.35 MPa VW PUSH-IN PRESSURE CELL W/ CPT 12M CABLE LENGTH	**1**	**EA**	1,950.00	1,950.00
4	 **EL380006** 6 CONDUCTOR 22AWG 0SD PP INSUL WB POLYURETHANE JACKET CABLE	**12**	**M**	5.90	70.80
	TASK 3 - MEASURE CONSOLIDATION OVER TIME				

QUOTE | **No.** 102020
Date 09-Sep-2014

BUCKNELL UNIVERSITY

Pos	Item Description	Qty	Unit	Price USD	Value USD
5	 **SS0001** SETTLEMENT PLATE-PLYWOOD 24x24" w/FLANGE	**6**	**EA**	44.50	267.00
6	 **FIPS00150** 1-1/2" STEEL PIPE SCH40 x 5ft THREADED	**6**	**EA**	25.50	153.00
	TASK 4 - MEASURE GROUND WATER LEVELS AND PORE PRESSURE				
7	 **PP0324** CASAGRANDE type STANDPIPE PIEZOMETER 24"	**10**	**EA**	55.00	550.00
8	**EPA075410** PVC THREADED PIPE 3/4" S40 x 10' SOLID UW	**20**	**EA**	12.60	252.00
9	 **EP2002C** COATED BENTONITE PELLET 3/8" DIAMETER, 50 LB. PAIL	**3**	**EA**	102.00	306.00
10	 **WL1015** 15m WATER LEVEL METER - POLY TAPE	**1**	**EA**	497.00	497.00
11	 **ICSC205** 2.75"/70mm INCLINOMETER CASING SNAP SEAL x 1.52m/5'	**12**	**EA**	46.25	555.00
12	 **ICSC2BC** 2.75"/70mm INCLINOMETER CASING SNAP SEAL BOTTOM CAP	**2**	**EA**	14.00	28.00
13	 **ICC2TC** 2.75"/70mm INCLINOMETER TOP CAP	**2**	**EA**	4.00	8.00
	TASK 6 - DATALOGGERS FOR ABOVE INSTRUMENTATION				

Q U O T E

BUCKNELL UNIVERSITY

N o .	**102020**
Date	09-Sep-2014
Page	3 / 3

Pos		Item Description	Qty	Unit	Price USD	Value USD
14		**DT2055B** 10 CHANNEL DATALOGGER (5 CABLE GLANDS)	**4**	**EA**	1,368.00	5,472.00
14.1		**CUSB2-AM506** CABLE, USB A-MINI B 5PIN 6ft	**4**	**EA**		
14.2		**MIG0280** RESOURCE DVD - data file: users manual only	**4**	**EA**		
		TASK 7 - SUCTION PRESSURES IN UNSATURATED ZONE				
15		**VW2100-0.7** VIBRATING WIRE PIEZOMETER 0.7 MPa CABLE LENGTH TO BE CONFIRMED. 15M EL380004 CABLE LENGTH	**4**	**EA**	440.00	1,760.00
16		**VW2100-HAE-2** HIGH AIR ENTRY FILTER STONE OPTION - 2 BAR FOR VW2100 PIEZO.	**4**	**EA**	35.00	140.00
17		**VW2100-HAE-CAP** FACTORY SEALED CAP FOR SHIPPING SATURATED HAE PIEZOMETER	**4**	**EA**	90.00	360.00
18		**EL380004** CABLE, 2 PAIR x 22 AWG, OSD, RED POLYURETHANE JACKET 0.250"ø	**60**	**M**	2.62	157.20

Value of Goods	26,481.00
Total Value	**26,481.00**

Terms of Payment	T/Transfer-Advance PMT
Terms of Delivery	EXW

VALIDITY OF QUOTE: 60 DAYS
ESTIMATED DELIVERY: TBD

Subject to RST Instruments Sales Terms and Conditions
(http://www.rstinstruments.com/StandardTerms.pdf).

