Water Resources Center
Annual Technical Report
FY 2015

Introduction

During Fiscal Year 2015 the Rhode Island Water Resources Center has supported two research grants and one information transfer project. The research project entitled "Improving Methods to Assess Liquifaction Potential of Embankment Dams in the Northeast Region," by Aaron Bradshaw presented the results of a study of of the potential for liquefaction of dams within Rhode Island. The second research project entitled, "Common Pool Resources and Water Quality Experiments," by Todd Gilfoos consisted of a series of group experiments to aid decision makers in water allocation. The information transfer project supported a Clean Water conference and a summer Water Academy for middle and high school students. In addition to these activities, the Rhode Island water Resources Center continued to support gradate and undergraduate students in their research.

Research Program Introduction

The research project entitled, "Improving Methods to Assess Liquefaction Potential of Embankment Dams in the Northeast Region", by Aaron Bradshaw presented the results of a case study at the Gainer Dam used to test the reliability of surface wave inversion methods (e.g., Spectral Analysis of Surface Waves, and Multichannel Analysis of Surface Waves) for the analysis of liquefaction potential. A shear wave velocity profile was obtained at the Gainer Dam in a previous study using a surface wave inversion approach that was used to assess liquefaction potential. In this study, a geotechnical boring was performed along with Standard Penetration Test (SPT) measurements at the same location where the previous seismic tests were performed. The SPT data were used to assess liquefaction potential that in turn was compared to the results obtained using the surface wave inversion method. The results show that the surface wave inversion method was able to capture the general subsurface conditions including the detection of a loose layer. However, the factors of safety obtained using the inverted shear wave velocity data were 13 to 47 percent higher than those obtained using the SPT procedures.

The second research project entitled, "Common Pool resources and Water Quality Experiments," by Todd Gilfoos focused on behavioral economics to address how individuals view the risks and uncertainty of social dilemmas and utilize laboratory experiments to understand the cognitive underpinning to cooperative and socially desired outcomes related to common pool resource extraction which could mitigate drinking water quality issues in the State of Rhode Island.

Common Pool Resources and Water Quality Experiments

Basic Information

Title:	Common Pool Resources and Water Quality Experiments
Project Number:	2015RI120B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	2
Research Category:	Social Sciences
Focus Category:	Economics, Groundwater, Water Use
Descriptors:	None
Principal Investigators:	Todd Guilfoos

Publications

There are no publications.

Common Pool Resources and Water Quality Experiments
Report

The research supported by this grant focused on behavioral economics to address how individuals view the risks and uncertainty of social dilemmas and utilize laboratory experiments to understand the cognitive underpinnings to cooperative and socially desired outcomes related to common pool resource extraction, which lead to drinking water quality problems in the state of Rhode Island.

This problem stems from the social dilemma that leads to over use of water, which in turn has water quality impacts through low flows. Some of these water quality problems can be a very serious health concern or have large economic consequences, such as fecal coliform bacteria which may cause beach closures in tourist spots like Newport or other locations along Narragansett Bay. When water is contaminated and then consumed it may infect consumers with a litany of diseases that can potentially be severe, such as typhoid or cholera. Other economic costs may include environmental costs when there is contaminates associated with nitrogen or phosphorous which lead to eutrophication and may damage fisheries which are important industries in Rhode Island. These water quality problems can be affected by groundwater pumping inshore when aquifers are unconfined and make up the base flow of rivers, as they do in Rhode Island. Coordination between alternative uses of water is needed to ensure that water quality is not greatly affected, or that the benefits of doing so strongly outweigh treatment options or the damage that is being caused. Some quantity issues in groundwater that are driven to having impacts to water quality are largely municipalities that pump water from aquifers heavily during times of low precipitation and lower the water table. Water pumped typically goes towards lawns, washing cars, or filling pools, which otherwise could provide large benefits in-stream.

The duration of the project was from March 2015 to February 2016, and this grant supported one graduate student RA whom worked to develop two social science lab experiments that investigated different cognitive aspects of cooperation with regards to economic social dilemmas. As stated in the research proposal the goals of the research are twofold: 1) understand the cognitive decision process when subjects are faced with a complex decision that have social implications 2) find the effective mechanism that increase social capital and sustain cooperative outcomes. The work has resulted in two manuscripts, one of which is in review at a top behavioral economics journal, the Journal of Economic Psychology. The other manuscript is being revised and will be submitted to a top economics journal by the end of the year. The experiments were paid for through support of a USDA Hatch Grant.

The results can be used to expand further studies into cognition and human behavior with water; of which there is very little. Or they could be used to design more cost effective policies that deal with extraction of water and effect drinking water quality. The goal is that the results will provide insight into basic human behavior and be useful for academics involved in natural resource management, namely water, and government agencies that manage the resource themselves or are charged with oversight in some capacity. Issues such as water quality span many agencies, such as the EPA, USDA, State, and local governments and a behavioral economics approach can be used to provide key insights into the rules and regulations that will be effective at achieving goals such as cleaner water.

Other ancillary benefits can be to the advancement of the understanding of human behavior and the processes that go into complex decisions. These types of decisions are ever present when thought of in a water context as water is typically a poorly understood resource that flows and whose quality is not easily detected through sight and smell. Though individuals sometimes rely on simple and often wrong assumptions about waters properties, this research hopes to shed light on some of the basic components human behavior surrounding water in general.

First Experiment

Under my direction the graduate RA developed and executed the first experiment during the Spring and Fall of 2015. We recruited 98 undergraduate subjects through announcements in class and through email at URI during the spring and fall of 2015. The experiment was programmed and conducted in z-Tree (Fischbacher 2007). The experiments were run in the SimLab at URI where subjects could not communicate or make eye contact with other subjects during the experiment.

The first experiment investigated cooperation in a social dilemma experiment through expectations of partner's personality traits in a non-cooperative economic experiment. Using a repeated one-shot continuous strategy Prisoner's Dilemma (two person Public Goods game), we test how the perceived personality traits of partners influence cooperative actions. Using the Big Five Inventory, categories of personality traits, and providing subjects with the rank-ordering of each personality trait of partners within a session in the experiment we find that subjects are more cooperative when paired with partners that are perceived as more 'Agreeable' or 'Open to Experience'. We find the primary reason for more cooperative behavior is driven by the expectation that partners will also give more to the public good.

Motivation for 1st Experiment

Cooperative actions are a key component of many economic situations, for example the co-management of common pool resources, treaty negotiations, or building teams. The institutions that influence individual cooperative actions are important, and so are the social contexts, motivations, and cognitive elements of cooperative decisions. Using a one-shot public goods game with two players, we test how the perceived traits of partners influence cooperative actions. This tests for a type of social heuristic that could influence cooperative economic behavior; for instance, choosing to cooperate when I believe my partner to be 'nice'. This type of heuristic could be influential in many microeconomic settings when perceptions of partners are important to establishing trust or reciprocity and there is limited information on past actions.

It is widely acknowledged that cooperation in repeated games can be maintained via reciprocity and trust (e.g. Fehr and Gächter 2000a, Cox 2004, Berg et al 1995, Nowak and Sigmund 2005). Many studies also find cooperative behavior when there is little chance to benefit in the future from reciprocity, as in one-shot social dilemma games (Dawes and Thaler 1988, Cooper et al 1996, Gächter and Herrmann 2009). Evidence of cooperative behavior has long been studied to understand differences from standard economic theory and reconcile this behavior with observed play in the lab and field. We extend the understanding of cognitive elements at work when individuals form expectations of partner's behavior. We know that behavior in social dilemmas depends on expectations about what others will do; so does information about personalities of others in the social dilemma change the beliefs and behavior of subjects?

In many social dilemmas outside the lab individuals would have the opportunity to form impressions about the traits of their partners (e.g. boat captains in a fishing fleet or farmers that share an aquifer) as they do not make decisions in isolation or behind a computer screen. And lab experiments have traditionally not investigated how these beliefs of player types may inform expectations or reinforce cooperative economic behavior. We investigate how these perceptions shape cooperative economic behavior as it could be important in sustaining or establishing cooperation. Economic experimentalists have generally attempted to remove most types of social interactions in experiments, but this may be an important element of how people make decisions in the real world. Social interactions, such as meeting partners, may play an important role in establishing cooperative behavior through perceptions of subject's partners that relate to the mechanisms that trigger cooperation, like trust. This could be integral to the social cognition that individuals employ when making judgements about partners. For instance, when new teams form to accomplish a given common task, each individual has an incentive to free ride on other team members in completing the task if individual contributions are hidden. This is a common problem that most college students are faced with when assigned to group work for a class where there are incentives to free ride on other group members.[1] Each team member must make a decision of how much effort to put towards the team objective, and typically have limited experience or knowledge of other team members. Therefore individuals are left with little information to draw inferences on and may use perceptions of their new team members. Even in repeated play situations, if information is incomplete, then perceptions of player types could be influential. In a common pool resource setting, the initial forming of a coalition of fisherman or farmers to undergo joint restrictions on extractive behavior based on their joint experience and perceptions, and observable behavior may be difficult to obtain. The commitment mechanisms that individuals may use to form agreements could have important social interaction components if previous behavior of partners is not available. This could be particularly important when adopting new rules or regulations in groups as play under the new rules are not observed. In addition to these examples, there are a host of other situations when perceptions of individual's cooperativeness are likely to be important, such as conflict resolution, negotiations (Hosmanek et al 2014), international agreements, complex governance agreements (Conca et al 2006), or research and design (Mora-Valentin et al 2004).

We focus on traits of individuals and how those traits are used in forming expectations about cooperative behavior, incorporating perceptions of player types into the analysis of economic games. Few studies in economics explore the perceptions of partners in a non-cooperative economic game, with the exception of using information about past play as the mechanism to predict or maintain cooperation of a partner. Though there are good reasons to believe that behavior in economic games can be conditional on perceptions of other's type. Schwieren and Sutter (2007) study the effect of gender in partners in an experimental trust game. Labels such as 'trust', 'cooperate', or 'defect' can affect the perceptions of other's strategic actions leading to changes in play (Zhong et al 2007). Tinsley et al (2002) demonstrate that perception of partner's experience in negotiations affected the reputation and ultimately the behavior of subjects. Experience is viewed negatively by novices in their experiment which reduces the ability of experienced negotiators to capitalize on their real negotiation expertise. Van Lange and Liebrand (1991a, 1991b) find that perceptions of intelligence and honesty in partners influences subject's contributions to the public good.

[1] Though there are mechanisms to overcome this situation, such as evaluations of each student by their peers.

These studies suggest that the expected value of a chosen strategy is not only conditional on past play but on perceptions of partners.

In our study, participants answer a 44 question Big Five Personality Inventory that scores subjects in each of the Big Five personality traits. Subjects then play a repeated one-shot public goods game with an anonymous partner and are provided with personality information of their partner. The continuous strategy space is more informative to evaluate changes in behavior along a gradient rather than evaluating the tipping point of a binary game choice, cooperate or defect, though these games are useful in many other settings. The one-shot game is used to isolate the effect of perceptions of partners and separate the perceptions from reciprocity from past or future play.[2] Specifically, repeated interactions could lead to cooperation in expectation of greater future profits through reciprocity. In five separate treatments subjects are provided with the rank-order of their partner of one of the Big Five Personality Traits (Agreeableness, Extraversion, Neuroticism, Conscientiousness, or Openness to Experience), along with a basic description of the personality trait and interpretations of high versus low rankings, listed in Table 1. Subjects are not given their own ranking or raw scores, and partner identity is anonymous. The information treatment is the relative position of their partner in the group on a given trait which is meant to prompt subjects with the perceived trait of a partner. Traits are perceived because we provide a ranking and the rank-order of any trait is only relative to the subject pool in a given session. Using a within-subject design we identify how the perceived trait information is used in making cooperative decisions. The use of rank-order information simplifies the interpretation of what a raw score (in a Likert Scale) of a particular personality trait means to subjects, and provides the hypothesis we wish to test: Do subjects cooperate more when their partners have certain perceived traits? We find that they do, specifically that subjects with partners that are ranked higher in terms of Agreeableness and Openness to Experience give more to the public good.

Experimental Design

There are three stages to this experiment. The first stage is comprised of collecting personality trait and demographic information through a questionnaire. The second stage is a repeated one shot two person public goods game with information treatments revealing partner's rank ordering of a given personality trait, as detailed in Table 2. In the third stage subjects are allowed to choose which of the Big Five personality traits they prefer as information in the next round of the public goods game, providing a measure of the relative value of personality information.

In the first stage, subjects take a 44 question personality inventory on the computer that is taken from Filiz-Ozbay et al (2013). Subjects were asked to provide truthful answers to these questions, and were not told of any further use of this data during the first stage. Since the questionnaire was implemented on the computer, the raw scores and rank-ordering of all subjects in a given session were calculated immediately upon completion of the survey. Rank-ordering refers to the rank of the subject relative to other subjects in the same session for a given trait. Subjects were not provided with their own scores or rankings at any point during the experiment.

[2] Repeat interactions between subjects would be an interesting future work, as it could identify the relative importance of characteristics of subject's partners relative to knowledge of past behavior.

In the second stage of the experiment subjects repeatedly play the one shot public goods game with an anonymous partner. This game is linear in that it has constant payouts for the private good and the public good. The private good pays $0.75 for each token invested and the public good pays $0.50 for each token invested by any group member, in this case there is only one partner in the group. Subjects are provided with 10 tokens each to allocate between the private and public goods. Subjects are provided with examples of payout situations and play four practice rounds to gain experience with the game. A treatment in this game is defined as a set of six rounds with information on one of the personality traits (the rank-ordering of the subject's partner). The rank-ordering information of a subject's partner is provided at the same time as the decision for the provisioning of the public good. There are six treatments in this stage of the experiment (36 rounds), five personality trait treatments and one treatment with no information about partner's personality traits. All treatments are within-subject treatments as the key information that we hope to gain is how a subject changes contributions as their partner's rank changes for each trait. We instruct subjects that the rank-ordering of a trait is taken from their responses to the personality questionnaire given in the previous stage. We provide a written description of the interpretation of a subject with high and low rankings of a personality trait as shown in Table 1. The experimenter read the instructions of the game as well as the description of the personality trait being used in each treatment before the treatment began. In each round subjects are randomly paired with a new partner, this randomization process was reiterated by the experimenter at the beginning of each treatment. Subjects are not told how many rounds or treatments they will play. Within each treatment subjects will not encounter the same partner twice to eliminate reciprocal play or punishment based on identity of their partner, this is meant to isolate the effect of perceived traits in behavior.[3] This identification is based on the assumption that experience does not also confound behavior in some way that is correlated with partner's personality traits or that we cannot controlled for these effects in our analysis. This should not be a concern since we use random assignment of partners, and that encountering partners with high rankings of a personality trait is equally likely in early and later rounds of a treatment. The public goods game is given a framing of taking away from the public good rather than giving to the public good, which is more representative of a common pool resource dilemma.

In the third stage of the experiment subjects are able to choose which personality trait rank-ordering information they gain access to in another anonymous one shot public goods game for one round. Subject's play an additional six rounds of the public goods game in this stage of the experiment. This provides data on which perceived traits are deemed most valuable to subjects.

Second Experiment

Under my direction the graduate RA developed and executed the second experiment during the Spring 2016. We recruited 110 undergraduate subjects through announcements in class and through email at URI during the Spring. The experiment was programmed and conducted

[3] We use a predetermined random matching system based on the subject's computer station in the lab that ensures that subjects do not encounter the same partner during the same treatment, as this information could be used to punish previous partners for low contributions to the public good in earlier rounds.

in z-Tree (Fischbacher 2007). The experiments were run in the SimLab at URI where subjects could not communicate or make eye contact with other subjects during the experiment.

The second experiment investigated at a dynamic common pool resource game and investigated how time pressure effects the decisions made about extraction. This can be useful to understand the cognitive elements of common pool resource decisions, under time pressure subjects are more likely to engage their system 1 thinking, which is based intuitive responses, versus system 2 thinking, which is based on a more deliberative. We find evidence that in a dynamic setting that subjects are likely to be more intuitively selfish. This is largely unexpected as we are not aware of studies that find a similar result and believe this suggests that the dynamic aspect of cooperation may lead to a greater intuitive discounting of future actions and rewards.

Motivation for 2nd Experiment

There is a series of recent investigations on the intuitive cooperation, though there is some debate about the robustness of the results (Bear and Rand, 2016). This debate has been focused on single shot games, such as the prisoner's dilemma. We take this one step further to investigate the common pool resource when the stock of the resource matters, such as in groundwater management. We find striking evidence that contradicts the previous work, and finds that time pressure causes greater extraction and is less cooperation between subjects.

The nature of this finding suggests that something cognitively is different between one shot games and dynamic games, and that this has implications for evolutionary theories of cooperation. Namely that they are context dependent. It also points to the need for a institutions over time to deal with over extraction and breed greater coordination and cooperation.

Experimental Design

There are two stages to this experiment. In the first stage, subjects take a cognitive reflection test (Fredrick 2005) which is timed and recovers some psychological information about how the deliberative subjects are. Subjects were then given written instructions to the dynamic common pool resource game and the experimenter read the instructions out loud to the subjects. Multiple examples were provided and qualification questions were provided to

In the second stage of the experiment subjects play the dynamic CPR game with a group of three other players. The basic structure of this game is based on the experiment by Kimbrough and Vostroknutov (2015). We use the treatment in their experiment that is equivalent to a low recharge of growth in the common pool resource which is more appropriate for groundwater recharge, and also has the similar theoretical prediction of over extraction of the resource, as the prisoner's dilemma. The unique subgame perfect nash equilibrium predicts that the resource will be exhausted after 3 rounds of play. Subjects play 3 cycles of this game, which is not known to them at the time of playing, and groups are randomly reshuffled after each cycle. The ending period of each cycle was randomly predetermined and unknown to subjects. Though this should have little effect on their play according to theory.

The key treatment in this experiment is that some sessions were subject to time pressure while other were not, and a between subjects investigation into their behavior would reveal any treatment effect. We analyze this data using a survival analysis on group's likelihood to have the common pool resource stock above the threshold over periods in the experiment.

Training and Mentorship. One first year PhD student is involved in this project. This was extremely beneficial to the student's development as a researcher. The student was able to develop skills running experiments and training on how to successfully design experiments, recruit, and execute a social sciences experiment about decision making. They will use these skills further on dissertation work that is based off of this project. Additionally one of the experiments the graduate student is the lead author and is learning valuable skills in writing and presenting an academic paper. This project was successful at recruiting a new student into these methods of academic inquiry which will lead to more work on cognition and common pool resource use, which is of great interest to effective water resource management.

Information Sharing Plan

The information transfer plan will be focused on academic publications in interdisciplinary journals or natural resource economics journals. The target audience will be academics, policymakers, and water managers whether waste water treatment mangers or agencies that monitor watershed quality such as the EPA. To fulfill this strategy the work has been presented at an international conference of psychologist and economists, and will be further distributed among policy makers and economists interested in water issues at an Agricultural Experiment Station meeting in the Fall of 2016, and through eventual publication.

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Improving Methods to Assess Liquefaction Potential of Embankment Dams in the Northeast Region

Basic Information

Title:	Improving Methods to Assess Liquefaction Potential of Embankment Dams in the Northeast Region
Project Number:	2015RI121B
Start Date:	3/1/2015
End Date:	2/28/2016
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Congressional District:	2
Research Category:	Engineering
Focus Category:	Water Supply, Water Quantity, None
Descriptors:	None
Principal Investigators:	Aaron Stephen Bradshaw

Publications

There are no publications.

IMPROVING METHODS TO ASSESS LIQUEFACTION POTENTIAL OF EMBANKMENT DAMS IN THE NORTHEAST REGION

Bivian Reyes

Aaron Bradshaw, Ph.D., P.E

DRAFT FINAL REPORT

Submitted to:

Rhode Island Water Resources Center

May 24, 2016

Abstract: This report presents the results of a case study at the Gainer Dam used to test the reliability of surface wave inversion methods (e.g., Spectral Analysis of Surface Waves, and Multichannel Analysis of Surface Waves) for the analysis of liquefaction potential. A shear wave velocity profile was obtained at the Gainer Dam in a previous study using a surface wave inversion approach that was used to assess liquefaction potential. In this study, a geotechnical boring was performed along with Standard Penetration Test (SPT) measurements at the same location where the previous seismic tests were performed. The SPT data were used to assess liquefaction potential that in turn was compared to the results obtained using the surface wave inversion method. The results show that the surface wave inversion method was able to capture the general subsurface conditions including the detection of a loose layer. However, the factors of safety obtained using the inverted shear wave velocity data were 13 to 47 percent higher than those obtained using the SPT procedures.