Geo-Solutions
Soil and Groundwater Problems Solved

1250 Fifth Avenue, New Kensington, PA 15068
T 724-335-7273 **F** 724-335-7271
www.geo-solutions.com

Sent via email to: evans@bucknell.edu
Cc: mam028@bucknell.edu, rwj003@bucknell.edu, kandromalos@bucknell.edu

September 9, 2014

Jeffrey C. Evans, Ph.D., P.E., F. ASCE
Chair, Dept. of Mechanical Engineering
Professor, Dept. of Civil and Environmental Engineering
Bucknell University
Lewisburg, PA 17837
Telephone: 570-577-1112
Fax: 570-577-3415

RE: FIXED PRICE PROPOSAL
CONSTRUCTION OF NSF RESEARCH WALL
LEWSIBURG, PA

Jeff,

This short letter proposal outlines our pricing for the installation of the proposed NSF research soil-bentonite cutoff wall.

Geo-Solutions, Inc (GSI) is a recognized expert in the specialty geotechnical construction industry and more specifically in the installation of cutoff walls using slurry trench construction. For this phase of the project, we would serve as your subcontractor. Details associated with the construction will be outlined in subsequent, more detailed documents including the construction specifications, work plan (if needed), and final contract. We will work with you to develop and finalize these documents prior to the field work.

Scope of Work

GSI understands that the work will include the installation of 200 m long x 7 m deep (~1,400 m^2) soil-bentonite slurry trench cutoff wall. Standard slurry trench installation practices, again outlined in subsequent more detailed documents, will be used for the trench installation. GSI will provide all oversight, equipment, labor, and materials for the wall construction as previously discussed verbally and agreed to in the final contract. In general, we expect to provide:

- Onsite Project Management
- Onsite Project Supervision
- 1 GSI Operator for bentonite slurry preparation and management
- Specialty slurry mixing and pumping equipment
- Bentonite materials
- 1 Case 330 Excavator (locally rented w/ operator fueled and maintained)
- 1 D5 Dozer (locally rented w/ operator fueled and maintained)
- Forklift, hose, and other misc. equipment and supplies

- Mobilization of specialty slurry mixing and pumping equipment from GSI's yard to the project site

Schedule

Based on the scope of work outlined above, we expect that the work will take 0.5 weeks to demobilize, 1.5 weeks to install the wall (which includes 0.5 weeks of work stoppages for instrumentation installation), and 0.5 weeks to demobilize.

Pricing

We will perform the wall installation outlined above for a fixed price of **$65,220.00**. See attached breakdown for more details.

Conclusion

We look forward to the working with Bucknell on this interesting and important construction project and to supporting the remainder of this proposed research project through our expected ongoing involvement in collection of data and the dissemination of the research findings.

Sincerely,

Geo-Solutions, Inc.

Daniel Ruffing, PE
Project Manager

<u>Attached:</u>
Pricing Breakdown

Geo-Solutions
Soil and Groundwater Problems Solved

1250 Fifth Avenue, New Kensington, PA 15068
T 724-335-7273 **F** 724-335-7271
www.geo-solutions.com

September 8, 2014

The National Science Foundation
4201 Wilson Boulevard
Arlington, Virginia 22230, USA

Re: Letter of Support
Bucknell University Slurry Wall Research

To Whom It May Concern:

Geo-Solutions, Inc. is committed and pleased to join Bucknell University in investigating the performance of soil-bentonite slurry trench cutoff walls. Geo-solutions has long been a leader in the field and recognizes the importance of the proposed research. Geo-Solutions is enthusiastic to have the opportunity to play an important part in this project.

Geo-Solutions will be committing expertise and time to the project through personnel. Daniel Ruffing will be assigned the lead role for Geo-Solutions on this project. Daniel is well prepared for this responsibility by his education, experience, and intellectual curiosity. Additional details about Daniel are included in the proposal. In addition, Daniel will rely on the resources and experience of other Geo-Solutions team members including Robert Schindler, President and Ken Andromalos, Vice-President of Engineering. The upper management team is enthusiastic about this project and is committed to its success.