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1. INTRODUCTION

1.1 Background and Previous Work

Increased demand for water, coupled with diminishing clean water sources, reinforces the need to protect our existing reservoirs from natural disasters. In Rhode Island there are numerous reservoirs that serve as lifelines (drinking water, fire-fighting, etc.) and are important to the local economy. For example, the Scituate reservoir is responsible for 60% of the state population including Providence (USGS 2013). The reservoir was created from the construction of the Gainer Dam at the south end of the reservoir in the 1920s shown in Figure 1.

The Authors recently completed a seismic study on the dam to evaluate its liquefaction potential in a design-level earthquake (Reyes et al. 2014). Though the analyses provided some insight as to the resiliency of the dam in a seismic event, it identified significant uncertainties with the analysis. In the previous study, liquefaction assessment was based on the measurement of shear wave velocity in the dam soils using a seismic testing method. The method used the measurement of surface waves to infer the properties of the soil at depth within the dam. Although the technique is well established in engineering practice, it is typically not solely relied upon for liquefaction assessments. Rather liquefaction assessments rely on other in situ tests such as the Standard Penetration Test (SPT) or Cone Penetration Test (CPT). Further studies on the surface wave testing approach could increase the confidence in the method as a tool to screen for liquefaction potential particularly when SPT or CPT data are not available.

1.2 Objectives

The objective of this project was to test the reliability of the surface wave inversion method using the Gainer Dam as a test site. This was achieved first by performing borings with SPTs at the Gainer Dam at the same location where the seismic tests were performed. The boring and SPT data could then be used to assess the subsurface conditions and liquefaction potential that would serve as a baseline for comparison to the surface wave results.

1.3 Scope of Work

The scope of work included three main tasks:

- Perform additional site investigations
- Reanalyze liquefaction potential
- Prepare final report

1.4 Structure of the Report

This report is structured into 3 remaining sections. Section 2 gives a summary of the additional site investigation performed at Gainer Dam. Section 3 describes the reanalysis of liquefaction potential. Conclusions are presented in Section 4.

Figure 1. Photograph of the Gainer Memorial Dam looking westward. Note the Scituate Reservoir to the right.

2. ADDITIONAL SITE INVESTIGATIONS

One geotechnical boring was performed at the Gainer Dam at the same location where the surface wave testing was performed in the previous study. The location was on the upper bench on the downstream side of the dam. The boring was performed by Pare Corporation under subcontract with Providence Water (PW). Standard Penetration Tests (SPT) were performed at 5-foot intervals down to bedrock. The resulting boring log is presented in Figure 2. As can be observed in the boring log, once past the top soil, very high blow counts (> 35 blows/inch in some areas) were encountered in the shell soils and no samples were able to be recovered likely due to the presence of large gravels.

Lower blowcounts were observed at depths of 85 and 95 feet below the ground surface. These lower blowcounts (around 30 blows/ 1 foot) correspond to the looser layer identified by the shear wave measurements in the previous study. A large split spoon sampler was used to recover bulk material from the loose layer for laboratory testing. The measured SPT blow counts are shown in Figure 3, along with the shear wave velocity profile obtained from the surface wave inversion from the previous study.

Sieve analyses were performed on the samples recovered from this layer in accordance with ASTM C136-01. The resulting grain distribution is shown in Figure 5. Sieve analysis on soil samples recovered in this layer indicated that it consists of 13% gravel, 82% sand, and 5% fines.

PARE CORPORATION 10 LINCOLN ROAD, SUITE 103, FOXBORO, MASSACHUSETTS ENGINEERS *** PLANNERS *** CONSULTANTS	BORING NO. B15-1 SHEET(S) 1 of 3

PROJECT	Gainer Memorial Dam	PROJECT NO.	14271.00
	Scituate, RI	CHKD. BY	SJM
BORING CO.	New England Boring Contractors	BORING LOCATION	267 feet NE of downstream steps, upper berm
FOREMAN	Orrin Cone	GROUND SURFACE ELEVATION	267 feet DATUM Assumed
INSPECTOR	J. Costa	DATE START	1/13/2015 DATE END 1/20/2015

SAMPLER: UNLESS OTHERWISE NOTED, SAMPLER CONSISTS OF A 2" SPLIT SPOON DRIVEN USING A 140 lb. HAMMER FALLING 30 in.

CASING: UNLESS OTHERWISE NOTED, CASING DRIVEN USING 300 lb. HAMMER FALLING 24 IN.

CASING SIZE: 4" OTHER:

GROUNDWATER READINGS				
DATE	TIME	WATER AT	CASING AT	STABILIZATION TIME
1-16-15	3PM	54 feet	±89 feet	45 minutes

DEPTH (ft)	CASING (bl/ft)	SAMPLE NO.	PEN. (in.)/ REC.	DEPTH (FT)	BLOWS/6"	TONS/FT² OR KG/CM²	SAMPLE DESCRIPTION (Burmister CLASSIFICATION)	REMARKS	STRATUM DESCRIPTION
		S-1A	12/6	0-1	4 9		1A: Moist, medium dense, black, fine to medium SAND, some silt, trace fine gravel, trace coarse sand, trace roots.		6" Topsoil
		S-1B	12/7	1-2	11 14				
							1B: Moist, medium dense, brown, fine to medium SAND, some silt.		
5									
		S-2	24/3	5-7	23 17		Moist, medium dense, tan, coarse GRAVEL, little fine to coarse sand, trace silt.		
					10 8				
									SANDY EMBANKMENT FILL
10	23								
	57	S-3A	12/6	10-11	18 16		3A: Moist, dense, brown to gray, fine to coarse SAND, some fine to coarse gravel, trace silt.		
	44	S-3B	12/6	11-12	11 25				
	20						3B: Moist, medium dense, white to gray, fine to medium SAND, little coarse sand, trace fine gravel.		
	48								
15									
		S-4	24/4	15-17	51 26		Wet, dense, tan, medium to coarse SAND, some fine gravel, trace fine sand, trace silt.		
	27				14 16				
	53								
	60								
20	36								
	33	S-5	24/4	20-22	37 34		Wet, very dense, tan, medium to coarse SAND, some fine to coarse gravel, trace fine sand, trace silt.		
	46				31 28				
	50								SAND AND GRAVEL EMBANKMENT FILL
	48								
25	40		24/0	25-27	24 28		No Recovery.	1	
					24 38				
	100+								
	111								
30	30								
	63	S-6	24/7	30-32	40 37		Wet, very dense, tan to gray, fine to coarse SAND, some fine to coarse gravel, trace silt.		
					34 31				

GRANULAR SOILS		COHESIVE SOILS	
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V.SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M.DENSE	4 - 8	M.STIFF
30 - 50	DENSE	8 - 15	STIFF
>50	V.DENSE	15 - 30	V.STIFF
		>30	HARD

REMARKS:
1. Drill rig bouncing while rollerbitting. Possible boulder/cobble.
2. Solid stem augers were utilized for the first 10 feet of sampling.

BURMISTER CLASSIFICATION	
TRACE	0 - 10%
LITTLE	10 - 20%
SOME	20 - 35%
AND	35 - 50%
PERCENT BY WEIGHT	

NOTES:
1) THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY BETWEEN SOIL TYPES, TRANSITIONS MAY BE GRADUAL.
2) WATER LEVEL READINGS HAVE BEEN MADE IN THE DRILL HOLES AT TIMES AND UNDER CONDITIONS STATED ON THE BORING LOGS. FLUCTUATIONS IN THE LEVEL OF GROUNDWATER MAY OCCUR DUE TO OTHER FACTORS THAN THOSE PRESENT AT THE TIME MEASUREMENTS WERE MADE.

BORING NO. B15-1

Figure 2. Boring log obtained at the Gainer Dam.

PARE CORPORATION
10 LINCOLN ROAD, SUITE 103, FOXBORO, MASSACHUSETTS
ENGINEERS *** PLANNERS *** CONSULTANTS

BORING NO. B15-1
SHEET 2 OF 3

PROJECT: Gainer Memorial Dam, Scituate, RI
PROJECT NO.: 14271.00
CHKD. BY: SJM

DEPTH (ft)	CASING (bl/ft)	SAMPLE NO.	PEN. (in.)/ REC.	DEPTH (FT)	BLOWS/6"	TONS/FT^2 OR KG/CM^2	SAMPLE DESCRIPTION (Burmister CLASSIFICATION)	REMARKS	STRATUM DESCRIPTION
	113							2	SAND AND GRAVEL EMBANKMENT FILL
	145								
35	123								
	55	S-7	24/5	35-37	85 55		Wet, very dense, tan to gray to blue, fine to coarse SAND and fine to coarse GRAVEL, trace silt.		
	45				45 39			3	
	67								
	93								
40	123	S-8	14/5	40-41.2	110 85		Wet, very dense, tan to gray, fine to coarse SAND, some fine gravel, trace silt.		
	60				50/2"				
	110								
	115								
	130								
45	117								
	106	S-9	4/4	46-46.3	100/4"		Wet, very dense, tan to gray, fine GRAVEL and fine to coarse SAND, trace silt.	3	
	110								
	140								
	138								
50	112	S-10	8/6	50-50.6	100 80/2"		Wet, very dense, gray, fine to coarse SAND, some fine gravel, trace silt.		
	98								
	112								
	100+								
	178								
55	160	S-11	3/3	55-55.25	112/3"		Wet, very dense, gray, fine to medium SAND, trace coarse sand, trace fine gravel.		
	139								
	120								
	163								
	230								
60	80		3/0	60-60.29	100/3"		No Recovery.	4	
	115								
	150		7/0	62-62.6	100 75/1"		No Recovery.*	5	
	250								
	130								
65	105		4/0	65-65.3	113/4"		No Recovery.		
	163								
	193								
	194								
	143							6	
70	57		3/0	70-70.2	104/3"		No Recovery.		NATURAL SAND AND GRAVEL
	72			70.25	113/3"		No Recovery.*		
	75								
	83								
	94								

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V.SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M.DENSE	4 - 8	M.STIFF
30 - 50	DENSE	8 - 15	STIFF
>50	V.DENSE	15 - 30	V.STIFF
		>30	HARD

REMARKS:
2. Possible cobble.
3. Hammer bouncing.
4. Washed to 62', used 3" split spoon with 140 lbs. hammer.
5. Drill rig bouncing while washing.
6. Change in casing hammer sound, possible change in stratum.

*Denotes that a 3 inch split spoon was used.

BURMISTER CLASSIFICATION	
TRACE	0 - 10%
LITTLE	10 - 20%
SOME	20 - 35%
AND	35 - 50%
PERCENT BY WEIGHT	

NOTES:
1) THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY BETWEEN SOIL TYPES, TRANSITIONS MAY BE GRADUAL.
2) WATER LEVEL READINGS HAVE BEEN MADE IN THE DRILL HOLES AT TIMES AND UNDER CONDITIONS STATED ON THE BORING LOGS. FLUCTUATIONS IN THE LEVEL OF GROUNDWATER MAY OCCUR DUE TO OTHER FACTORS THAN THOSE PRESENT AT THE TIME MEASUREMENTS WERE MADE.

BORING NO. B15-1

Figure 2 (cont.)

PARE CORPORATION

10 LINCOLN ROAD, SUITE 103, FOXBORO, MASSACHUSETTS

ENGINEERS *** PLANNERS *** CONSULTANTS

BORING NO. B15-1

SHEET 3 OF 3

PROJECT	Gainer Memorial Dam	PROJECT NO.	14271.00
	Scituate, RI	CHKD. BY	SJM

DEPTH (ft)	CASING (bl/ft)	SAMPLE NO.	PEN. (in.)/ REC.	DEPTH (FT)	BLOWS/6"	TONS/FT² OR KG/CM²	SAMPLE DESCRIPTION (Burmister CLASSIFICATION)	REMARKS	STRATUM DESCRIPTION
75	77								
	90	S-12	24/5	75-77	79 48		Wet, very dense, gray to blue, fine to coarse SAND, some fine gravel, trace silt.	6	NATURAL SAND AND GRAVEL
	118				27 30				
	124	S-13	18/15	77-78.57	75 95		Wet, very dense, gray to blue, fine to coarse SAND, little fine to coarse gravel, trace silt.*	7	6" F/M SAND
	103				95 95				
80	122	S-14	3/3	80-80.25	100/3"		Wet, very dense, gray to blue, fine to medium SAND, little coarse sand, trace fine gravel, trace silt.		
	140								
	173								
	215								
	182								
85	136								
	128	S-15	24/12	85-87	34 17		Wet, dense, gray to blue, fine to coarse SAND, little fine gravel, trace silt.	8	
	231				16 22				
	215								NATURAL SAND AND GRAVEL
	236							6	
90	195						No Sampling.	9	
	180								
	176								
	175								
	188								
95	94	S-16	24/24	95-97	17 8		Wet, medium dense, gray to blue, medium to coarse SAND, little fine gravel, trace silt, trace fine sand.	6	
	106				21 57			10	
	118/6"			97-97.1	70/1"		No Recovery	11	
				97.5-98.5	3min/ft			12	
				98.5-99.5	3min/ft		Fair, moderately wide fractures, slightly weathered, blue to pink to black, very hard, sound, coarse grained GRANITE.		
100				99.5-100.5	2min/ft				GRANITE
				100.5-101.5	2min/ft		RQD=57%		
				101.5-102.25	4min/9in				
							Bottom of Exploration at 102.25 feet		
105									
110									
							Boring was backfilled through tremie grouting procedures utilizing 11 bags of Portland Cement, ±180 gallons of water, 1.5 bags of Quick-Gel Bentonite Clay, and 2 bags of Bentonite Clay Chips. Grout measured 8 feet below the existing ground surface. The remaining void was filled with wash cuttings.		
115									

GRANULAR SOILS BLOWS/FT	DENSITY	COHESIVE SOILS BLOWS/FT	DENSITY
0 - 4	V. LOOSE	<2	V.SOFT
4 - 10	LOOSE	2 - 4	SOFT
10 - 30	M.DENSE	4 - 8	M.STIFF
30 - 50	DENSE	8 - 15	STIFF
>50	V.DENSE	15 - 30	V.STIFF
		>30	HARD

REMARKS: *Denotes that a 3 inch split spoon was used.

6. Very little water returning from casing while washing.
7. Upper 6" of spoon is fine to medium sand.
8. Upper 1" of spoon is fine to medium sand.
9. Casing @ 89', 2.5' of sand blew into casing, no sampling performed.
10. Rope broke after 6" of sampling, drove remaining 18", sample disturbed.
11. Casing hammer bouncing at 97.5 feet.
12. Began rock core at 97.5 feet.

BURMISTER CLASSIFICATION	
TRACE	0 - 10%
LITTLE	10 - 20%
SOME	20 - 35%
AND	35 - 50%
PERCENT BY WEIGHT	

NOTES:
1) THE STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARY BETWEEN SOIL TYPES, TRANSITIONS MAY BE GRADUAL.
2) WATER LEVEL READINGS HAVE BEEN MADE IN THE DRILL HOLES AT TIMES AND UNDER CONDITIONS STATED ON THE BORING LOGS. FLUCTUATIONS IN THE LEVEL OF GROUNDWATER MAY OCCUR DUE TO OTHER FACTORS THAN THOSE PRESENT AT THE TIME MEASUREMENTS WERE MADE.

BORING NO. B15-1

Figure 2 (cont.)

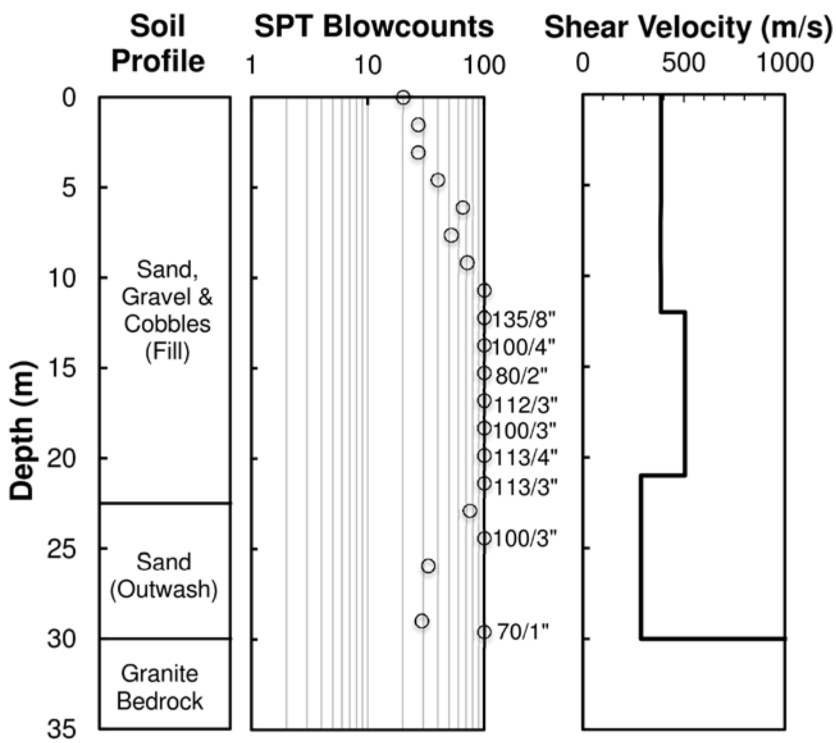

Figure 3. Representative geotechnical profile resulting from site investigations.

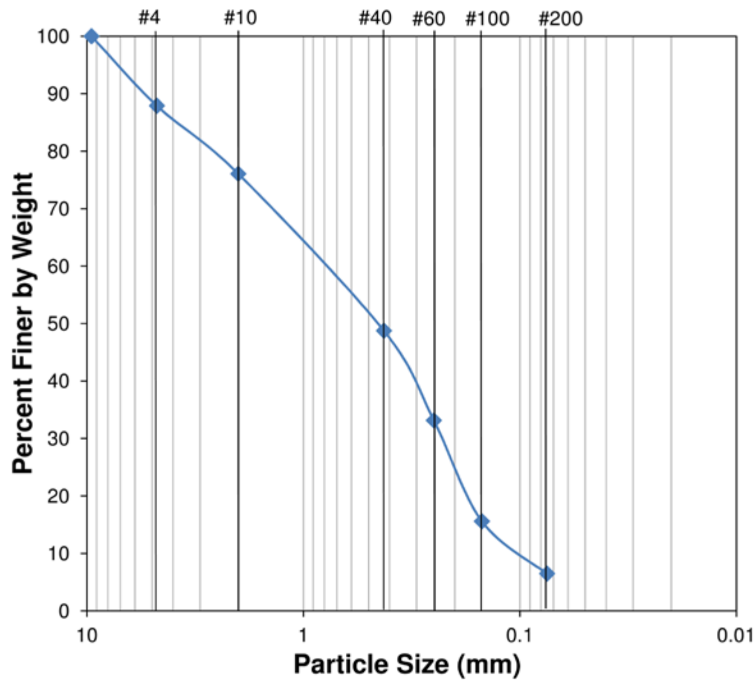

Figure 4. Grain size analysis results for samples recovered at depth of 95 feet below ground surface.

3. ANALYSIS OF LIQUEFACTION POTENTIAL

This section describes the reanalysis of liquefaction potential at the Gainer dam.

3.1 Updated Model Cross Section

Additional information was obtained that allowed a more detailed assessment of the dam cross-section. The additional information included additional construction drawings as well as a detailed USGS soil map at the site location. From this information a representative cross section was developed as shown in Figure 5.

3.2 Seismic Hazard

Seismic hazard analyses involve the quantitative estimation of ground shaking hazards at a particular site, and are necessary in order to evaluate the site's liquefaction potential. FEMA 65 guidelines cite both deterministic and probabilistic approaches as suitable options to perform a seismic analysis of an embankment dam. Probabilistic Seismic Hazard Analyses (PSHA) performed by the United States Geological Survey (USGS) were used to identify the controlling seismic events. The input ground motions needed for the site response were selected deterministically to represent the controlling events. The seismic hazard deaggregations were obtained using the 2008 data set for a probability of occurrence of 2% in 50 years (2,475 year return period).