Specifically, Geo-Solutions will be:

- Providing oversight of the design (including help with the technical specs), construction procedures, and quality control testing program;
- Assisting with the planning for the monitoring and in situ testing programs;
- Overseeing and performing construction of the cutoff wall;
- Providing consulting assistance with data interpretation;
- Assistance in preparation and delivery of industrial seminars;
- Assistance with preparation of technical papers, reports, and conference presentations;
- Assistance with undergraduate education (one presentation on the BU campus per year);

- Participation in summer internship/January externship (job shadowing) programs with BU students (one or two students per year).
- Hosting semi-annual project meetings (one per year at Geo-Solutions)
- Attending semi-annual project meetings (one per year at Bucknell University)

As evidenced above, Geo-Solutions is committed to making this project a success and looks forward to working with Bucknell University on this research.

Sincerely,
Geo-Solutions, Inc.

Ken Andromalos, P.E.
Vice President of Engineering

Central Builders Supply Company

READY MIX CONCRETE • CONCRETE BLOCK • SAND & GRAVEL P.O. BOX 162 • ISLAND PARK • SUNBURY, PA 17801 • 570-286-6461

September 4, 2014

The National Science Foundation
4201 Wilson Boulevard
Arlington, Virginia 22230, USA

Re: Letter of Support
Bucknell University Slurry Wall Research

To Whom It May Concern:

Central Builders Supply Company is pleased to provide this letter of support to Bucknell University for their NSF proposal regarding soil-bentonite slurry trench cutoff wall research. Bucknell University plans to build, instrument and test an cutoff wall approximately 600 m long, 7 m deep and 0.6 m wide and has worked with us to find a suitable location for the project.

Central Builders Supply Company is the owner of a large sand and gravel quarry in Montandon, PA near Bucknell University and both Bucknell University and Central Builders have agreed upon an ideal portion of this site for their research project. Near the southern end of the site, along the eastern boundary is a large, level, grass covered area deemed suitable. At this location there is a wide buffer zone between the active quarry and an adjacent wetlands. Construction of the cutoff wall along this boundary would not interfere with our quarrying plans and could benefit the site by reducing flow from the wetlands towards the quarry at certain times of year. The buffer zone is within the permitted area of the site so no additional construction or environmental permits would be required for the work. Any excess soils from the construction can be processed in our sedimentation ponds.

Central Builders Supply Company is a community minded organization (http://centralbuilderssupply.com) and is pleased to be able to contribute the use of a portion of their Montandon sand and gravel site for this research. We'd be pleased to answer any questions should they arise.

Sincerely,
Central Builders Supply Company

Anthony B. Markunas
President

MERRILL W. LINN
LAND & WATERWAYS
CONSERVANCY

September 8, 2014

The National Science Foundation
4201 Wilson Boulevard
Arlington, VA 22230

Re: Letter of Support
Bucknell University Slurry Wall Research

To Whom It May Concern:

The Merrill W. Linn Land & Waterways Conservancy is pleased to provide this letter of support to Bucknell University for their NSF proposal regarding soil-bentonite slurry trench cutoff wall research. A wetland is located adjacent to the location where Bucknell University plans to build, instrument and test a cutoff wall and we appreciated their concern for the wetland and for asking us our opinion on the project. The Linn Conservancy works to protect and preserve significant ecological sites in its home region for present and future generations [http://linnconservancy.org].

The wetland is east of a large sand and gravel quarry in Montandon, PA operated by Central Builders Supply Company. We have worked closely with Central Builders in our mutual efforts to protect the environment. Bucknell University and Central Builders have agreed upon a portion of the site for their research project. At this location there is a wide buffer zone between the active quarry and an adjacent wetland. We believe the construction of the cutoff wall along this boundary would not negatively impact the wetland, either in the short or long term. In fact, the cutoff wall may benefit the wetland by reducing flow from the wetland towards the quarry at certain times of year.

The Linn Conservancy has had a long and positive connection with Bucknell University faculty and students. Faculty and students have conducted numerous environmental, geologic and engineering studies on properties on the Conservancy. This has helped the Conservancy better understand and protect the ecosystems of their properties. We are pleased to be in support of this most recent project.

Sincerely,
Merrill W. Linn Land & Waterways Conservancy

Susan Warner-Mills
President, Board of Directors

P.O. Box 501
Lewisburg, PA 17837

570.524.8666
linn@ptd.net
linnconservancy.org

Linking Landscapes