The deaggregation corresponding to the fundamental period of the dam was selected from the USGS website because modal events with a similar period or frequency will produce the largest response of the dam. The fundamental period of the dam was estimated using the shear beam approach (Gazetas1987; Dakoulas and Gazetas 1985) given by the equation below:

$$T_1 = \frac{16\pi}{(4+m)(2-m)\beta_1}\frac{H}{V_{SA}} \quad (1)$$

where H =height of the dam, V_{SA} = average shear wave velocity of the soil in the dam, and m and β = variables in a period relation developed by Dakoulas and Gazetas (1985). The average shear wave velocity in the equation above was calculated using a weighted average, by soil mass, of the approximate shear wave velocity values obtained from the surface wave inversion. The resulting fundamental period of the dam was estimated to be 0.34 seconds and thus the deaggregations were observed at closest available oscillator periods of 0.2, 0.3 and 0.5 seconds. At periods 0.3 seconds and smaller the hazard is dominated by a small magnitude modal event of 4.8 to 5.0 at a site-to-source distance of 14 to 32 km. At a period of 0.5 seconds the hazard is dominated by a larger magnitude modal event of 6.2 to 6.8 at a distance of 124 to 174 km. Liquefaction analyses were performed for these two controlling scenarios. The deaggregations for the periods of 0.3 and 0.5 seconds are shown in Figures 6 and 7.

3.3 Site Response

The first step in the analysis was to estimate the initial geostatic stress state in the dam, given the updated cross section. This was accomplished using Phase 2, which is a two-dimensional elasto-plastic finite element analysis software program. Best estimates of the material properties including unit weight, friction angle, and permeability were chosen. The permeability of the dam core soils was refined to obtain an agreement between the calculated and the actual outflow at the toe, and from observation well information on the downstream side of the dam provided by Providence Water. The back-calculated values of permeability of 3x10-5 cm/s suggested that the core was composed primarily of silty soils. The resulting contours for vertical effective stress, mean effective stress and static shear stress are shown in Figures 8 through 10.

Input ground motions were selected from McGuire et al. (2001) who established a database of ground motion records applicable to the Central and Eastern United States. The records contained in this database have been scaled using response spectral transfer functions based on a single-corner, point source model. These functions relate active seismic region motions to stable continental region motions and are binned according to magnitude and site-to-source distance. Six motions consisting of one horizontal component and one vertical component were selected from the database for each of the two modal events identified in the deaggregations. Ground motions were selected to be within ±25 km and ±0.25 magnitude of the modal events. No additional amplitude scaling of the ground motions was applied. The sets of ground motions used in this study are presented in Table 1.

The site response analysis was performed using QUAD4M, which is an equivalent linear two-dimensional finite element program (Hudson et al. 1994). The program was used to estimate the maximum cyclic shear stresses and strains in the dam soils induced by the design earthquakes. The dam was modeled using three main materials: shell, core, and foundation soils. The finite element mesh had a total of 415 elements as shown in Figure 11.

Small strain shear modulus properties were calculated from the estimated shear wave velocity data. Since measurements were only made at one location on the downstream side of the dam, the V_S data were extrapolated to other portions of the dam using the following equation (Richart et al. 1970):

$$V_S = A(\sigma'_m)^{0.25} \qquad (2)$$

where A = soil-specific coefficient related to void ratio, σ'_m = mean effective confining pressure, and n= exponent. The A parameter was adjusted to fit the equation to the inverted shear wave velocity in the shell and outwash soils. Values of 190 and 110 were obtained for the A coefficient in the shell and foundation soils, respectively. A coefficient of 130 was assumed for the compacted core soils. The initial mean effective confining pressure was obtained from the Phase2 results. Modulus degradation and damping curves were calculated for each material sub-layer using the empirical correlations developed by Ishibashi and Zhang (1993) using the initial mean confining stresses calculated with Phase2.

3.4 Liquefaction Potential

The liquefaction potential of the dam was evaluated using the cyclic stress approach, in which the factor of safety against liquefaction is defined as:

$$FS = \frac{CRR}{CSR} \qquad (3)$$

where CRR = cyclic resistance ratio, and CSR = cyclic stress ratio. The factor of safety was calculated at each element within the dam soils using two shear wave velocity-based approaches: Andrus and Stokoe (2000) and Kayen et al. (2013). Both methods are based on a database of liquefaction case studies throughout the world for level ground. In the Andrus and Stokoe (2000) approach the factor of safety was calculated at a reference magnitude of 7.5. The CSR at an equivalent magnitude of 7.5 was estimated from the site response analysis results from the following equation:

$$CSR = 0.65 \frac{\tau_h}{\sigma'_{vo}} \frac{1}{MSF} \tag{4}$$

where τ_h = cyclic shear stress on the horizontal plane, and MSF = magnitude scaling factor recommended by Andrus and Stokoe (2000). Each input record yielded one CSR value at each element. In the calculation of factor of safety the median CSR plus one standard deviation was used assuming a log normal distribution.

The CRR at a magnitude of 7.5 was calculated from the following equation:

$$CRR = \left[0.222\left(\frac{V_{S1}}{100}\right) + 2.8\left(\frac{1}{207 - V_{S1}} - \frac{1}{207}\right)\right] K_\sigma K_\alpha \tag{5}$$

where V_{S1} = measured shear wave velocity corrected for overburden stress, K_σ = correction factor for overburden stress, and K_α = correction factor for static shear stresses. Although K_σ was not recommended in Andrus and Stokoe (2000), K_σ was conservatively applied based on the 1996 NCEER recommended values for loose soils (Youd et al. 2001). The K_α is an important parameter for embankment dams but little guidance is given in Youd et al. (2001). However, recent work by Boulanger (2003) provides a rational framework for estimating K_α using relative density (D_R) and σ'_m. Since V_S correlates with void ratio and not D_R it was necessary to conservatively assume a relative density of 30% that represents a very loose condition.

In addition to the Andrus and Stokoe (2000) approach, the CRR equation presented by Kayen et al. (2015) was also used to determine the liquefaction potential of the soils at the dam. This equation accounts for the effect of earthquake magnitude directly, therefore CSR was calculated using Equation 4 with MSF =1 and CRR was calculated using the following equation (Kayen et al. 2015):

$$CRR = \exp\left\{\frac{\left[\left(0.0073 \cdot V_{S1}\right)^{2.8011} - 2.6168 \cdot \ln\left(M_w\right) - 0.0099 \cdot \ln\left(\sigma'_{vo}\right) + 0.0028 \cdot FC + 0.4809\phi^{-1}\left(PL\right)\right]}{1.946}\right\} K_\alpha \tag{6}$$

where M_w = earthquake moment magnitude, σ'_{vo} =initial vertical effective overburden stress, FC = fines content of the soil, and ϕ^{-1} (P_L) = inverse of the cumulative normal distribution of the probability for liquefaction (P_L). Consistent with Kayen's recommendations the P_L was assumed to be 0.15 for a deterministic analysis. The values used for K_α were the same as the ones above.

In addition to the shear wave velocity-based methods described above, the liquefaction potential of the dam was also assessed through the use of two SPT-based approaches as described below.

The first approach used is that recommended in Youd et al. (2001) for soils with corrected SPT $(N_1)_{60}$ of less than 30. Soils with $(N_1)_{60} \geq 30$ are generally considered too dense to liquefy. In this method, the cyclic resistance ratio can be calculated by the following equation:

$$CRR_{7.5} = \frac{1}{34 - (N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{\left[10 \cdot (N_1)_{60} + 45\right]^2} - \frac{1}{200} \tag{7}$$

where $(N_1)_{60}$ is the raw SPT blow count value corrected for overburden pressure, energy ratio, borehole diameter, rod length and sampling method. In addition, the SPT value was also corrected for the influence of fines content (FC) through the use of the equations developed by I. M. Idriss and R. B. Seed as presented in Youd et al. (2001).

The second approach used was that described in Idriss and Boulanger (2008), where the cyclic resistance ratio can be approximated by the following equation:

$$CRR_{M=7.5,\sigma'_{vc}=1} = \exp\left(\frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 2.8\right) \quad (8)$$

where $(N_1)_{60cs}$ is the value of SPT corrected blowcounts for clean sands (FC≤5%).

Since the case history set used to develop the simplified procedure was rather limited, corrections for overburden pressure and static shear stress are required in order to properly apply this procedure to soils with larger overburden stresses and/or static shear stress conditions (i.e. sloped ground). The overburden correction factor (K_σ) used in conjunction with the Youd et al. (2001) approach is that also recommended in their paper and described by Figure 12. Given the $(N_1)_{60}$ values obtained, the curve corresponding to a 60% relative density (Dr) was used to estimate the K_σ values.

For the Idriss and Boulanger (2008) approach, the K_σ values were estimated by the use of the set of equations also recommended on their paper, and presented below:

$$K_\sigma = 1 - C_\sigma \ln\left(\frac{\sigma'_{vc}}{P_a}\right) \leq 1.1 \quad (9)$$

where

$$C_\sigma = \frac{1}{18.9 - 2.55\sqrt{(N_1)_{60}}} \leq 0.3 \quad (10)$$

As for the static shear stress correction factor (K_α), given that the Youd et al. (2001) NCEER/NSF workshop does not recommend any set of values, the equations recommended by Idriss and Boulanger (2008) were used for both approaches. These equations are presented below:

$$K_\alpha = a + b \cdot \exp\left(\frac{-\xi_R}{c}\right) \tag{11}$$

where

$$a = 1267 + 636\alpha^2 - 634\exp(\alpha) - 632 \cdot \exp(-\alpha) \tag{12}$$

$$b = \exp(-1.11 + 12.3\alpha^2 + 1.31 \cdot \ln(\alpha + 0.0001)) \tag{13}$$

$$c = 0.138 + 0.126\alpha + 2.52\alpha^3 \tag{14}$$

$$\xi_R = \frac{1}{Q - \ln\left(\frac{100(1+2K_o)\sigma'_{vc}}{3P_a}\right)} - \sqrt{\frac{(N_1)_{60}}{46}} \tag{15}$$

and α=shear stress divided by effective vertical stress. It is important to note that the value of α is restrained to an upper limit of 0.35, and ξ_R has to fall between -0.6 and 0.1.

3.5. Results and Discussion

The minimum factors of safety obtained using the surface wave inversion data are presented in Table 2, which occurred in the glacial outwash layer near the toe of the dam. The shear wave data are extrapolated at this location but the lower factors of safety were due mostly to shear stress concentrations. The lowest factor of safety of 2.3 was controlled by the smaller, local event. Factors of safety of greater than 1.5 would suffer relatively minor cyclic pore pressure generation and thus a low potential to undergo a flow type failure (Seed and Harder, 1990). The analysis also indicated that the shell and core soils were non-liquefiable.

Consistent with the inversion results, the very high SPT blow count in the shell soils indicate that they are likely non-liquefiable even if the blow counts are likely inflated from the gravels. The SPT N values of 29 and 33 in the outwash layer correspond to $(N_1)_{60}$ values of 13 and 15, respectively. The relatively low $(N_1)_{60}$ is attributed to the very high overburden stresses (~460 kPa) where the SPT measurements were made. When the $(N_1)_{60}$ of 13 and 15 were extrapolated laterally in the outwash layer the minimum computed factor of safety was 1.7.

Table 3 presents a comparison of the factors of safety computed at the same locations where both the surface wave testing and SPT were performed. The comparison was made at the two depths were the $(N_1)_{60}$ was lowest. As shown in the table the SPT procedures of Youd et al. (2001) and Idriss and Boulanger (2008) yielded similar factors of safety ranging from 3.0 to 3.6. The V_S procedure of Kayen et al. (2013) yielded lower factors of safety in comparison to Andrus and Stokoe (2000), but were 13 to 47 percent higher than the factors of safety obtained using the SPT procedures.

In surface wave testing Rayleigh waves penetrate down to approximately one wavelength and hence the estimates of the shear speeds in the soft layer between 21-30 m correspond to the data from the low end of the frequency band. The data at these frequencies has larger scatter that will result in larger errors in the estimate. The standard error of the estimates for depths less than 20 m is of the order of 7 to 10 m/s. This increases to 2 to 3 times between depths 20 to 30 m. The resolution length also increases with depth. At 30 m depth the resolution length is approximately 5 to 7 m. Also, it has to be noted that the estimates are averages over the source to receiver range. The quality of the estimates can be increased by taking advantage of the higher order modes if they can be identified correctly. Advanced signal processing techniques are being developed for the identification of higher order modes and estimation of their phase velocity dispersion.

Both the V_S and SPT procedures yielded the same outcome in terms of identifying a low potential for liquefaction in the design level events (i.e. FS>1.5). However, it is uncertain if the inversion approach would yield the same conclusion in looser soils. Clearly this study was limited to a few data points in soils with a $(N_1)_{60}$ of ~14 and additional comparisons at other dam sites would be useful to test the inversion procedures in looser soils.

Table 1. McGuire et al. (2001) ground motions selected for the 2500-year design event.

File Name	Moment Magnitude	Site-to-source distance (km)
Local Event		
B-A3E	5.4	31
B-KOD	5.4	17
C-ATC	5.2	11
C-ATP	5.2	11
C-OLC	5.2	10
C-TSM	5.2	10.4
Distant Event		
A-SON	6.8	124
ISD	6.6	113
MA1	6.6	115
MA2	6.6	113
RIV	6.7	101
SON	6.6	122

Table 2. Minimum factors of safety computed using surface wave inversion data.

Event type	Minimum factor of safety (FS) using	
	Andrus and Stokoe (2000)	Kayen et al. (2013)
Smaller, Local Event	4.1	2.3
Larger, Distant Event	3.3	3.1

Table 3. Comparison of the factors of safety computed at the same locations and depths where both the surface wave testing and SPTs were performed.

Depth (m)	$(N_1)_{60}$	V_{S1} (m/s)	Inversion (V_S)		SPT	
			A & S	Kayen	Youd	I & B
26.2	15	203	6.4	4.1	3.6	3.3
29.2	13		6.7	4.4	3.2	3.0

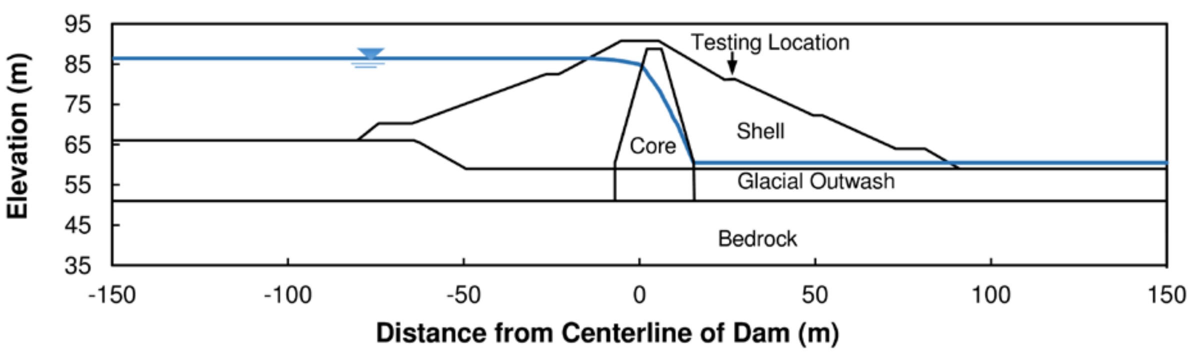

Figure 5. Updated model cross-section of the Gainer Dam.

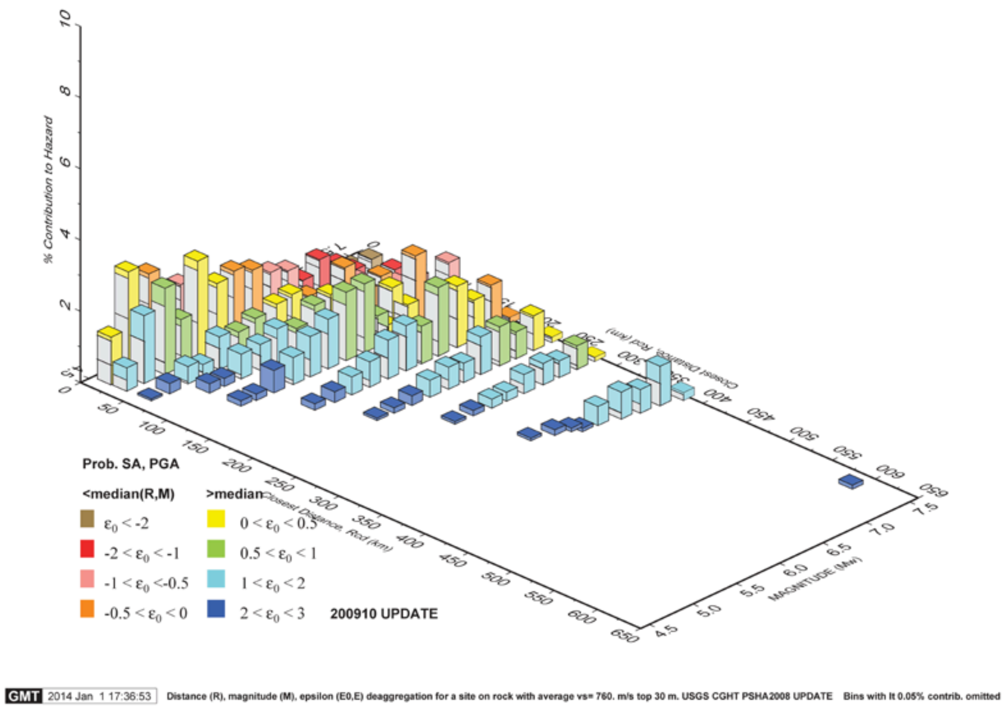

Figure 6. Deaggregation at an oscillator period of 0.3 seconds for the 2,500-year return period event (USGS.gov).

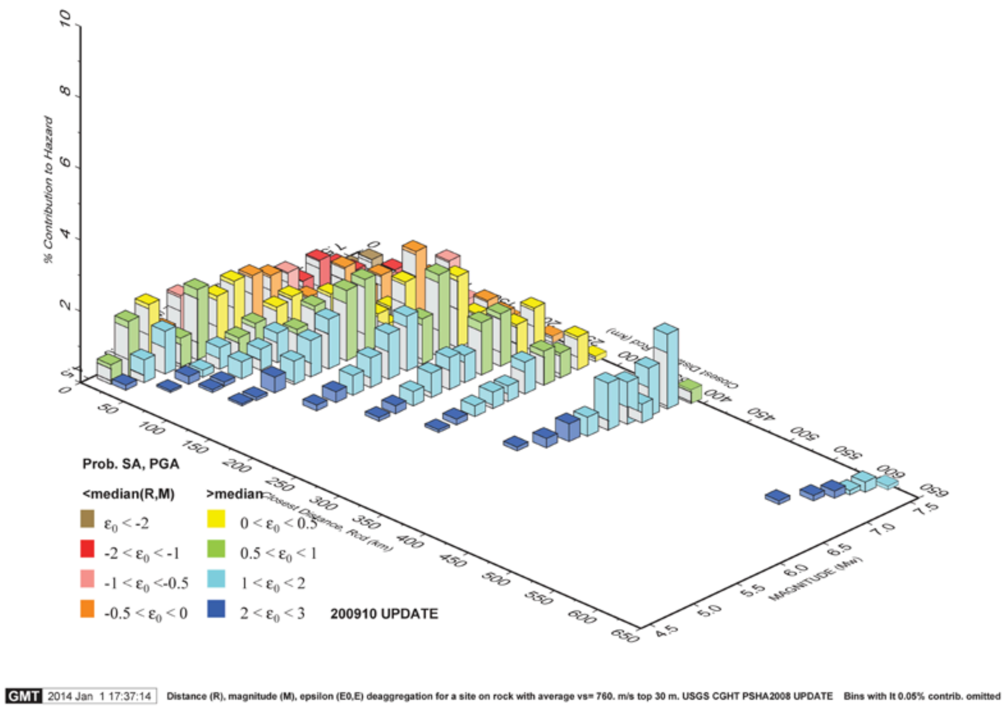

Figure 7. Deaggregation at an oscillator period of 0.5 seconds for the 2,500- year return period event (USGS.gov).

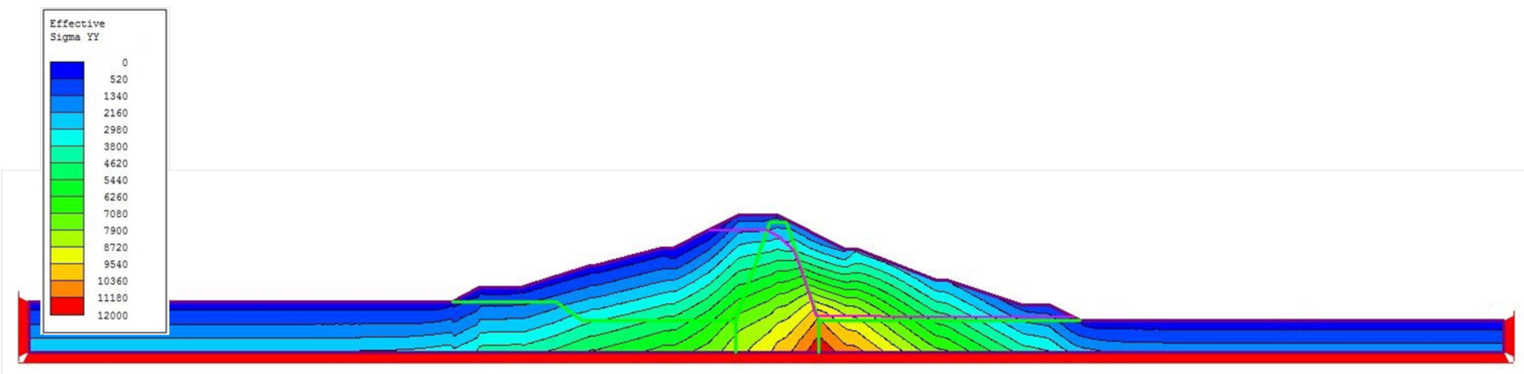

Figure 8. Phase2 output showing effective vertical stress contours.

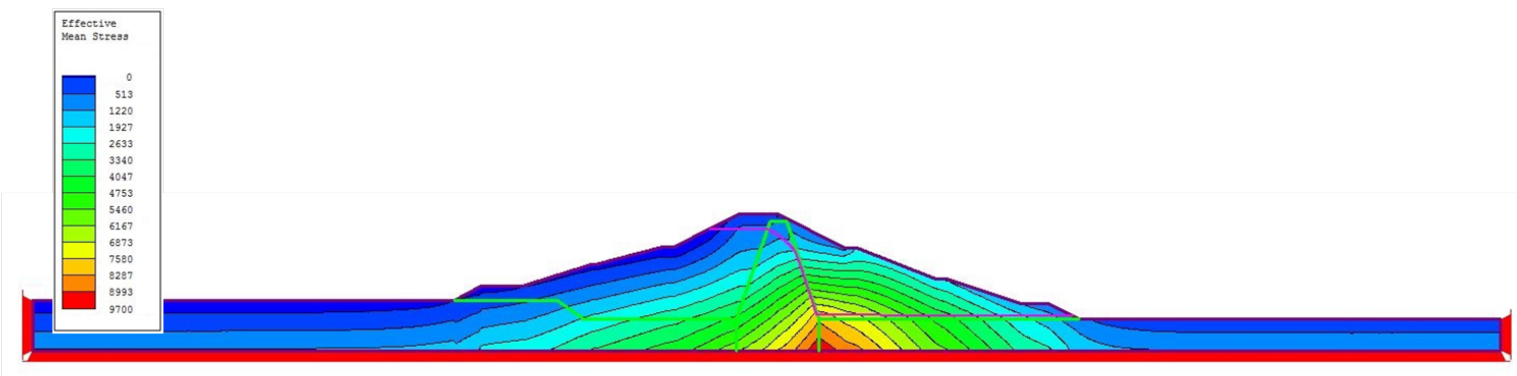

Figure 9. Phase2 output showing mean effective stress contours.

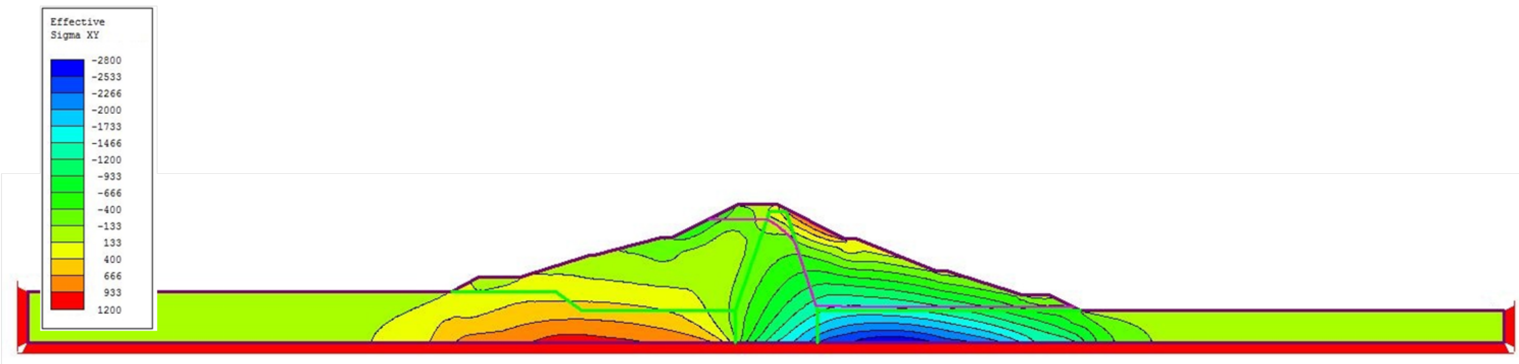

Figure 10. Phase2 output showing static horizontal shear stress contours.

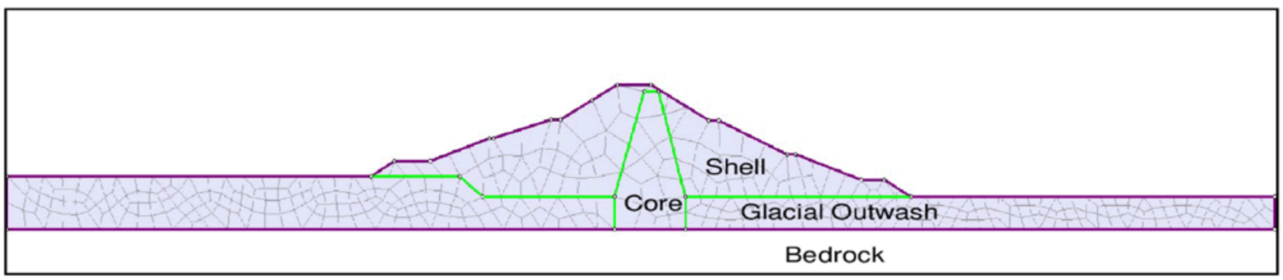

Figure 11. Finite element mesh used for QUAD4M input.

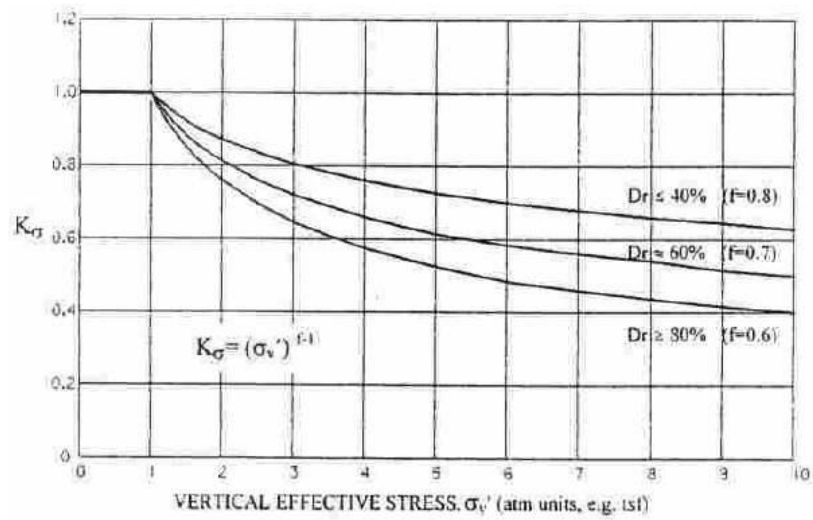

Figure 12. Youd et al. (2001) recommended values for estimating K_σ.

4. SUMMARY AND CONCLUSIONS

Field investigations and engineering analyses were performed at the Gainer Memorial Dam to evaluate the reliability of surface wave inversion as a screening tool to assess liquefaction potential at dams when SPT or CPT data are not available. In-situ shear wave measurements were performed using a surface wave inversion method, and the data were used to evaluate liquefaction potential. As part of this study, a verification boring was performed and the potential for liquefaction was evaluated using the SPT data. Upon comparison, the inversion and SPT results both indicated a low potential for liquefaction in the design events, but the inversion method yielded factors of safety 13 to 47 percent higher than those obtained through SPT methods for the specified testing locations. Uncertainties in the inverted shear wave velocity, particularly in the deep outwash layer, could be due to scatter in the data at low frequencies and high-resolution length at these depths. The results are promising but further research is needed to improve the quality of the shear wave estimates, possibly through identification of higher order modes and estimation of their phase velocity dispersion.

ACKNOWLEDGEMENTS

The work presented in this paper was supported by the Rhode Island Water Resources Center. The authors also gratefully acknowledge the support of the staff at Providence Water including Jacqueline Brosco, Peter LePage, Gregg Giasson and Steve Soito. The authors would also like to thank Jeffrey Costa and Matthew Bellisle at Pare Corporation for assistance with the exploration program, Dr. Gonzalo Castro at GEI Consultants for his review and comments on an early draft of this work, and Kevin Broccolo from the University of Rhode Island for his technical support.

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Information Transfer Program Introduction

The Information Transfer Project had two components. The first component was the Ninth Clean Water Conference focused on Clean Water Challenges in Rhode Island. The conference featured speakers from Providence Water, the largest water utility in Rhode Island, Kingston Water District, the largest of the small groundwater based water utilities and speakers from both the RI Health Department on private wells and the RI Department of Environmental Management speaking on Clean Water Challenges in Rhode Island.

The second component was the clean water camp for middle and high school students. This summer workshop promotes interest in clean water concepts using lectures, laboratories, and field trips. The goal of the workshop was to promote and encourage students to pursue STEM related careers.

Clean Drinking Water in Rhode Island

Basic Information

Title:	Clean Drinking Water in Rhode Island
Project Number:	2015RI122B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Water Quality, Education, None
Descriptors:	None
Principal Investigators:	Christopher Dickerson Hunter

Publications

There are no publications.

Technology Transfer Report

Clean Water Conference

The Ninth Annual Clean Drinking Water Conference was held on February 25, 2016 at the University of Rhode Island. The theme of this conference was Emerging Issues of Water Quality in Rhode Island. Stephen Soito the Senior Manager of Water Supply for Providence Water, the largest water utility in Rhode Island spoke about the changes in raw water quality that could be expected and Providence Water would meet the challenges. The next speaker was Alisa Richardson, Supervising Sanitary Engineer at the RI Department of Environmental Management who spoke about Freshwater Emerging issues from the perspective of a state regulatory agency. June Swallow from the RI Department of Health was originally scheduled to speak but she was unable to attend. Peter DiPippo, the Private Well Program Manager for the RI Department of Health spoke in her place. The final speaker was Henry Meyer, Manager of the Kingston Water District, gave his perspective on groundwater clean water challenges.

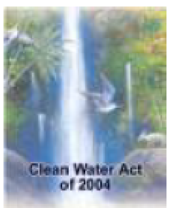
The conference was sponsored by the Civil and Environmental Engineering Department and the Chemical Engineering Department at the University of Rhode Island. Refreshments were providenc by the Chemical Engineering Department. Approximately 50 members of the university and surrounding community attended the water conference.

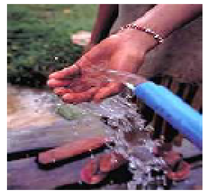
Seventh Annual Clean Drinking Water Conference

February 25, 2016

Thursday 2 pm to 4:30 PM

Upper College Road, Kingston Campus - across from University Club





Planning Committee Members
From the College of Engineering
Dr. Harold Knickle, Dr. Leon Thiem

Sponsored by

RI Water Resources Center

Department of Chemical Engineering

Department of Civil and Environmental Engineering

Conference is Free
All Welcome

UNIVERSITY OF
Rhode Island

URI

Cherry Auditorium

PRELIMINARY PROGRAM

CLEAN DRINKING WATER CONFERENCE

1:50 to 2:00 pm Registration

2:00 Welcome Remarks
Dean Wright,
Dr. Thiem

Session 1: 2:10 pm to 2:45 pm
"Drinking Water Quality Challenges: Providence Water,"
Stephen Soito, P.E., Senior Manager – Water Supply, Providence Water

COFFEE BREAK

Session 2 3:00- 3:30 pm
"Drinking Water Quality Challenges: State of RI"
June Swallow, Chief Division of Drinking Water Quality, RI DOH

Session 3: 3:30 to 4:00 pm
"Freshwater Emerging Issues."
Alisa Richardson, MS PE, Supervising Sanitary Engineer, RI DEM

Session 4: 4:00 to 4:30
"Emerging Drinking Water Issues: Small Water Utility," Henry Meyer, Manager, Kingston Water District

The 2015 University of Rhode Island (URI) Clean Water Science and Engineering Academy

From July 6 through July 10, 2015, 22 high school students participated in the 2015 URI Water Science and Engineering Academy. Most of the students were from Times^2 STEM Academy High School in Providence, and sessions were held there for three of the days and at URI for two of the days. Students were involved with activities from approximately 9:30AM to 3:30PM each day. The academy was free for the students, and it included a light breakfast, as well as lunch and snacks.

Activities for the students involved numerous presentations, various laboratory exercises, and two major field trips. Among the presentations were those on of the water cycle, chemistry of water, water quality and treatment, sewage treatment and biological technology, runoff and storm water, industrial water pollution, pollution prevention. Laboratory exercises included water quality sampling and testing, pH and dissolved oxygen measurement, bacteria pollution testing, conductivity testing, acid rain testing, aeration, adsorption and health effects, and filtration experimentation. Field work included the collection of samples from various locations, including 30 Acre Pond at URI, where students were allowed, with guidance and observation, to enter into the shallow areas of the pond to sample for macro-invertebrate life in the pond. This was definitely one of their favorite activities. Field trips were taken to the Holton Water Purification Facility at the Scituate Reservoir and the Warwick Advanced Wastewater Treatment Facility.

Dr. Hunter, from URI, was responsible for most of the presentations and establishing the activities. Helping throughout the process was Dr. Fontaine, a science teacher from Times^2 STEM Academy. He was involved in the recruitment process and in assisting with labs and activities throughout the week. Davi DeBarros, a URI undergraduate engineering student, was able to assist in the academy for two of the days, helping with the initial day's setup and the helping prepare lab materials.

Teams were established in groups of 3 to 4 persons for each laboratory exercise. In Figure 1, we show different teams as they investigated a settling process. Students were to make observations and also do write-ups of each lab. Figure 2 shows one team in their development of a filtration system using various materials. Figures 3 through 5 show other activities done throughout the week.

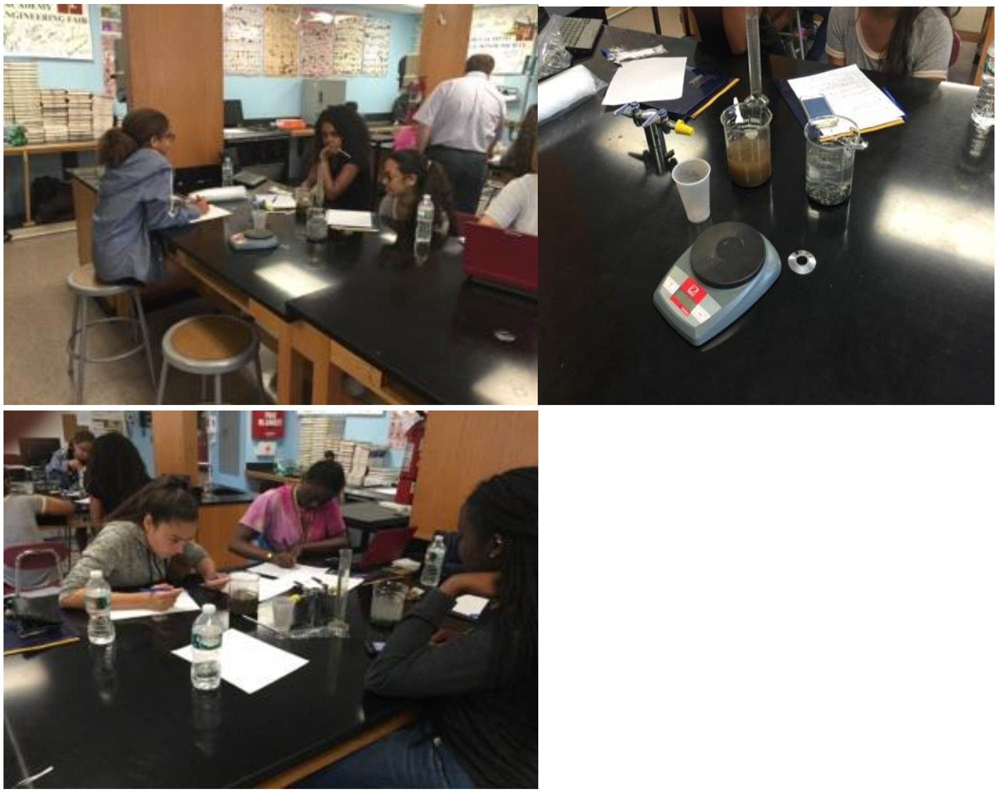


Figure 1. Pictures for the Initial lab at Times@ STEM Academy.

Figure 2. One team developing a filtration system using various materials.

Figure 3. Pictures from the Warwick Advanced Wastewater Treatment Facility.

Figure 4. Pictures from the Holton Water Purification Facility, including a view of one of their labs and one picture from the monitoring center.

Figure 5. Sampling from 30 Acre Pond and then the identification of macro-invertebrates found after coming back to the URI lab in Bliss Hall.

Figure 6. The favorite time of each day…lunch!

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3	0	0	0	3
Masters	1	0	0	0	1
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	6	0	0	0	6

Notable Awards and Achievements

An article about Aaron Bradshaw"s work at the Gainer Dam was published in the Providence Journal. In addition, Providence Water, owner of the Gainer Dam, provided funding for an outside contractor to conduct field borings to characterize the soils withing the core of the Gainer Dam.

Publications from Prior Years

1. 2013RI115B ("Seismic Evaluation of the Gainer Memorial Dam") - Articles in Refereed Scientific Journals - Reyes, B., A. S. Bradshaw, G. Potty, and C. Norton, 2016, ":Surface Wave Inversion as a Screening Tool for Liquefaction Potential: A Case Study at the Gainer Dam," ASDSO Journal, 14(1), 23-31.
2. 2013RI115B ("Seismic Evaluation of the Gainer Memorial Dam") - Conference Proceedings - Bradshaw, A. S., 2015, "Using Surface Wave testing to Screen for Liquefaction Potential of Embankment Dams: A Case Study at the Gainer Dam," Meeting of the Rhode Island Water Works Association, Johnston, RI
3. 2014RI119B ("Water Security, Sustainability, and Climate Impacts in Urban Regions") - Other Publications - Akanda, A. S., et al , 2014, "Co-evolving Hydroclimatic signatures and Diarrheal Disease Dynamics in Bangladesh: Implications for Water Management and Public Health" AGU Fall Meeting Abstracts, Vol. 1.
4. 2014RI119B ("Water Security, Sustainability, and Climate Impacts in Urban Regions") - Other Publications - Hasan, M. A., 2015, "Understanding Hydroclimatic Extremes in Changing Monsoon Climates with Daily Bias Correction of CMIP5 Regional Climate Models Over South Asia," AGU Fall Meeting Abstracts.
5. 2014RI119B ("Water Security, Sustainability, and Climate Impacts in Urban Regions") - Other Publications - Serman, E. V., H. Ginsberg, J. Couret, A. S. Akanda, 2015, "Understanding Environmental and Climatic Influences on Regional Differences and Spatio-temporal Scale Issues of Dengue Fever Transmission in Puerto Rico," AGU Fall Meeting Abstracts.